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No. 4 1 487

# BEAM DIRECTOR DESIGN REPORT

**AUGUST 1986** 

**VOLUME II** 

UCRL--15901-Vol.2

DE87 008490

# Prepared by:

Brobeck Corporation 1235 Tenth Street Berkeley, California 94710 415-524-8664

Report Number 4500-316-R1 Francis C. Younger, Principal Investigator

Prepared for:

Lawrence Livermore National Laboratory
Livermore, California, USA

Under LLNL Subcontract 8652605, U. S. Department of Energy Contract W-7405-ENG-48

Sponsored by:

MASTER

PMS-405 Naval Sea Systems Command Washington, DC



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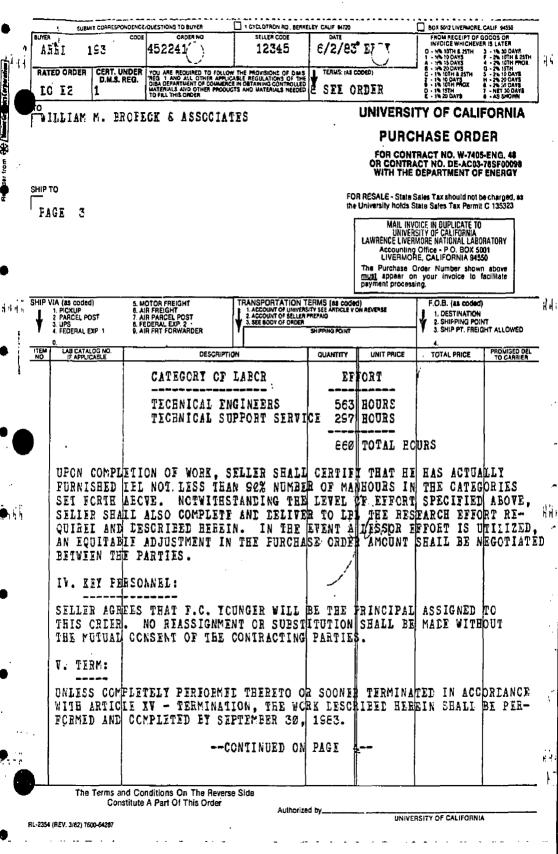
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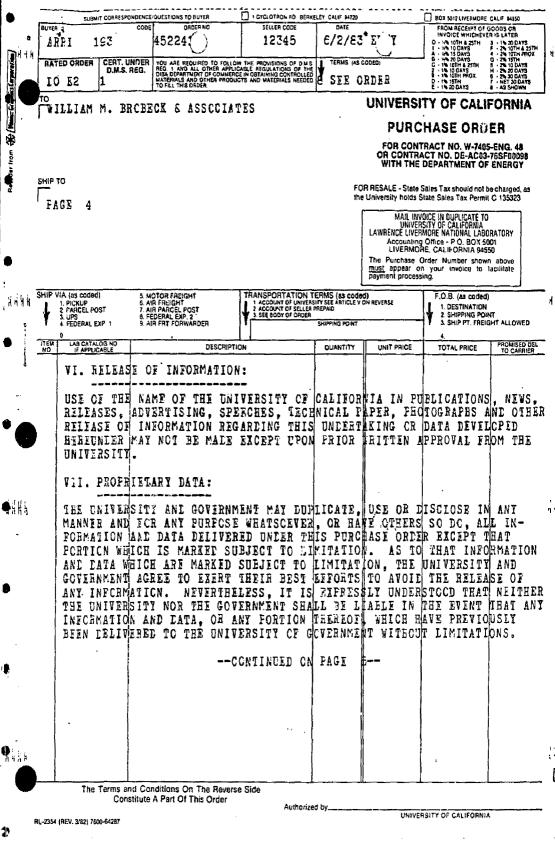
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#### APPENDIX A - SCOPE OF WORK to PURCHASE ORDER 4522410

#### between

#### THE REGENTS OF THE UNIVERSITY OF CALIFORNIA

and

## WILLIAM M. BROBECK & ASSOCIATES

#### INTRODUCTION

As approved and directed by the University, the Seller will undertake certain engineering work for the conceptual design of a electron beam director. It is estimated that approximately 860 man hours of technical effort will be required to complete this program. This engineering work is to be closely coordinated with the scientific work being done by LBL staff members on the same project.

#### II. PURPOSE

The overall objective of the proposed effort is to perform conceptual design engineering work leading to a final report that sets forth a conceptual design for an electron beam director and indentifies segments needing research and development.

#### III. TECHNICAL SCOPE OF WORK

The Seller shall perform the following tasks:

#### TASK 1 Conceptual Design

Select suitable configurations and perform engineering calculations establishing conceptual designs for the various segments of an electron beam director system including:

- . Magnet lattice
- . Vacuum rotary joints
- . Vacuum or air transition
- . Vernier steering system
- . Mechanical mount and slewing system
- . Radiation effects
- . Estimates of size, weight and cost

William M. Brobeck & Associates Purchase Order 4522410

#### TASK 2 Liaison

The Seller shall meet with LBL project staff Bi-Monthly so that the engineering work hereunder is coordinated with that being performed by LBL staff members.

#### TASK 3 Final Report

The Seller shall prepare and submit drafts of those portions of the Final Report that pertain to the conceptual design engineering work undertaked hereunder by August 31, 1983. After review, a final draft of said portions of the Final Report shall be submitted by September 30, 1983.

## IV. REPORT SUBMITTALS AND DELIVERABLES

The reports and deliverables required are those described in Section III, Tasks 2 and 3.

Two (2) copies of the above reports are to be addressed and submitted to:

University of California
Lawrence Berkeley Laboratory
One Cyclotron Road
Berkeley, CA 94720
Attention: Dr. Edward P. Lee, Building 47-112

One copy of the transmittal letter for each of these reports shall be furnished to the Purchase Order Administrator addressed as follows:

University of California Lawrence Berkeley I aboratory One Cyclotron Road Berkeley, Ca 94720 Attention: Mr. R. J. Arri

The Seller shall not distribute reports of work, drawings, specifications, etc. under this purchase order to any individual or organization other than those indicated above without the prior written approval of the Purchase Order Administrator.

#### V. LIAISON

- A. University's Purchase Order Administrator is Mr. R. J. Arri, or his designee or successor. He will assure compliance with the terms and conditions of this order, process any contractual approvals required and monitor expenditures hereunder. He shall also be responsible for review of all invoices submitted under the progress payments provisions to assure compliance with the order requirements.
- B. University's Technical Director under this order is Dr. Edward P. Lee, his successor or designee. He will be responsible for monitoring technical performance under this order, approving the form and content of technical reports and accepting the final task reports.

## VII. ASSIGNMENT OF PERSONNEL

Any substitution, reassignment, replacement or other change involving Seller's key technical personnel assigned to this work, shall be made only with persons of equal abilities and qualifications. Any such change shall be subject to prior University approval.

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## UNIVERSITY OF CALIFORNIA

#### **PURCHASE ORDER**

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# WILLIAM M. BROBECK & ASSOCIATES

## **PURCHASE ORDER**

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#### FIRST MODIFICATION TO APPENDIX A - SCOPE OF WORK

to

#### PURCHASE ORDER 4522410

#### with

#### WILLIAM M. BROBECK AND ASSOCIATES

#### INTRODUCTION

This First Modification to Appendix A - Scope of Work to Purchase Order 4522410 issued to provide contract coverage for additional work to be performed.

#### **PURPOSE**

The purpose of this First Modification is to add an additional work task under this order.

#### CHANGES

Appendix A - Scope of Work is modified by mutual agreement of the parties as follows:

#### TECHNICAL SCOPE OF WORK - is changed to read:

Task 4 is added as follows:

"TASK 4 consist of planning how the concepts and configurations developed in the following tasks can be carried forward to a successful demonstration on ATA at Lawrence Livermore National Laboratory.

- Magnet Lattice
- Vacuum Rotary Joints
- Vacuum-to-Air Transition
- Vernier Steering System
- Mechanical Mount and Slewing System
- Radiation Effects
- Estimates of Size, Weight and Cost"
- All other provisions of Appendix A Scope of work to Purchase order 4522410 remain unchanged.

#### ELEVENTH AMENDMENT

to

## SUBCONTRACT 2700700

#### between

#### THE REGENTS OF THE UNIVERSITY OF CALIFORNIA

and

#### BROBECK CORPORATION

## INTRODUCTION

This Eleventh Amendment to Subcontract 2700700 is entered into by and between The Regents of the University of California, hereinafter called "University", and Brobeck Corporation, hereinafter called "Subcontractor".

## PURPOSE

The purpose of this Eleventh Amendment is to recognize a change in Subcontractor's name; to provide for additional Tasks under existing Part A - Organic Materials and to add a new Part E - Beam Director; to increase the level of effort; to increase the funding; and to extend the Subcontract term through February 29, 1984.

NOW, THEREFORE, effective upon Subcontractor's receipt of a fully executed Amendment, Subcontract 2700700 between the University and the Subcontractor is hereby amended by mutual agreement of the parties as follows:

#### CHANGE OF NAME

This Amendment acknowledges that University and Subcontractor have executed a CHANGE OF NAME AGREEMENT on November 22, 1983, recognizing the Subcontractor has changed its corporate name to BROBECK CORPORATION.

# ARTICLE II - TERM - is changed, in part, as follows:

Delete "and shall continue through December 31, 1983", and substitute in lieu thereof "and shall continue through February 29, 1984".

ARTICLE III - ESTIMATE OF COST - Paragraph A. Initial Estimate of Cost and Fixed Fee: delete as written and substitute therefor:

"The presently estimated cost of work under this Subcontract is THREE HUNDRED SEVENTY-SEVEN THOUSAND THREE HUNDRED FIVE AND NO/100 DOLLARS (\$377,305.00), exclusive of Subcontractor's fixed fee. Subcontractor's fixed fee is THIRTY-SEVEN THOUSAND SEVEN HUNDRED TWENTY-TWO AND NO/100 DOLLARS (\$37,722.00). The aggregate of presently estimated cost and fixed fee is FOUR HUNDRED FIFTEEN THOUSAND TWENTY-SEVEN AND NO/100 DOLLARS (\$415,027.00)."

APPENDIX A - REIMBURSEMENT OF COSTS is hereby revised to add Paragraph C.3. as follows:

"C.3. Notwithstanding Paragraphs C.1 and C.2, above, the parties hereto agree that University shall not be obligated to pay any amount for General and Administrative Expenses (G&A) exceeding 30.0% of total direct cost and Overhead, for the period commencing January 1. 1984."

## APPENDIX 8 - SCOPE OF WORK, is hereby revised as follows:

Paragraph III. TECHNICAL SCOPE OF WORK, is revised as follows:

# Part A - Organic Materials, add the following:

## "Task XII

"Initiate efforts to extend RDUCT to include additional procedures for transition computation including "microscopic" computations of internal cell heat transfer."

## "Task XIII

"Provide support analyses in the area of weapons vulnerability, as requested and under the technical direction of the LLNL Technical Coordinator, or his designee."

Add the following new task:- -

#### "Part E - Beam Director

"Initiate planning and preliminary design of three elements of the electron beam director system and detail design of the Vernier Steering and Achromat for the LLNL Advanced Test Accelerator (ATA) project.

"The prioritized elements are:

- Vernier Steering
- 2. Achromat
- Vacuum-to-Air Rotating Window

"Work shall be performed as approved and directed by the University's Technical Coordinator, and generally as described in the WORK STATEMENT (4 pages) contained in Subcontractor's Proposal No. 8400-260-20A dated February 10, 1984."

"The Final Report for this Part E shall be an informal summary of work performed, in form and content acceptable to the University's Technical Coordinator."

Paragraph IV. LEVEL OF EFFORT; is modified in its entirety to read as follows:

"The allocation of effort under	Subcontract is estimated to be:
Type of Personnel	Level-of-Effort (Man-Hours, Cumulative)
PAICT A	
Engineer 15 Engineer 16	1,412 2,330 (increase 174)
PART B	:
Engineer 16 Engineer 15 Engineer 12 Engineer 11 Engineer Associate 7	320 861 470 610 446
PART C	
Engineer 16	35
PART D	
Engineer 12	8
PART E	
Engineer 16 Engineer Associate 7 Engineer Associate 5	670 (added) 358 (added) _240" (added) 170°
Part VI. COORDINATION AND A following:	<u>IDMINISTRATION</u> , is revised to add the
"The University's Technical Coo Coleman Johnson, or his designee	rdinator for Part E - Beam Director, is
All other terms and conditions of : force and effect except as amended h	Subcontract 2700700 shall remain in full perein.
IN WITNESS WHEREOF, the parties have	e executed this Eleventh Amendment.
~ ACCEPTED:	AUTHORIZED:
BROBECK CORPORATION	THE REGENTS OF THE UNIVERSITY OF CAMPIFORNIA
BY Warren W. Eukel	BY M. R. Eaton
TITLE The following Vice President	TITLE Deputy Contracts Manager Lawrence Livermory National Laboratory
DATE 2/2/84	DATE ANGE
11th Amendment A- S/C 2700700 2/84 (2233N:30i)	-16

#### SUBCONTRACT 4368005

between

## THE REGENTS OF THE UNIVERSITY OF CALIFORNIA

and

#### BROBECK CORPORATION

## INTRODUCTION

This Cost Plus Fixed Fee Subcontract is made and entered into by and between The Regents of the University of California, hereinafter called the "University", and Broberk Corporation, hereinafter called the "Subcontractor".

The Regents of the University of California, a California corporation, have entered into a contract, W-7405-ENG-48 with the United States Government, hereinafter called "Government", represented by the Department of Energy, hereinafter called "DOE", for the performance of certain energy research and development work at the University of California Lawrence Livermore National Laboratory. This Subcontract is entered into in furtherance of the performance of the work provided for in the prime contract.

In accepting this Subcontract, the Subcontractor agrees to perform the Subcontract work in accordance with the following documents which collectively constitute the Subcontract and are attached hereto and by this reference made a part hereof:

> Subcontract Signature Page Schedule consisting of 5 pages General Provisions dated July, 1983 Exhibit 1 - Scope of Work

(Revised 6/83)

ACCEPTED: BROBECK CORPORATION

AUTHORIZED:

THE REGENTS ( UNIVERSITY LOE

Warren W. Eukel Vice President

L. Halunen

Date: February 29, 1984 Contracts Manager

Lawrence Livermore National Laboratory

Title:

#### SCHEDULE

## ARTICLE I - SCOPE OF WORK

The Subcontractor shall furnish the necessary facilities, supplies, equipment and personnel, except such as are furnished by the University or the Government, to conduct certain work generally described as a) Task I - Analysis of Weapons System Explosives Component Vulnerability, and b) Task II - ATA Beam Director, to be performed by the Subcontractor at locations approved by the University and Subcontractor's facility at Berkeley California the nature and extent of which are more specifically described in EXHIBIT 1 - STATEMENT OF WORK hereto, and shall also deliver such materials, products, supplies and incidental services and reports as may be set forth in said EXHIBIT I.

The University and DOE shall have the right to inspect Government property and the work and activities of the Subcontractor under this Subcontract at such time and in such manner as they shall deem appropriate. The Subcontractor shall include in all subcontracts and purchase orders under this Subcontract involving research and development or fabrication, or where costs incurred are a factor in determining the amount payable to the vendor, a similar provision making this paragraph applicable to the Subcontractor or vendor.

(Revised 6/83)

#### ARTICLE II - TERM

Unless completely performed prior thereto or sooner terminated in accordance with CLAUSE 14 - TERMINATION, the work described in ARTICLE I - SCOPE OF WORK, shall begin March 1, 1984 and shall continue through December 31, 1984 which is the current period of time estimated as necessary for completion of said work, provided that the term of this Subcontract shall continue for such period of time as required to comply with the reporting and close out procedures of this Subcontract. Neither party guarantees the aforestated estimate of time and work under this Subcontract and, except as necessary to comply with reporting and close out procedures, the term shall cease on the last date mentioned unless the University by writter notice to Subcontractor extends, at its sole option, such period for such time or times as it considers appropriate for completion of the work described in ARTICLE I - SCOPE OF WORK. Such an extension of time will not be a basis for a claim of additional fee by Subcontractor.

(Revised 2/83)

## ARTICLE III - ESTIMATES AND FIXED FEE

## A. Initial Estimate of Cost and Fixed Fee

The presently estimated cost of the work under this Subcontract is \$96,257.00 exclusive of the Subcontractor's fixed fee. The Subcontractor's fixed fee is \$9,618.00. The aggregate of presently estimated cost and fixed fee is \$105.875.00.

The presently estimated rost of the work under this Subcontract may be

## B. Revised Estimate of Cost

(Task II: \$52,310.00)

C. Limit on Total Amount of Allowable Costs

Payments on account of costs shall not in the aggregate at any time exceed the amount of estimated costs specified in the Subcontract.

increased or decreased by written agreement of the parties.

# D. Notice of Costs Approaching Subcontract Amount - Subcontractor Excused Pending Increase

Whenever the Subcontractor has reason to believe that the total costs of the work under this Subcontract, exclusive of fixed fee, will exceed the estimated cost of the work then in effect, the Subcontractor shall promptly notify the University in writing. The Subcontractor shall also notify the University in writing when the aggregate of expenditures and outstanding commitments allowable under this Subcontract, excluding fixed fee, is equal to 75% (or such other percentage as the University may from time to time establish by notice to the Subcontractor) of the estimated cost of the work then in effect. When such expenditures and outstanding commitments, excluding fixed fee, equal 100% of such amount, the Subcontractor shall make no further commitments or expenditures (except to meet existing commitments) and shall be excused from further performance of the work unless and until the University shall increase the estimated cost of the work in accordance with Paragraph 8, above.

# E. The University's Right to Terminate not Affected

The giving of any notice by either party under this ARTICLE III shall not be construed to waive or impair any right of the University to terminate the Subcontract under the provisions of CLAUSE 14 - TERMINATION.

## F. Cost Information

The Subcontractor shall maintain current cost information adequate to reflect the cost of performing the work under this Subcontract at all times while the work is in progress and shall prepare and furnish to the University such written estimates of cost and information in support thereof as the University may request.

## G. Correctness of Estimates not Guaranteed

Neither the University nor the Subcontractor guarantees the correctness of any estimate of cost or estimate of time for the performance of the work under this Subcontract, and there shall be no adjustment in the amount of the Subcontractor's fixed fee by reason of errors in the computation of estimates or differences between such estimates and the actual cost or time for the performance of the work.

(Revised 2/83)

## ARTICLE IV - CONSIDERATION

Payment for allowable costs, reimbursable in accordance with ARTICLE V - REIMBURSEMENT OF COSTS, and of the fixed fee set forth in ARTICLE III - ESTIMATES AND FIXED FEE, shall constitute complete compensation for Subcontractor's services, including profit and all items or kinds of expenses not allowable under the terms of this Subcontract.

(Revised 2/83)

## ARTICLE V - REIMBURSEMENT OF COSTS

A. The allowable cost of performing the work under this Subcontract shall be the costs and expenses (less applicable income and other credits) that are actually incurred by the Subcontractor, are applicable and properly chargeable, either as directly incident or as allocable through appropriate distribution or apportionment, to the performance of the Subcontract in accordance with its terms and are determined to be allowable pursuant to this paragraph. The determination of the allowability of cost hereunder shall be based on: 1) reasonableness, including the exercise of prudent business judgment; 2) consistent application of generally accepted accounting principles; and 3) recognition of all exclusions and limitations set forth in this ARTICLE V, or elsewhere in this Subcontract as to types or amounts of items of cost. This Subcontract recognizes that audit hereunder will be in accordance with this Subcontract and Contract cost principles and procedures of DOE (DOE PR 9-15.50) in effect on the date of this Subcontract, as supplemented by Subpart 1-15.2 of the Federal Procurement Regulations (4) CFR 1-15.2) and in DOE PR 9-15.205-3 "Bidding Cost" and 9-15.205-35 "Independent Research and Development (IR&D) and Bid and Proposal (B&P) Costs". The audit might be performed by the Government Agency having the preponderant workload. However, DOE reserves the right to conduct its own audit of expenditures under this Subcontract.

(Revised 6/83)

#### 8. OVERHEAD

- Pending final audit and determination of overhead, the Subcontractor shall be paid a provisional overhead rate, as approved by the University from time to time and authorized in writing by the University. Such provisional payments will be adjusted to the actual overhead costs and expenses determined as set forth in this ARTICLE V and principles herein established.
- When actual reimbursable overhead costs have been determined pursuant to this Subcontract, adjustment shall be made for the difference between the sum to be determined and the sum of the provisional payments made under Paragraph 1., above.
- Notwithstanding Paragraphs B.1 and B.2 above, the parties hereto agree that University shall not be obligated to pay any amount for General and Administrative Expenses (G&A) exceeding 30.0% of total direct costs and Overhead, for the period commencing March 1, 1984.

(Revised 2/83)

## AKTICLE VI - RIGHTS TO PROPOSAL DATA

Except for technical data contained in pages (None) of the Seller's proposals dated February 10, 1984 which are asserted by the Seller as being proprietary data, it is agreed that as a condition of the award of this subcontract, and notwithstanding the provisions of any notice appearing on the proposal, the University and Government shall have the right to use, duplicate and disclose and have others do so for any purpose whatsoever, the technical data contained in the proposal upon which this order is based.

(Revised 2/83)

## ARTICLE VII - GENERAL PROVISIONS

- A. The Subcontractor shall comply with the CLAUSES set forth in the General Provisions dated July 1983 as may be altered or modified hereunder and in the ARTICLE VIII ALTERATIONS and ADDITIONS.
- 8. CLAUSE 31, paragraphs A.1, A.2, Authorization and Consent (page no. 26 and 27), shall or shall not be applicable to this Subcontract as follows:

Paragraph A.1 is [X] is not [ ] applicable to this Succontract.

Paragraph A.2 is [ ] is not [X] applicable to this Subcontract.

C. CLAUSE 31, paragraphs B.1, B.2, Patent Indemnity (page no. 27), shall or shall not be applicable to this Subcontract as follows:

Paragraph B.1 is [X] is not [ ] applicable to this Subcontract.

Paragraph B.2 is [ ] is not [X] applicable to this Subcontract.

D. CLAUSE 31, paragraphs D.1, D.2, Patent Rights (page no. 28 or 36), shall be applicable to this Subcontract as follows:

Paragraph D.1 PATENT RIGHTS (LONG FORM) is [ ] is not [X] applicable to this Subcontract.

Paragraph D.2 PATENT RIGHTS (SMALL BUSINESS FIRMS AND NONPROFIT ORGANIZATIONS, MARCH 1982) is [X] is not [ ] applicable to this Subcontract.

E. CLAUSE 31, paragraph G, Rights in Technical Data, subparagraphs G (page no.41) and H (page no.44) shall or shall not be applicable to this Subcontract as follows:

Subparagraph G is [X] is not [ ] applicable to this Subcontract.

Subparagraph H is [ ] is not [X] applicable to this Subcentract.

(Revised 6/83)

# ARTICLE VIII - ALTERATIONS AND ADDITIONS

The following Optional clause is hereby incorporated into and made a part of this Subcontract.

Clause 35 Cost or Pricing Data (page 48)

In addition, the following Article is hereby incorporated into and made a part of this Subcontract:

ARTICLE 38 - Foreign Ownership, Control, or Influence Over Contractor, Form LL 2358 FOCI-2 (8/83)

Revised 2/83)

#### EXHIBIT 1 - SCOPE OF WORK

to

#### SUBCONTRACT 4368005

#### between

#### THE REGENTS OF THE UNIVERSITY OF CALLFORNIA

and

#### BROBECK CORPORATION

#### I. INTRODUCTION

Ш

As approved and directed by the University, Subcontractor shall provide technical and professional effort directed toward the studies specified in Part III - Technical Scope of Work.

As provided in CLAUSE 3 - CHANGES, the University may direct, in writing, changes within this Scope of Work.

## II. PURPOSE

The purpose of this work is a) to provide design and analysis for two phase hydrodynamic calculations, and to provide weapons vulnerability studies (Task I), and b) to provide planning and design engineering for an electron beam director vernier, achromat and window (Task II).

# III. TECHNICAL SCOPE OF WORK

As approved or directed by the University, Subcontractor shall furnish all necessary personnel, materials and facilities, except as may be provided for elsewhere herein, to conduct the investigations and Tasks described below:

# TASK I - CHEMISTRY DEPARTMENT SUPPORT

I. A Engineering Design and Analysis for Two Phase Hydrodynamic Calculations:

Initiate efforts to extend RDUCT to include additional procedures for transition computation including "microscopic" computations of internal cell heat transfer. (Note: this is a continuation of efforts initiated under Part A-Task XII of Subcontract 2700700.)

## I.8 Weapons Vulnerability Studies:

Provide support analyses in the area of weapons vulnerability, as requested and under the technical direction of the LLNL Technical Representative. (Note: this is a continuation of efforts initiated under Part A - Task XIII of Subcontract 2700700.)

## TASK II - ADVANCED TEST ACCELERATOR (ATA) SUPPORT

#### II.A Beam Director:

Complete the planning and preliminary design of three elements of the electron beam director system and detail design of the Vernier Steering and Achromat for the LLNL Advanced Test Accelerator (ATA) project.

The prioritized elements are:

- 1. Vernier Steering
- 2. Achromat
- 3 Vacuum-to-Air Rotating Window

Work shall be performed as approved and directed by the University's Technical Representative, and generally as descirbed in the WORK STATEMENT (4 pages) contained in Subcontractor's Proposal No. 8400-260-20A dated February 10, 1984. (Note: this is a continuation of efforts initiated under <a href="Part E-Beam Director">Part E-Beam Director</a> of Subcontract 2700700.)

## IV. LEVEL OF EFFORT

TYPE OF PERSONNEL

The distribution and allocation of technical and professional effort under this Subcontract shall be approximately as follows:

MAN HOURS (ESTIMATED)

<del></del>	<del></del>		
	Task I Chemistry Support	Task II ATA Support	
Engineer 16	767	699	
Engineering Associate	7	83	

# V. REPORTS

Subcontractor shall prepare and submit the following reports to the University:

- A. Financial Reports (Type A) shall be submitted by the fifteenth of each month and shall include all costs incurred during the preceding month and outstanding commitments to the end of the month. In the event actual cost data is unavailable, Subcontractor's monthly financial report shall contain estimated expenditures, identified as such. Data shall be segregated and indentified by Task.
- B. Monthly Progress Reports (Type B) shall be submitted by the fifteenth of each month and may be informal letter summaries in a format approved by the University's Technical Representative. These reports should contain a description of work performed during the month reported and work planued for the succeeding month. Data shall be segregated and indentified by Task. (Subcontractor may elect to submit separate reports for each Task).
- C. <u>Final Report (Type C)</u> shall be submitted upon completion of each Task and contain a comprehensive summary of all work results and conclusions. The form and content of Type C Reports shall be acceptable to the University's Technical Representative. If so requested, a draft copy of the Report shall be submitted to the University's Technical Representative for approval prior to final typing.
- D. <u>Distribution of Reports</u>

Reports shall be separately addressed and transmitted to:

University of California Lawrence Livermore National Laboratory P. O. Box 5012 Livermore, CA 94550 Attention: (Intended Recipient)

Type of Report	No. of Copies	Recipient
A and B	1	Diane Melendez
A and B	As Requested	Technical Representative for
_		Each Respective Task
C	As Requested	Diane Melendez

Subcontractor shall not distribute reports of work under this Subcontract to any individual or organization other than those indicated above or an authorized representative of the U.S. Department of Energy without prior written approval of the Contract Administrator.

## E. Interim Reports

It is understood that there will be other information exchanged between the parties from time to time. These data may be exchanged directly between the parties concerned; formal reporting and distribution is not required in these cases.

## VI. COORDINATION AND ADMINISTRATION

The University's Technical Representative(s) under this Subcontract as designated below, or their designee(s), shall represent the University in matters relating to the technical performance of the Scope of Work described herein. During the established term of this Subcontract. the Technical Representatives will interpret the technical requirements of the Scope of Work and will determine the emphasis and direction of the Subcontractor in the conduct of the work within the level and allocation of effort established herein. All other matters relating to the performance of this Subcontract are reserved to the Contract Administrator. Provided, however, any technical direction which will affect the estimated cost or time for performance of this work shall require prior formal amendment of this Subcontract or prior written direction from the Procurement Manager, or his designee, as provided in CLAUSE 3 - CHANGES of the Terms and Conditions. Technical direction resulting in work outside the general Scope of Work requires prior formal amendment of this Subcontract.

<u>Task</u>	Technical Representative
Task I	E. Lee
Tack II	Colleman Johnson

The University's Contract Administrator is Diane Melendez, or her designee. All matters relating to the interpretation and administration of this Subcontract shall be conducted through the Contract Administrator. Subcontractor will direct all notices and requests for approval to the Contract Administrator; and any notice or approval from the University to the Subcontractor will be issued by the Contract Administrator.

# VII. ASSIGNMENT OF PERSONNEL

It is understood and agreed that Subcontractor's key technical personnel assigned to this work shall not be reassigned or replaced without prior University approval, except where such circumstances are beyond the reasonable control of the Subcontractor.

## VIII. HEALTH, SAFETY AND FIRE PROTECTION

The Subcontractor shall take all reasonable precautions in the performance of the work under this Subcontract to protect the health and safety of employees and members of the public and to minimize danger from all hazards to life and property, and shall comply with all pertinent health, safety, and fire protection regulations and requirements (including reporting requirements) of the University and DOE communicated to the Subcontractor.

In the event the Subcontractor fails to comply with said regulations or requirements of the University or the DOE, the University may without prejudice to any other legal or contractual rights of the University, issue an order stopping all or any part of the work; thereafter, a start order for the resumption of work may be issued at the discretion of the University.

## SECOND AMENDMENT

to

#### SUBCONTRACT 4368005

#### between

#### THE REGENTS OF THE UNIVERSITY OF CALIFORNIA

and

#### BROSECK CORPORATION

#### INTRODUCTION

This Second Amendment to Subcontract 4368005 is entered into by and between The Regents of the University of California, hereinafter called "University", and Brobeck Corporation, hereinafter called "Subcontractor".

## PURPOSE

The purpose of this Second Amendment to Subcontract 4368005 is to incorporate the following changed documents into this Subcontract.

NOW, THEREFORE, by mutual agreement of the parties, the following Subcontract documents attached hereto are made a part of this Subcontract:

Second Modification to Schedule

Second Modification to Exhibit I

All other terms, conditions and provision of Subcontract 4368005 shall remain in full force and effect, except as amended herein.

In witness whereof, effective upon Subcontractor's signature acceptance of this Second Amendment, Subcontract 4368005 is hereby amended by mutual agreement of the parties.

AUTHORIZED:

BROBECK CORPORATION	THE REGENTS OF THE UNIVERSITY OF CALIFORNIA
BY Mariage He had	BY In R Th
Warren W. Eukel	M. R. Eaton
TITLE Vice President	TITLE Deputy Contracts Manager
	Lawrence Livermore National Laboratory
DATE June 26, 1984	DATE C/25/81

2nd Amendment S/C 4368005 6/84 (2589F)

ACCEPTED:

#### SECOND MODIFICATION TO SCHEDULE OF

#### SUBCONTRACT 4368005

#### between

#### THE REGENTS OF THE UNIVERSITY OF CALIFORNIA

and

#### BROBECK CORPORATION

## INTRODUCTION

This Second Modification to Schedule of Subcontract 4368005 between the University and the Subcontractor amends, by mutual agreement of the parties, the Schedule in the following particulars only:

ARTICLE III - ESTIMATES AND FIXED FEE - delete paragraph A only and substitute therefor:

"The presently estimated cost of the work under this Subcontract is ONE HUNDRED SIXTY-SEVEN THOUSAND, EIGHT HUNDRED NINETY-SIX AND NO/100 DOLLARS (\$167,896.00) exclusive of the Subcontractor's fixed fee. The Subcontractor's fixed fee is SIXTEEN THOUSAND, SEVEN HUNDRED EIGHTY-TWO AND NO/100 DOLLARS (\$16,782.00). The aggregate of presently estimated cost and fixed fee is ONE HUNDRED EIGHTY-FOUR

THOUSAND, SIX HUNDRED SEVENTY-EIGHT AND NO/100 DOLLARS (\$184,678.00)."

All other provisions of the Schedule of Subcontract 4368005 shall remain in full force and effect, except as amended herein.

(Increase \$39,774.00)

#### SECOND MODIFICATION TO EXHIBIT I OF

#### SUBCONTRACT 4368005

#### between

#### THE REGENTS OF THE UNIVERSITY OF CALIFORNIA

and

#### BROBECK CORPORATION

## INTRODUCTION

This Second Modification to Exhibit I - Scope of Work of Subcontract 4368005 between the University and the Subcontractor amends, by mutual agreement of the parties. Exhibit I in the following particulars only:

SECTION III - TECHNICAL SCOPE OF WORK is modified, in part, in the following particulars only:

"Task II. C - Engineering Design and Detail for an Electron Beam Window

The objective of this task focuses on the Vacuum-to-Air Rotating Window design study which concentrates upon the mechanical and thermal problems of the spinning disk and its support system. Critical design items: gyrodynamics, balance and stress.

The Subcontractor's efforts shall be directed toward engineering design and detail drawings for fabrication of a prototype of the Vacuum-to-Air Rotating Window.

In conduct of this task, the stresses due to high centrifugal force, thermal shock and vacuum loading shall be part of the design consideration. University acceptable combinations of material properties, dimension and configurations shall be selected by Subcontractor for design. Subcontractor shall calculate bearing friction, aerodynamic drag and turbo-molecular pumping loads to determine drive power and parasitic heat loads. Means for radiation and convection cooling of the rotating disk shall be evaluated.

Upon completion of the engineering design for the rotating elements, Subcontractor shall complete the detail design for the Rotating Window and provide a set of drawings suitable for shop fabrication as the final documentation of this effort, acceptable to the University's Technical Representative.

SECTION IV - LEVEL-OF-EFFORT - delete as written and substitute therefor:

"The distribution and allocation of technical and professional effort under this Subcontract shall be approximately as follows:

Type of Personnel	Man Hours (Estimated)	
	Task I Chemistry Support	Task II ATA Support
Engineer 16	767	1049
Engineering Associate 7		1160"

All other provisions of Exhibit I of Subcontract 4368005 shall remain in full force and effect, except as amended herein.

#### TELECON

DATE:

February 11, 1985

File: 7300-962A 7300-976

FROM:

Diane Melendez - LLNL Warren H. Eukel

TO:

SJJUECT:

CONTRACT AUTHOR ZATION

Ms. Melendez gave verbal authorization to proceed with the long lead item procurement on a CPFF Contract #6551805. The total amount authorized is \$83,997. This is from our proposal 7300-962A. Our consolidated Proposal #7300-976 for \$240,262 has not been approved because purchasing does not have a requisition for the proposal.

WWE:jw

cc: K.M. Thomas

#### SUBCONTRACT 6551805

#### between

#### THE REGENTS OF THE UNIVERSITY OF CALIFORNIA

and

## BROBECK CORPORATION

## INTRODUCTION

This Cost Plus Fixed Fee Subcontract is made and entered into by and between The Regents of the University of California, hereinafter called the "University" and Brobeck Corporation hereinafter called the "Subcontractor".

The Regents of the University of California, a California corporation, have entered into a contract, W-7405-ENG-48 with the United States Government, hereinafter called "Government", represented by the Department of Energy, hereinafter called "DOE", for the performance of certain energy research and development work at the University of California Lawrence Livermore National Laboratory. This Subcontract is entered into in furtherance of the performance of the work provided for in the prime contract.

In accepting this Subcontract, the Subcontractor agrees to perform the Subcontract work in accordance with the following documents which collectively constitute the Subcontract and are attached hereto and by this reference made a part hereof:

> Subcontract Signature Page Schedule consisting of 6 pages Exhibit 1 - Statement of Work General Provisions dated July 1983

,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,	
ACCEPTEO:	AUTHORIZED:
BROEECK CORPORATION	THE REGENTS OF THE UNIVERSITY OF CALIFORNIA
BY: Marren W. Eukel	BY: M. R. Eaton
TITLE: Mis Pris.	TITLE: Deputy Contracts Manager Lawrence Livermore National Laboratory
DATE: 2/ay 6, 1985	DATE: 4/2/8T

FORM RL-2365A

(Revised 6/83)

#### SCHEDULE

## ARTICLE I - SCOPE OF WORK

The Subcontractor shall furnish the necessary facilities, supplies, equipment and personnel, except such as are furnished by the University or the Government, to conduct certain work generally described as the procurement of long lead time materials for the beam director. Subcontractor shall specify, procure, coordinate and generally provide technical guidance during the procurement of critical materials for the beam director project to be performed by the Subcontractor at locations approved by the University and Subcontractor's facility at Berkeley, California the nature and extent of which are more specifically described in EXHIBIT 1 - STATEMENT OF WORK hereto, and shall also deliver such materials, products, supplies and incidental services and reports as may be set forth in said EXHIBIT 1.

The University and DOE shall have the right to inspect Government property and the work and activities of the Subcontractor under this Subcontract at such time and in such manner as they shall deem appropriate. The Subcontractor shall include in all subcontracts and purchase orders under this Subcontract involving research and development or fabrication, or where costs incurred are a factor in determining the amount payable to the vendor, a similar provision making this paragraph applicable to the subcontractor or vendor.

(Revised 6/83)

## ARTICLE II - TERM

Unless completely performed prior thereto or sooner terminated in accordance with CLAUSE 14 - TERMINATION, the work described in ARTICLE I - SCOPE OF WORK, shall begin February 11, 1985 and shall continue through December 31, 1985 which is the current period of time estimated as necessary for completion of said work, provided that the term of this Subcontract shall continue for such period of time as required to comply with the reporting and close out procedures of this Subcontract. Neither party guarantees the aforestated estimate of time and work under this Subcontract and, except as necessary to comply with reporting and close out procedures, the term shall cease on the last date mentioned unless the University by written notice to Subcontractor extends, at its sole option, such period for such time or times as it considers appropriate for completion of the work described in ARTICLE I - SCOPE OF WORK. Such an extension of time will not be a basis for a claim of additional fee by Subcontractor.

(Revised 2/83)

## ARTICLE III - ESTIMATES AND FIXED FEE

## A. Initial Estimate of Cost and Fixed Fee

The presently estimated cost of the work under this Subcontract is SEVENTY-SIX THOUSAND THREE HUNDRED SIXTY-ONE AND 00/100 DOLLARS (\$76,361.00) exclusive of the Subcontractor's fixed fee. The Subcontractor's fixed fee is SEVEN THOUSAND SIX HUNDRED THIRTY-SIX AND 00/100 DOLLARS (\$7,636.00). The aggregate of presently estimated cost and fixed fee is EIGHTY-THREE THOUSAND NINE HUNDRED NINETY-SEVEN AND NO/100 DOLLARS (\$83,997.00).

## B. Revised Estimate of Cost

The presently estimated cost of the work under this Subcontract may be increased or decreased by written agreement of the parties.

## C. Limit on Total Amount of Allowable Costs

Payments on account of costs shall not in the aggregate at any time exceed the amount of estimated costs specified in the Subcontract.

# D. <u>Notice of Costs Approaching Subcontract Amount - Subcontractor Excused</u> Pending Increase

Whenever the Subcontractor has reason to believe that the total costs of the work under this Subcontract, exclusive of fixed fee, will exceed the estimated cost of the work then in effect, the Subcontractor shall promptly notify the University in writing. The Subcontractor shall also notify the University in writing when the aggregate of expenditures and cutstanding commitments allowable under this Subcontract, excluding fixed fee, is equal to 75% (or such other percentage as the University may from time to time establish by notice to the Subcontractor) of the estimated cost of the work then in effect. When such expenditures and outstanding commitments, excluding fixed fee, equal 100% of such amount, the Subcontractor shall make no further commitments or expenditures (except to meet existing commitments) and shall be excused from further performance of the work unless and until the University shall increase the estimated cost of the work in accordance with Paragraph 8. above.

# E. <u>The University's Right to Terminate not Affected</u>

The giving of any notice by either party under this ARTICLE III shall not be construed to waive or impair any right of the University to terminate the Subcontract under the provisions of CLAUSE 14 - TERMINATION.

#### F. Cost Information

The Subcontractor shall maintain current cost information adequate to reflect the cost of performing the work under this Subcontract at all times while the work is in progress and shall prepare and furnish to the University such written estimates of cost and information in support thereof as the University may request.

## G. Correctness of Estimates not Guaranteed

Neither the University nor the Subcontractor guarantees the correctness of any estimate of cost or estimate of time for the performance of the work under this Subcontract, and there shall be no adjustment in the amount of the Subcontractor's fixed fee by reason of errors in the computation of estimates or differences between such estimates and the actual cost or time for the performance of the work.

(Revised 2/83)

#### ARTICLE IV - CONSIDERATION

Payment for allowable costs, reimbursable in accordance with ARTICLE V - REIMBURSEMENT OF COSTS, and of the fixed fee set forth in ARTICLE III - ESTIMATES AND FIXED FEE, shall constitute complete compensation for Subcontractor's services, including profit and all items or kinds of expenses not allowable under the terms of this Subcontract.

(Revised 2/83)

## ARTICLE V - REIMBURSEMENT OF COSTS

Α. The allowable cost of performing the work under this Subcontract shall be the costs and expenses (less applicable income and other credits) that are actually incurred by the Subcontractor, are applicable and properly chargeable, either as directly incident or as allocable through appropriate distribution or apportionment, to the performance of the Subcontract in accordance with its terms and are determined to be allowable pursuant to this paragraph. The determination of the allowability of cost hereunder shall be based on: 1) reasonableness, including the exercise of prudent business judgment; 2) consistent application of generally accepted accounting principles; and recognition of all exclusions and limitations set forth in this ARTICLE V, or elsewhere in this Subcontract as to types or amounts of items of This Subcontract recognizes that audit hereunder will be in accordance with this subcontract and cost principles and procedures of Subpart 1-15.2 of the Federal Procurement Regulations (41 CFR 1-15.2) as supplemented or modified by DOE PR 9-15.2 (41 CFR 9-15.2) including DOE PR 9-15.205.3 "Bidding Costs" and 9-15.205-35 "Independent Research and Development (IK&D) and Bid and Proposal (B&P) Costs", and as supplemented or modified by DOE PR 9-15.50 (41 CFR 9-15.50), in effect on the date of this Subcontract. The audit might be performed by the Government Agency having the preponderant workload. However, reserves the right to conduct its own audit of expenditures under this Subcontract.

(Revised 9/84)

#### B. OVERHEAD

- Pending final audit and determination of overhead, the Subcontractor shall be paid a provisional overhead rate, as approved by the University from time to time and authorized in writing by the University. Such provisional payments will be adjusted to the actual overhead costs and expenses determined as set forth in this ARTICLE V and principles herein established.
- When actual reimbursable overhead costs have been determined pursuant to this Subcontract, adjustment shall be made for the difference between the sum to be determined and the sum of the provisional payments made under Paragraph 1., above.
- 3. Notwithstanding Paragraphs B.1 and B.2 above, the parties hereto agree that University shall not be obligated to pay any amount for Labor Overhead exceeding 92.8% of direct labor, and General and Administrative Expenses (G&A) exceeding 30.0% of total direct cost and Overhead, for the period commencing February 11, 1985.

(Revised 2/83)

## ARTICLE VI - RIGHTS TO PROPOSAL DATA

Except for technical data contained in pages (None) of the Subcontractor's proposal dated November 27, 1984 which are asserted by the Subcontractor as being proprietary data, it is agreed that as a condition of the award of this Subcontract, and notwithstanding the provisions of any notice appearing on the proposal, the University and Government shall have the right to use, duplicate and disclose and have others do so for any purpose whatsoever, the technical data contained in the proposal upon which this Subcontract is based.

(Revised 2/83)

#### ARTICLE VII - GENERAL PROVISIONS

- A. The Subcontractor shall comply with the CLAUSES set forth in the General Provisions dated July 1983 as may be altered or modified hereunder and in the ARTICLE VIII ALTERATIONS and ADDITIONS.
- 8. CLAUSE 31, paragraphs A.1, A.2, Authorization and Consent (page no. 26 and 27), shall or shall not be applicable to this Subcontract as follows:

Paragraph A.1 is [X] is not [] applicable to this Subcontract.

Paragraph A.2 is [ ] is not [X] applicable to this Subcontract.

C. CLAUSE 31, paragr phs B.1, B.2, Patent Indemnity (page no. 27), shall or shall not be applicable to this Subcontract as follows:

Paragraph B.1 is [X] is not [ ] applicable to this Subcontract.

Paragraph 8.2 is [ ] is not [X] applicable to this Subcontract.

D. CLAUSE 31, paragraphs D.1, D.2, Patent Rights (page no. 28 or 36), shall be applicable to this Subcontract as follows:

Paragraph D.1 PATENT RIGHTS (LONG FORM) is [ ] is not [X] applicable to this Subcontract.

Paragraph D.2 PATENT RIGHTS (SMALL BUSINESS FIRMS AND NQNPROFIT ORGANIZATIONS, MARCH 1982) is [X] is not [ ] applicable to this Subcontract.

E. CLAUSE 31, paragraph G, Rights in Technical Data, subparagraphs G (page no.43) and H (page no.44) shall or shall not be applicable to this Subcontract as follows:

Subparagraph G is [X] is not [ ] applicable to this Subcontract.

Subparagraph H is [ ] is not [X] applicable to this Subcontract.

(Revised 6/83)

## ARTICLE VIII - ALTERATIONS AND ADDITIONS

The following Clauses shall be applicable to this Subcontract:

Clause 35 Cost or Pricing Data (page no. 48)

In addition, the following Articles are herby incorporated into and made a part of this Subcontract:

ARTICLE 38 - Foreign Owership, Control, of Influence Over Contractor, Form LL 2358 FOCI-2 (8/83)

## ARTICLE 39 - Organizational Conflict of Interest

- A. The primary purpose of this article is to aid in ensuring that the Subcontractor is not biased in the performance of the work under this Subcontract, and does not obtain any unfair competitive advantage over other parties by virtue of its performance of this Subcontract. However, nothing herein shall be construed to interfere with Subcontractor's right to the normal flow of benefits from performance of this Subcontract.
- B. In the event DOE, the University or the Subcontractor are of the opinion that such bias or unfair competitive advantage may exist, or appear to exist, then, (1) the University or Subcontractor will notify DOE and supply information requested by DOE based on such potential conflict of interest, subject to proprietary rights of others, and (2) if DOE is of the opinion that applicable criteria in the DOE regulations, DOE or the University upon notice from DOE will promptly inform the Subcontractor. DOE, the University and the Subcontractor will then enter into good faith discussions concerning whether a conflict of interest actually exists, and if so what appropriate measures might be taken to eliminate, avoid or mitigate such conflict.

#### EXHIBIT 1 - STATEMENT OF WORK

to

#### SUBCONTRACT 6551805

between

#### THE REGENTS OF THE UNIVERSITY OF CALIFORNIA

and .

#### BROBECK CORPORATION

#### I. INTRODUCTION

As approved and directed by the University, Subcontractor shall provide technical and professional effort directed toward the effort specified in Part III - TECHNICAL SCOPE OF WORK.

As provided in CLAUSE 3 - CHANGES, the University may direct, in writing, charges within this Scope of Work.

#### II. PURPOSE

The purpose of this work is to provide technical guidance and engineering support to assure material acquisition and proper fabrication of long lead time items for the Beam Nirector.

## III. TECHNICAL SCOPE OF WORK

As approved or directed by the University, Subcontractor shall furnish all necessary personnel, materials and facilities, except as may be provided for elsewhere herein, to conduct the Task described below:

#### TASK I - Beam Director Long Lead Material

Subcontractor shall initiate the procurement process to specify, procure, coordinate and generally provide technical guidance and engineering support during the procurement of the following material.

- ACHROMAT Permanent Magnets (1 lot)
   Housing (Tooling & Material) (1 each)
   VERNIER Conductor (1 lot)
- IV. LEVEL OF EFFORT

The distribution and allocation of technical and professional effort under this Subcontract shall be approximately as follows:

Engineer Senior Engineer Designer

90 60

## V. REPORTS

Subcontractor shall prepare and submit the following reports to the University:

- A. Financial Reports (Type A) shall be submitted by the fifteenth of each month and shall include all costs incurred during the preceding month and outstanding commitments to the end of the month. In the event actual cost data is unavailable, Subcontractor's monthly financial report shall contain estimated expenditures, identified as such.
- B. Monthly Progress Reports (Type 8) shall be submitted by the fifteenth of each month and may be informal letter summaries in a format approved by the University's Technical Representative. These reports should contain a description of work performed during the month reported and work planned for the succeeding month.
- C. Final Report (Type C) shall be submitted upon completion of the work and contain a comprehensive summary of all work results and conclusions. The form and content of Type C Reports shall be acceptable to the University's Technical Representative. If so requested, a draft copy of the Report shall be submitted to the University's Technical Representative for approval prior to final typing.

# D. <u>Distribution of Reports</u>

Reports shall be separately addressed and transmitted to:

University of California Lawrence Livermore National Laboratory P. O. Box 5012 Livermore, CA 94550 Attention: (Intended Recipient)

Type of Report	No. of Copies	Recipient
A and B A and B	l As Requested	Diane Melendez, L-650 Dave Milani, L-544
С	As Requested	Coleman Johnson, L-544 Diane Melendez, L-650

Subcontractor shall not distribute reports of work under this Subcontract to any individual or organization other than those indicated above or an authorized representative of the U. S. Department of Energy without prior written approval of the Contract Administrator.

## E. Interim Reports

It is understood that there will be other information exchanged between the parties from time to time. These data may be exchanged directly between the parties concerned; formal reporting and distribution is not required in these cases.

## VI. COORDINATION AND ADMINISTRATION

The University's Technical Representative(s) under this Subcontract are Dave Milani and Coleman Johnson, or their designee(s), who shall represent the University in matters relating to the technical performance of the Scope of Work described herein. During the established term of this Subcontract, the Technical Representatives will interpret the technical requirements of the Scope of Work and will determine the emphasis and direction of the Subcontractor in the conduct of the work within the level and allocation of effort established herein. All other matters relating to the performance of this Subcontract are reserved to the Contract Administrator. Provided, however, any technical direction which will affect the estimated cost or time for performance of this work shall require prior formal amendment of this Subcontract or prior written direction from the Procurement Manager, or his designee, as provided in CLAUSE 3 - CHANGES of the Terms and Conditions. Technical direction resulting in work outside the general Scope of Work requires prior formal amendment of this Subcontract.

The University's Contract Administrator is M. R. Eaton, or his designee. All matters relating to the interpretation and administration of this Subcontract shall be conducted through the Contract Administrator. Subcontractor will direct all notices and requests for approval to the Contract Administrator; and any notice or approval from the University to the Subcontractor will be issued by the Contract Administrator.

## VII. ASSIGNMENT OF PERSONNEL

It is understood and agreed that Subcontractor's key technical personnel assigned to this work shall not be reassigned or replaced without prior University approval, except where such circumstances are beyond the reasonable control of the Subcontractor.

# VIII. HEALTH, SAFETY AND FIRE PROTECTION

The Subcontractor shall take all reasonable precautions in the performance of the work under this Subcontract to protect the health and safety of employees and members of the public and to minimize danger from all hazards to life and property, and shall comply with all pertinent health, safety, and fire protection regulations and requirements (including reporting requirements) of the University and DOE communicated to the Subcontractor.

In the event the Subcontractor fails to comply with said regulations or requirements of the University or the OOE, the University may without prejudice to any other legal or contractual rights of the University, issue an order stopping all or any part of the work; thereafter, a start order for the resumption of work may be issued at the discretion of the University.

- 0 - 1 - 1 - 1 FIRST AMENDMENT

to

SUBCONTRACT 6551805

between

THE REGENTS OF THE UNIVERSITY OF CALIFORNIA

and

**BROBECK COROPORATION** 

#### INTRODUCTION

This First Amendment to Subcontract 6551805 is entered into by and between The Regents of the University of California, hereinafter called "University", and Brobeck Corporation, hereinafter called "Subcontractor".

# <u>PURPOSE</u>

The purpose of this First Amendment to Subcontract 6551805 is to incorporate the following changed documents into this Subcontract.

NOW, THEREFORE, by mutual agreement of the parties, the following Subcontract documents, attached hereto are made a part of this Subcontract:

Modification to SCHEDULE Modification to Exhibit 1 - STATEMENT OF WORK

All other terms, conditions and provisions of Subcontract 6551805 shall remain in full force and effect, except as amended herein.

IN WITNESS WHEREOF, effective upon Subcontractor's signature acceptance of this First Amendment, Subcontract 6551805 is hereby amended by mutual Agreement of the parties.

ACCEPTED:

AUTHORIZED:

BROBECK CORPORTION

THE REGENTS OF THE UNIVERSITY OF CALIFORNIA

BY Marien W Eury!

BY H. L. Halunen

TITLE This thes.

TITLE Contracts Manager
Lawrence Livermore National Laboratory

DATE May 13, 1985

DATE 5/10/85

11E 11 (lleg / 3, 1 / 0 3)

A-43

1st Amendment S/C 6551085 4/85(1524X:30i)

#### FIRST MODIFICATION TO SCHEDULE

of

#### SUBCONTRACT 6551805

#### between

## THE REGENTS OF THE UNIVERSITY OF CALIFORNIA

and

#### BROBECK CORPORATION

## INTRODUCTION

This First Modification to SCHEDULE of Subcontract 6551805 between the University and the Subcontractor amends, by mutual agreement of the parties, the SCHEDULE in the following particulars only:

ARTICLE III - ESTIMATES AND FIXED FEE, delete Paragraph A only and substitute therefor:

"The presently estimated cost of the work under this Subcontract is TWO HUNDRED EIGHTEEN THOUSAND FOUR HUNDRED TWENTY DOLLARS AND NO/100 (\$218,420.00) exclusive of the Subcontractor's fixed fee. The Subcontrator's fixed fee is TWENTY THOUSAND SEVEN HUNDRED FIFTY DOLLARS AND NO/100 (\$20,750.00). The aggregate of presently estimated cost and fixed fee is TWO HUNDRED THIRTY-NINE THOUSAND ONE HUNDRED SEVENTY DOLLARS AND NO/100 (\$239,170.00)"

All other provisions of the SCHEDULE of Subcontract 6551805 shall remain in full force and effect, except as amended herein.

#### FIRST MODIFICATION TO EXHIBIT 1

ta

#### SUBCONTRACT 6551805

#### hetween

#### THE REGENTS OF THE UNIVERSITY OF CALIFORNIA

and

#### BROBECK CORPORATION

## INTRODUCTION

This First Modification to EXHIBIT 1 - STATEMENT OF WORK to Subcontract 6551805 between the University and the Subcontractor amends, by mutual agreement of the parties, EXHIBIT 1 in the following particulars only:

SECTION III - TECHNICAL SCOPE OF WORK is modified, in part, in the following particulars only:

Add TASK II:

# "TASK II - Engineering Support, Fabrication, Assembly and Bench Test Vernier and Achromatic Magnet Assembly

Subcontractor shall fabricate, assemble, bench test, and deliver to LLNL the Achromat Magnet Assembly and the Vernier Steering Magnet Assembly. In conduct of this work, Subcontractor's work shall include, but is not limited to the following:

Procurement of materials, fabrication, selection, and supervision of specialty sub-subcontractors."

SECTION IV - LEVEL OF EFFORT, is hereby amended to add the following estimate of effort:

Type of Personnel	Man Hours (Estimated)
Engineer Senior Engineer Designer Engineer Associated 7 (Tech)	214 398 1314"

Add <u>SECTION IX - Materials</u>, to this Subcontract.

# "SECTION IX - Materials

Subcontractor shall deliver all assemblies to LLNL FOB Destination."

All other provisions of EXHIBIT 1 of Subcontract 6551805 shall remain in full force and effect, except as amended herein.

1st Mod. to Exhibit 1 A-45 S/C 6551805 5/85(1624X:30b)

# APPENDIX B. REQUESTS FOR QUOTATIONS (RFQ's)

RFQ	DATE	PART(S)	P.O.	AWARDED TO
4500-300-A	2-12-85	Magnet segments	086	Permag Sierra Corp.
4500 <b>-</b> 300-B	2-20-85	Hous i ng	110	Edwards Enterprises
4500-300-1	4-23-85	Segment carriers	122	Bennett-Hopkins
4500-300-2	5-1-85	Magnet spacers, etc.	128	Accurate Mfg.
4500-301-3	5-17-85	Spool, coil spacers,	etc 143	Diamond Tool
4500-300-C	10-1-85	Spare segment carrie	rs 239	Diamond Tool
4500-301-6	10-4-85	Vacuum housing parts	(253 (254	(Caral, Inc. (Schrader Scientific
4500-300-7	10-9-85	Vacuum vessel parts	255	Jensen Prototype Machines



February 12, 1985

File: 4500-3<del>01</del>

[RFQ 4500-300-A]

Ms. Gail Fernandez Permag Sierra Corporation 1159 Sonora Court Sunnyvale, California 94086

Dear Ms. Fernandez:

You will recall your Quotation No. 2761 of 9-4-84 for dipole and quadrupole magnets. You had been contacted by Mr. Francis C. Younger of our firm. Since them, there have been some minor changes which necessitate an updated quotation.

We are requesting a quotation on permanent magnets shown dimensionally on our drawings:

95D1734	Dipole 11 sets of 16	=	176 segments
95D17 <b>33-</b> 1	Quadrupole Double Defocusing -		·
	5 sets of 1		80 segments
95D1733 <b>-</b> 2	Quadrupole Single Defocusing -		
	3 sets of 1	16 =	48 segments
9501732	Quadrupole Double Focusing		
	6 sets of 1	.6 ≈	96 segments
	•		400 segments

Please note that some of the quadrupoles are long and some are short. This is described on the enclosed drawings.

The magnets are to be made of a material having the magnetic properties of Crucible Magnetics "Ferrimag 7B." A residual induction of 3800 Gauss and a coersive force of 3500 Oersteds are required. The residual induction and coercive force shall not vary by more than 2% from magnet to magnet and the direction of magnetization shall be as shown on the drawings plus or minus 2 degrees. This requires that all the magnet segments shall be of the same botch and shall be so certified.

Please note that the ends of the dipole segments are not orthogonal to the sides whereas the ends of the quadrupole segments are orthogonal. This will undoubtedly require special care in machining operations.

The magnetic orientation of each finished segment must be clearly shown to facilitate proper assembly in the magnet housings. We prefer arrows showing North as is done in the drawings. Each segment shall be marked with the proper drawing number so as to assist the assembly operation.

(415) 524-8664

1235 Tenth Street Berkeley, CA U.S A. 94710-1593 If you have any questions, please call Mr. Younger at 524-8664.

Very truly yours,

Jack T. Guan

Senior Mechanical Engineer

JTG:jw

Enclosures.



February 20, 1985

File: 4500-300

FOR FILE: See attached mailing list.

[ADR]

Subject: REQUEST FOR QUOTATION 4500-300-B

ACHROMAT HOUSING

Dear [NAME]

We request your quotation on furnishing one (1) Achromat housing per Brobeck Corporation Drawing Number 9531739.

Because of budget constraints, the work is to be performed in two stages as outlined below. Each stage should be separately priced and quoted as to required delivery time after your receipt of our order to proceed with each phase.

## Phase One - Tooling and stock procurement.

- a. Purchase aluminum stock.
- b. Machine parting line surfaces.
- c. Temporarily join the two halves.
- d. Machine outside diameter to finish size.
- e. Manufacture all jigs necessary for Phase Two.

#### Phase Two - Fabrication.

 Perform all work necessary to produce the finished part per Drawing No. 9501739.

Prices should be based on delivery to Brobeck Corporation in Berkeley, CA.

We would appreciate any constructive suggestions you care to make that will, in your opinion, reduce the cost without impairing function.

(415) 524-8664

1235 Tenth Street Berkeley, CA U.S.A. 94710-1593 Your attention is particularly directed to Note 3 of Drawing S5J1739. This may require extra care in the machining and annealing sequence. Please have your quotation in amation to Brobeck Corporation by March 15, 1985.

Very truly yours,

Jack T. Gunn

Senior Mechanical Engineer

JTG:jw

Enclosure: Dwg. No. 95J1739.

#### BIDDER'S ADDRESS LIST

## RFQ 4500-300-8 sent to:

[ADR] 1;

Allied Engineering Company 2421 Blanding Street Alameda, CA 94501

[ADR] 2;

Bennett-Hopkins Company 3592 Haven P.O. Box 53076 Redwood City, CA 94063

[ADR] 3;

Caral Inc. 578 Cleveland Avenue Albany, CA 94706

[ADR] 4;

Edwards Enterprises 8455 Cabot Court Newark, CA 94560

[ADR] 5;

Numeric Machine Company 4439 Enterprise Fremont, CA 94538

FILE 300 REF BROBECK **LALCULATION** BERKELEY, CALIFORNIA SHEET PAGE J08 OF RFQ 4500 - 300 - B CHK DATE END NOTES PH. 1 END FIRM TOTAL PAICE PH. 1 PAICE PH.2 Will 42,500 CARAL INC. 10,625 10 weeks hold ARO .004 0 Bob Sand NUMERIC MACH. (2) Another 90 Days 52,715 28,375 90 Days ARG Ted Foster A-RO ALLED ENGR. NoBel No Bid NoBid Earl Powell. Another 3 BENNET HOPKINS 16 Wareks 4 weeks 12,720 9,840 ARO John Hopkins Another 5weeks 22,000 5 weeks EDWARDS ENTERP. 9,500 ARD Pete Breidbach 800. 2) Tool runouts & Inspection procedures need definition 3 Includes inspection on coordinate measuring Machine



April 23, 1985

File: 4500-300

FOR FILE: See attached mailing list.

[ADR]

Subject: REQUEST FOR QUOTATION 4500-300-1

SEGMENT CARRIERS

Dear [NAME]

We request your quotation on the fabrication and delivery of the following items.

Item 1. 8 each Segment Carrier - Dipole #95C1737

1tem 2. 7 each Segment Carrier ~ Quadrupole, long #9501736-1

Item 3. 2 each Segment Carrier - Quadrupole, short #9501736-2

DELIVERY: Two of Item 1, two of Item 2, and two of Item 3 within 6 weeks ARO.

Balance, 10 weeks ARO.

Please quote according to above.

Since these carriers are for the support of critical elements in a physics apparatus, it is important that the form tolerances be met. If you have any reservations about meeting these requirements, please so indicate on your bid.

We request your written quotation within ten (10) days of receipt of this letter.

Very truly yours,

Jack T. Gunn Senior Engineer

JTG:jw

(415) 524-8664

1235 Tenth Street Berkeley, CA U.S.A. 94710-1593

## BIDDER'S ADDRESS LIST

# RFQ 4500-300-1 sent to:

[ADR] 1;

Allied Engineering Company 2421 Blanding Street Alameda, CA 94501

[ADR] 2;

Bennett-Hopkins Company 3592 Haven P.O. Box 53076 Redwood City, CA 94063

[ADR] 3;

Caral Inc. 578 Cleveland Avenue Albany, CA 94706

[ADR] 4;

Coast Metal Cutting Company 2500 Bay Road Redwood City, CA 94063

[ADR] 5;

Diamond Tool & Die Company 508 - 29th Avenue Oakland, CA 94601

[ADR] 6;

Edwards Enterprises 8455 Cabot Court Newark, CA 94560

[ADR] 7;

Numeric Machine Company 4439 Enterprise Fremont, CA 94538



May 1, 1985

File: 4500-300

FOR FILE: See attached mailing list.

[ADR]

Subject: REQUEST FOR QUOTATION 4500-300-2

MAGNET SPACERS + OTHER PARTS

Dear [NAME]

We solicit your bid on the following items:

Quantity	<u>Name</u>	Drawing No.
18	Magnet Spacer	9581738
1	Flange Ring	9501744
1	Adjusting Sleeve	9501745
1	Retaining Flange	95B1746
1	Retaining Sleeve	95B1747
2	Barrier Ring	9581748

Please quote based on delivery via UPS to Brobeck Corporation in Berkeley.

Close of bidding is May 15, 1985.

Please feel free to telephone me to discuss any questions you may have regarding these parts.

Yery truly yours,

Jack T. Gunn

Senior Mechanical Engineer

JTG:jw

Enclosures: Drawings.

(415) 524-8664

1235 Tenth Street Berkeley, CA U.S.A. 94710-1593

#### BIDDER'S ADDRESS LIST

ŀ	₹	F(	) (	150	J-3(	00-2	. se	nt '	to:

[1]

Accurate Manufacturing Company 4770 San Pablo Avenue Emeryville, CA 94608

[2]

August Manufacturing Company 1466 36th Avenue Oakland, CA 94601

[3]

Caral Inc. 578 Cleveland Avenue Albany, CA 94706

[4]

International Precision Machining 23839 Connecticut Street, Unit #5 Hayward, CA 94545

[5]

McNeill Manufacturing Company 2914 E. Seventh St. Oakland, CA 94601



May 17, 1985

File: 4500-301

FOR FILE: See attached mailing list.

[ADR]

Subject: REQUEST FOR QUOTATION 4500-301-3

SPOOL, COIL SPACERS, AND OTHER PARTS

Dear [NAME]

We solicit your quotation on the following parts (drawings enclosed):

## GROUP A

Number	Name	<u>Qty</u>
95-#1707	Spool	1
9501708	Locknut	1
95B1717-1	Clamp	4
9581717-2	Clamp	4
95C1723	Power Flange	1
95C1724	Cooling Flange	ī
95B1727	Spreader	ī
95B1729	Terminal	ī

Since somewhat different machining capabilities are involved, we would appreciate a separate quote on:

## GROUP B

95C1712	Y Coil Spacer	1
· · · <del>-</del>		-
95C1713	X Coil Spacer	1
	" oo i i opacci	*

Close of bidding is May 31, 1985. Please quote separately on either, or both, of Groups A and B. State terms and conditions and include delivery to Brobeck Corporation via UPS.

I am available to clarify any aspect of the drawings. We would appreciate your comments and suggestions as to how to improve the cost or the design of these parts. Please feel free to phone.

Jack

Jack T. Gunn Senior Mechanical Engineer

Enclosures: Drawings.

(415) 524-8664

WWE:jw

1235 Tenth Street Berkeley, CA. U.S.A. 94710-1593

#### BIDDER'S ADDRESS LIST

#### RFQ 4500-301-3 sent to:

[1]

Allied Engineering Company 2421 Blanding Street Alameda, CA 94501

[2]

August Manufacturing Company 1466 36th Avenue Oakland, CA 94601

[3]

Caral Inc. 578 Cleveland Avenue Albany, CA 94706

[4]

Diamond Tool & Die Company 508 - 29th Avenue Oakland, CA 94601

[5]

Edwards Enterprises 8455 Cabot Court Newark, CA 94560

BROBECK REF BERKELEY, CALIFORNIA USA **CALCULATION** SHEET Achining PK1-VEP. NIER .301-3 PAGE SUMMINAY RFQ 4500-301-3 BID GF.OUP B GROUP A FIRM CARAL \$4350 + Time & Mala il On 95 C 1707 6 weeks 7v1-= KS P6666 # +471 EDWARDS ENTER PRISES 6 weeks 4 Wreks Diamond Tool Sweeks. 5 weeks 4402 TX

19/85 achomst J. Gunn Spare begnet Carriers two short Dund carriers one dipole carrier # 3200 lot 5 week 4 RO Bennet - Hopkins Redword City \$1626 lot 4 weeks ARO Dismond tool & Acenste Mg Co Energially (beyond their capacity) Discommend award to Diamed Tool P.D. #239



October 4, 1985

File: 4500-301

FOR FILE: See attached mailing list.

[ADR]

Subject: REQUEST FOR QUOTATION 4500-301-6 VACUUM HOUSING PARTS

Dear [NAM2]

We solicit your bid on the listed vacuum housing parts. All parts are to be certified leak free when tested with a helium mass-spectrometer leak detector and must be scrupulously clean for high vacuum service. All sealling surfaces must be protected so as to be free of scratches and nicks.

CLOSE OF BIDS: October 14, 1985.

SCHEDULE REQUIREMENTS: Parts needed by November 6, 1985.

Please bid each item separately. We reserve the right to award bids on a piece-by-piece basis. Telephone bids are encouraged. We welcome any suggestions which will make these parts less expensive without compromising their performance.

Drawing No.	Name	<u>Qty</u>
95C1772	Cover Plate	2
95C1771-1	Pumpout Spool	ì
95C1771-2	Pumpout Spool	1
95C1770	Spool	1
95D1769	2 Port Tank	1
9501724	Cooling flange	1
95C1773	Port Cover	1

Drawings are enclosed for bid purposes only.

Very truly yours,

(415) 524-8664

1235 Tenth Street Berkeley, CA U.S.A. 94710-1593 Jack T. Gunn Senior Engineer

#### BIDDER'S ADDRESS LIST

RFQ	4500	-301	-6	sent	to:

[1]

[3]

- Accurate Manufacturing Company 4770 San Pablo Avenue Emeryville, CA 94608
  - [2]
  - Caral Inc. 578 Cleveland Avenue Albany, CA 94706
    - Diamond Tool & Die Company
    - 508 29th Avenue Oakland, CA 94601
    - McNeill Manufacturing Company 2914 E. Seventh St. Oakland, CA 94601
    - [5]
      Schrader Scientific Company
      2976 Arf Avenue
  - Hayward, California 94545
  - Jensen Prototype Machines 940 Lemon Street Martinez, California 94553

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October 9, 1985

File: 4500-300

FOR FILE: See attached mailing list.

[ADR]

Subject: REQUEST FOR QUOTATION 4500-300-7

VACUUM VESSEL PARTS

Dear [NAME]

We solicit your bid on the following vacuum vessel parts. Since they will be in a high-vacuum environment, they must be scrupulously clean. Strict adherence to the drawing tolerances is required, particularly to the concentricity call outs.

CLOSE OF BIDS: October 17, 1985.

SCHEDULE REQUIREMENTS: Parts needed by November 12, 1985.

Telephone bids are encouraged. We we come any suggestions which will make these parts less expensive without compromising their performance.

	Drawing No.	Name	Oty .
	95B1777	Plate	2
	9581778	Spoo!	1
	95B1779	Bearing	1
	9581780	Bar	2
	9501774	Flange	1
	9501773	Cover Plate	1
	95C1775	Adapter Plate	1
	9501776	Bolt Ring	1
יינפיינ	dinos are enclose	d for hid nurnoses on	1v

Drawings are enclosed for bid purposes only.

Very truly yours,

(415) 524-8664 1235 Tenth Stre

Jack T. Gunn Senior Engineer

1235 Tenth Street Berkeley, CA U.S.A. 94710-1593

## BIDDER'S ADDRESS LIST

RFQ	4500-300-7	sent to:

[1]

Accurate Manufacturing Company 4770 San Pablo Avenue Emeryville, CA 94608

[2]

Allied Engineering Company 2421 Blanding Street Alameda, CA 94501

[3]

Bennett-Hopkins Company 3592 Haven P.O. Box 53076 Redwood City, CA 94063

[4]

Caral Inc. 578 Cleveland Avenue Albany, CA 94706

[5]

Diamond Tool & Die Cumpany 508 - 29th Avenue Oakland, CA 94601

[6]

Jensen Prototype Machines 940 Lemon Street Martinez, California 94553

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#### APPENDIX C. PURCHASE ORDERS

All purchase orders from the achromat and vernier design-and-build project are included here, in numerical order. The purchase orders are listed in Tables 9-1 (achromat) and 9-3 (vernier) in 89.0, Volume I.

NOTE: The achromat is Job Number 300 (Account 4500-300) and the vernier is Job Number 300 (Account 4500-301).

#### WILLIAM M. BROBECK & ASSOCIATES

ALL ITEMS PRINTED IN RED MUST BE FILLED IN BY REQUISITIONER PURCHASE REQUISITION Berkeley Ekeprist DISPOSITION DATE NEEDED TYPE P.O. & MAIL ADDRESS 2-15-85 ORDER WIRED ATTN. OF OFFICER TELEPHONED MCCOUNT 4500-301 F.0.8. DATE PROMISEO TAXABLE DATE N-30 2-15-15 ESTIMATED TOTAL DESCRIPTION (USE SEPARATE REQUISITION FOR EACH VEHOOR) ITEM QUANTITY SALES TAX ESTIMATED TOTAL VALUE OF ORDER MUST BE STATED BY REQUISITIONER - \$ DELIVER TO Suggested Sources REQUESTOR PURCHASING Previous Purchase Order No. APPROVED

BA-30 (REV 1-79)

# **BROBECK CORPORATION**

COPY

PURCHASE ORDER NUMBER

080

THIS HUMBER MUST APPEAR
ON ALL INVOICES, PACKAGES
AND SHIPPING PAPERS.

1235 TENTH STREET . BERKELEY, CA 94710 . (415) 524-8664

Ship to:

PURCHASE ORDER

PERMALUSTER INC. 1844 North Keystone Burbank, CA 91504

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BROBECK CORPORATION 1235 Tenth Street Berkeley, CA 94710

2-2	0-85		3-15-85	4540-301	SESALE YES MO	C.O.D. Advance	Proback	JTG
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he acknowledge receipt of your order for above material and will make shipment according to dalivery promise on this order, or as noted, acceptance of this order in implies agreements to price; and discounts shown my corrections in prices to be indicated by vender and accemtantied by much of supplies and acceptance of supplication. Prices omitted no original are to be inserted as this acknowledgment by sender, Conditions on "ginal are made a part of this order to which sailer ocrees by acceptance of this order.

BROBECK CORPORATION

BY Original signed by: M. Moshtaghi

# **BROBECK CORPORATION**

COPY

PURCHASE ORDER NUMBER 086

1235 TENTH STREET • BERKELEY, CA 94710 • (415) 524-8664

Ship to:

PURCHASE ORDE

**PERMAG** 1159 Sonora Court Sunnyvale, CA 94086 BROBECK CORPORATION 1235 Tenth Street Berkeley, CA 94710

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2.	80	segmen	ts per	Drawing	9501733-1	per Quota	ation #2871, 2-22	56.86	4,548.80
3.	48	segmen	ts per	Drawing	95D1733-2	per Quota	ntion #2872, 2-22	47.39	2,274.72
4.	96	segmen	ts per	Drawing	9501732 per	r Quotati	ion #2873, 2-22-85	56,86	5,458.56
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BROBECK CORPORATION

BY Original signed by: Kenneth M. Thomas

PINK: Purchasing Shipping

VENDOR BY

C-4

GOLD. Accounting

# WILLIAM M. BROPECK & ASSOCIATES RESEARCH - DEVEL MENT - ENGINEERING

FOR

INDUSTRY - BUSINESS - SCIENCE

1235 Tenth St. Barkeley, CA 94710 (415) 524-8664

EDWARDS ENTERPRISES

8455 CABOT COURT

PURCHASE ORDER NUMBER

# PURCHASE ORDE

SHIP AND BILL TO

1235 Tenth Street Berkeley, CA 94710

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WILLIAM M. BROBECK & ASSOCIATES By ory lest t. chil

Accounting

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RESEARCH - DEVEL MENT - ENGINEERING

BROBECK CORPORATIO FOR
INDUSTRY - BUSINESS - SCIENCE
1235 Tenth St. Berkeley, CA 94710 (415) 524-8664

. FESTER: PIPE & ENGINEERING

SAN FRANCISCO, CA 94124

1465 YOSEMITE AVENUE

PURCHASE ORDER NUMBER

THIS NUMBER MUST APPEAR OH ALL INVOICES, PACKAGES AND SHIPPING PAPERS.

# PURCHASE ORDER

SHIP AND BILL TO

1235 Tenth Street Berkeley, CA 94710

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WILLIAM M. BROBECT & ASSOCIATES
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BY

MADE A PART OF THIS ORDER. SELLER AGREES TO THESE

CONDITIONS BY ACCEPTANCE OF THE ORDER.

55 C. CONTINUATE RE

RESEARCH - DEVEL MENT - ENGINEERING ror

**INDUSTRY - BUSINESS - SCIENCE** 

1235 Tenth St. Berkeley, CA 94710 (415) 524-8664

BENTETT-EOPMINS CORPORATION

3592 HAVEN AVENUE

REDIFINE CITY, CA 94003

THIS NUMBER MUST APPEAR ON ALL INVOICES, PACKAGES AND SHIPPING PAPERS.

122

URCHASE ORDER NUMBER

# PURCHASE ORDER

SHIP AND BILL TO 1235 Tenth Street Berkeley, CA 94710

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WILLIAM M. BROBECK & ASSOCIATES BREET COMPRESSION

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VENDOR BY

ANOTHER DARCO PRODUCT . CARLAND 266800

IMPORTANT TERMS AND CONDITIONS ON THE BACE OF THIS ORDER ARE MADE A PART OF THIS ORDER, SELLER AGREES TO THESE

CONDITIONS BY ACCEPTANCE OF THE ORDER.

RESEARCH - DEVEL PMENT - ENGINEERING

INDUSTRY - BUSINESS - SCIENCE

1235 Tenth St. Berkeley, CA 94710 (415) 524-8664

BEOT BOX CONTROL

· ACCURATE MUNIFACTURING CO.

4773 SAR PABLO AVENUE

PURCHASE ORDER NUMBER

\*\*\* 128 \*\*\* THIS NUMBER MUST APPEAR ON ALL INVOICES, PACKAGES AND SHIPPING PAPERS,

SHIP AND BILL TO

1235 Tenth Street Berkeley, CA 94710

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WILLIAM M. BROBECK & ASSOCIATES UITAR

ALL ITEMS PRINTED IN RED MUST BE FILLED IN BY REQUISITIONER **PURCHASE REQUISITION** DISPOSITION ASSOCIATED DATE NEEDED ADDRESS \_ TYPE P.O. & MAIL ORDER WIRED SHIP VIA ATTN. OF ORDER TELEPHONED DATE PROMISED FOB 11-30 ESTIMATED UNIT PRICE DESCRIPTION (USE SEPARATE REQUISITION FOR EACH VENDOR) QUANTITY TOTAL AS 103474 SPRINC 390.00 RESALE NO. SR CH .21-140517 Personal New Medical LES TAX ESTIMATED TOTAL VALUE OF ORDER MUST BE STATED BY REQUISITIONER + \$ 390.00 DELIVER TO Suggested Sources REQUESTOR J.T- 64~~

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#### **PURCHASE REQUISITION**

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RESEARCH - DEVEL

rOR

340 1100 DOFF CHATLES

INDUSTRY - BUSINESS - SCIENCE

1235 Tenth St. Borkeley, CA 94710 (415) 524-8664

. FRATCIS PLATING

755 - 7th Street

Oalliand, CA 54607

PURCHASE ORDER NUMBER

\*\* 31\*\*

THIS MUNISH MUST APPEAR ON ALL INVOICES, PACKAGES AND SKIPPING F. PEUS.

#### SHIP AND BILL TO

1235 Tenth Street Berkeley, CA 94710

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WILLIAM M. BROBECK & ASSOCIATES BRELLING TO PRESENT BY

SHOTHER HARCO PRODUCT . DABLERD 244400

# WILLIAM M. BROPFCK & ASSOCIATES FILE RESEARCH DEVEL MENT ENGINEERING

FOR

INDUSTRY - BUSINESS - SCIENCE

1235 Tenth St. Berkeley, CA 94710 (415) 524-8664



PURCHASE ORDER NUMBER THIS NUMBER MUST APPEAR ON ALL INVOICES, PACKAGES AND SHIPPING PAPERS.

URCHASE ORDER

### SHIP AND BILL TO

1235 Tenth Street

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WILLIAM M. BROBECK & ASSOCIATES

BY

ALL ITEMS PRINTED IN RED MUST BE FILLED IN BY REQUISITIONER

#### **PURCHASE REQUISITION**

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			·—		REQUESTOR	97	12		~ <u></u>
Pro	evious Purchas	e Order No.			PURCHASINI	- Just	Æ.	<u>5/2,</u>	DATE
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BA-30 (REV 1-79)

COPY

143
THIS HUMBER MUST APPEAR
ON ALL INVOICES, PACKAGES

PURCHASE ORDER NUMBER

1235 TENTH STREET . BERKELEY, CA 94710 . (415) 524-8664

Ship to:

PURCHASE ORDER

To

DIAMOND TOOL CO. 5085 29th Avenue Oakland, CA 94609 BROBECK CORPORATION 1235 Tenth Street Berkeley, CA 94710

							-		
	L	ATTN:	Don Holz		<u> </u>				١
PATE			DATE PROMISED	ACCOUNT	BRIF VIA	TERM		P.4.6.	# E E E E E E E E E E E E E E E E E E E
Ju	ine 3,	1985	5 wks ARO	4500-301	X	1-10	N-30	Oakland	JTG
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			PRICES PER QUOTE	BY DON HOLT	COP	ATTA Y	CHED		
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We acknowledge receipt of yest order for above finishist and will finish shippest accessing in delivery promotion of our order, or as anish. Accessing of this order implies agreements to prive and discounts shown, after contract and access and the state of explanation. Prices excited on eviginal are to be inerted on this ecknowledgement by vendor. Canditesa we original are made a part of this order to which seller agrees by exceptance of this order.

BROBECK CORPORATION

BY Original signed by: K. M. Thomas

VENDOR BY

C-14

**MENT - ENGINEERING** RESEARCH - DEVEL

Bkc31. .K COLPGLATION

INDUSTRY - BUSINESS - SCIENCE 1235 Tenth St. Berkeley, CA 94710 (415) 524-8664

FOR

THIS NUMBER MUST APPEAR ON ALL INVOICES, PACKAGES AND SHIPPING PAPERS.

PURCHASE ORDER NUMBER

# PURCHASE ORDE

SHIP AND BILL TO

1235 Tenth Street Berkeley, CA 94710

. ACCURATE MARITACTURING CO.

1770 SAL PABLO AVE.

INCREVIALE, CA 9460s

MTR			SATE PROFISED	ACCOUNT	BHIP VIA	TERM	7.0.2.	REQUESTOR
	II, Pa	r	JUNE 24, 1985	4540-370-21	ARY NO	NET 30 DAYS		J. T. C
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				C TOTAL AMOUNT O	r Ptiro	RACT OTHER		\$1,600.00 LOT
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				IMPORT ND CONDITIONS ON THE PART OF THIS ORDER.	BACK OF			

esign of year order for above material and will make shipment according to delivery of as noise. Accordance of this order implies agreements to prices and discounts a prices to be indicated by varier and accompanied by note of explanation. Prices of he inserted on this acknowledgment by varier. Conditions on original are made a p a seller agrees by acceptance of this order.

WILLIAM M. BROBECK & ASSOCIATES

RESEARCH - DEVELOI-MENT - ENGINEERING

BRODECT CORPURATION

INDUSTRY - BUSINESS - SCIENCE 1235 Tenth St. Berkeley, CA 94710 (415) 524-8664

FOR

URCHASE ORDER NUMBER

L INVOICES, PACKAGES

# PURCHASE ORDE

SHIP AND BILL TO 1235 Tenth Street Berkeley, CA 94710

PIRMALUSTER, INC. 1844 N. KEYSTONE AVE.

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WILLIAM M. BROBECE & ASSOCIATES

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RE FILLED IN BY REQUISITIONER	

#### PURCHASE REQUISITION

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PURCHASE REQUISITION

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BA-30 (REV 1-79)

ALL ITEMS PRINTED IN RED MUST NE FILLED IN BY REQUISITIONER

#### PURCHASE REQUISITION

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ggested Sources			DELIVER TO	J,	<u>(-</u>			
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			APPROVED	700	<del></del>	DATE		

BA-30 (REV 1-79)

1235 TENTH STREET . BERKELEY, CA 94710 . (415) 524-8664

182\*\*

RCHASE ORDER NUMBER

Ship to:

PURCHASE ORDER

PERMAG CO.

1159 SONORA COURT

SUNNYVALE, CA 94086

	L				SHIP VIA			_
TR			BAYE PROCINED	ACCOUNT	PERALE TES DE	TERMS	7,6,1.	BEQDESTOR
	AY 11,			4540300	X	N-30		J.T.GUNN
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er for above material and will make ablument acc systems of this order implies agreements to price cated by versior and accompanied by acts of any his action-indepensant by vender. Conditions on only recognizate of this order.

BROBECK CORPORATION

VENDOR BY

BLUE: Requestor WHITE: Vendor

GREEN: Project File

YFLLOW: Vendor Acknowledgement

PINK: Purchasing/Shipping

GOLD. Accounting

PURCHASE ORDER NUMBER \*\*\*183\*\*\*

1235 TENTH STREET • BERKELEY, CA 94710 • (415) 524-8664 Ship to: PURCHASE ORDER

ELECTRICAL SPECIALTIES CO.

SAN FRANCISCO, CA

	•	INN LIGHT	icisco, ca					
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BAT	July 11,	1985	BATE PROESES	4540-300	YES NO	C.O.D.	7.0.0.	PERUTEYOR
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YELLOW: Vendor Acknowledgement

PINK: Purchasing/Shipping

GOLD: Accounting

BROBECK CORPORATION

1235 TENTH STREET • BERKELEY, CA 94710 • (415) 524-8664

Ship to:

PURCHASE ORDER

PERMALUSTER, INC. 1844 N. Keystone Ave. Burbank, CA 91504

BROBECK CORPORATION 1235 Tenth Street Berkeley, CA 94710

	L. AT	T.i. He	nrv Walker :		L VIA	UPS		
11-2	5-85		12-7-85	4500-301-20	PESALE TES 80	Net 20	Frobeck Corp.	KIAT
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1.	1200	ft.	i .	nductor 0.250 📩 . Dunded edges, free TOTAL	of bu		ier I	\$629.89/Lot
			RECEIPT OF 1 ACCEPTED LAT	IMPORTA AND CONDITIONS ON THE APART OF THIS ORDER, B	NO CA	SE WILL IT BE  ON AMY CONDITI	oks.	

acknowledge resulpt of your order for above material and will make shipment according — delivery pre-en this order, or an nested. Acceptance of this eries: implies acrossments to prices and discounts above corrections in prices to be indicated by worder and access pasted by note of explanations. These soults be registed are to be irrarred or this order-order present by resider. Conditions on original are made a part this order to which celler agrees by recognized of this order.

BROBECK CORPORATION

VENDOR BY

WHITE: Vendor

BLUE: Requestor GREEN: Project File

YELLOW: Vendor Acknowledgement

PINK: Purchasing Shipping

GOLD: Accounting

LL ITEMS PRINTED IN RED MUST BE FILLED IN BY REQUISITIONER

#### PURCHASE REQUISITION

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BA-30 (REV 1-79)

ALL ITEMS PRINTED IN RED MUST BE FILLED IN BY REQUISITIONER

#### PURCHASE REQUISITION

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BA-30 (REV 1-79)

ALL ITEMS PRINTED IN RED MUST BE FILLED IN BY REQUISITIONER

#### **PURCHASE REQUISITION**

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ALL ITEMS PRINTED IN RED MUST BE FILLED IN BY REQUISITIONER

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PURCHASE ORDER NUMBER 224

THIS NUMBER MUST APPEAR ON ALL INVOICES, PACKAGES AND EMIPPING PAPERS.

PURCHASE ORDER

Ship to:

# 1235 TENTH STREET . BERKELEY, CA 9471u . (415) 524-8664

ACCURATE MANUFACTURING CO. 4770 San Pablo Ave. Emeryville, CA

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	1			MADE A PART OF THIS ORDER, SELLER AGREES TO TRUSS. CONDITIONS BY ACCEPTANCE OF THE ORDER.		

BROBECK CORPORATION Kenneth M. Thomas, President

**VENDOR BY** 

**BLUE: Requestor** 

GOLEEN: Project File

YELLOW: Vendor Acknowledgement

PINK: Purchasing Shipping

GOLD: Accounting

1235 TENTH STREET . BERKELEY, CA 94710 . (415) 524-8664

Ship to:

225 THIS NUMBER MUST APPEAR ON ALL IMPOICES, PACHAGES AND SHIPPING PAPERS.

FURCHASE ORDER NUMBER

**PURCHASE ORDER** 

ACCURATE MANUFACTURING CO. 4770 San Pablo Ave. Emeryville, CA

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VENDOR BY

WHITE: Vendor BLUE: Requestor GREEN: Project File

YELLOW: Vendor Acknowledgement

PINK: Purchwing:Shipping

GOLD. Accounting

ALL ITEMS PRINTED IN RED MUST BE FILLED IN BY REQUISITIONER

PURCHASE REQUIRITION

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ALL ITEMS PRINTED IN RED MUST BE FILLED IN BY REQUISITIONER

#### **PURCHASE REQUISITION**

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ugge	sted Sources				REQUESTOR				
7		ious Purchase Order No.	· ·····		J.	<u>. T. GUNN</u>			DATE
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ALL ITEMS PRINTED IN RED MUST

1235 TENTH STREET • BERKELEY, CA 94710 • (415) 524-8664

URCHASE ORDER NUMBER
236

THIS NUMBER HUST APPEAR ON ALL INVOICES, PACEAGES AND SMIPPING PAPERS.

Ship to:

PURCHASE ORDER

D<sub>To</sub>

WESTERN PIPE & ENGINEERING CO. 1485 Yosemite Ave. South San Francisco, CA 94724

BROBECK CORPORATION 1235 Tenth Street Berkeley, CA 94710

ATE	Ken-Fre		822-6464 (ALTE PROGUES	ACCOUNT	MIP VIA	Brobeck Corp.	P.O.B.	OCON SETON
25-	B <b>5</b>		10-11-85	300-26	TES X	N-30	F.G.B.	JTG
EN PC.	PEARTITY	FRIT	<del> </del>	DEACRI	7104		SMIT PRICE	EXTENSION
•	1	<b>e</b> a	Achromat Bea Brobeck Draw	am Tube ving 95C1752A	(enclosed	i)	\$800.00	\$300.00
					Sales	Tax 6.5%		52.00
			}		TOTAL			\$852.00
			[					
				CONFIRMATION (	ONLY			
	1			*DO NOT DUPLIC				
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e echnowining receipt of your order for showe material and will make abipment according to delivery present this order, or an acted, Asseptance of this order implies agreements to prive and discernite shown corrections in prices to be indicated by vender and accompanied by note of explanation. Prices cratific order to which called a price of explanation of the price of the contraction of the price of the

BY A L. A M human Kenneth M. Thomas, Pres.

VENDOR BY

WHITE: Vendor BLUE: Request

GREEN: Project File

YELLOW: Vendor Acknowledgement

PINK: Purchasing Shipping

GOLD: According

1235 TENTH STREET \* BERKELEY. CA 94710 \* (415) \$24-8664

THIS NUMBER MUST APPEAR ON ALL INVOICES, PACKAGES AND BKIPPING PAPERS.

Ship to: PURCHASE ORDE

• PERMAG SIERRA CORP. 1159 Sonora Ct.

Sunnyvale, CA 94086

BROBECK CORPORATION 1235 Tenth Street Berkeley, CA 94036

	6-85		ACCOUNTY PRODUCTS ACCOUNTY TEACH NAME NO. 100 No. 30	7.A.B.	JTG
1.	2	Assy	Short Quadrupole Assemblies Brobeck Drawing No. 95D1733-2B This is 32 segments.	47.39	\$1516.48
2.	1	Assy	Dipole Assembly Brobeck Drawing No. 95D17848 This is 16 segments.  DRAHINGS NOTED ABOVE ARE ENCLOSED.	75.86	1213.76
					\$2730.24
			6.5% Sales Tax		177.47
			TOTAL		\$2907.7
			CONFIRMATION ONLY		
			**DO NOT DUPLICATE**		
			NOTE: Previous Purchase orders 086 and 182.		
			I M P O R T A N T TERMS AND CONDUCTIONS ON THE BACE OF THIS ORDER AND MADE A PART OF THIS ORDER, SELLER AGREES TO THESE CONDUCTIONS BY ACCEPTANCE OF THE ORDER.		

VENDOR BY

WHITE: Vendor BLUE: Requestor

GREEN: Project File

File YELLOW: Vendor Acknowledgement

PINK: Purchasing/Shipping

GOLD. Accounting

Kenneth M. Thomas, President

1235 TENTH STREET • BERKELEY, CA 94710 • (415) 524-8664

239

Ship to:

PURCHASE ORDER

To

DIAMOND TOOL COMPANY 5085 29th Avenue Oakland, CA 94609

**BROBECK CORPORATION** 1235 Tenth Street Berkeley, CA 94710

	L	534-705	OPS UPS		١
BATE			SATE PROFESED ACCOUNT PERALE YEARS	F.O.B.	RESUESTON
06	ctober 1,	1985	Nov. 1, 1985   4500-300-30     X   N-30		JTG
Hall	BC. BEAUTIFY	im (7	DESCRIPTION	west paics	EXACRITOR
1.	. 1	ea	Segment Carrier Dipole Drawing No. 95C1737B		
2.	. 2	ea	Segment Carrier Short Quadrupole Drawing No. 95C1736-2B		
			LOT		\$1,626.00
			SALES TAX 6.5%		105.69
_			TOTALLLOT		\$1,731.69
			NOTE Drawings enclosed		
			·		
			I M P O R T A N T TERMS AND CONDITIONS ON THE BACK OF THIS ORDER ARE MADE A PART OF THIS ORDER, SELLER AGREES TO THESE CONDITIONS BY ACCEPTANCE OF THE ORDER.		

BROBECK CORPORATION Kenneth M.

**VENDOR BY** 

WHITE: Vendor BLUE: Requestor GREEN: Project File

YELLOW: Vendor Acknowledgement

PENK: Purchwing Shipping

GOLD: Accounting

1235 TENTH STREET • BERKELEY, CA 94710 • (415) 524-8664

EQU
THIS NUMBER MUST APPEAR
ON ALL INVOICES, PACKAGES
AND SHIPPINE PAPERS.

URCHABE ORDER NUMBER

PURCHASE ORDER

Ship to:

- MDC CORPORATION 23842 Cabot Blvd. Hayward, CA 94545

BROBECK CORPORATION 1235 Tenth Street Berkeley, CA 94710

10-1-	<b>e</b> 5		PATE PROBLECTS	4500-360-30	SHIP VIA	N-30	P.G.G.	JTG
Z.B. 80. 94	ANTITY	PRIT		DESCRIPTIO			SOLT PRICE	POICHSTRE
1.	1	ea	Centering Ring	#K200-CR			\$ 5.00	\$ 5.00
2.	1	<del>2</del> 8	Clamp #K200-C				15.00	15.00
3.	4	69	0 Ring - Vite	n ∉K200-0			5.00	20.00
								40.00
				Sales	Tax 6	.5%		2.60
	1			TOTAL				\$42.60
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		į	TELMS AND	IMPORT	ANT			

We acknowledge receipt of your order far above material and will make shipment according to delivery prometed on this order, or on noted, Accordance of this order implies agreements to prive and discounts there or corrections in prices to be indicated by rector and accompanied by note of capitantics. Prices emitted original are to be instituted on this acknowledgment by vendor. Conditions on original are made a part of order to which caller agrees by companies by vendor. Conditions on original are made a part of order to which caller agrees by acceptance of this order.

BY Jan Wiste

VENDOR BY

WHITE: Vendor BLUE: Request

GREEN: Project File

YELLOW: Vendor Acknowledgement

PINK: Purchasing Shipping

GOLD: Accounting

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<u> </u>				PEQUESTOR	J. G	<u>u                                    </u>	<u>n</u>	
<b>6</b>	Previous	urchase Order No. 2	33	PURCHASING				DATE
				APPROVED				DATE

I ALL ITEMS PRINTED IN RED MUST

1235 TENTH STREET • BERKELEY, C4 94710 • (415) 524-8664

THIS NUMBER MUST APPEAR ON ALL INVOICES, PACKAGES AND SHIPPING PAPERS.

PURCHASE ORDER NUMBER

PURCHASE ORDER

- MDC CORPORATION
23842 Cabot Blvd.
Hayward. CA 94545

BROBECK CORPORATION 1235 Tenth Street Berkeley, CA 94710

Ship to:

	Hi	eyward,	, CA 94545			Berkeley, CA	94710	
	L					ine		_
1			DATE PROBLES	ACCOUNT	SMIP YTA SESALE TES NO	UPS TERRO	ras.	200000703
10-	-3-85		Nov. 4, 1985	300-30	Xen	N-30		JTG
# PC.	- CANTITY	9917		DENCRIF	7100		MINT PRICE	EXTERSION
1.	2	ea	Vacuum Feed th	1/2"			\$100.00	\$ 200.00
2.	1	ea	Vacuum Feed th #DBF-75 size	1 <b>ru</b> 3/4"			100.00	100.00
								300,00
	<u>.</u>			6.5%	Sales Ta	ıx		19.50
-				TOTA	L			\$ 319.50
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We achieve independent of your criter for alone; material and will make shipment according to delivery present on this order, or m netted. Assoptance of this arises lampiles agreements to prices and direcents; shown a corrections in prices to be indicated by vender and accordinated by note of explanation. Friend maintenfering and the control of the

Kenneth M. Thomas

BROBECK CORPORATION

VENDOR BY

WHITE: Vendor

BLUE: Requestor

GREEN: Project File

YELLOW: Vendor Acknowledgement

I H P O R T A N T
TERMS AND CONDITIONS ON THE BACK OF THIS ORDER ARE
MADE A PART OF THIS ORDER. SELLER AGREES TO THESE
CONDITIONS BY ACCEPTANCE OF THE ORDER.

PINK: Purchasing/Shipping

GOLD: Accounting

THIS NUMBER MUST APPEAR ON ALL INVOICES, PACKAGES AND SMIPPING PAPERS.

URCHASE ORDER NUMBER

1235 TENTH STREET • BERKELEY, CA 94710 • (415) 524-8664

PURCHASE ORDER

· OMEGA ENGR. INC.

Box 4047 Stamford, CONN. 0690? BROBECK CORPORATION 1235 Tenth St.

Berkeley, CA 94710

Ship to:

10-4			10-31-85	301-24	IP VTA	UPS TEEBE Pre-pay 2% disc.	P.O.B.	JTG
1.	12	69	Thermocouple Ins	sulators #ORX18	14 -6	i" long	\$ 6.00	\$ 72.00
				2% prepay	y dis	count		(1.44)
				TOTAL				\$ 70.56
	į		(From 1984 Catal	og. Pg. 8-12)				
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	[   							
		j						
				IMPORTAL CONDITIONS ON THE BA	n T			

VENDOR BY

WHITE: Vendor BLUE: Requessor

GREEN: Project File

YELLOW: Vendor Acknowledgement

PINK: Purchasing Shipping

Kenneth M.

GOLD: Accurating

BROBECK CORPORATION

ALL ITEMS PRINTED IN RED MUST BE FILLED IN BY REQUISITIONER PURCHASE REQUISITION DISPOSITION DATE NEEDED ADDRESS : TYPE P.O. & MAIL ORDER WIRED ORDER TELEPHONED DATE PROMISED TAXABLE ACCOUNT YES | NO ESTIMATED TOTAL PRICE TOTAL DESCRIPTION (USE SEPARATE REQUISITION FOR EACH VENDOR) ITEM QUANTITY 100 6,60 Washows 160 17.80 35.00 25 23.20 5 S 11.5% 60 100 11J 55 100 100 50 018

SALES TAX 11.56 ESTIMATED TOTAL VALUE OF ORDER MUST BE STATED BY REQUISITIONER → \$ 184.39 CELIVER TO Suggested Sources REQUESTOR PURCHASING Previous Purchase Order No. DA\* APPROVED

BA-30 (REV. 1-79)

252

PURCHASE ORDER

THIS NUMBER MUST APPEAL ON ALL INVOICES, PACKAGES AND SHIPPING PAPERS

Ship to:

1235 TENTH STREET . BERKELEY, CA 94710 . (415) 524-8664

OAKLAND VALVE COMPANY

2487 Estand Way Pleasant H111, CA 94523 **BROBECK CORPORATION** 1235 Tenth Street Berkeley, CA 94710

13 PA	4-85		Needed: 11-1-85 4500-301-25 13 - 10; Net 30	F.A.S.	JTG
	BEARTITY	Jen 17	DESCRIPTION	90 17 PRICE	EXTENSION
1.	8	ea	Swagelock Unions Stainless Steel 3/16" #SS 300-6	\$ 6.55	\$ 52.40
			6.5% Sales Tax		3.41
		ļ	TOTAL		\$ 55.31
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			CONFIRMATION ONLY		ر نگری ایک ایک ایک ایک ایک ایک ایک ایک ایک ای
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			NOTE: Application for Credit with Credit References attached.		
			I M P O R T A N T TERMS AND CONDITIONS ON THE SACE OF THIS ORDER ARE		

VENDOR BY

WHITE: Vendor

BLUE: Requestor

GREEN: Project File

YELLOW: Vendor Acknowledgement

PINK: Purchasing Shipping

GOLD: Accounting

Secettary

BROBECK CORPORATION

# **BROBECK CORPORATION**

1235 TENTH STREET . BERKELEY, CA 94710 . (415) 524-8664

Ship to:

PURCHASE ORDER

CARAL INC. 578 Cleveland Ave. Albany, CA 94706

BROBECK CORPORATION 1235 Tenth St. Berkeley, CA 94710

10-15-8	Bob Sand 35	11-6-85	4500-301-25	PERALE 123 XIII	Brobeck Corp.	7.0.B. PE	JTG
EB Ira. 0944777	ry 100 FT		SEEC RIPTION			BRIT PRICE	ERF ENSION
l. 1	ea	Two Port Ta	nk - Drawing No.	95D17	69	\$2750.00	\$2750.0
							\$2750.0
			•	6.5% S	ales Tax		178.7
			•	TOTAL			\$2928.7
		DRAWING ENC	LOSED.				
		PRICES PER E RFQ 4500-301	BID IN RESPONSE 1 1-6 DATED 10-4-85	0			
				•			
			IMPORT. IND CONDITIONS ON THE PART OF THIS ORDER, S	BACK OF			

VENDOR BY

BLUE: Requestor WHITE: Vendor

GREEN: Project File

YELLOW: Vendor Acknowledgement

PINK: Purchasing Shipping

Kenneth M. Thomas

GOLD: Accounting

BEOBECK CORPORATION

254

THIS NUMBER MUST APPEAR ON ALL INVOICES, PACKAGES AND SHIPPING PAPERS.

1235 TENTH STREET • BERKELEY. CA 94710 • (415) 524-8664

Ship to:

PURCHASE ORDER

SCHRADER SCIENTIFIC
 2976 Arf Avenue

Hayward, CA 94545

To

BROBECK CORPORATION 1235 Tenth Street Bekkeley, CA 94710

10-	-15-85		11-6-85	4500-301-25	TES   MG	N-30	7.0.0.	JTG
EM 170.		PRIT		DESCRIPTION	<u> </u>		bust_fuses	EETERSION
ι.	2	ea	Cover Plate	- Dwg. No. 95C1	772		\$95.00	\$ 190.00
2.	1	<b>e</b> &	Pumpout Spo	o1 - Dwg. No. 95	01771-	1		435.00
; <b>.</b>	1	69	Pumpout Spoo	o <b>1 - Dwg.</b> No. <b>9</b> 5	01771-	2		435.00
.	1	69	Spool - Dwg.	. No. 95D1779				791.00
.	1	ea	Cooling Flam	nge - Dwg. No. 9	5 <b>C</b> 1724	В		220.50
.	1	ea	Port Cover -	- Dwg. No. 95C17	73			125.00
								2196.50
				ı	5 <b>.5%</b> §	les Tax		142.77
				•	TOTAL			\$ 2339.27
		j	DRAWINGS ENC	LOSED.				
				ID IN RESPONSE 1 -6 DATED 10-4-89				
				IMPORT				

We acknowledge results of your order for above material and will make obliment accounting to delivery precised on this order, or so metal. Associations of this order in public acrossments to prive and discounts above the property of the p

BY Cu My University Kenneth M. Thomas

URCHASE ORDER NUMBER 255

1235 TENTH STREET \* BERKELEY, CA 94710 \* (415) 524-8664

Ship to:

PURCHASE ORDE

JENSEN PROTOTYPE MACHINES 940 Lemon Street Martinez, CA 94553

BROBECK CORPORATION 1235 Tenth Street

10	-17-85		11-14-85	4500-300-30	BESALLE YES   NO	Brobeck Corp.	P.O.B.	REBUESTO?
EN NO.	BUARTITY	UNIT	11-14-05	4300-300-30	,	Net 30	SHIT PRICE	JTG
1.	2	ea	Plate No. 95				<b>\$130</b>	\$ 260.00
2.	1	ea	8pool No. 95				<b>1913</b> 0	· .
3.	1	69	Bearing No.					160.00 90.00
4.	2	ea	Bar No. 9581				55	110.00
5.	1	ea	Flange No. 9	•			33	680.00
6.	1	ea	Cover Plate					140.00
7.	1	ea	Adapter No.					405.00
в.	1	88	Boit Ring No				1	270.00
٠.	•	""	)	. 3301770				270.50
								2115.00
		1		6.5%	Sales	Tax		137.48
	<b>t</b>			TOTA	L			\$2252.48
,		:	DRAWINGS ATTA Awarded per b RFQ 4500-300-	CHED. id submitted in 1 7 dated 10-9-85.	espon	se to		
			RFQ 4500-300-	id submitted in 17 dated 10-9-85.  IMPORT. AND CONDITIONS ON THE	ANT			

VENDOR BY

BLUE: Requessor WHITE: Vendor

GREEN: Project File

YELLOW: Vendor Acknowledgement

PINK: Purchasing/Shipping

GOLD: Accounting

# **BROBECK CORPORATION**

1235 TENTH STREET . BERKELEY, CA 94710 . (415) 524-8664

PURCHASE ORDER NUMBER

Ship to:

**PURCHASE ORDER** 

HERRINGTON-OLSON 769 22nd Street

Oakland, CA 94612

HAND DELIVERY

ı	L,	452-050 <u>1</u>	l		HAND DELIVERY		
MYI	10-22-8	5	10-22-85	4500E50BE198W T	C.O.D.	F.O.S.	JIM
27EH )	O. BRANTITY	Special Part		DESCRIPTION		BRIT PRICE	227581000
1.	!		Photography				\$ 294,37
				S1 fdes (7300-10	•		34.61
				TOTAL (Tax in	cluded)		\$ 328.98
		}				:	
			MADE A PA	IMPORTANT CONDITIONS ON THE SACE OF SET OF THIS ORDER. SELLER A SET ACCEPTANCE OF THE ORD	GREEN TO THESE		

Joann Wiste

VENDOR BY

BLUE: Requestor WHITE: Vendor

GREEN: Project File

YELLOW: Vendor Acknowledgement

PINK: Purchasing Shipping

GOLD: Accounting

ALL ITEMS PRINTED IN RED MUST BE FILLED IN BY REQUISITIONER

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ALL ITEMS PRINTED IN RED MUST BE FILLED IN BY REQUISITIONER

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		ź	W-29 X	NO N-3	30	5,,	60.71		1-11-5
ITEM	QUANTITY	UNIT		PARATE REQUISITION FOR EAC			ESTIMATED TOTAL PRICE	NET UNIT PRICE	TOTAL
1	56	50	SOCKET HE	CAP SCRE	w	1-11/11	256		
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				APPROVED			DATE

ALL ITEMS PRINTED IN RED MUST BE FILLED IN BY REQUISITIONER

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	<b>)</b> ,	-a	IA C	Z per file	EEZII	4-	P.O. NO.	27	73 <u> </u>	1	DISPOS	ITION
ADDI	RE5S						DATE N	EDÉC	)		TYPE P.	Q. & MAIL
		June	IA C.	. Co.	_	]		U	N 85	┢╌		
ATTN	. 05	110	-1404	PIN	an A	1000	SHIP VIA			<u> </u>	ORDER	
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À		- Lynny rull					APPRO	VED			12	DATE
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LL ITEMS PRINTED IN RED MUST BE FILLED IN BY REQUISITIONER

#### **PURCHASE REQUISITION**

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ADDR	ESS	940	(Emil)	57		D/	ATE NEEDE	, ,		TYPE P	O. & MAIL
		1111	PRIVEZ		94553	1	/95/9/			ORDER	WIRED
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BA-30 (REV 1-79)

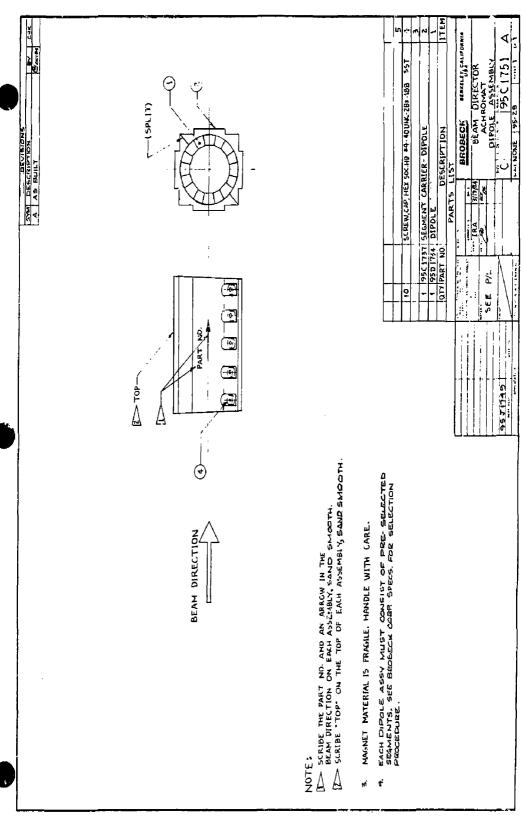
ALL ITEMS PRINTED IN RED MUST BE FILLED IN BY REQUISITIONER

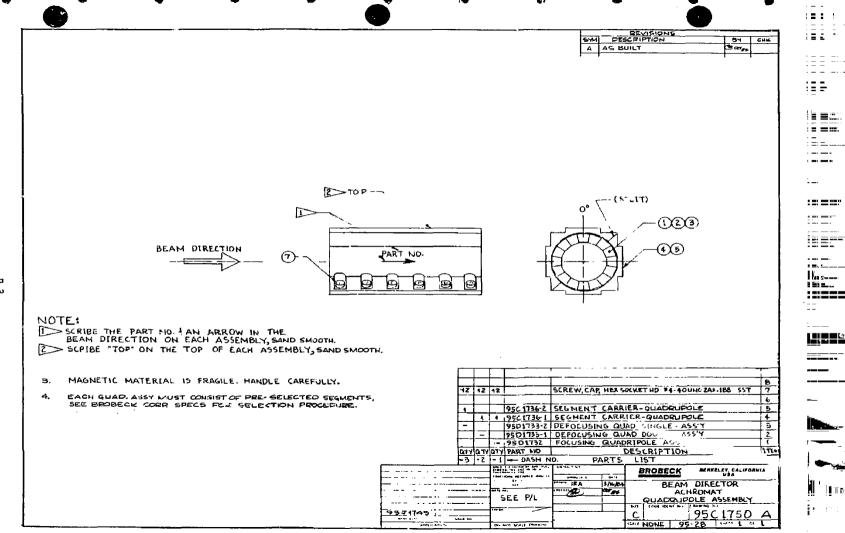
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	17/85		4500-300	VES NO	<u> </u>		COTIMATED.	COTINATOR	12/17/8		<del>,</del> -
ITEM	QUANTITY	UNIT	DESCRIPTIO	N (USE SEPARA)	TE REQUISITION FOR EACH VENDOR	)	ESTIMATED UNIT PRICE	ESTIMATED TOTAL PRICE		T UNIT RICE	TOTAL
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1	Pro	vious Pu	rchase Order No.				PURCHASING	Jin Hil	ler.		DATE
							APPROVED				DATE

#### APPENDIX D. DRAWINGS: ACHROMAT

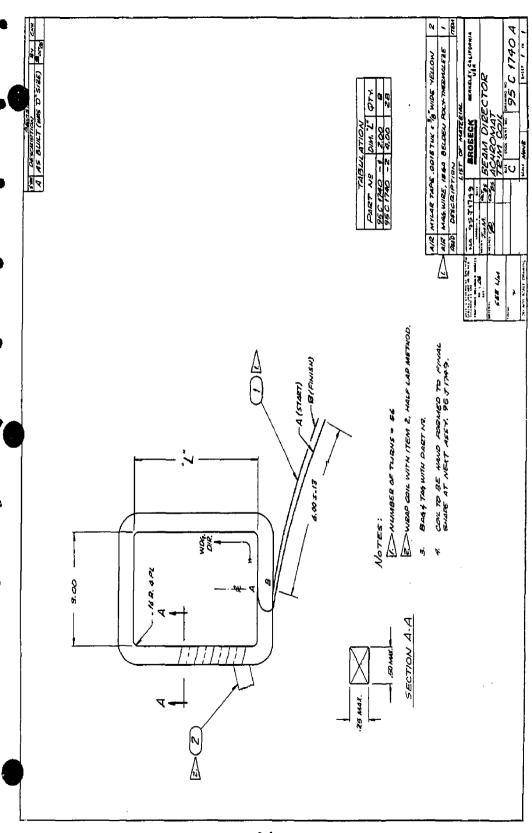
A complete set of as-built drawings for the achromat is included in this appendix.

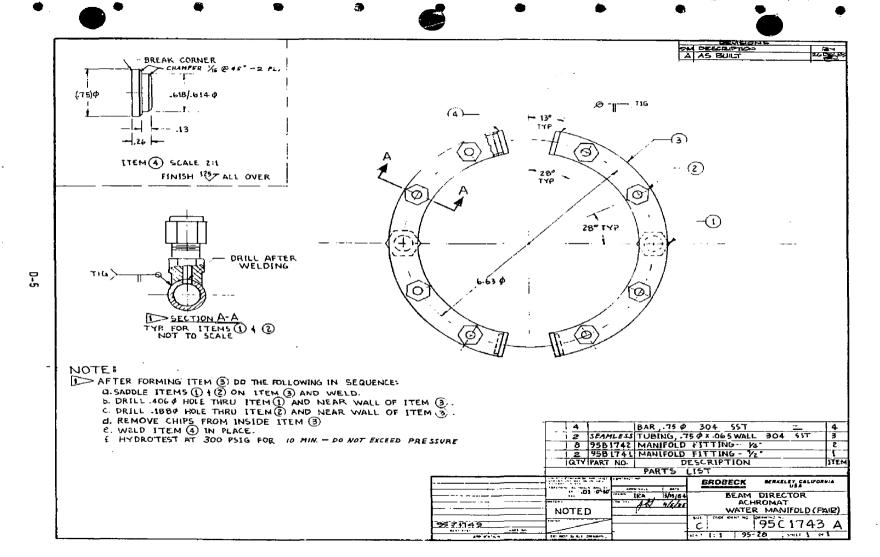
Dipole Assembly	<b>95</b> 01751
Quadrupole Assembly	95C1750
Trim Coil Assembly	95C1740
Water Manifold	95C1740
Achromat Assembly	95J1749
Interface & Vacuum Test Assembly	9501749
Focusing Quad	9501732
Defocusing Quad	95D1733
Dipole	9501734
Segment Carrier - Quad	95C1736
Segment Carrier - Dipole	9501737
Magnet Spacer	9581738
Housing	95J1739
Manifold Fitting 1/2"	9581741
Manifold Fitting 1/4"	9581742
Flange Ring	95C1744
Adjusting Sleeve	9501745
Retaining Flange	9581745
Retaining Sleeve	95B1747
Barrier Ring	95B1748
Beam Tube	95C1752
Vacuum Transition Flange	95C1774
Adapter Plate	9501775
Bolt Ring	95C1776
Diaphragm Plate	9581777
Adapter Spool	95B1778
Bearing	95B1779
Alignment Bar	95B1780
Downstream Mounting Plate	95B1782
Spacer	95B1783
Stud	95B1784
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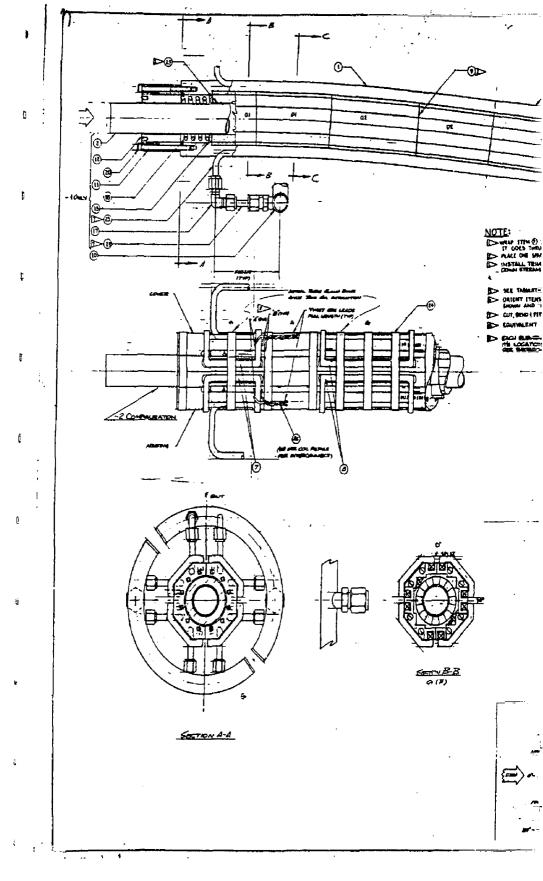


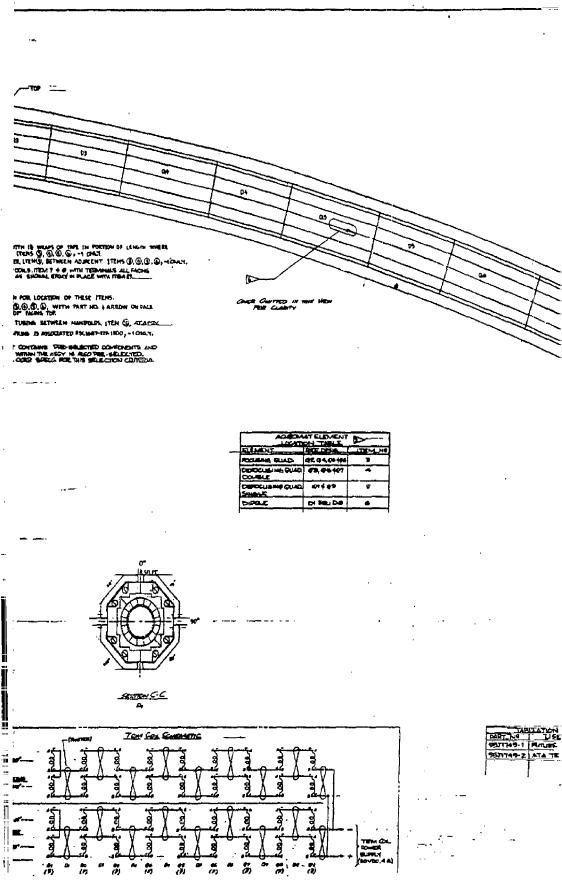


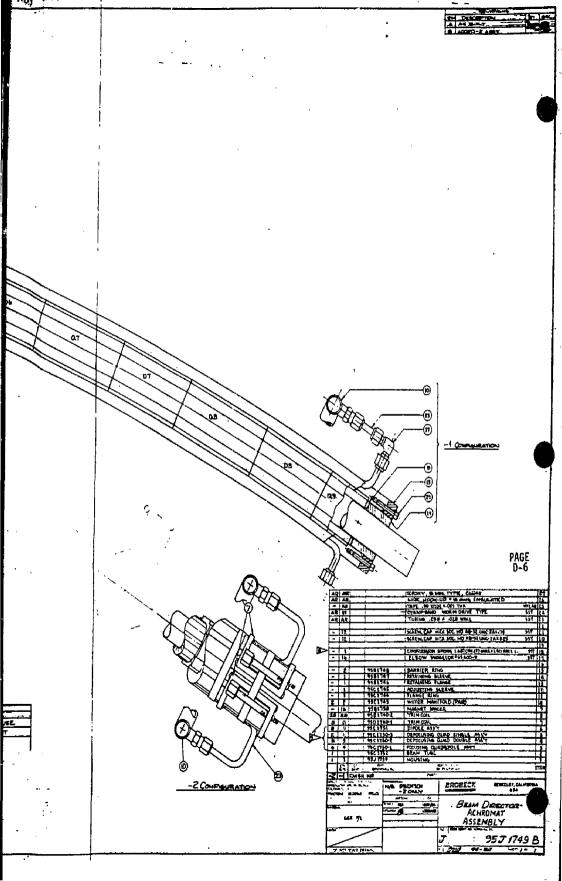
| Yan 25----

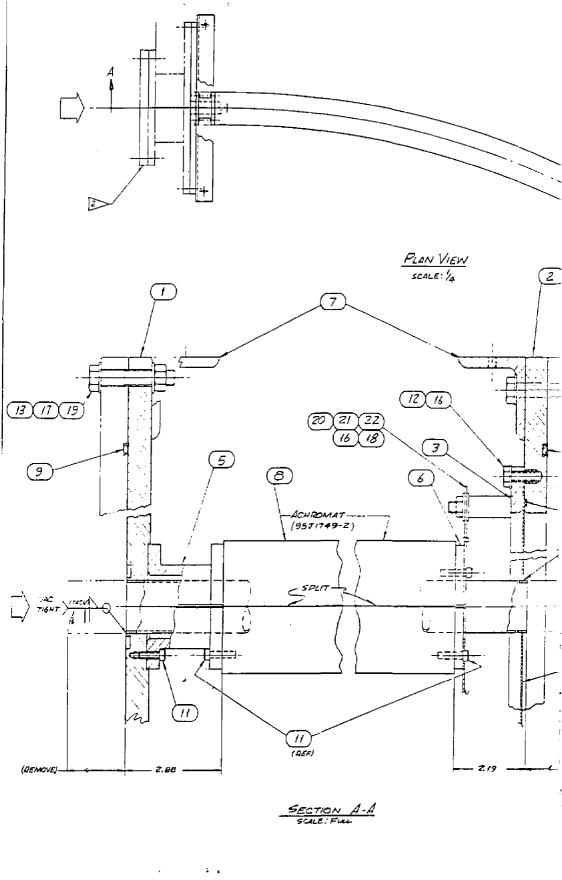




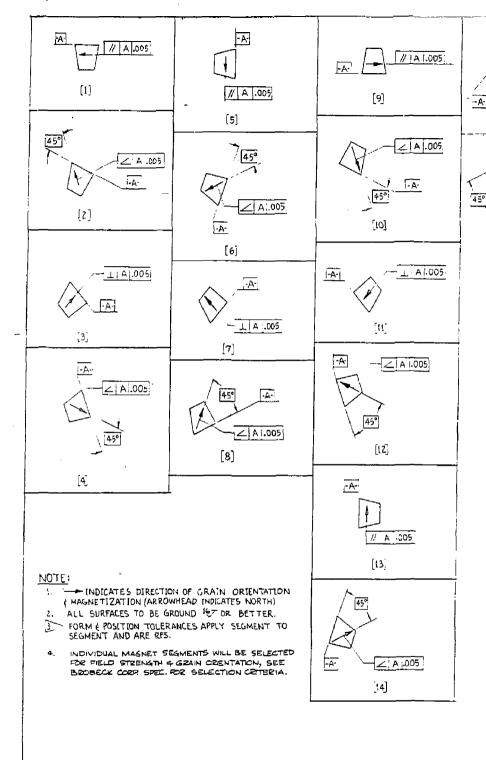


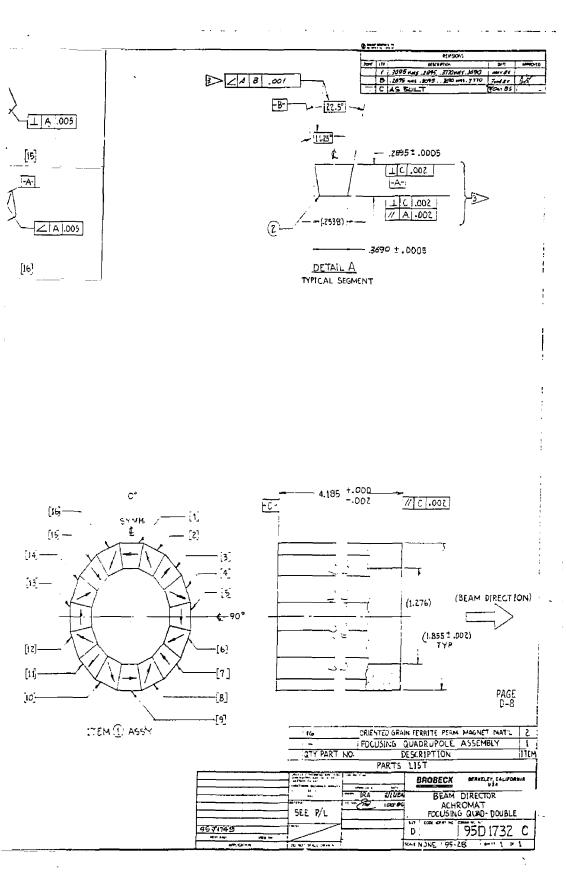


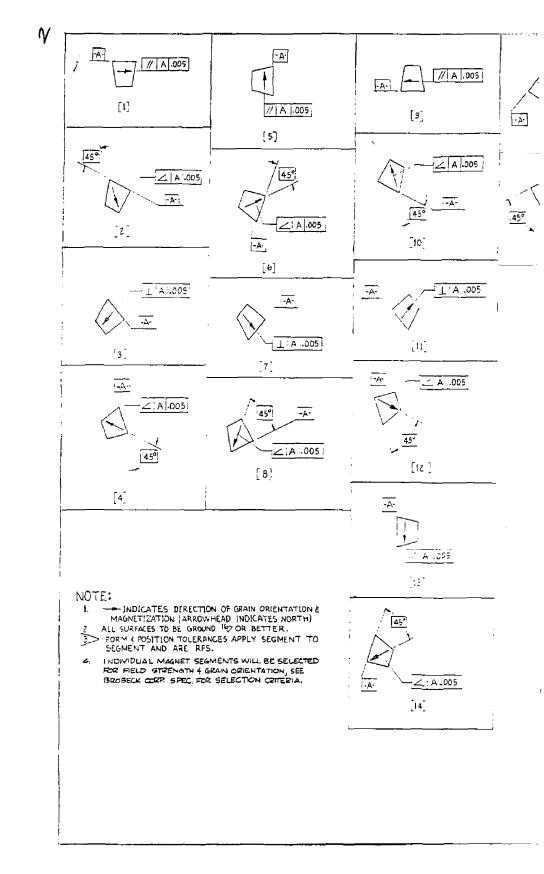




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(14) (17) (19)	23
4 9581784 STUD	_; zz]
4 7581763 SPACER	_
NOTES: Z 958178Z DOWNSTREAM MTG. PLATE	<u>ر ا</u>
1. ALL WELDS TO BE VAC. TIGHT. TOTAL LEAK ZA NUT, PLAINHEA 1/8-16 SS RATE TO BE LESS THAN 1 x 10-0 5TD. ATTA,	7 19
2ADIAL ADT. CCISEC AT A MAR. BASE PIESS, OF LA 10-6 NOT, PLAIN WE 19-20 SI	T 18
TORR WHEN MEASURED WITH A HEMASS 48 WASHER, FLAT 754 S.	FT 17
(10) SPECTZOMETEZ. 16 WISHER, FLAT 14 & 5	57 16
/ VAC. Z FOR SPOOLS, COVER RATES & NOW. NOT	15
SPECIFIED, SEE VERNIED STEEDING 4 SCREW, HEX -2 18-16 x 2 12 14, 51	7. 14
20   SCOEW, NEX Q 7/3-16x Z 6 LG SS	
12   SCHEW, MEX Q 14-80 a 1/4 LG. 55	7 12
36   SCREW, SKT. NO. 8-37x acc 55	7 11
1 O-RING PARKER Z-17Z VII	DU 10
2 C-RING DARKER 5-569 VI	20V 9
4) (4 ENISH	в
THIS SIDE CUT) 2 9581780 ALIGNMENT BAR	7
1 95BITT9 BEARING	6
/ 95BITTB ADAPTER SPECI	5
I 9581777 DURIEM PLOTE	4
1 95C1776 BOLT RING	3
1 95C1775 ADAPTER PLATE	2
(REMOVE) 1 95C 1778 VAC TRANSITION FLANGE	1
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BROBECK BERELLY, CALIFO	PRIA
I Tou M. "TO BEAM DIRECTOR	1
ACHROMAT INTERFACE & VAC TEST.	1554
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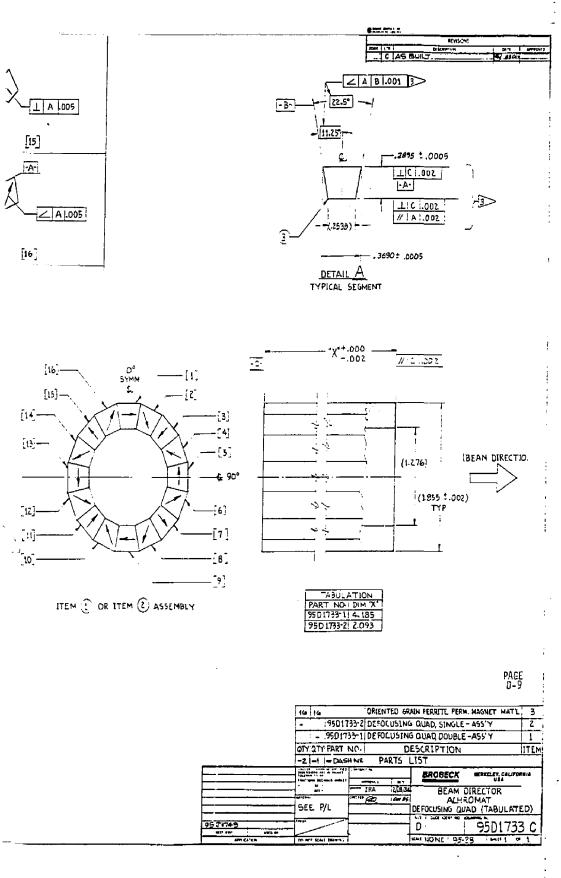




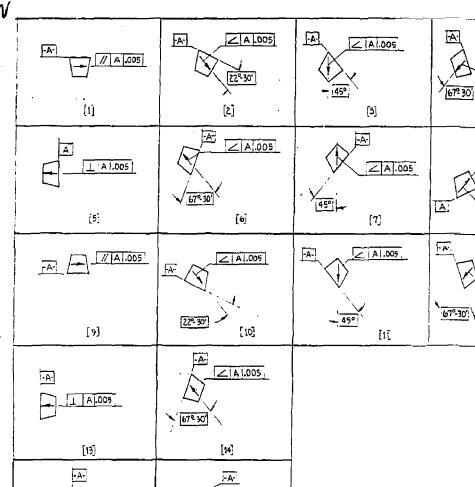


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NOTE:

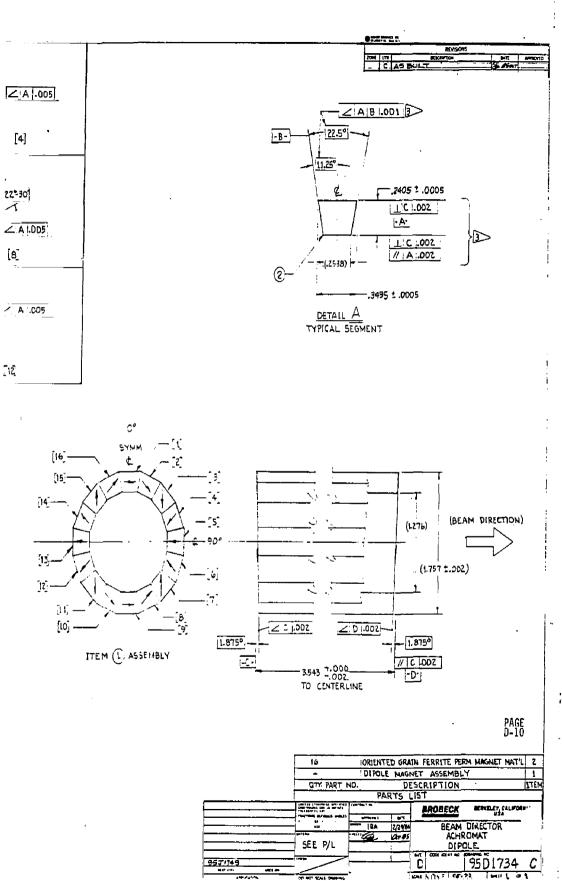
450

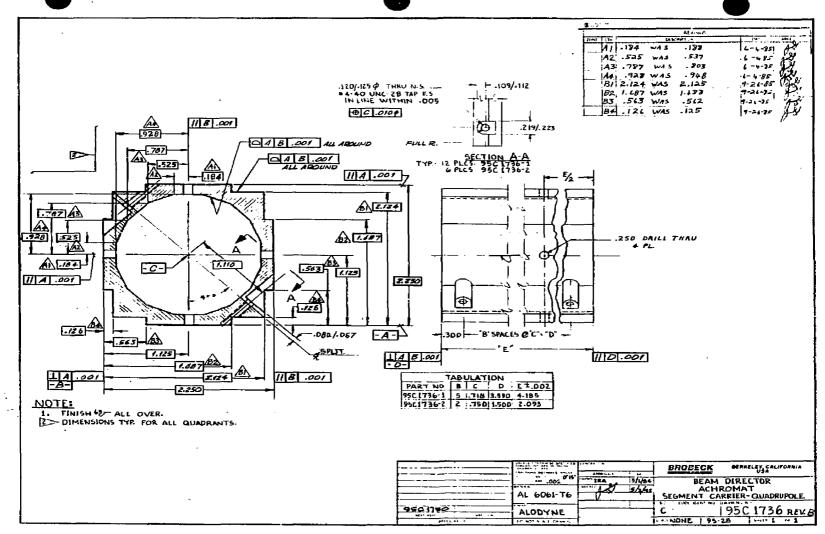
INDICATES DIRECTION OF GRAIN ORIENTATION MAGNETIZATION (ARROWHEAD INDICATES NORTH) ALL SURFACES TO BE GROUND TO BETTER. FORM 4 POSITION TOLERANCES APPLY SEGMENT TO SEGMENT AND ARE RES.

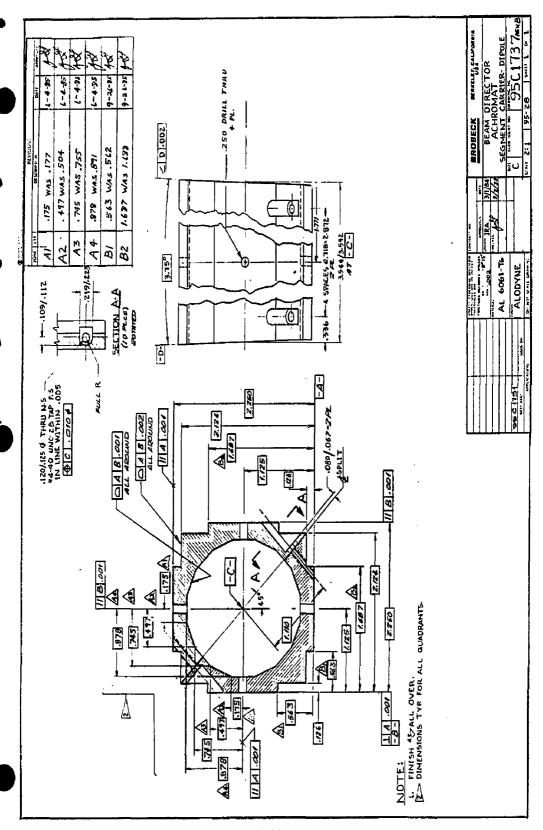
∠|A|.005

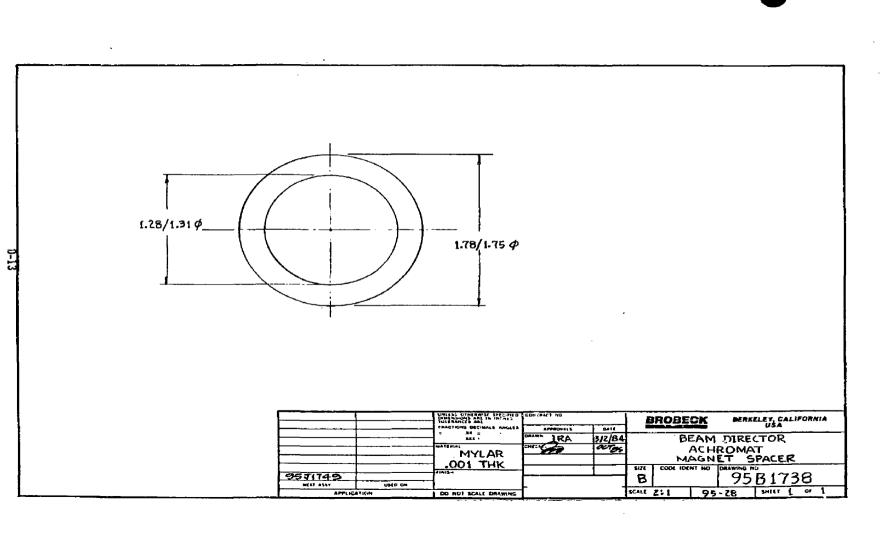
[15]

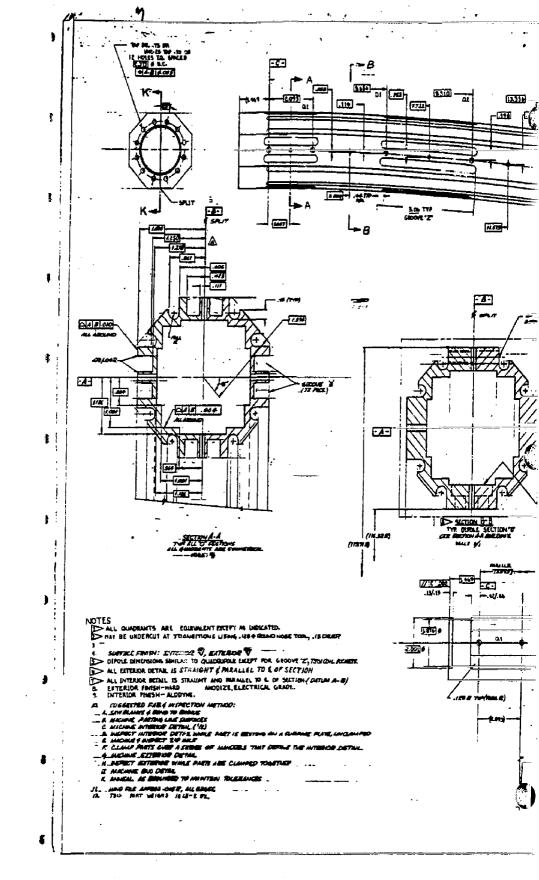
4. INDIVIDULE MAGNET SEGMENTS WILL BE SELECTED FOR FIELD STREAGTH & GRAIN ORIENTATION, SEE BROBECK CORR SPEC. ROR SELECTION CRITERIA.

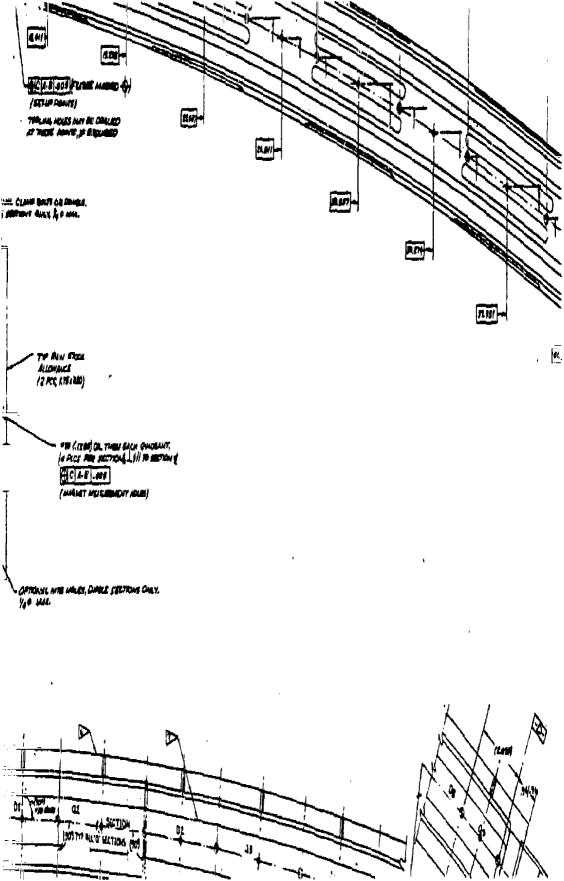


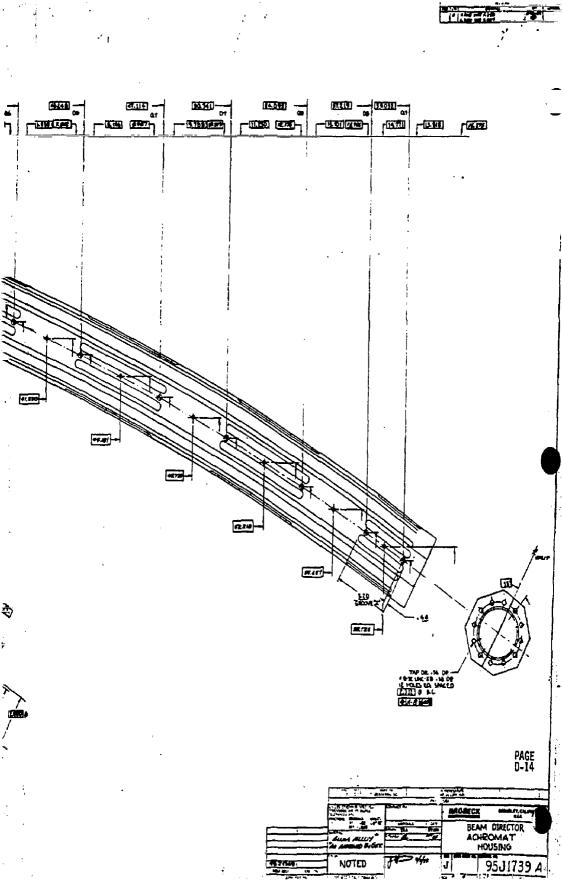


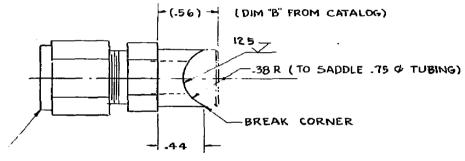






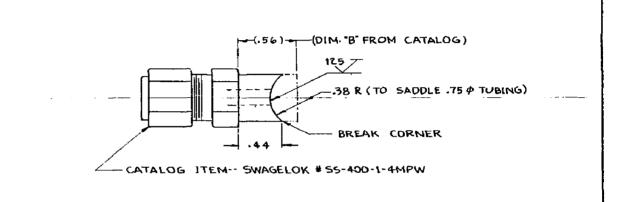




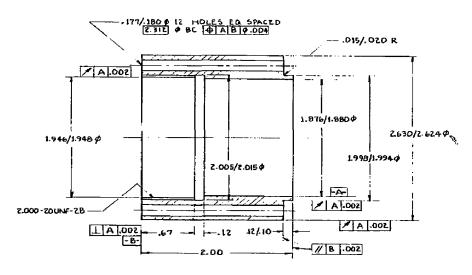


← CATALOG ITEM -- SWAGELOK #55-810-1-6MPW.

			UNLESS OTHERWISE SHITTED DIMENSIONS AND IN INCHES TOLIRANCES AND PRACTIONS DECISIONS AMOUNTS	CONTRACT IN 3	Conta	BROBE		BERKE	LEY, CALIFO	RNIA
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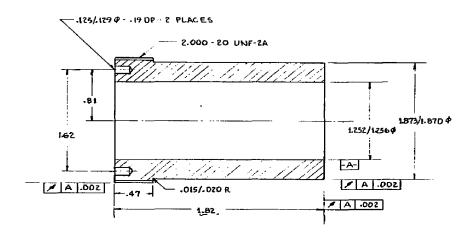
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NOTE:

- 1. FINISH 1257 ALL OVER
- 2. BREAK ALL CORNERS

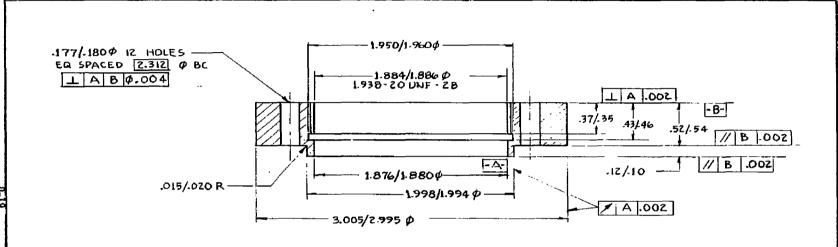
		total and the same of the same	C-81 / L		BROBECK	SERNELEY CALIFORNIA	
		20°- 20	APPENIA L	P#1		U 3.4	
		341	TRA	3/14/24	BEAM	DEFLECTOR	
		94718-4,	ACHROMAT				
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NOTE:

1. FINISH 1257 ALL OVER . 2. BREAK ALL CORNERS .

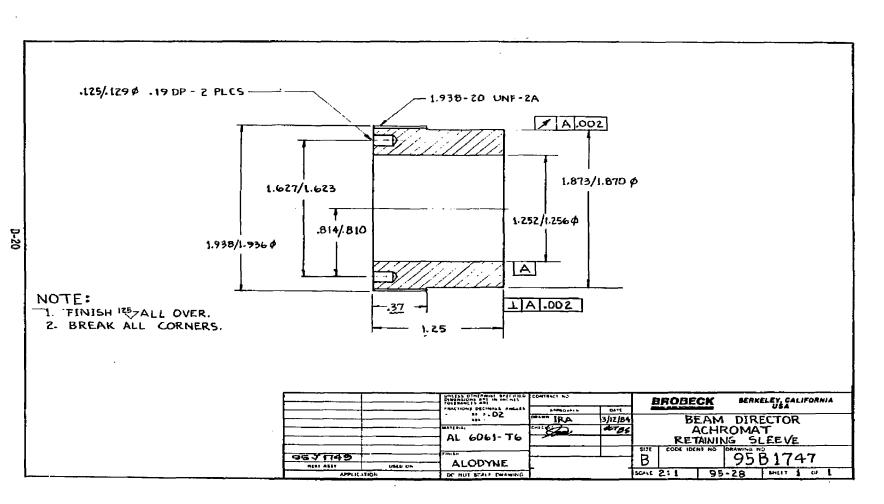
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ı			1RA	3)14/24	BEAM	DIRECTOR
ı		MATERIAL TO STATE OF THE STATE		200		ROMAT
ı		AL 6061-76		-	TOULDA	ING SLEEVE
ļ	95 71749	ALODYNE	<b></b>	<u>.                                      </u>	c	95C1745
	APPLICATION.	P. Sec.   S. ALE   SASSING	<u> </u>		2:1 95	-78   1 ·- 1

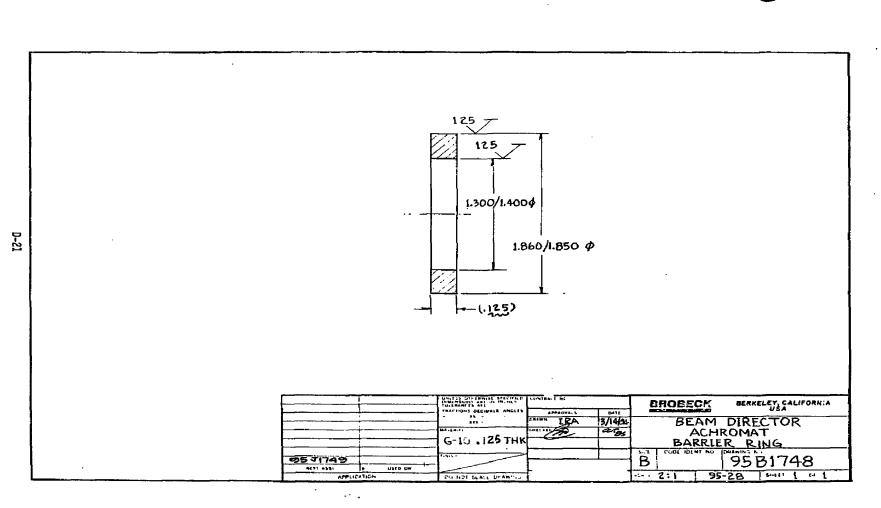


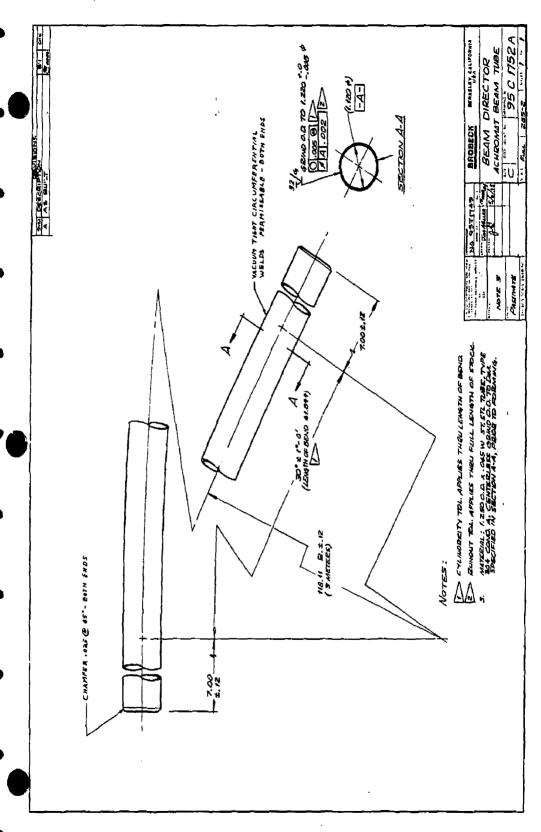
## NOTE:

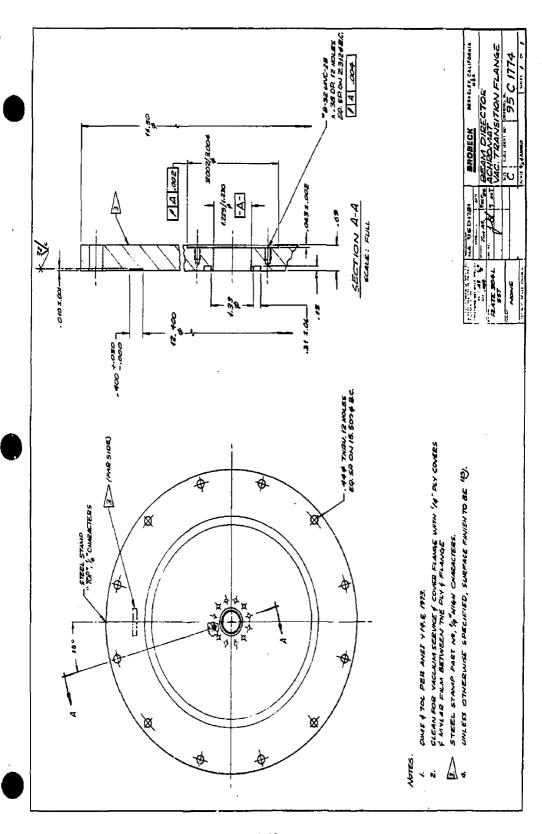
- 1. FINISH IZET ALL OVER.
- 2. BREAK ALL CORNERS.

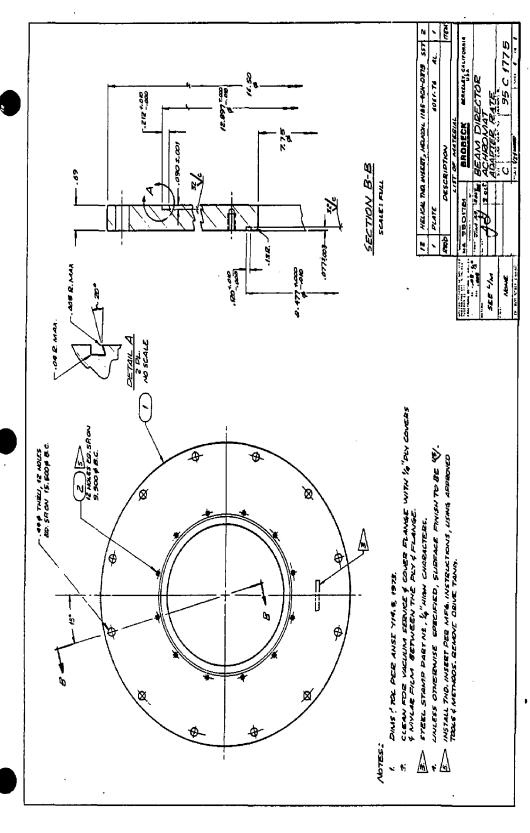
F			UNITES OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ARE				E	ROBE	CK	SERR	ELEY, CALIFO	ORNIA
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Г	APPLICA	TIDN	DO NOT SCALE DRAWING	1			SCALL	1:5	95-	28	SHEEL S	of 1

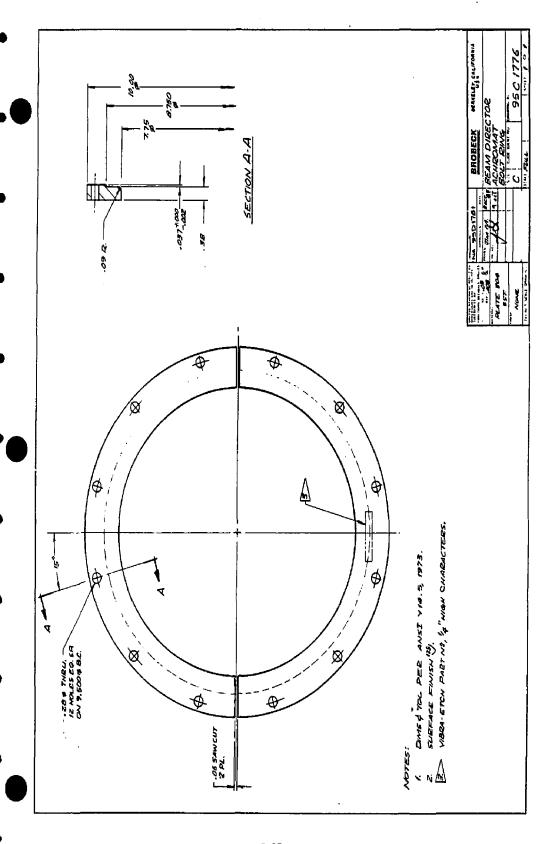


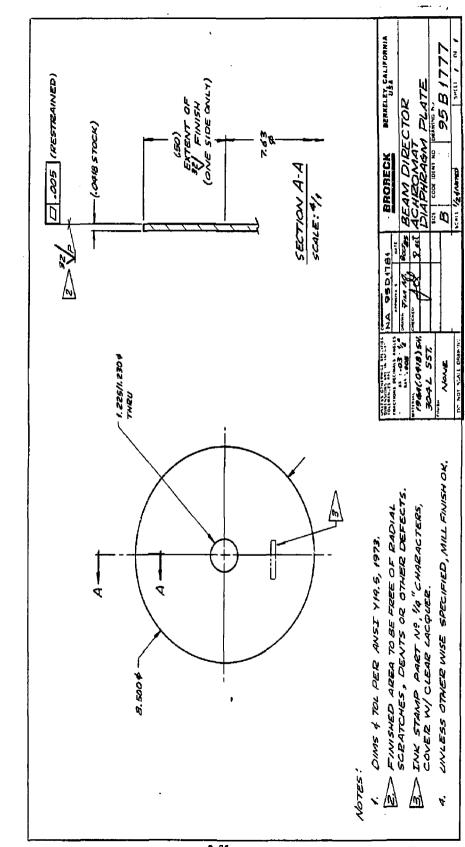


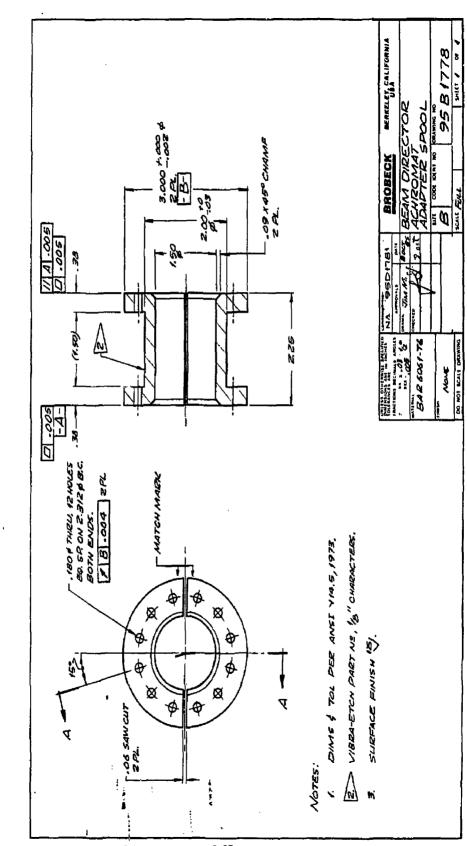


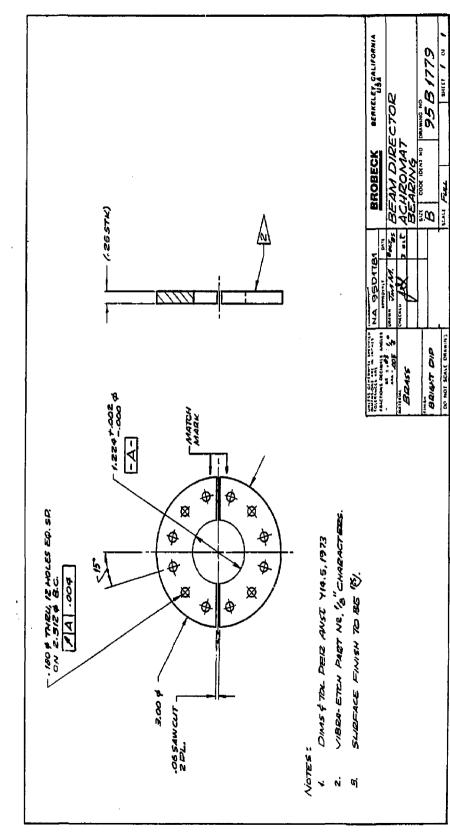


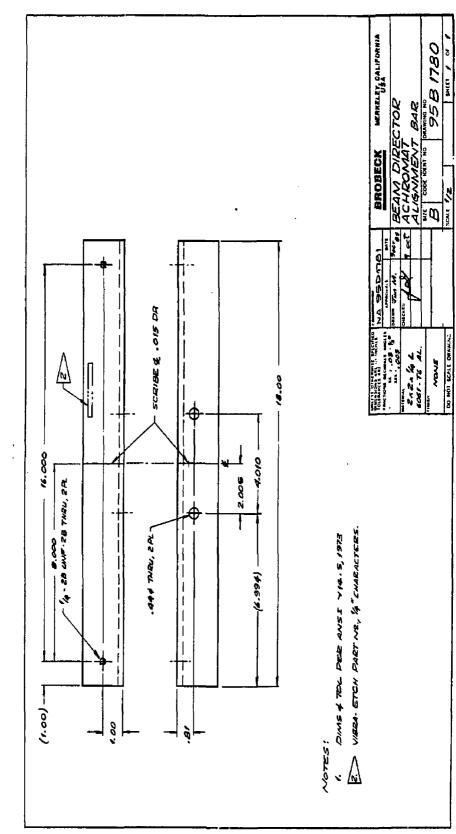


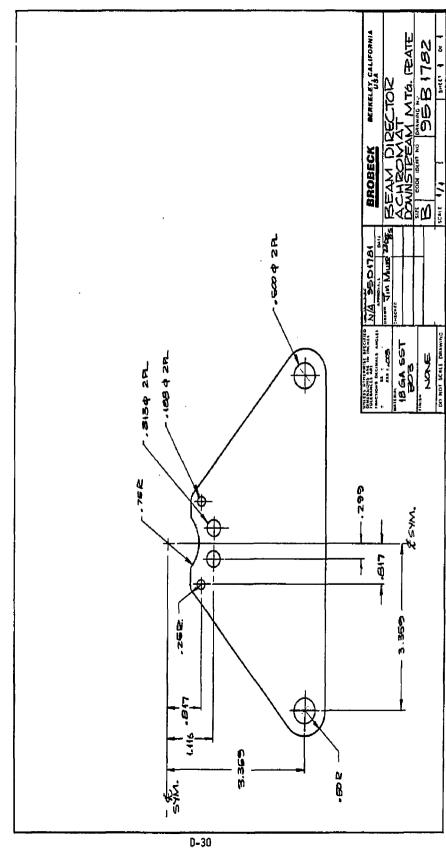


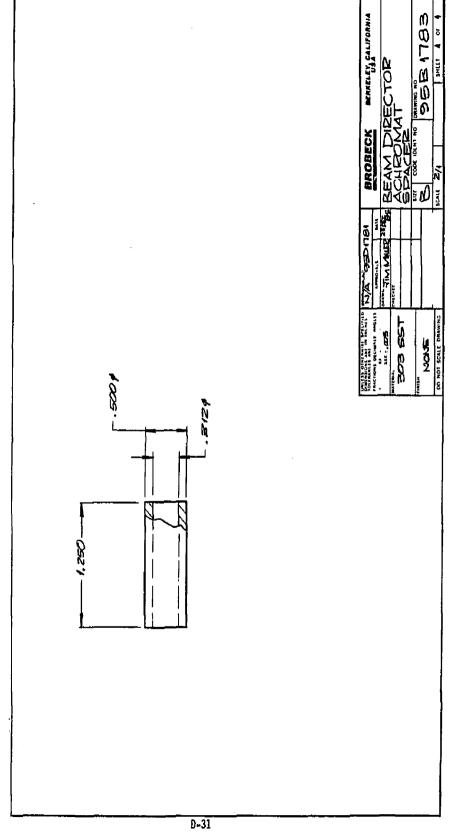


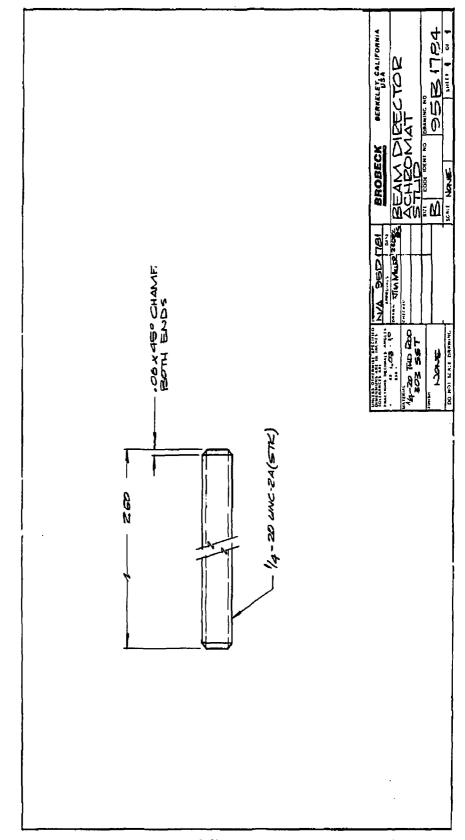








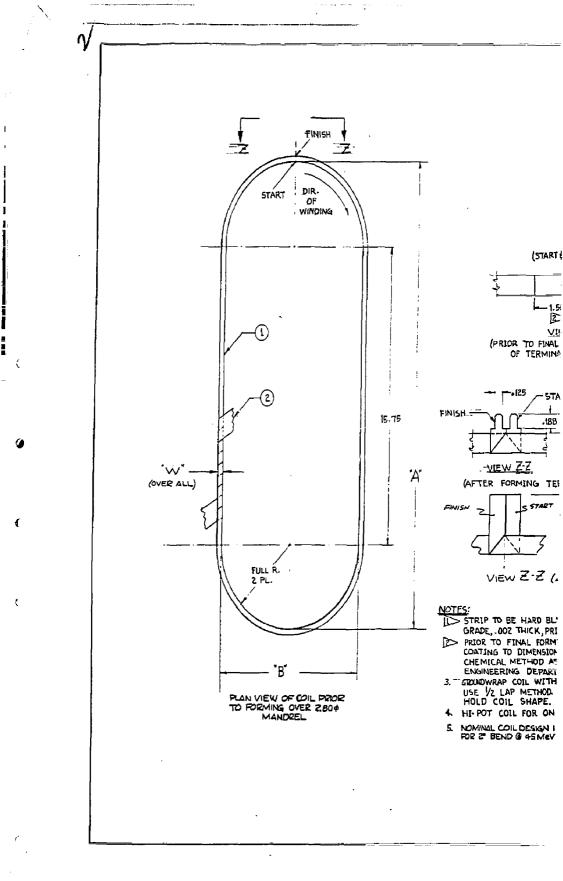


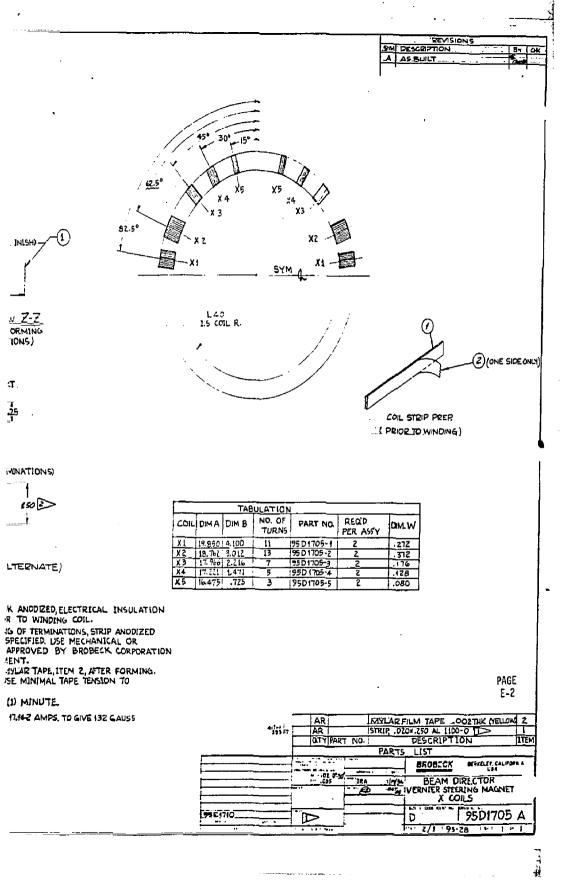


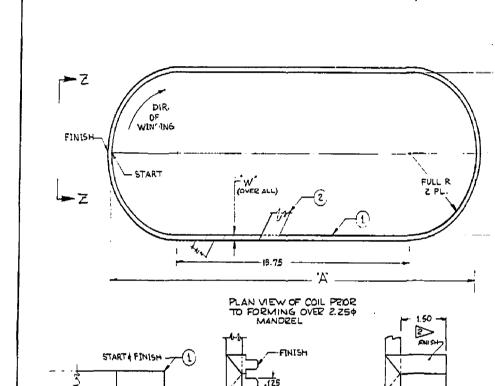
## APPENDIX E. DRAWINGS: VERNIER

A complete set of as-built drawings for the vernier is included in this appendix.

Coil X <sub>1</sub> - X <sub>5</sub>	9501705
Coil Y <sub>1</sub> - Y <sub>5</sub>	95D1706
Coil Assembly	95E1710
Installation	95J1728
Coil Spool	9501707
Lock Nut	95C1708
Cooling Coil	95C1709
Y Coil Spacer	95C1712
X Coil Spacer	9501713
Interface Flange	95E1714
Downstream Mounting Plate	95E1714
Manifold Clamp	95B1717
Manifold Fitting 1/2"	95B1718
Manifold Fitting 3/16"	95B1719
Supply Manifold	9501720
Return Manifold	9501721
Magnet Power Input Flange	9501723
Magnet Cooling Input Flange	95C1724
Water Supply Connector	9581725
Water Return Connector	9 <b>5B172</b> 6
Spreader	95B1727
Magnet Power Terminal	95B1729
2-Port Exp. Tank	95D1769
Tank Spool (50 cm)	9501770
Pump-out Spool	9501771
Cover (6" Port)	9501772
Cover (12" Port)	95C1773
•	=







START

VIEW Z-Z

(ALTERNATE)

-.188

-.25 -

VIEW Z-Z

ROTATED 190° (AFTER FORMING TERMINATIONS)

## NOTES:

VIEW Z-Z

(PRIOR TO FINAL FORMING

OF TERMINATIONS)

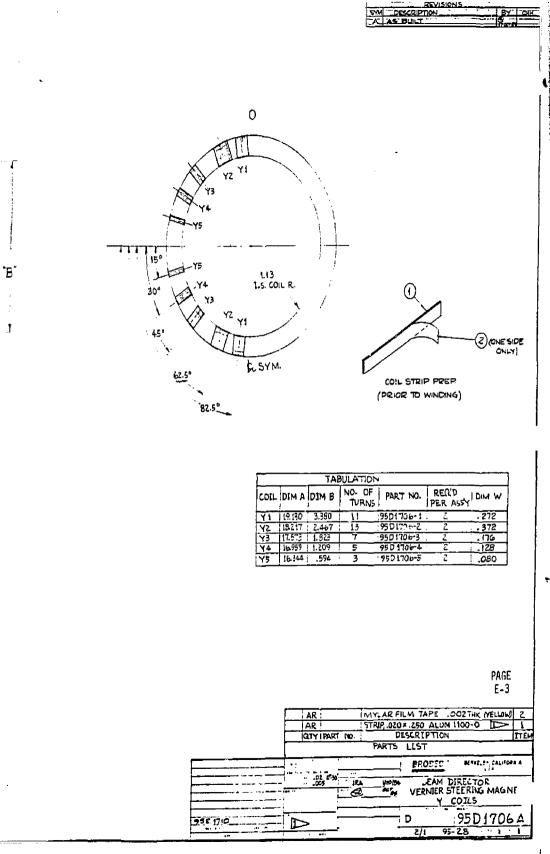
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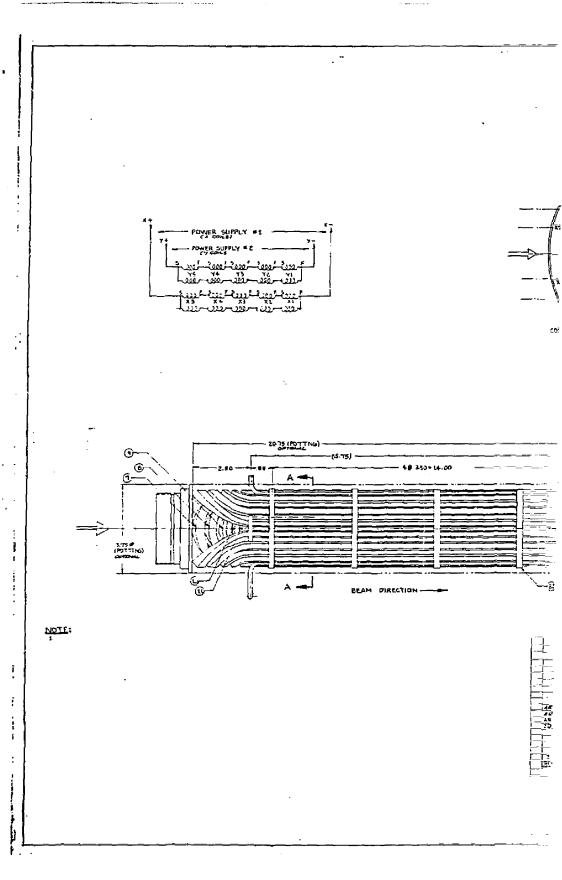
STRIP TO BE HARD BLACK ANODIZED ELECTRICAL INSULATION GRADE, .002 THICK, PRIOR TO WINDING COIL.

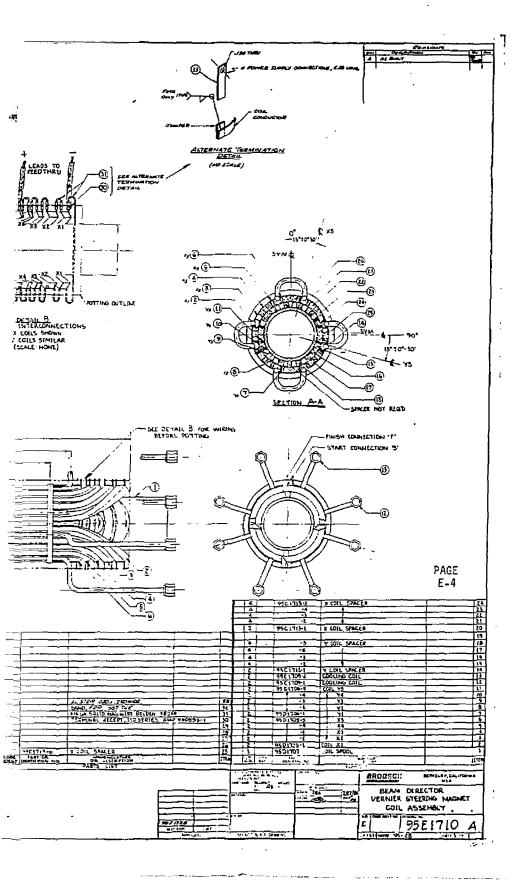
PRIOR TO FINAL FORMING OF TERMINATIONS, STRIP ANODIZED COATING TO DIMENSION SPECIFIED. USE MECHANICAL OR CHEMICAL METHOD AS APPROVED BY BROBECK CORPORATION ENGINEERING DEPARTMENT.

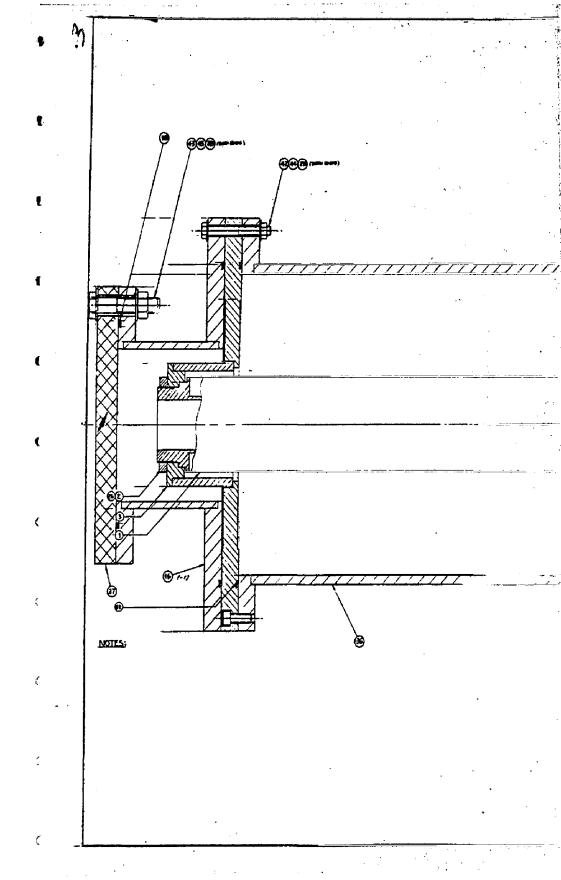
3 GOUDWRAP COIL WITH MALAR TAPE, ITEM 2, AFTER FORMING. USE 1/2 LAP METHOD. USE MINIMAL TAPE TENSION TO HOLD COIL SHAPE.

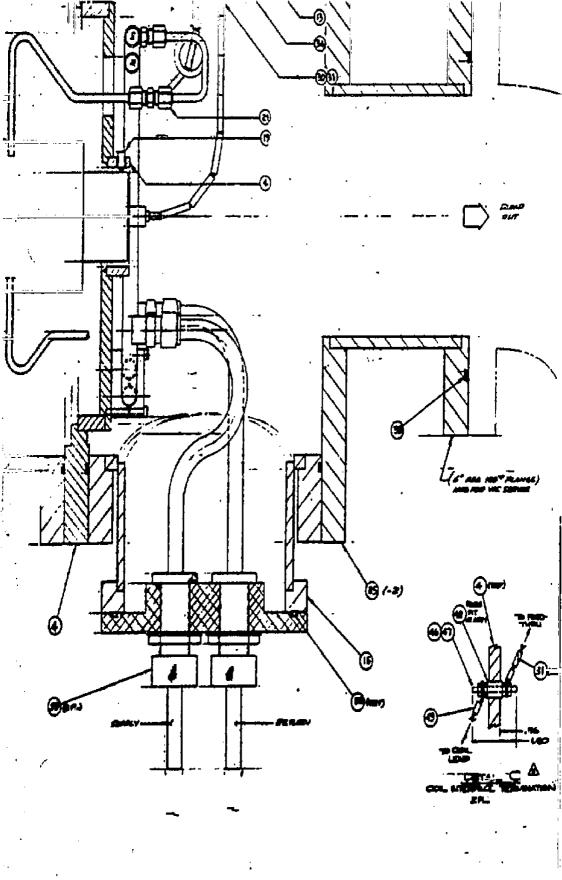
4. HT-POT COLL FO., ONE (L) MINUTE.
5. NOMINAL COLL DESIGN 15 20.830 AMPS TO GIVE 132 GAUSS FOR 2° BEND @ 45 MeV.

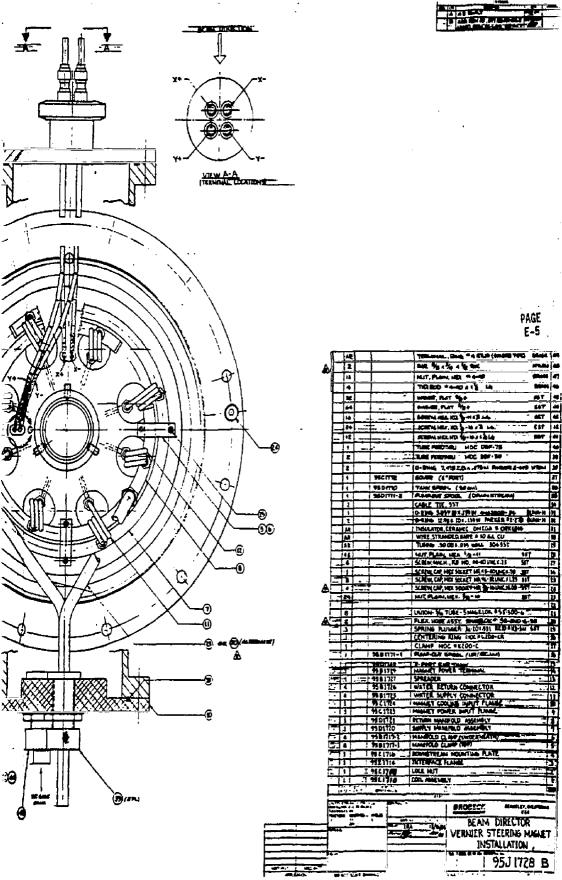


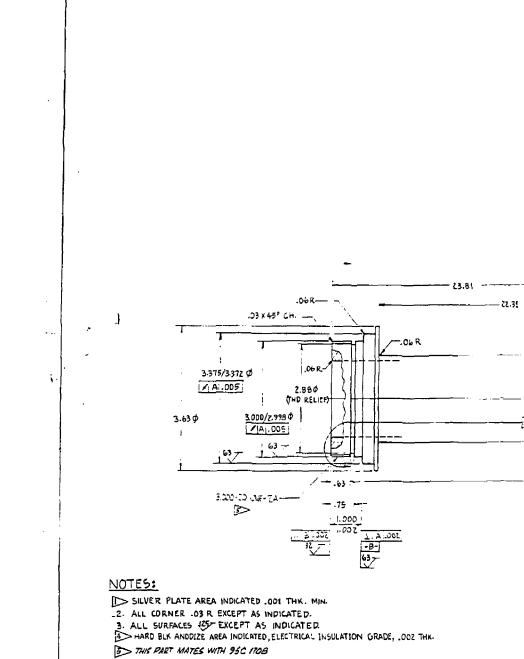










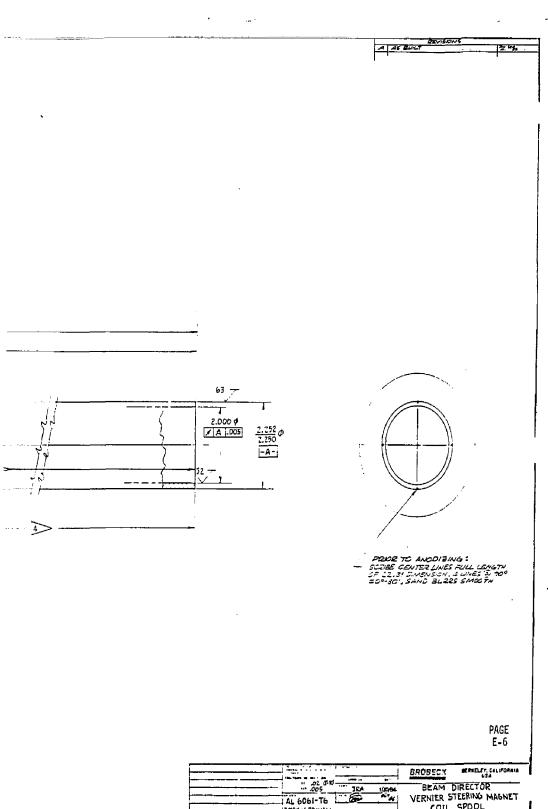


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ALL PLATING SOLUTIONS MUST BE COMPLETELY NEUTRALITED & RESIDUE ROMONED.

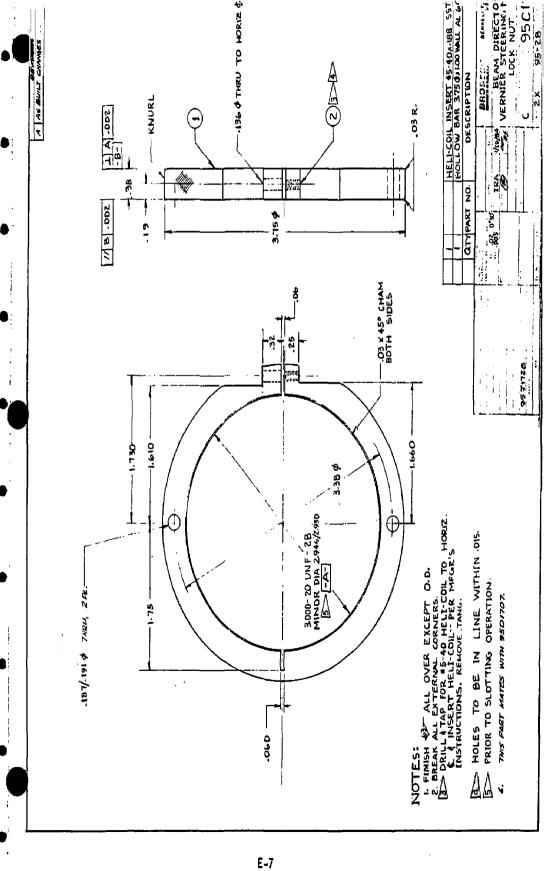


3750 1100 WALL NOTED

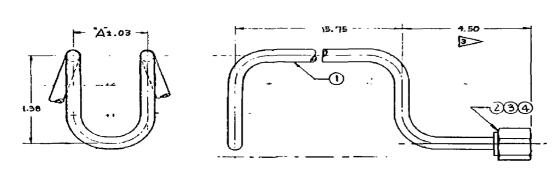
95.E 1710

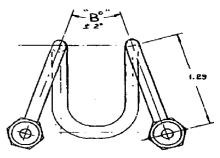
COIL SPOOL ----. FULL 95-28

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## NOTE:

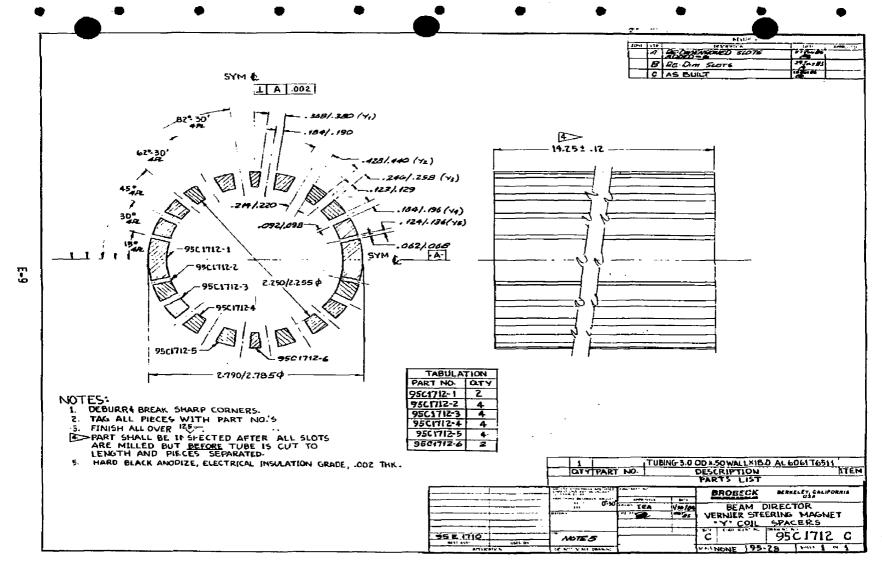
I. ALL BEND RADII = .44

2. ITEMS 344 ARE INSTALLED PER MANUFACTURER'S
INSTRUCTIONS USING A SWAGELOK PRE-SWAGING
TOOL.

3 THIS DIMENSION IS WITH NUT AGAINST SWAGED ON
FERRULES.

TABULATION						
PART Nº	DIM.	ANGLE B	QTY REOD			
95 C (109 -1	.97	34°	2			
956 1109-2	1.24	44°	2			

	Ž	Ι		FRONT FER	RULE, SWAGELOK	155-303-1 STLS	57 4
	2			BACK FERN	DLE, SWAGELOK	55-304-1 5NS	T 3
	2			NUT, 3/4.	SWAGELOK #55-3	OZ 1 STLS ST	2
	AR			TUBING .18	8 00x . 020 WAL	1 304 55 ·	1
Γ	QTY	PART	No		DESCRIPTION		TTEM
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	•	-				EERING MAGN UG COIL	ET
					THE RESERVE		
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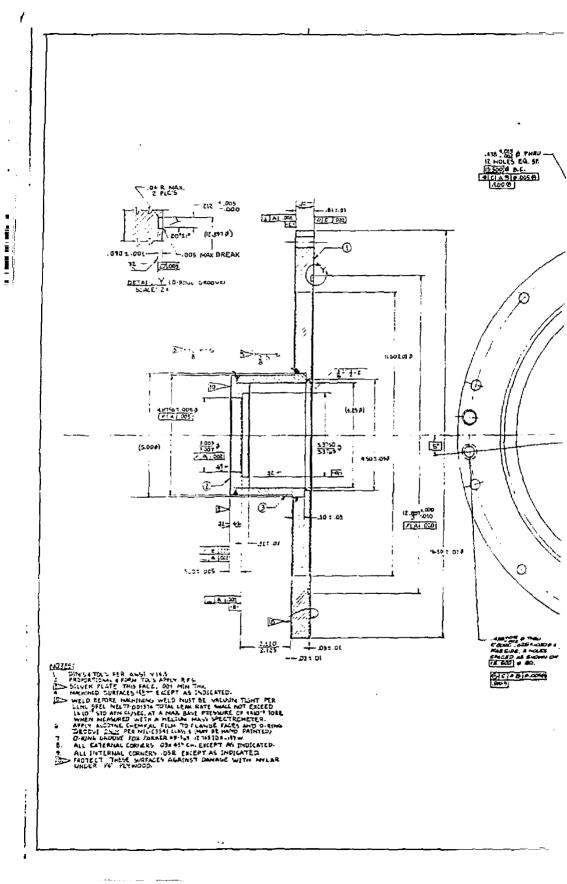
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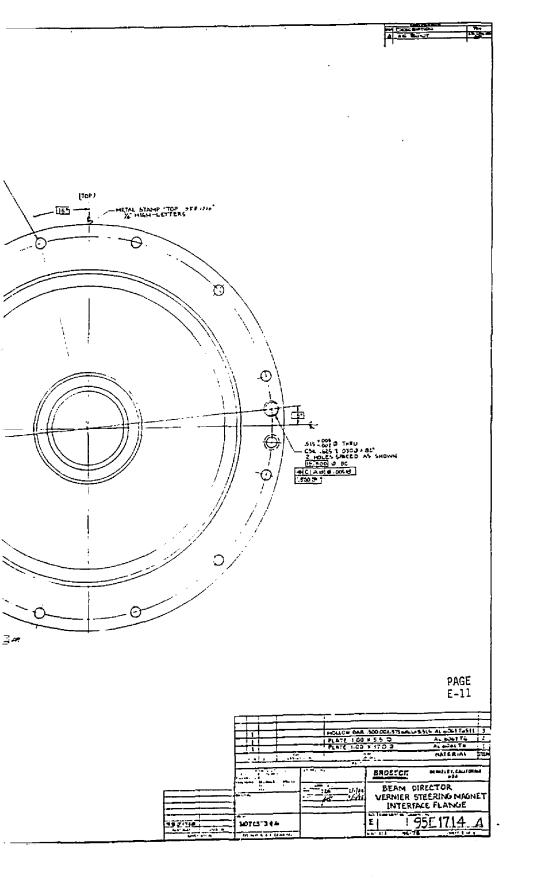
3. AL

95-28

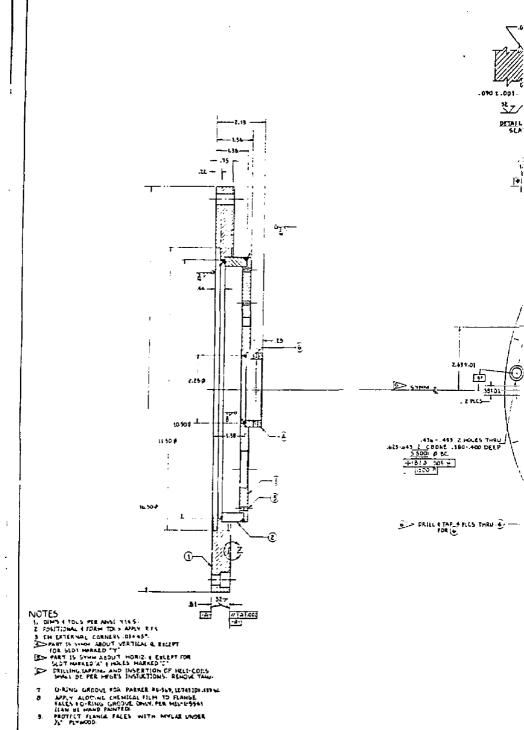
ADTES

INT BUIL STALL DRAWN

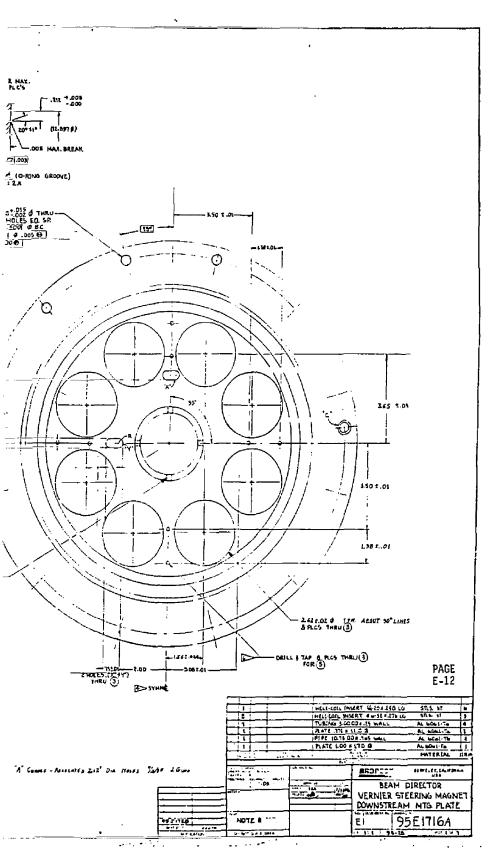


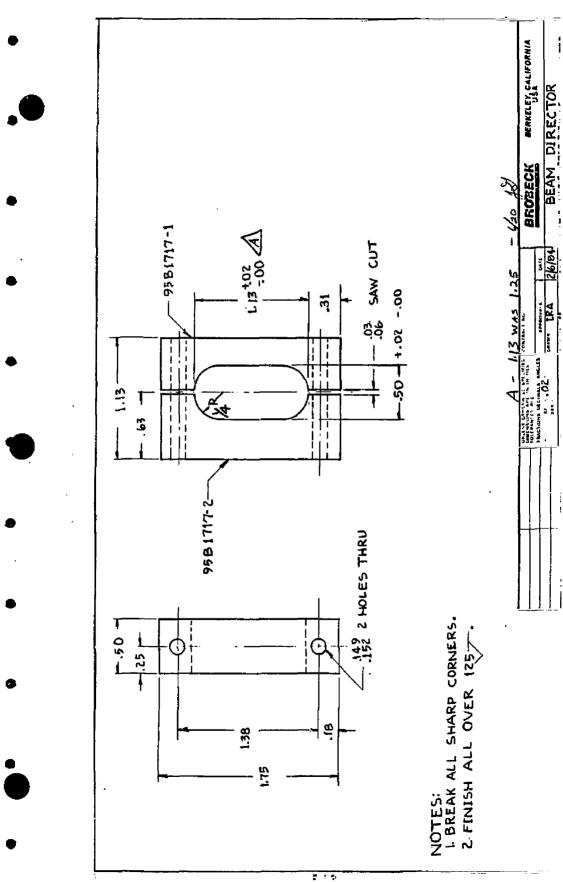


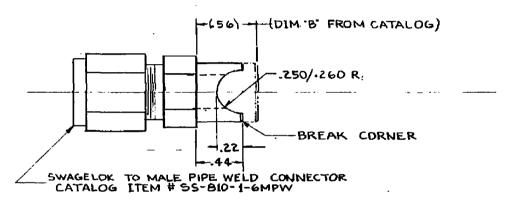
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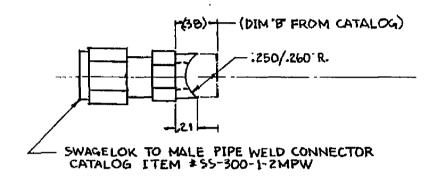






NOTE: 1. UNLESS OTHERWISE SPECIFIED, SURFACE FINISH 1257.

	<del></del>	Cherry Charleman British	CORTHAL! NO	•	BROBECK	BERKELEY, CALIFORNIA		
		FRACTIONS DECIMALS ANLIES	APPROVA S	CATE		USA		
			TRA	47/84	BEAM D	RECTOR		
		STABLESS STL	CHO! PIL	CETES	VERNIER STEERING MAGNI			
		SIMULTESS SIL			MANIFOLD F	1TTING - 1/2"		
95 D 1721					SITE CODE IDENT NO	DRAWING NO		
95D1720		A I M I P 44	<del></del>	<del></del>	l e l	95 B 1718		
HE21 A35"	OPI O OM		L	_		750110		
APPLICA'	THO N	DO NOT SCALE IMAMING	1		SCALE 2:1 95-	Z&   SHEET 1, OF 1.		



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MEAT ASST

APPLICATION

### NOTE: I UNLESS OTHERWISE SPECIFIED, SURFACE FINISH 1257.

BERKELEY, CALIFORNIA **BROBECK** FRACTIONS DECIMALS ANGLES -± 1.02. DALLIN IRA 2784 BEAM DIRECTOR VERNIER STEERING MAGNET MANIFOLD FITTING - 1/16 MATERIAL STAINLESS GTL 95D1721 COOR IDENT NO DRAWING NO 1719 812E 95 D1720 В

DO NOT SCALE DRAWING

95-7B

SCALE 7: 1

50 ¢ -3:8/392 Ø 125-FINISH DRILL AFTER WELDING ITEM 4 SCALE ZX SECTION A-A TYP FOR LTEMS (

DAFTER FORMING ITEM DO THE FOLLOWING IN SEQUENCE:

a. SADDLE TIEMS () () ON ITEM () AND TIG WELD.

b. DRILL 125 & THRU ITEM () | NEAR WALL OF ITEM ().

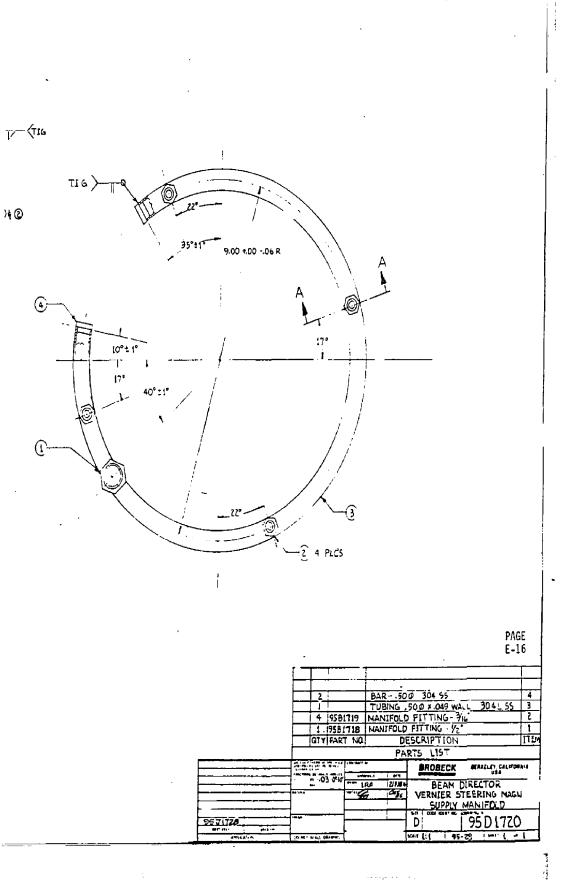
c. DRILL 126 & THRU ITEM () | NEAR WALL OF ITEM ().

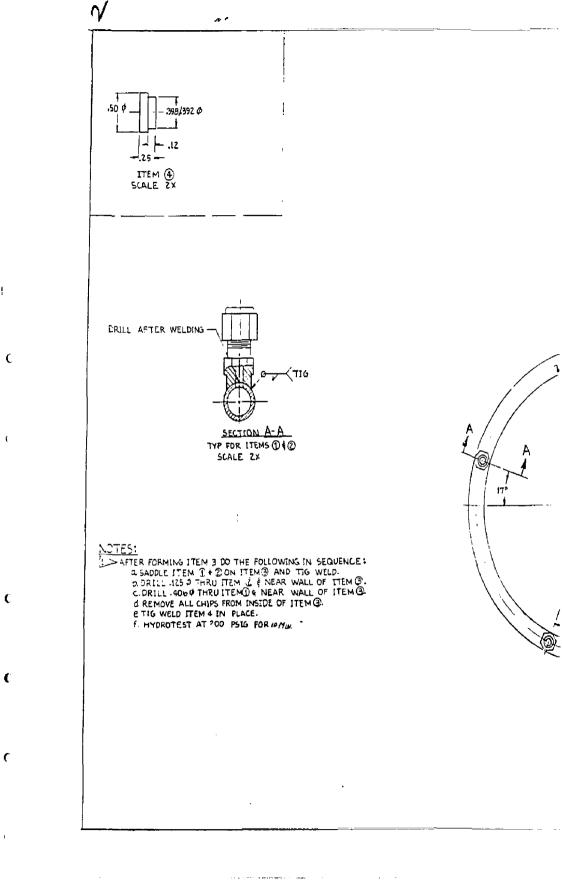
J. REMOVE ALL CAIPS FROM INSIDE OF ITEM ().

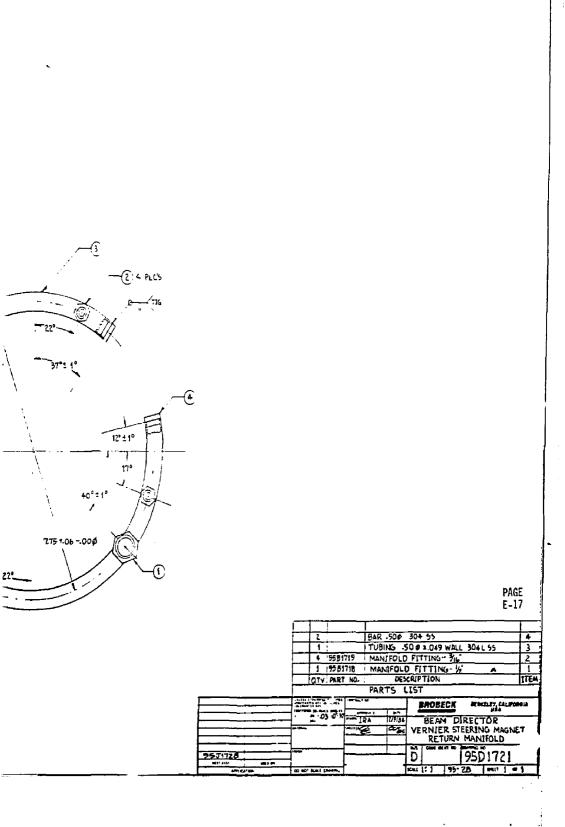
e. TIG WELD ITEM () IN PLACE.

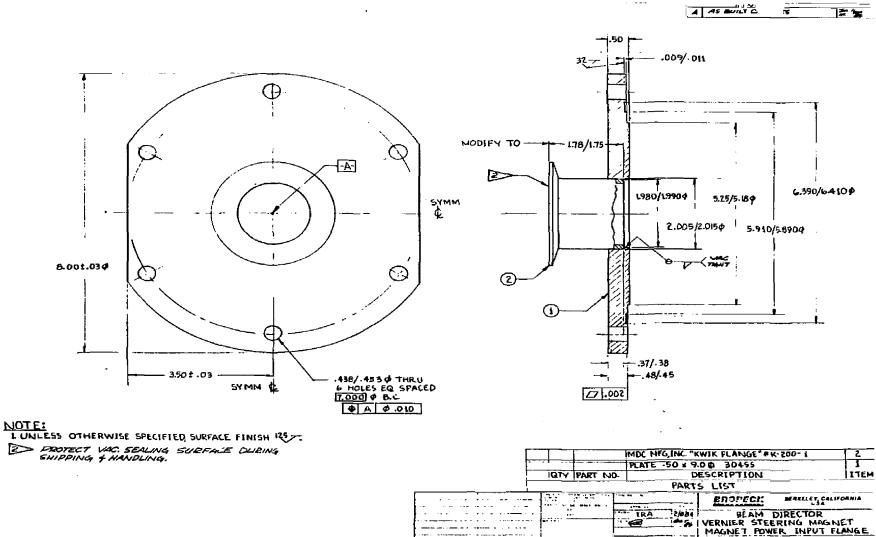
f. HYDRO-TEST AT 200 PSIG FOR 10 MIN.

NOTES:

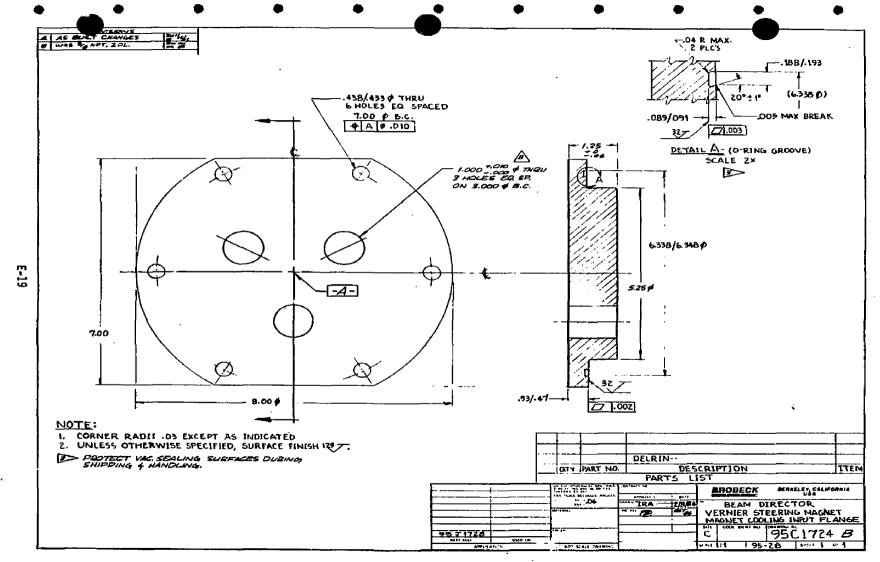


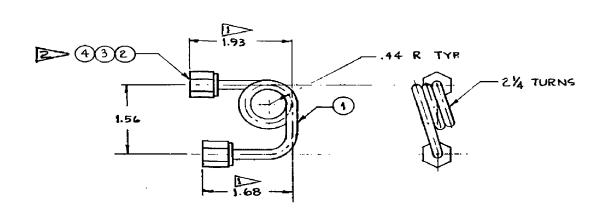






c 95C1723 A





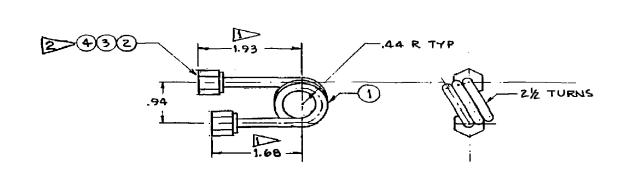
### NOTE:

THESE DIMENSIONS ARE WITH NUTS AGAINST SWAGED-ON FERRULES.

2. ITEMS 344 ARE INSTALLED PER MFGR'S INSTRUCTIONS USING A SWAGELOK PRE-SWAGING TOOL

FRONT FERRULE SWAGELOK 3/16" STL5 ST	
BACK FERRULE" SWAGELOK 36 STLS ST	3
NUT - SWAGELOK 3/16" STLS. ST.	2
TUBING .188 OD X.020 WALL 304 55	1
DESCRIPTION	ITEM
PARTS LIST	,
	BACK FERRULE: SWAGELOK 16 STLS ST NUT - SWAGELOK 16 STLS. ST. TUBING 188 OD X.020 WALL 304 SS DESCRIPTION

<u> </u>		UNLESS OTHERWISE SPECIFIED DIMERSIONS ARE IN INCHES TOLERANCES ARE	CONTRACT NO		E	ROBEC	K	BERKELEY, GALIF	ORNi
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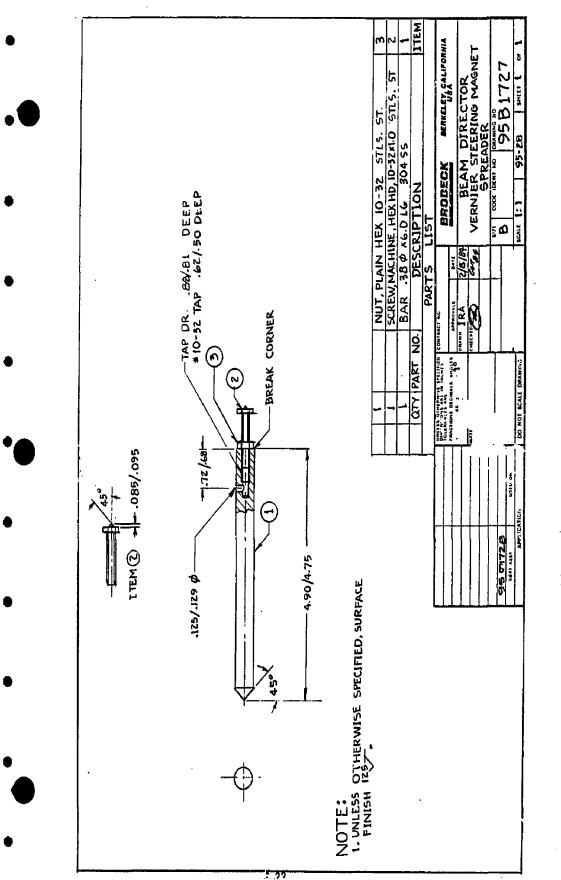
### NOTE:

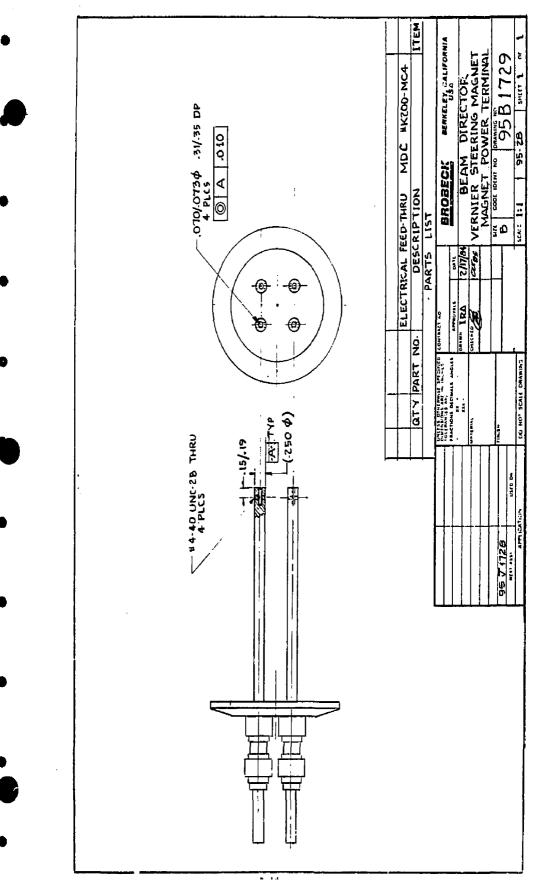
THESE DIMENSIONS ARE WITH NUTS AGAINST SWAGED-ON FERRULES.

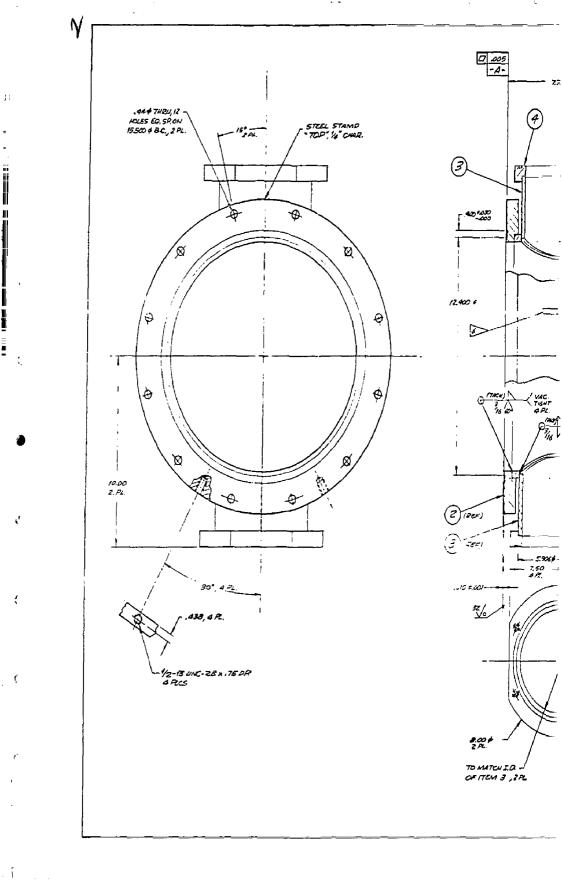
2. ITEMS 3&4 ARE INSTALLED PER MFGR'S INSTRUCTIONS USING A SWAGELOK PRE-SWAGING TOOL.

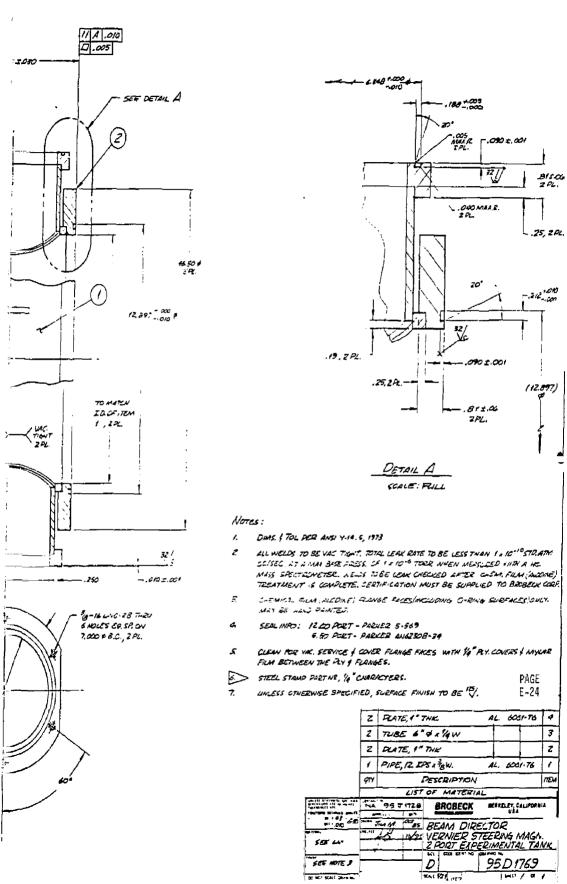
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1   c   NO INSWAGELOK AR SIES SI   c	2 AUST-CHACELON 34 F CTIC CT	2 BACK FERRULE- SWAGELOK 7/6, 57 L5 ST  2 NUT-SWAGELOK 3/6" STLS. ST	7 2	AUIT CHACELOW 3/ / CTIC CT	7	

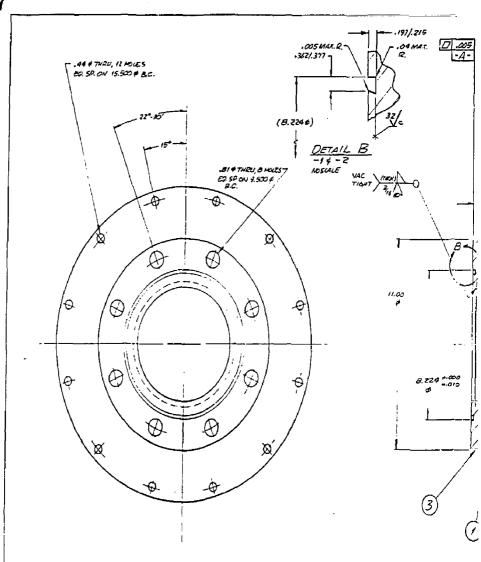
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					ETURN CONNECTOR
	Finish	-	1	BIZE CODE IDENT NO	DRAWING NO
9571728				l Bi	95B1726
MENT ASSY USED ON		<u> </u>	_		<u> </u>
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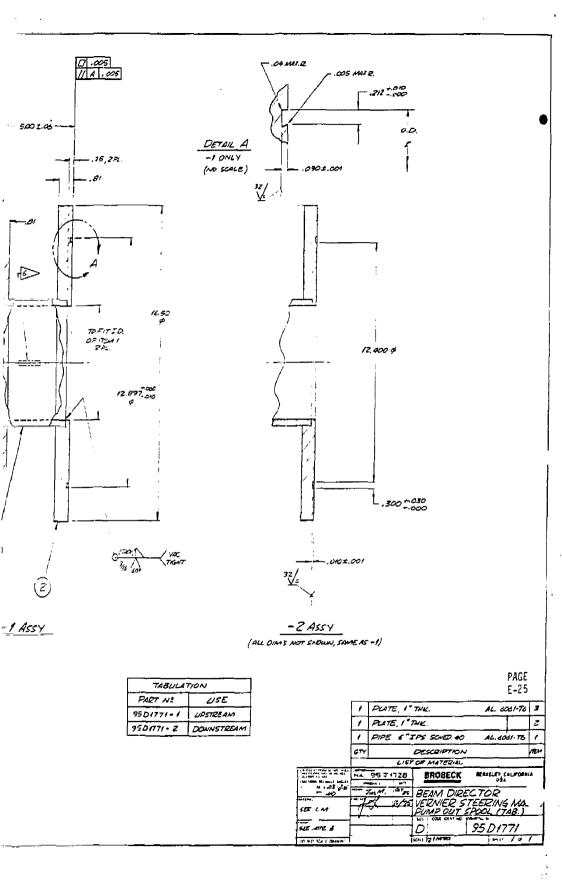


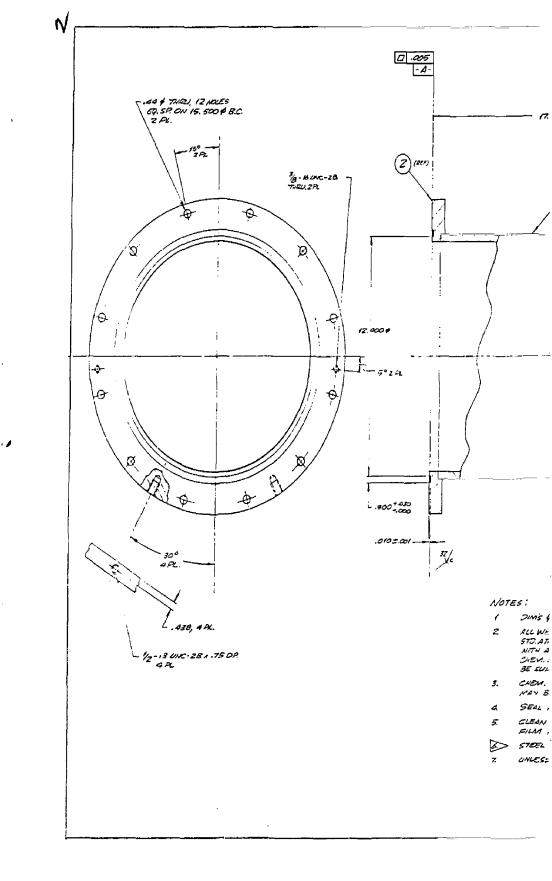


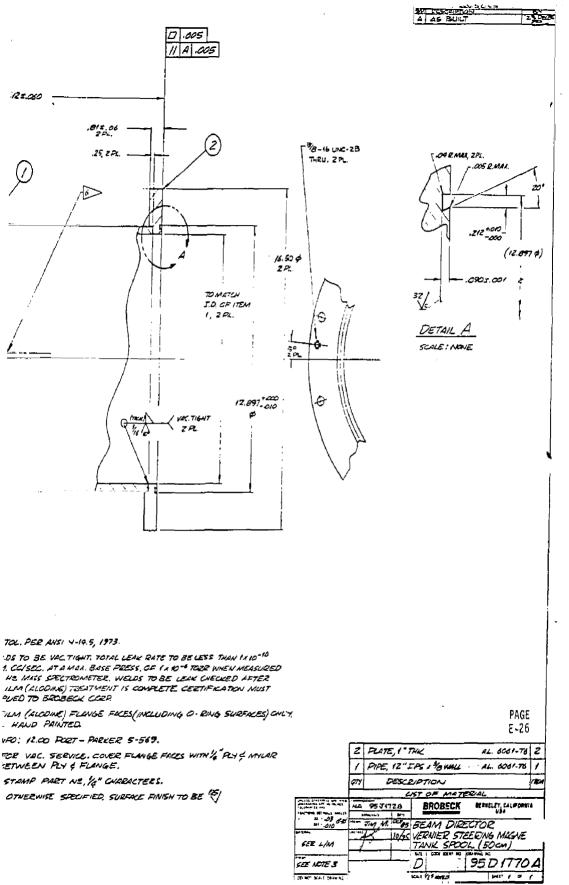


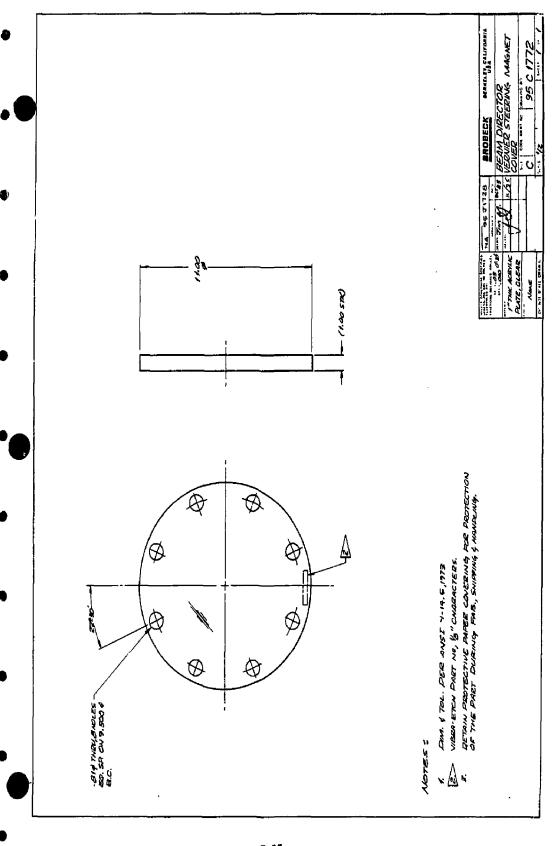
#### NOTES:

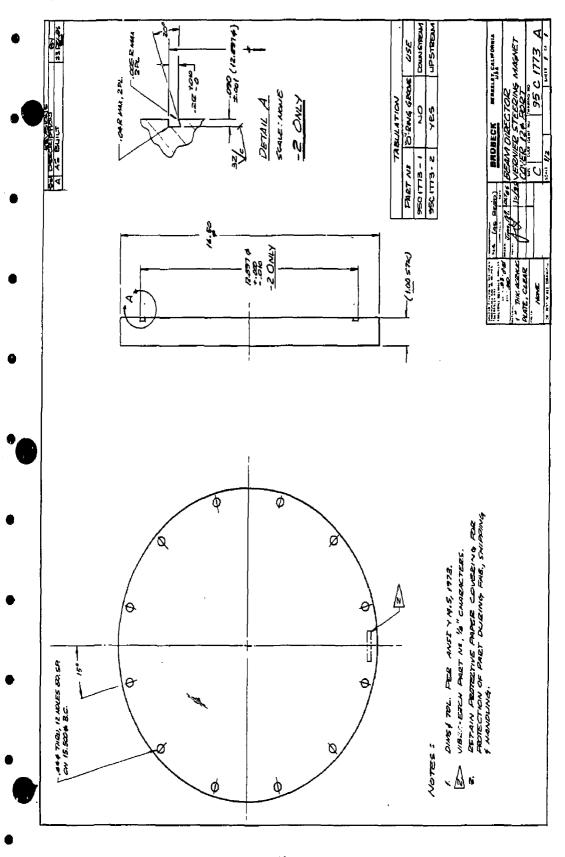
- 1 DIMS & TOL PER ANSI Y-14.5, 1973
- 2. ALL WELDS TO BE VAC. TIGHT, TOTAL LEAK RATE TO BE LESS THAN IN 10<sup>-10</sup> STD. ATM. CC/SEC, AT A MAX. BASE PRESS. OF I X 10<sup>-6</sup> TORR WHEN MEASURED WITH A HE MASS SHITTRIMETER. WELDS TO BE LEAK CHECKED AFTER CHEM. RIM (ALDONE) TREATMENT IS COMPLETE. CERTIFICATION MUST BE SURPLIED TO BEDBELL CORP.
- 3. CHEMICAL FILM (ALDOING) FLANGE FIXES (INCLUDING O-RAG GROVES) CAXY.
  MAY BE HAND PANTED.
- 4. SEAL INFO: FOR 16.50 & FLANGE PARKER 6-869 FOR 11.00 & FLANGE - FRENCE 2-443
- 5. CLEON FOR VAC. SERVICE & COVER FLANGE FICES WITH 1/4" PLY & MILDREILM BETWEEN THE PLY & FLANGES.
- 5 STEEL STAMP PART Nº & DASH Nº , 1/4" CHARACTERS.
- 7. UNLESS OTHERWISE SPECIFIED, SURFACE FINISH TO BE "











E-28

## APPENDIX F. MAGNETIC MEASUREMENTS REPORTS, LAWRENCE BERKELEY LABORATORY

This appendix contains data provided by the Magnetic Measurements Engineering Group at Lawrence Berkeley Laboratory (LBL). Their report on the measurements of the individual magnet segments is included in its entirety. This is followed by excerpts from their reports on measurements of the quadrupole assemblies, dipole assemblies, and the vernier steering magnet. Full data reports are available from LBL upon request.



SUMMARY OF MEASUREMENTS AND SORTING

OF

PERMANENT MAGNETS FOR THE ATA BEAM DIRECTOR \*

ΒY

DONALD H. NELSON & DAVID A. VAN DYKE

NOVEMBER, 1985

LBL Electronics Engineering Note MT 352

(LBID 1047)

This work was supported by the Director, Office of Energy Research, Office of High Energy and Nuclear Physics, High Energy Physics Division, U.S. Dept. of Energy, under Contract No. DE-AC03-76SF00098.

#### INTRODUCTION

ic "ciabt-banded"

The purpose of this Engineering Note is to document measurements and sorting conducted by the LBL Magnetic Measurements Engineering Group.

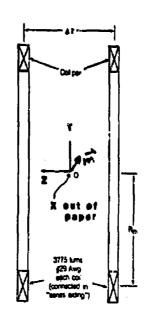
This work was undertaken to provide a basis for selectively distributing 367 permanent magnets among 17 beam-line elements for the LLNL Advanced Test Accelerator (ATA) Beam Director. The measurements described in this report fall into the following three categories:

- Calibration measurements for the Magnetic-moment Measurement and Sorting System (MMSS),
- II) Measurements for determining the accuracy and reproducibility of the MMSS. and
- III) Measurements and sorting of 367 ferrite magnets Results.

Measurements of strength and quality of the beam-line elements will be the subject of a separate report.

### COORDINATE SYSTEM

To simplify descriptions of the MMSS we introduce two coordinate systems and define rotational error terms. Figure 1 represents a cross section of a pair of coils, coaxial on the z-axis and located symmetrically with respect to the origin of a cartesian coordinate system. We define the angular errors roll, pitch, and yaw as rotations about the z, x, and y axes respectively - counter clockwise as viewed from the positive axis toward the origin. Figure 2 shows a second cartesian coordinate system (primed) for a typical magnet tested. The origin of the primed coordinate system is at the centroid of the magnet. y' is normal to the large rectangular base formed by b2 and e1; and +y' is directed as shown in figure 2. The z' axis is parallel to edge e1. The z'-axis is directed outward from the trapezoidally shaped end marked with an arrow signifying the easy axis (of magnetization).



A magnetic dipole (in) at the origin of a sertestan coordinate system centered on a Helmholtz coil pair; the axial separation ( $\Delta z$ ) equals the mean radius of the coil bundle ( $R_{\rm m}$ )

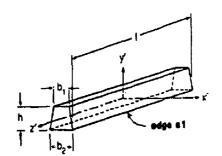


FIGURE 2.

FIGURE

Representative magnet--ATA beam director

### CALIBRATING THE MMSS

axis is defined as the z-axis of a cylindrical coordinate system with its origin midway between the two coils, that Equation 1 describes the equiv-

We have shown, for a pair of identical, coaxial coils whose common

alence of two ratios: 1) the ratio of axial magnetic moment at the origin to magnetic flux linking the coils, and 2) the ratio of current in the coils to the magnetic intensity at the origin.

$$m_{Z}(0,0,0) / V(m_{Z}) = I / H_{Z}(0,0,0,I) = A_{I} I / B_{Z}(0,0,0,I)$$

$$= R * (1 + Z / R) / n \text{ [meters]}$$
 (1)

where:

$$m_{\mathbf{Z}}(0,0,0)$$
 = (axial,z, component of) magnetic moment at the origin [Wbm]
$$\mathcal{W}(m_{\mathbf{Z}})$$
 = magnetic flux linkage due to  $m_{\mathbf{Z}}(0,0,0)$  [Wb]
$$= \text{current flowing in each coil [A]}$$

 $H_{\mathbf{Z}}(0,0,0,1)$   $\approx$  (axial,z, component of) magnetic intensity at the origin

due to I [A/m]

$$\mathbf{z}_{\mathbf{Z}}^{(0,0,0,1)} = \boldsymbol{\mu}_{\mathbf{0}} \mathbf{H}_{\mathbf{Z}}^{(0,0,0,1)} = \text{magnetic induction corresponding to H}$$

Henries/ml

n ≈ number of turns in each coil [dimensionless]

The last expression in equation 1 describes the geometry of the coaxial

coil pair. For Helmholtz geometry  $Z_0 = R_{\rm m}/2$ , so  $(1 + Z_0^2/R_{\rm m}^2)^{\frac{3}{2}}$  ~1.398

We calibrated the sensitivity of the MMSS coil pair to magnetic moment at the origin by determining the ratio (I/H $_{\bf Z}$ (0,0,0,1). Figures 3 and 4 illustrate the principles involved in the derivation of Eq. 1. Table I describes the equipment used. We measured current with an accuracy of 0.1% by means of the current monitoring shunt. We measured B $_{\bf Z}$ (0,0,0,1) with the search-coil and the electronic integrator. The coil/integrator combination was calibrated with the Flux-Standard.

In preparation for calibrating the MMSS we verified the ratio of flux-linkage produced by the flux-standard to the turns area of the search coil ( $N_{\rm MSS}$ / $n_{\rm AGD}$ ). Using a Nuclear Magnetic Resonance (NMR) magnetometer as a standard for magnetic induction and the LBL standard reference magnet as a transfer device, we verified that ( $N_{\rm MSS}$ / $n_{\rm MSS}$ ) is the same value (to +/- 0.2%) as when it was first determined about 15 years ago.

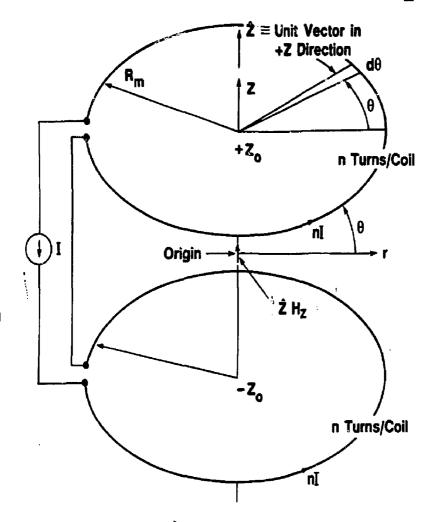
We concluded that our calibration of the MMSS was accurate to  $\emptyset.2\%$ .

Table I Equipment Used For Calibrating the MMSS

Device	Description	DOE #, S/N etc.
Search Coil Flux Standard	LBL, nA = 11.82 m LBL Drwg. # 5V4944	Di
TIEN OCERTICAL D	Flux = 0.05499 [V sec]	42.05
Integrator	LBL Drwg. No. 6V1763	S/N 1
-	R = 46.4 [kOhms], $C = 0.1$ [MF].	,
	Attenuator = 10.0	
DVM1	Keithley Mad 177	S/N 10445
Power Supply	Elec. Prod. Shop Mod 49385	
Shunt	Leeds Northrup Co.	AEC # B29
DVM2	Keithley Mod 177	S/N 10444
NMR Control Unit	LBL Drwg. No. 16V111F1	5/N 22
NMR Amplifier	LBL Drwg. No.16V112P1	S/N 27
NMR Probe	LBL Drwg. No.16V113P1 R. 4	S/N 175
Magnet "BIG BERTHA"	LBL Reference Magnet (Permanent B <sub>y</sub> ≈ 6.245 kG @ 21 Deg C	:)
Miniscope	NLS <b>Mod.</b> MS 215	S/N 1973

# FIGURE 3.

# POWERED COILS DERIVATION OF HZ(I)

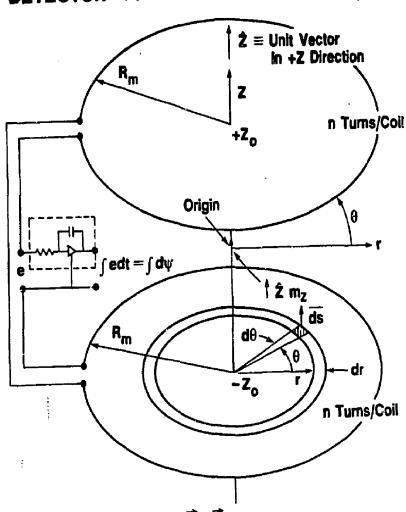


$$\begin{split} H_{Z}(2nl) &= \overrightarrow{H}(2nl) \cdot \hat{Z} \\ &= 2n \int\limits_{\theta=0}^{2\pi} \frac{lR_{m}^{2}d\theta}{4\pi (R_{m}^{2} + Z_{o}^{2})^{3/2}} \\ &= \frac{nl}{R_{m}(1 + (Z_{o}/R_{m})^{2})^{3/2}} \end{split}$$

Ramo, Whitnery and Van Duzer, "Fields and Waves in Communications" Electronics" (1967), p. 110.

# FIGURE 4.

# DETECTOR COILS DERIVATION OF $\psi(\vec{m})$



$$\begin{array}{ll} \psi(m_Z(0,0,0)) \; = \; 2n \quad \bigcap \stackrel{\ \, B}{\ \, \cdot \ \, ds} \\ \\ = \; 2n \quad \int \limits_{\theta \; = \; 0}^{2\pi} \quad \int \limits_{r \; = \; 0}^{R_m} \; \frac{m_Z \times (2Z_o^{\; 2} \; - \; r^2)^{\frac{1}{2}}}{4(r^2 \; + \; Z_o^{\; 2})^{5/2}} \; dr \; d\theta \end{array}$$

$$= \frac{nm_Z}{R_m(1 + (Z_o/R_m)^2)^{3/2}}$$

- Dols, Nelson, "Point Dipole Approximation for the Magnetic Field of a Solenoid" LBL Eng. Note MT 253 (1976), Eq. 1.
- \* Neison, Lae, "Proposal for Measuring and Softing Permanent Magnet Blocks" LBL Eng Note MT 346 (1985), Appendix A.

To measure the accuracy and reprpoducibility of the MMSS, we made (in addition to the calibration measurements discussed previously) the following tests:

- dero resolution tests measurements of the noise level of a complete measurement sequence without a magnet installed in the positioning fixture,
- reproducibility tests comparisons of repeated measurements of three components of magnetic moment of the same magnets,
- 3. translation tests measurements of the three components with the magnet translated S cm along the x, y, or z axes, and
- 4. rotation tests measurements of the three components with the magnetat the origin, but rotated 100 milliradians about the x, y, or  $\Lambda$

The zero resolution tests were made without a magnet in the positioning fixture. The reproducibility tests were conducted with two magnets, one with its easy axis (of magnetization) along the x-axis (s/n 105013) and the otherwith its easy axis along the y-axis (s/n 103003). The translation tests were conducted with magnet s/n 103003. The rotation tests were conducted with magnet s/n 405253. The results of these tests are represented in Tables II - V.

Since magnets have been reworked, i.e., demagnetized, ground to fit into sub-assemblies, and remagnetized, the magnitudes of magnetic moment are not of interest. For this reason we present the test results in te ms of percent of magnetic moment amplitude in the x'y' plane. For the reader's convenience we define terms used in Tables II - V below:

```
(x,y,z) coordinates of Helmholtz coil-pair
roll rotation about the z-axis
pitch rotation about the x-axis
yaw rotation about the y-axis
i x',y',or z' (coordinate of) magnet
m; m, m, or m, (component of magnetic moment, [Maxwell cm])
< .05 less than 0.05 % of (m, = (m, + m, r))
Glossary of Terms used in Tables II ~ V</pre>
```

### Table II Summary of Yero Resolution Tests (measurements with no magnet in the positioning fixture) Quantity Tabulated-----Magnitude [% of (12000. Maxwell cm) ]

< 0.05 18 Measurement Average 18 Measurement Standard Deviation 0.05 +/- 0.07 Maximum Deviation (from zero)

Table III Standard Deviations of 10 Measurements of Each Quantity Component Tabulated S/N of Magnet Std. Dev. [% may] 11890 103003

Table :	(V The measured effects	of Translation Erro	rs (S/N 103003)
· · · · · · · · · · · · · · · · · · ·		Error Terms Tabula	
(moment) component (i) measured	delta delta		delta z
ж.,	+0.01	+0.01	+0.02
у′	+0.02	0.00	+0.01
z'	0.00	~0.02	0.00

(moment) (component (i) measured	Erro: [% m // 100 m <u>delta m</u> : delta roll	Terms Tabulater ; m = m + delta m; delta pitch	m,= 15274 Max cm delta m, delta yaw
x'	< .05	< .05	< .05
,,	ć. <b>0</b> 5	-0.77	-0.62

< .05 < .05 . 05 Test Equipment

111

Figure 5 is a block diagram of the MMSS. Table VI lists specific equipment used for measuring 367 magnets for the ATA Beam Director. Both the data acquisition and sorting codes are saved on a total of 10 floppy discs. Hard copies of directories (of) and source listings (for) programs and subroutines on the floppy discs are filed, in LEL Engineering Data Book MME Baok # 691-0.

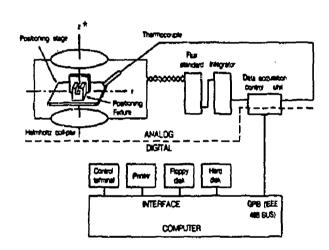


FIGURE 5. Magnetic-moment measurement and sorting system (MMSS) schematic diagram

\*Since Bevatron pulsing induced a significant vertical field at the location of the MMSS, we rotated the coil pair 90° so the z-axis was horizontal as shown in Figure 1.

Table VI Equipment List

Device

Coil Pair Positioning Stage Positioning Fixture Flux Standard

Integrator

Data Acquisition & Control Unit Computer

Description

None

None

None

S/N 1

(ea) 3775 turns # 29 AWG, Rm = .363 [m] LBL Precision, Special Purpose LBL Precision Cube 5"x5"x5" Alaminum

LBL Drwg. # 5V4994, Flux = .05499 [V sec] S/N 42.05 LBL Drwg. # 6V1763, 8 = 46.4 [kOhms]

C = 0.1 (µFd), Atten. = 10.0

HP Mod. 3421 A

LSI 11/23

DOE 532**5**28

DOE #, 5/N etc

DOE 532219(Sy:

Test Procedure (Minimizing Rotational Error Effect)

Computer generated "prompts" instruct the operator to move the positioning fixture a total of 20 times for measuring and recording flux—linkage. Changes in flux—linkage (corresponding to 180 degree rotations of the fixture about the y-axis of the coil-pair coordinate system) are extracted from these data to determine three orthogonal components of magnetic moment.

For each measurement sequence, magnet identification and raw data are saved along with the calibration constants needed to calculate magnetic moment from flux-linkage. At the end of the measurement sequence the program computes and displays information from which the operator may evaluate the data set. At any time the operator may restart or cancel the measurement sequence. At the end of a measurement sequence, the operator has the option of saving or not saving the previous data, recalibrating, repeating measurements of the same magnet, measuring a different magnet, or terminating the data set (closing the file).

A significant feature of our test-procedure/processing-algorithm is that it minimizes the effects of misalignment of the pos: ioning stage with respect to the Helmholtz coil-pair coordinate system (see figure 5). Outer surfaces of the positioning fixture (a precision cube) mating with the horizontal and vertical surfaces of the positioning stage determine the orientation of the magnet under test. Misalignment of the positioning stage introduces systematic angular errors which we have defined as roll, pitch, and yaw. We developed a measurement sequence and data reduction scheme that effectively cancels errors due to systematic pitch and yaw. (Because of the cylindrical symmetry of the coil-pair roll doesn't contribute significantly to measurement error.) In order to illustrate the procedure we first, write Equation 2 that describes the flux-linkage of one of the specified fixture positions (for other positions the equations the equations have the same form). Next, we approximate the cosine terms by 1.00, assumming roll, pitch, and yaw are small and reduce Eq. 2 to Eq. 3. Equations 4-a -- 4-d represent the flux linkages due to the 4 prientations of the positioning fixture for determining the x' component of magnetic moment.

$$E(3) = m_{cos}(pitch)cos(yaw) + m_{cos}(roll)sin(pitch) + m_{cos}(roll)sin(yaw)$$
 (2)

$$E(2) = E(4) \sim -m_{\chi} + m_{\chi} \sin(\text{pitch}) - m_{\chi} \sin(\text{yaw})$$
 (4a)

$$E(3)$$
 ~ +m\_, + m\_sin(pitch) + m\_sin(yaw) (4b = 3)

$$E(5) = E(7) \sim -m_{\chi} \sim m_{\chi} \sin(\text{pitch}) + m_{\chi} \sin(\text{yaw})$$
 (4c)

$$E(6)$$
 ~ +m ~ m sin(pitch) - m sin(yaw) (4d

Simultaneous solution of equations 4a -4d yields a value for m, while cancelling the other terms. Table VII indicates the orientations of the positioning fixture during a measurement sequence, and suggests the way the data are combined to determine three components of magnetic moment.

Table VII MMSS 20 Measurement Sequence Diagram

<b>D</b> i	View of Cube	к′	У,	z '	1st Diff	Moment (component)	total drift
2	1 up	*	^	> <b>)</b>			)
3	2 up		A	< <b>}</b>	EX1		)
4	1 up	*	^	> 1		Mx' =	)
5	1 down	*	V	< >		G*(EX1+EX2)/2	)
6	2 down		V	> <b>}</b>	EX2		)
7	1 down	*	<b>v</b>	٠, ١			)
8	3 up	A	*	< ↑			}
9	4 up	^		> <b>}</b>	EY1		)
107	3 up		*	₹ 5		'My' =	\ DRIFT/
11	3 down	V	*	>.ງ	/	G*(EY1+EY2)/2	/ SECOND
12	4 <b>down</b>	V	•	< }	EY2		)
13	a down	V	*	>1			)
14	5 պր	A	>	* <b>ງ</b>			)
15	6 up	A.	<	٠, ٢	EZ1 🧸		)
16	5 աթ	A	>	* J		. Mz′ =	)
17	5 down	V	<	* 7	_	• G*(EZ1+EZ2)/2	)
18	6 down	ν	>	٠, ٢	EZ2		}
19	5 down	V	ζ	* J			>

	)	DEFINITIONS OF TERMS &SYMBOLS	
	TERM	DEFINITION	[UNITS]
		t	
	I	Sequence Number	[Dimensionless]
	Mi'	i-th component of Magnetic Moment	[Maxwell cm]
1		i'≔ x', y', or z'	
	EX1	E(Mx') + E(Mz') + SIN(YAW)	[V]
	EX2	E(Mx') - E(Mz') * SIN(YAW)	[7]
	EY1	E(My') + E(Mz') + SIN(YAW)	[V]
	EY2	$E(My') \sim E(Mz') * SIN(YAW)$	[V]
	EZ1	E(Mz') + E(My') * SIN(YAW)	[V]
1	EZ2	E(Mz') - E(My') * SIN(YAW)	[V]
	G	Multiplier to covert pot-	[Maxwell cm / Volt]
		ential to magnetic moment	
	SYMBOL	(NOMINAL) DIRECTION	
	_	IN COIL-PAIR COORDINATE SYSTEM	

#### Test Results

We measured a total of 367 magnets for the ATA Beam Director.

One or more data sets for each of these magnets are filed in a Magnetic Measurements Engineering Data Book and on Floppy Disks. Directories of these Floppies and a (measurement & processing) log are included in each book.

Figure 6 is a copy of information printed while measuring magnet I.D. 301217. Figure 7 is a copy of one page of sorted data that includes magnet I.D. 301217. The sorting program uses "RT Sort" to search data files and to order records by selected criteria. The 367 magnets we measured were classified into 40 subsets like the two shown in Figure 7. Within each subset we sorted the magnets in order of decreasing magnitude of magnets.

Table VIII is an updated version of the Test Summary Table from reference 2. (At the time of publication of reference 2, dipoles had not been measured.)

Appendix A (distributed with the Nov. 85 status report; available on request) lists the sorted results of measurements of 368 magnets.

Appendix B (available on request) is a record of the blocks selected for installation in 19 beam-line elements (dipoles and quadrupoles).

Francis Younger of Brobeck Corporation selected the magnet blocks for each element and produced the list represented by Appendix B.

Appendix C (not for general distribution) will document the measurements of 80 magnet blocks to be kept as spares. These blocks have not been measured (they were recieved at LBL on 85 November 27).

### FIGURE 6.

# SAMPLE DATA SET

DATA TAKEN DN 23-JUL-85 AT 15:29:55

DEG

DATA SET ADZ: 0723CB. ASC

MAGNET BIZE: 3 MAGNET ORIENTATION: 01 MAGNET NUMBER: 217

EX [volta]	~4,57655	-6.57786	-6.57721	6.00131
EY [volte]	-B. 04146	-0.04372	-0.04259	0.60226
E2 [volts]	9.80451	0.00485	8.80548	8.80144
THF Edeg C3	22.74588	22.75790	22.75180	0.01200

END

DIF

drift [mV/second] 6.89810

mx my m2 mxy tHTAXY EMax+cm3 [Max+cm3 [Max+cm3 [Max+cm3 [Ideg] -22538.71 -145.89 19.46 22531.18 -179.63

PX PY F2 CX(MXY)3 CX(MXY)3 -100. -1. 0.

1	Elapsed Time	Integrator Potential	1	Elapsed Time	Integrator Potential
[13	(Seconds)	[V]	[13	[Seconds]	[43
1	8.8	6.68230	2	B.5	3.28988
3	13.7	-3. <i>28850</i>	4	19.6	3.28780
5	26.1	3,28810	6	32,2	-3.29828
7	38.8	3.28720	Ð	46.6	0.02097
9	54.3	-0.02024	10	62.1	0.82147
11	69.6	0.02157	12	77.6	~0.02255
12	84.7	4.82981	14	94.4	0.60028
15	101.8	9.00680	16	108,4	8.62039
17	115.0	-R.68316	16	121.6	0.00445
19	129.7	0,90102	20	138. Z	0.01448

FACTOR = 0.695
HELMHOLTZ RADIUS = 0.367
HELMHOLTZ TURNS = 3775.000
SLFS SENSITIVITY = 0.054995
AVERAGE CALIBRATION = 10.727840

**G**000

TIME

## FIGURE 7.

MXY

[Max-Cm]

# SAMPLE SORTED SUBSET

4.165 INCHES LONG WITH EASY AXIS OF 188.8 DEGREES

ĦΖ

[Max-Cm]

THTAXY

[Degrees]

_						
	381217	>22533.	-179.6	28.	23-JUL-85	15: 29:55
-	301143	22565.	176. 1	-147.	23-JUL-85	13:04:01
	301137	22469.	-176.9	254.	19-JUL-85	15: 97: 88
	381169	22656.	-179.5	179.	12-JUL-85	12:52:46
	301201	22693.	-177.4	-212.	18-JUL-85	18:58:52
	301155	22731.	-173.6	334.	23-JUL-85	14: 62: 18
		22883.	179.2	-271.	12-JUL-85	13:36:26
	301177	22987.	-178.5	416.	18-JUL-95	11:15:29
	381193	22933.	-178.9	-160.	18-JUL-85	89:44:36
	381289		-178.8	354.	17-JUL-85	13:48:26
	301129	22936.		387.	12-JUL-85	11:28:51
	301161	22969.	178.4	1101.	12-JUL-85	15:61:61
	381185	23871.	-178.4		28-JUN-65	16:09:67
	381145	2225BB.	176.1	-159.		
٠	381145	222598.	176.2	-159.	28-JUN-85	16: 13: 47
	391291	222653.	-177.4	-223.	D1-JUL-85	14: 22: 52
	381153	222780.	-173.6	332.	81-JUL-85	10: 15: 22
	381137	222815.	-176.9	243.	28-JUN-85	15: 18: 15
	301193	222891.	-178.6	424.	81-JUL-85	13: 20: 31
	301129	222992.	-178.8	342.	28-JUN-85	14:01:43
	301185	223869.	-178.3	1896.	12-JUL-85	14:55:55
	361102	11,000				
			PUCC LONG MI	TH EASY AXIS OF	135.0 DEGREE	5
	MAGNETS	WXX	THTAXY	MZ	DATE	TIME
	MAGID		[Degrees]	(Max-Cm)		
		[Max-Cm]	fnediens	\$ 1000 Y - Chin a		
	302178	22572.	135.8	-109.	12-JUL-85	13:40:59
	302146	22586.	136.8	147.	23-JUL-85	13:09:27
		22600.	137.7	-393.	19-JUL-83	15:11:85
	392138	22614.	134.5	-126.	12-301-65	15:05:48
	382186		131.4	-222,	23-JUL-85	15:34:07
	202218	22629.		59.	02-AUG-85	11:51:10
	302160	22659.	135.3	577.	23-JUL-85	14:07:01
	300154	22668.	139.0		23-JUL-65	15:00:50
	205510	22793.	134,9	96.		13:00:30
	202184	22827.	135.2	<b>5</b> 1.	01-JUL-85	15: 25: 38
	302170	22878.	174, I	3 <b>66</b> .	02-AUG-95	
	202202	22921.	134.2	377.	01-JUL-85	14:2B:30
	302130	22951.	135. B	80.	19-JUL-65	13:59:47
	302178	222587.	137.9	-399.	28-JUN-85	15: 25: 33
	30214e	222472.	136.9	155.	0:-Jul-85	Q9: 14: 23
	202146	222656.	136.9	147.	61-141-83	89:86:14
	302154	2226BB.	139.4	359.	01-JUL-85	10: 20: 14
	302162	222847.	153.3	A5.	12-JUL-95	11:34:82
	302130	222932.	135.7	79.	19-JUL-83	13:52:26
	382138	222958.	135.9	87.	28-JUN-83	14:12:22
		222790.	141.0	-49.	12-JUL-85	12:56:54
	302170	£77£,	171.0			

(Brobeck) Drwg. No.	Number measured	Average moment [m̄ <sub>wy</sub> ] [Maxwell cm]	Standard deviation	Valume EV3 Ecc. 3	Average Magnetizatio [Mxy] [10 <sup>3</sup> Gauss]
9 <b>5</b> 01733-1	80	22626.	1.40	<u>ර</u> 3 <b>09</b>	3.423
<b>● 95</b> 01733-2	47 *	11336	<b>0.</b> 73	. 304	3.431
9501732	96	22725	0.87	6.609	3.438
9 <b>5</b> 01734	144	15513	1.28	4.421	3.509

Table VIII Summary of Magnetic Moment Measurements

\* One magnet block (Drwg. No. 95D1733-2, S/N 106006) was damaged while being reworked. Its magnetic (moment m<sub>ky</sub> (106006) = 36D2 [Maxwell cm]} was not included in the average & standard deviation data in Table YII

#### References

- Nelson, D.H., Green, M.I., Van Dyke, D.A., "Froposal for Measuring and Sorting Permanent Magnet Blocks" LBL Engineering Note MT 346. (LBID 995), February, 1985.
- Nelson, D.H., Barale, P.J., Green, M.I., Van Dyke, D.A., "The Law-2. rence Berkeley Laboratory Magnetic-moment Measurement & Sorting System, LBL Report LBL 19292, July 1985, presented at the 9-th International Conference on Magnet Technology, Zurich Switzerland, September, 1985.
- 3. Macondray, F.W., "The 'Square Loop' Flux Standard: A Frecision Fulse Generator". LBL Report UCRL 17439, presented at the Second International Conference on Magnet Technology, Oxford, England, July, 1967.
- Magnetic Measurements Engineering Data Book No. 691-C. MMSS-2. 4, May,1985.
  - 5. Magnetic Measurements Engineering Data Book No. 691-E.F.G.&H. "Data-Sets ADO.AD1.AJ1. & AD3 respectively, May through September, 1985.

#### Acknowledgements

We thank Dr. Michael I. Green for his continuing support throughout this project - From specifying and structuring the CDAS through editing this Engineering Note. We thank Paul Barale for programming support, especially for his effort in programming with RTSORT. We thank Dr. Edward P. Lee for supporting our request to develop the MMSS.

Magnetic Measurements Engineering (4)

Technical Information Dept. (2)

Electronics Engineering Dept. (Original + 2)

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LBID-1105



## MAGNETIC MEASUREMENTS

OF THE

ATA BEAM DIRECTOR

PERMANENT MAGNET

ACHROMAT QUADRUPOLES

AUTHORS: Michael I Green Paul J Barale David A Van Dyke

Magnetic Measurements Engineering Group Lawrence Berkeley Laboratory University of California Berkeley, California 94720

> MT NOTE #357 20 December, 1985

\*This work was supported by the Director, Office of Energy Research, Office of High Energy and Nuclear Physics, High Energy Physics Division, U.S. Dept. of Energy, under Contract No. DE-ACØ3-76SFØØØ98.

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#### .Ø INTRODUCTION

Ed Lee requested that the LBL Magnetic Measurements Engineering (MME) Group measure the characteristics of the ATA Beam Director Achromat Focusing and Defocusing Quadrupole Magnets (Brobeck Company Drawing Numbers 95D1732 & 95D1733). Each magnet is fabricated from sixteen oriented-grain-ferrite permanent-magnet-blocks, arranged in a circular array to form a permanent magnet quadrupole. There are eight such arrays with a length of 10.63 cm and two arrays with a length of 5.315 cm. Of the eight "long" quadrupoles, four are designated "focussing" quadrupoles (1F, 3F, 4F & 5F) and four are "defocussing" quadrupoles (2D, 6D, 7D, 8D). The beam tube aperature radius of the permanent magnet quadrupoles is 1.42 cm.

We have measured the strength, and azimuthal orientation of the quadrupoles. Also measured and analyzed are the error harmonics and the dipole content of the quadrupole field. The original data is stored in MME Log Book #700A and on florpy disks MG305, MME315.

#### 2.0 HARDWARE

The hardware used to measure the ATA Beam Director Permanent Magnet Quadrupoles was the MME small quadrupole system.

The search coil drive mechanism used was one of the Magnetic easurements Group standard systems and is documented on LBL drawing 17M3273. his drive operated one of the Magnetic Measurements Group's standard search coils, known as the HILAC coil #5. The parameters of this search coil are documented in the subroutine SCDSC3. Our standard data acquisition hardware (Search Coil Switching Module, V/f Module and NIM 3 Channel Up/Down Counter), and monitoring and control units were used. Details of the hardware used and a block diagram detailing the system interconnections are given in Table 1 and Figure 1 respectively.

# TABLE 1: ATA PERMANENT MAGNET QUADRUPOLE HARMONIC ANALYSIS HARDWARE

MAGNET ATA BEAM DIRECTOR - PERMANENT MAGNET QUADRUPOLE

BROBECK DWGS 95D1732 AND 95D17433

COMPUTER DEC LSI 11/73, S/N SG14285641

MEMORY CAMINTONN 1 MBYTE RAM S/N 2155

CLOCK CALENDAR DIGITAL PATHWAYS, TCU-50DYR, S/N 16574

LINE PRINTER DEC LA 120, DECWRITER III, DOE 519478

GRAPHICS PRINTER EPSON FX-185, DOE 534943

CRT CONTROL TERMINAL GRAPHON GO16Ø, DOE 534949

FLOPPY DISC DRIVE DATA SYSTEMS DSD 440, DOE 519465

HARD DISK DRIVE DEC RLØ2, DOE 522851

WINCHESTER CONTROLLER MTI MLV11M-2, S/N 1687F

INCHESTER DRIVE #1 RODIME MODEL RØ 204, S/N 2403571

WINCHESTER DRIVE #2 RODIME MODEL RØ 204, S/N

PLOTTER TEKTRONIX 4051, DOE 504556

HARDCOPY TEKTRONIX 4631, DOE 504505

\*GPIB INTERFACE NATIONAL INSTRUMENTS GPIB11V-1, S/N 145

\*MPX HEWLETT PACKARD MODEL 3495A SCANNER,

OPTIONS 005, 100, DOE 517528

\*DVM1 HEWLETT PACKARD MODEL 3455A DIGITAL VOLTMETER.

DOE 517459

CAMAC CRATE & PS STANDARD ENGINEERING, MODEL 3472 CRATE & PS

DOE 512946, PS S/N 2683

CAMAC CONTROLLER STANDARD ENGINEERING, CCLSI-11, DOE 524892

INPUT/OUTPUT REGISTER JOERGER MODEL IR-1 IN/OUT REGISTER, DOE 512965

CHANGE-OF-STATE MODULE BI RA 3326 DIGITAL INPUT MODULE S/N Ø63

INARY INPUT MODULE STANDARD ENGINEERING PR604 DUAL I/P REGISTER

S/N Ø393

NARY OUTPUT MODULE

STANDARD ENGINEERING PR612 DUAL O/P REGISTER

S/N Ø326

RELAY SWITCH MODULE

KINETIC SYSTEMS 3075-E1A RELAY OUTPUT REGISTER

S/N 83

SEARCH COIL DRIVE

MOTOR ROT.OPT.ENC. ADAPTER BOX LBL DWG 17M3273

BODINE NO. 766HA5Ø14, TYPE KYC-22T5, 2 RPM DISC INSTR. ROTASWITCH MODEL 811-256-IBLS-TTL

NIM BIN

ORTEC 401B

NIM BIN PS

ORTEC MODEL 4020, S/N 2340

NIM 3 CHAN UP/DOWN COUNTER

LBL DWG 16V1323, S/N 1

V/F CONVERTER

LBL DWG 16V12Ø, S/N 1, DOE 521827

SCSM

SEARCH COIL SWITCHING MODULE, WITH PREAMP

LBL DWG 16V121, S/N 1

CABLE 1

LBL DWG 16V124-1

EARCH COIL ARRAY & SUBROUTINE

SCDSC3

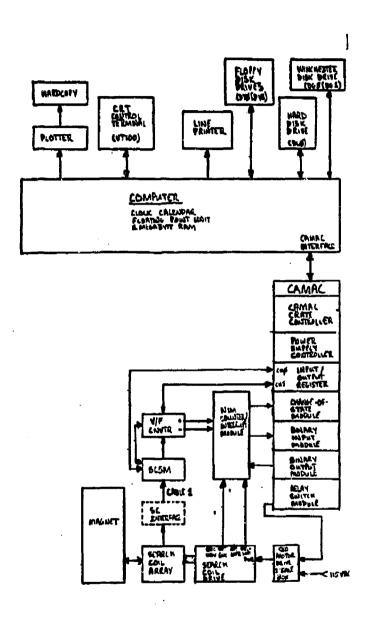
HILAC #5

SOFTWARE

QD2.SAV Ø4 NOV 85

-CONTROL PROGRAM

\*INDICATED DEVICES AVAILABLE BUT NOT USED WITH THIS SYSTEM



LBID-1106

MAGNETIC MEASUREMENTS

OF THE

ATA BEAM DIRECTOR

PERMANENT MAGNET

ACHROMAT DIPOLES

AUTHORS: Michael I Green Paul J Barale David A Van Dyke

Magnetic Measurements Engineering Group Lawrence Berkeley Laboratory University of California Berkeley, California 94720

> MT NOTE #358 20 December, 1985

<sup>\*</sup>This work was supported by the Director, Office of Energy Research, Office of High Energy and Nuclear Physics, High Energy Physics Division, U.S. Dept. of Energy, under Contract No. DE-AC03-76SF00098.

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#### 1.Ø INTRODUCTION

Ed Lee requested that the LBL Magnetic Measurements Engineering (MME) Group measure the characteristics of the ATA Beam Director Achromat Dipole Magnets (Brobeck Company Drawing Number 95D1734). Each magnet is fabricated from sixteen oriented-grain-ferrite permanent-magnet-blocks, arranged in a circular array to form a permanent magnet dipole. There are nine such arrays with a length of 9.00 cm. The beam tube aperature radius of the permanent magnet dipoles is 1.42 cm.

We have measured the strength and azimuthal orientation of the dipoles. Also measured and analyzed are the error harmonics and the dipole angular deviation. The original data is stored in MME Log Book #700B and on floppy disks MG305, MME315.

#### 2.Ø HARDWARE

The mechanical hardware used to measure the ATA Beam Director Permanent Magnet Dipoles was the MME small quadrupole system adapted for use in measuring the dipoles. The search coil drive mechanism used was one of the Magnetic Measurements Group standard systems and is documented on LBL drawing 17M3273. This drive operated a new search coil array, known as the "30mm.OD Dipole 2-pair search coil". This search coil was designed and fabricated specifically for these measurements. It and so documented on LBL drawing 16V133, and it operating parameters are immarized in the subroutine SCDSC7. Our standard data acquisition hardware (Search Coil Switching Module, V/f Module and NIM 3 Channel Up/Down Counter), and monitoring and control units were used. Details of the hardware used and a block diagram detailing the system interconnections are given in Table 1 and Figure 1 respectively.

# TABLE 1: ATA PERMANENT MAGNET DIPOLE HARMONIC ANALYSIS HARDWARE

MAGNET ATA BEAM DIRECTOR - PERMANENT MAGNET DIPOLES

BROBECK DWG 95D1734

COMPUTER DEC LSI 11/73, S/N SG14285641

MEMORY CAMINTONN 1 MBYTE RAM S/N 2155

CLOCK CALENDAR DIGITAL PATHWAYS, TCU-50DYR, S/N 16574

LINE PRINTER DEC LA 120, DECWRITER III, DOE 519478

GRAPHICS PRINTER EPSON FX-185, DOE 534943

CRT CONTROL TERMINAL GRAPHON GO160, DOE 534949

FLOPPY DISC DRIVE DATA SYSTEMS DSD 440, DOE 519465

HARD DISK DRIVE DEC RLØ2, DOE 522851

WINCHESTER CONTROLLER MTI MLV11M-2, S/N 1687F

INCHESTER DRIVE #1 RODIME MODEL RØ 204, S/N 2403571

WINCHESTER DRIVE #2 RODIME MODEL RØ 204, S/N

PLOTTER TEKTRONIX 4Ø51. DOE 5Ø4556

HARDCOPY TERTRONIX 4631. DOE 504505

GPIB INTERFACE NATIONAL INSTRUMENTS GPIB11V-1, S/N 145

MPX HEWLETT PACKARD MODEL 3495A SCANNER,

OPTIONS 005, 100, DOE 517528

DVM1 HEWLETT PACKARD MODEL 3455A DIGITAL VOLTMETER,

DOE 517459

CAMAC CRATE & PS STANDARD ENGINEERING, MODEL 3472 CRATE & PS

DOE 512946, PS S/N 2683

CAMAC CONTROLLER STANDARD ENGINEERING, CCLSI-11, DOE 524892

INPUT/OUTPUT REGISTER JOERGER MODEL IR-1 IN/OUT REGISTER, DOE 512965

CHANGE-OF-STATE MODULE BI RA 3326 DIGITAL INPUT MODULE S/N Ø63

CINARY INPUT MODULE STANDARD ENGINEERING PR604 DUAL I/P REGISTER

S/N Ø393

INARY OUTPUT MODULE

STANDARD ENGINEERING PR612 DUAL O/P REGISTER

S/N Ø325

RELAY SWITCH MODULE

KINETIC SYSTEMS 3075-E1A RELAY OUTPUT REGISTER

S/N 83

SEARCH COIL DRIVE

MOTOR ROT. OPT. ENC.

ADAPTER BOX

LBL DWG 17M3273

BODINE NO. 766HA5Ø14, TYPE KYC-22T5, 2 RPM DISC INSTR. ROTASWITCH MODEL 811-256-IBLS-TTL

NIM BIN

ORTEC 401B

NIM BIN PS

ORTEC MODEL 4020, S/N 2340

NIM 3 CHAN UP/DOWN

COUNTER

LBL DWG 16V1323, S/N 1

V/F CONVERTER

LBL DWG 16V12Ø, S/N 1, DOE 521827

SCSM

SEARCH COIL SWITCHING MODULE, WITH PREAMP

LBL DWG 16V121, S/N 1

SEARCH COIL ARRAY & SUBROUTINE

SCDSC7

30mm OD DIPOLE 2-PAIR SEARCH COIL:

LBL DWG 16V133

SOFTWARE

DP5.SAV 2Ø NOV 85 -CONTROL PROGRAM

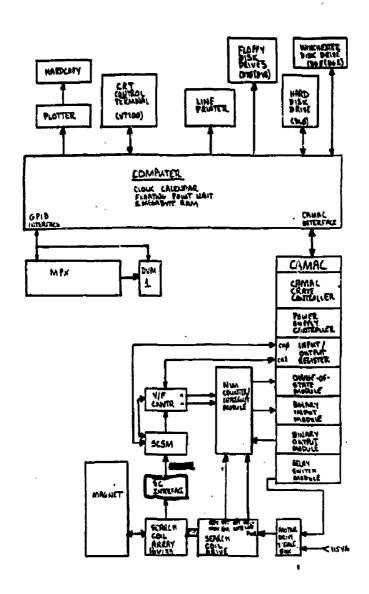


FIGURE 1. HARMONIC ANALYSIS MEASUREMENT HARDWARE BLOCK DIAGRAM

## MAGNETIC MEASUREMENTS

OF THE

ATA BEAM DIRECTOR
VERNIER DIPOLE MAGNET\*

AUTHORS: Paul J Barale Michael I Green David A Van Dyke

Magnetic Measurements Engineering Group Lawrence Berkeley Laboratory University of California Berkeley, California 94720

MT NOTE #353

\*This work was supported by the Director, Office of Energy Research, Office of High Energy and Nuclear Physics, High Energy Phyrics Division, U.S. Dept. of Energy, under Contract No. DE-AC03-76SF00098.

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APPE	ND1 CES
A	. DIRECTORY OF SOFTWARE FILES
В	. SUMMARY OF FIELD AND POWER DATA
C	. SUMMARY OF DATA USED TO CALCULATE AZIMUTHAL ORIENTATION
D	. SUMMARY OF DATA USED TO CALCULATE AXIAL CENTERS

#### 1.8 INTRODUCTION

Ed Lee requested that the LBL Magnetic Measurements Engineering Group measure the operating characteristics of the ATA Beam Director Vernier Steering Magnet manufactured by the Brobeck Company. This ironless magnet consists of two perpendicular dipole coils approximately 40 cm long, wound on a 2" I.D. bore tube.

We have measured the transfer function, harmonics, azimuthal orientation, effective axial position, and coil power requirements. The original data is stored in MME Log Book #694 and on floppy disks MG272, MME282.

#### 2.0 HARDWARE

The hardware setup used to measure the ATA Beam Director Vernier magnet was a variation of a typical setup used for measurement of a superconducting dipole. The magnet's inner and outer coils were powered alternately using an adjustable 40 volt, 50 amp power supply. The search coil drive mechanism used was borrowed from the Supercon Group, and drove an obsolete Supercon Group search coil array. Our standard data acquisition hardware (Search Coil Switching Module, V/f Module and NIM 3 Channel Up/Down Counter), and monitoring and control units were used. Our universal water manifold was used to provide low conductivity water for magnet cooling. Details of the hardware used and a block diagram detailing the system interconnections are given in Table 1 and Figure 1 respectively.

# TABLE 1: ATA VERNIER DIPOLE HARMONIC ANALYSIS HARDWARE

MAGNET ATA BEAM DIRECTOR - 2 DEGREE VERNIER DIPOLE

COMPUTER DEC LSI 11/73, S/N SG14285641

MEMORY CAMINTONN 1 MBYTE RAM S/N 2155

CLOCK CALENDAR DIGITAL PATHWAYS, TCU-SØDYR, S/N 16574

LINE PRINTER DEC LA 120, DECWRITER III, DOE 519478

CRT CONTROL TERMINAL DEC VT100. DOE 526336

FLOPPY DISC DRIVE DATA SYSTEMS DSD 440, DOE 519465

HARD DISK DRIVE DEC RLØ2, DOE 522851

WINCHESTER CONTROLLER MTI MLV11M-2, S/N 1687F

WINCHESTER DRIVE RODINE MODEL RØ 204, S/N 2403571

PLOTTER TEKTRONIX 4051, DOE 504556

HARDCOPY TEKTRONIX 4631, DOE 504505

GPIB INTERFACE NATIONAL INSTRUMENTS GPIB11V-1, S/N 145

MPX HEWLETT PACKARD MODEL 3495A SCANNER,

OPTIONS 005, 100, DOK 517528

DVM1 HEWLETT PACKARD MODEL 3455A DIGITAL VOLTMETER,

DOE 517459

CAMAC CRATE & PS STANDARD ENGINEERING, MODEL 3472 CRATE & PS

DOE 512946, PS S/N 2683

CAMAC CONTROLLER STANDARD ENGINEERING, CCLSI-11, DOE 524892

INPUT/OUTPUT REGISTER JOERGER MODEL IR-1 IN/OUT REGISTER, DOE 512965

CHANGE-OF-STATE MODULE BI RA 3326 DIGITAL INPUT MODULE S/N 963

BINARY INPUT MODULE STANDARD ENGINEERING PR604 DUAL I/P REGISTER

B/N Ø393

BINARY OUTPUT MODULE STANDARD ENGINEERING PR612 DUAL O/P REGISTER

S/N Ø326

RELAY SWITCH MODULE KINETIC SYSTEMS 3075-E1A RELAY OUTPUT REGISTER

S/N 83

DP MOTOR DRIVE LBL DWG 16132 (SMALL PORTABLE BOX)

INTERFACE BOX

## MOTOR DRIVE ELECTRONICS

MOTOR INTERFACE

FIELD MAPPING MOTOR REVERSING BOX

LBL DWG 13W567

MOTOR CONTROLLER

MINARIK MODEL TR9020 (old out 84 oct 25)

(new in 64 oct 25 1400 & labeled)

MOTOR

ELECTRO CRAFT CORP. MOTORMATIC MOTOR GENERATOR.

PART NO. Ø650 00 972, S/N H Ø3880 (out 84 oct 25)

5/N H Ø50Ø2 (in 84 oct 25 1400 hours)

SEARCH COIL DRIVE

LBL DWG ???????? ROT.OPT.ENC.

DISC INSTR. ROTASWITCH MODEL 811-256-IBLS-TTL

NIM BIN

ORTEC 401B

NIM BIN PS

ORTEC MODEL 4020, 5/N 2340

NIM 3 CHAN UP/DOWN

LBL DWG 16V1323. S/N 1

COUNTER

V/F CONVERTER

LBL DWG 16V12Ø, S/N 1, DOE 521827

SCSM

SEARCH COIL SWITCHING MODULE, WITH PREAMP

LBL DWG 16V121, 6/N 1

SEARCH COIL ARRAY

LBL DWG 19M8144A-Ø (1.2" OD ALUMINUM)

DIPOLE PS

HARRISON MODEL 6269A. 40 VOLTS. 50 AMPS

S/N 118; AEC #194587

CONTROL VOLTAGE PS

LAMBDA MODEL LP-520-FM

REGULATED P.S.: ØV - 1ØV ● 5AMPS, S/N B1414Ø

PS SHUNT

LEEDS & NORTHRUP, CAT. NO. 4361, S/N 792989

0.01 OHMS, 100 AMP

INNER COIL SHUNT

KMPRO HA-25-50

25 AMPS, 50 MV

Ø.002000 OHMS € 5A; Ø.002001 OHMS € 20A

OUTER COIL SHUNT

EMPRO HA-25-50

25 AMPS, 50 MV

Ø.902001 OHMS ● 5A; Ø.002001 OHMS ● 20A

DVM2

(USED TO MONITOR CONTROL VOLTAG' P.S.)

FLUKE 77 S/N 35070710 - HAND HELD VOM

WATER MANIFOLD

LBL DWG 16V131

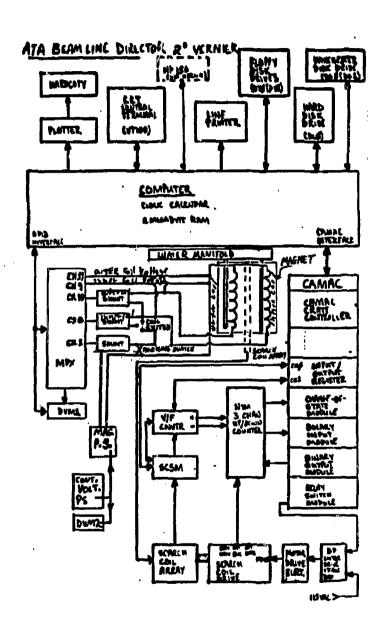


FIGURE 1. HARMONIC ANALYSIS MEASUREMENT HARDWARE BLOCK DIAGRAM

APPENDIX G. CONCEPTUAL DESIGN OF AN ELECTRON BEAM DEFLECTOR

# CONCEPTUAL DESIGN OF AN ELECTRON BEAM DEFLECTOR

For

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#### ABSTRACT

A design of an electron beam director has been conceptualized and analyzed. Its performance objective is an ability to rapidly and accurately direct a high-intensity pulsed-beam of high-energy electrons to any desired threget spot within a 60 degree helf-angle cone. The beam director has a number of elements which can be separately analyzed, but which must all be integrated to give a suitable overall design concept. The separate elements of the design study are the following:

- Magnet Lattice
- Vacuum Rotary Joints
- Vacuum-to-Air Transition
- Vernier Steering System
- Mechanical Mount and Slewing System
- Radiation Effects
- Size, Weight and Cost Estimate

The magnet lattice design has been reviewed for acceptable beam optics, achromaticity, mechanical integrity and quality materials availability. A review of vacuum requir ments was made with due consideration to rotary joints in the tube, beam loss to vacuum wall causing outgassing, and feasibility of a rotating foil mechanism at the exit end of the beam director.

Analysis of a typical mount and associated vibration was made using slewing rates fast enough to respond to firing multiple pulses anywhere in a  $60^{\circ}$  cone within one second. Electronic fine tuning and mechanical sensors have been considered for accurately controlling the beam director within the short time period.

Radiation has been studied to the extent it affects the vacuum and mechanical operation.

An estimate of size, weight, and cost has been made for the conceptual design.

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<sup>\*</sup> This effort has been coordinated with Dr. Edward P. Lee, Lawrence Berkeley Laboratory, and we acknowledge his valuable advice and guidance.

Since this is a conceptual design, unusual problems have been identified as areas requiring further research and development. The Vacuum-to-Air Transition and the magnetic lattice are two most critical areas requiring near term effort. The success of the design is highly dependent on these elements.

The mechanical mounts and slewing system needs a great deal of design optimization if the desired high slewing rates are to be realized. System weight and vibration are seen as problems that will require a substantial development effort.

There are no technical reasons to doubt that a successful development can be achieved. No new materials are required. Existing technologies can be extended to meet the identified needs of the program.

#### 1.0 INTRODUCTION

The object of this conceptual design study is the selection and integration of suitable design concepts which can provide a very rapid and accurate deflection of a high-intensity pulsed-beam of high-energy electrons. The performance objective for the beam director is to accurately direct the electron beam to any target spot within a 60 degree half-angle cone and to be able to rapidly redirect it to any new target spot within this cone in a few tenths of a second. High accuracy and high slewing rates are required. It is desirable to keep the weight and size of the beam director at a minimum to achieve the desired high slewing rates with a minimum drive power.

The use of a system of permanent magnet devices for bending and focussing the electron beam is a way to minimize weight and to simplify the design. Alternative complicated electro-magnetic systems and their associated power supplies, cooling systems and electrical connections seem very difficult to accommodate in a director subjected to high rotational accelerations.

Since the system must be designed to handle electrons of some high energy yet to be determined (probably well in excess of 10 MeV), the dipole bending magnets and quadrupole focussing magnets must have fairly high magnetic fields. The conceptual design should approach the limits of technology. The best available materials and methods for achieving the objectives of the conceptual design should be explored.

The conceptual design must provide an exit window or transition for bringing the electron beam out of the vacuum system into the air. It also must have an accurate electromagnetic steering system for providing precise

adjustments in the final exit angle of the beam. This steering system must be able to compensate for small aiming errors and to cancel the adverse effects of mechanical vibrations.

The study effort was divided into three tasks:

Conceptual Design Ligison Final Report

The first of these tasks, Conceptual Design, consisted of selecting likely concepts and configurations and performing those engineering calculations required to evaluate the suitability of these concepts. The conceptual design engineering work included the following segments of the electron beam director:

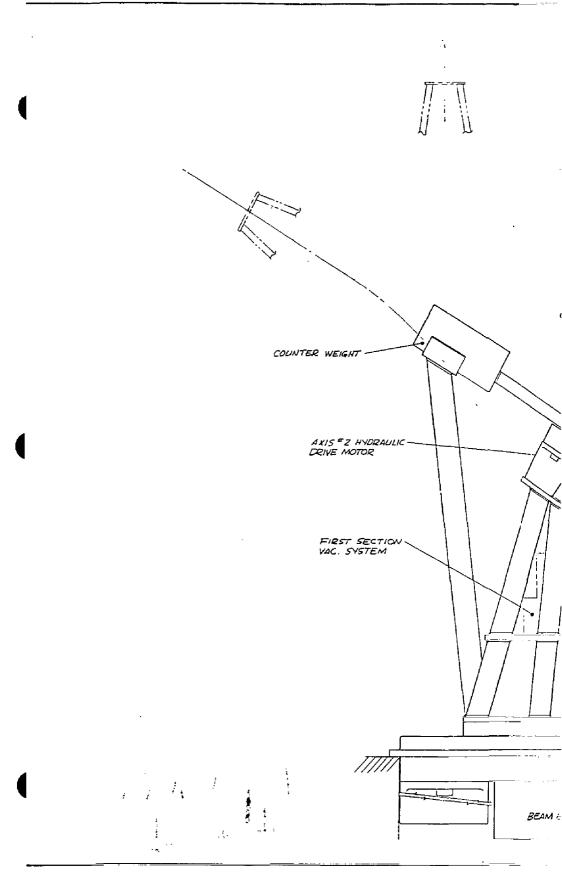
- Magnet Lattice
- Vacuum Rotary Joints
- Vacuum-to-Air Transition
- Vernier Steering System
- Mechanical Mount and Slewing System
- Radiation Effects
- Estimates of Size, Weight and Cost

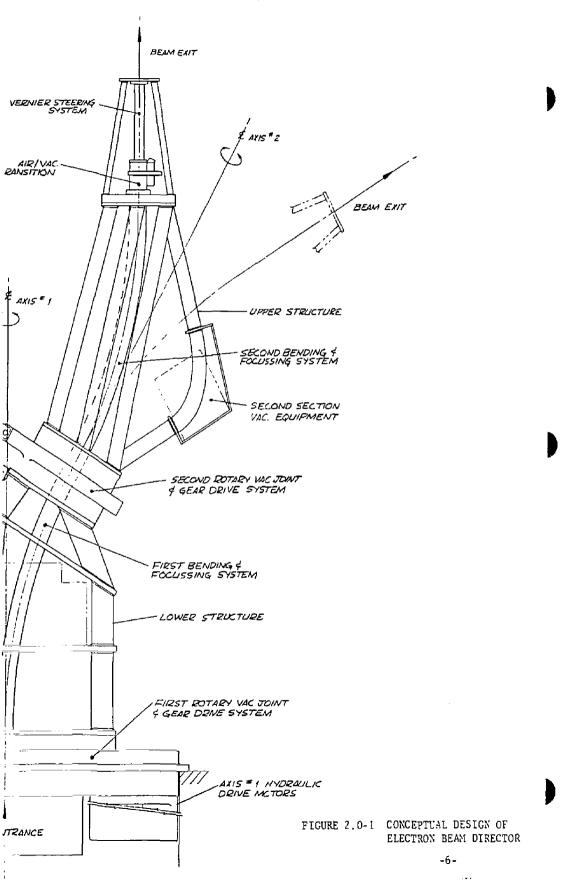
#### 2.0 CONCEPTUAL DESIGN

The conceptual design for the beam director is shown in Figure 2.0-1. This director consists of a pair of magnetic bending and focussing systems which are mounted and supported on rotatable atructures. The direction of deflection of the beam is dependent upon the orientation of the bending system and the angle of bend of each system. Since each bending system is supported on its own rotatable structure, the orientation can be continuously changed to provide any desired resultant direction of the exit beam within a limited cone angle equal to twice the bend angle of each system.

The conceptual design shown in Figure 2.0-1 also illustrates the drive systems for rotating the two structures and certain necessary auxiliary equipment. Most important of the auxiliary items are the Vacuum-to-Air Transition Section and the Vernier Steering System. The interior of the bending and focussing systems is held at a moderately high vacuum\* by a suitable set of vacuum pumps. A high vacuum in this beam transport system is a necessity and, therefore, the rotary joints must be vacuum tight. Since the electron beam must come out of the evacuated bending system and enter the atmosphere, a suitable transition vacuum/air section is required. This transition section has vacuum on one side and atmospheric pressure on the beam exit side. It must be nearly vacuum tight and must be provided with sufficient vacuum pumping capability to handle any leaks which may be inherent in the system. The transition section must also be nearly transparent to the high energy electron beam because any significant blockage of

<sup>\*</sup>approximately 10-3 torr





the beam will cause an extremely high heat load. The heat load is potentially high enough to melt or otherwise destroy most materials.

The final element at the exit of the beam director is a Vernier

Steering System. This system consists of electrical coils designed to give sufficient magnetic field to bend the beam slightly in any desired direction. This system will provide "fine tuning" of the beam exit angle and must have very rapid response so that it may be useful in compensating for any residual vibration in the mechanical structure.

The direction of the beam leaving the beam director is dependent upon the rotation of the bending systems as illustrated in Figure 2.0-2. Rotation of the upper structure through an angle  $\alpha_2$  about Axis 2 produces angular displacement  $\theta$  measured downward along a meridian through the  $\pi$  axis (Axis 2). This rotation  $\alpha_2$ , also produces the  $\theta$  component of azimuthal displacement,  $\theta$ , about the  $\pi$  axis. The rotation of the lower structure through an angle  $\alpha_1$  about Axis 1 produces additional azimuthal displacement. The total azimuthal displacement,  $\theta$ , is given by

$$\emptyset = \alpha_1 + \beta = \alpha_1 + \tan^{-1} \left( \frac{\sin \alpha_2}{\cos \gamma(\cos \alpha_2 + 1)} \right)$$

Where y is the bend angle for a single bending system.

The downward displacement,  $\theta$ , is given by

$$\theta = \frac{\pi}{2} - \sin^{-1} \left( \sin \gamma \left( 1 + \sin \gamma \left( 1 - \cos \alpha_2 \right) \right) \right)$$

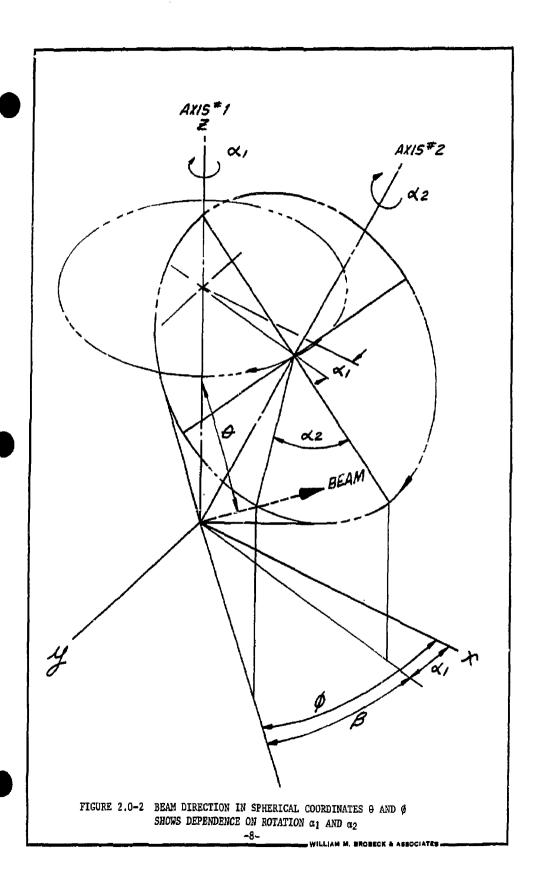
Selecting y having a value of 30 degrees gives

$$\theta = \alpha_1 + \tan^{-1} \left( \frac{2}{\sqrt{3}} \cdot \frac{(\sin \alpha_2)}{\cos \alpha_2 - 1} \right)$$

and

$$\theta = \frac{\pi}{2} - \sin^{-1} (.75 - .25 \cos \alpha_2)$$

The value of  $\theta$  will vary from 0 to 60 degrees  $(\pi/3)$ . The value of  $\theta$  will cover a full 360 degrees  $(2\pi)$ .



#### 2.1 Magnetic Lattice

The high energy electron beam is bent and focussed by a series of permanent magnet dipoles and quadrupoles. These must be arranged to produce an achromatic bend and sufficient focussing to keep the beam size small enough to avoid collisions with the wall of the beam tube. The magnetic strength required is dependent upon the beam energy and the desired radius of curvature in the bending section. A characteristic value for the bending and focussing system is the magnetic rigidity of the electron beam. This value can be expressed as the Br product where B is the magnetic field in tesla and r is the radius of curvature in meters. The Br value may be tound from

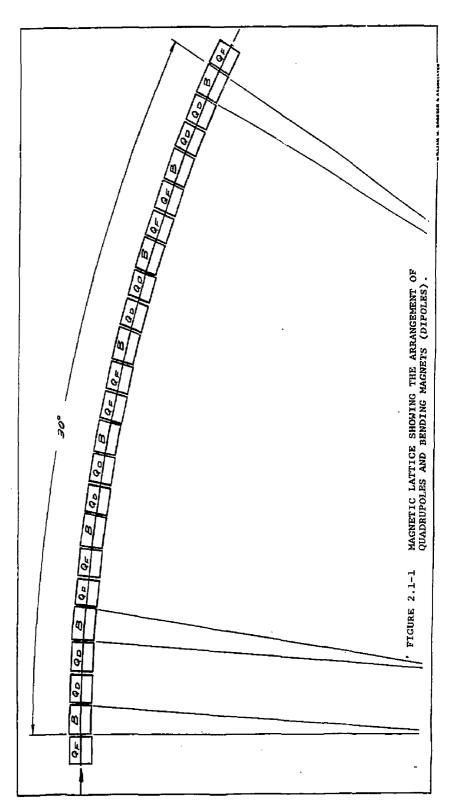
$$Br = [T (T + 2 Wo)]^{\frac{1}{2}} \div 300$$

Where T and Wo are respectively the kinetic energy of the electrons and its rest mass, both in MeV. For highly relativistic electrons, the Br value approaches a linear function of the kinetic energy.

In order to achieve a bend with a radius of curvature of one meter, the required magnetic field is as follows:

T, MeV	<u>B, Tesla</u>
10	.035
50	.168
100	.335
200	.668
500	1.668
1000	3.335

Achieving a field much in excess of 1.67 tesls will be difficult using permanent magnets; so a radius of curvature greater than one meter will be required if a beam of energy greater than 500 MeV is desired.



The best energy for which a beam director should be designed is not known, but the conceptual design can, in principle, be applied to any energy value within the range of 10 to 1000 MeV.\* Without loss of generality, a specific example can be selected for illustration of the basic concepts. The specific example will use a Br value of 1.666667 tesla meters.

The general arrangement of dipoles and quadrupoles is shown in Figure 2.1-1, where a 30° bend is achieved using an array of 8 dipoles and 16 quadrupoles grouped in four identical combinations or cells. A cell consists of 4 quadrupoles and 2 dipoles arranged with mirror symmetry to give a focus, bend, defocus, defocus, bend and focus. This arrangement of elements to make up a single cell can be made to produce a 90° phase advance per cell if the magnetic properties and dimensions are properly selected.

The combination of mirror symmetry and  $90^{\circ}$  phase advance per cell will give this system the advantage of maintaining a tightly focussed beam and will assure acceptable achromaticity. The total bend of  $30^{\circ}$  will have a  $360^{\circ}$  phase advance.

A baseline design case was selected for which the dipoles occupied one-third of the length along the beam path. For this baseline case, the dipole strength was selected to give a bending radius of curvature of one meter and a bend angle per dipole of 3.75°. The quadrupoles occupying two-thirds of the length had their gradient set to achieve a 90° phase advance.

The method of calculation involved a determination of the matrix elements for the focusing and defocussing quadrupoles and performing the necessary matrix multiplication to find the overall transformation matrix for a beam transversing the bending system. A simple program was set up so

<sup>\*</sup>For energy values greater than 1000 MeV, the moments of inertia appear to be too great to permit slewing on a useful time scale.

that a number of trial calculations could easily be made and that after the baseline case was calculated, numerous alternative cases would be easily examined.

The matrix analysis was made for the vertical plane so that the dipole regions could be treated as drift spaces. The transport matrix equations are then as follows:

For focussing quads

$$\begin{vmatrix} y \\ y \end{vmatrix} = \begin{vmatrix} \cos \theta & \frac{1}{K} \sin \theta \\ -K \sin \theta & \cos \theta \end{vmatrix} \begin{vmatrix} x \\ y'_1 \end{vmatrix}$$

For drift

$$\left|\begin{array}{c|cccc} y & & & & & & & & & & & & \\ y' & & & & & & & & & & & \\ y' & & & & & & & & & \\ \end{array}\right| \quad x \left|\begin{array}{c|cccc} y_1 & & & & & \\ x & & & & & \\ y_1' & & & & & \\ \end{array}\right| \quad y_1'$$

For defocussing quads

Where 
$$K = \sqrt{\frac{G}{Br}}$$
 and  $\theta = K \ell$ 

S = Drift length

G = Magnetic gradient

B = Magnetic field

r = Bend radius

Length of quadrupole

y, y' = Particle coordinate and angle

For the baseline case, the magnetic properties and dimensions for the dipoles and quadrupoles were found to be as follows:

#### Dipoles

Field	1.66667	
Radius of curvature	1.000	meters
Length	65.44	11111
Bend angle	3.75	degrees

#### Quadrupoles

Gradient	123.50	tesla/meter
Length	65.44	mm.

This gives a total length for a 30° bending section of 1.57 meters.

A variety of design approaches for the dipoles and quadrupoles were examined.\* Designs using permanent magnets are desirable. Designs using permanent magnets are clearly possible at the field and gradient values required. Designs using soft iron pole tips and iron flux return paths appear to require slightly less permanent magnet material than do ironless designs. However, designs using soft iron are heavier overall and appear to present some serious fringe field problems which are avoided in the ironless design.

The ironless designs for dipoles and quadrupoles are based on the design methods given by Klaus Halbach, LBL8906. His method assumes that a linear superposition of fields is valid. This is a reasonably valid assumption for most rare-earth-cobalt magnets and for some oriented ferrites. An important criteria for validity of this assumption is that the demagnetization curve for the permanent magnet must be linear over the range of B values used in the design and that the value of intrinsic magnetization, B-H, be nearly constant over the design range.

<sup>\*</sup>The selected lattice has separated focussing and bending elements.

Lattices with combined functions were analyzed and found to be less desirable than those with separated functions.

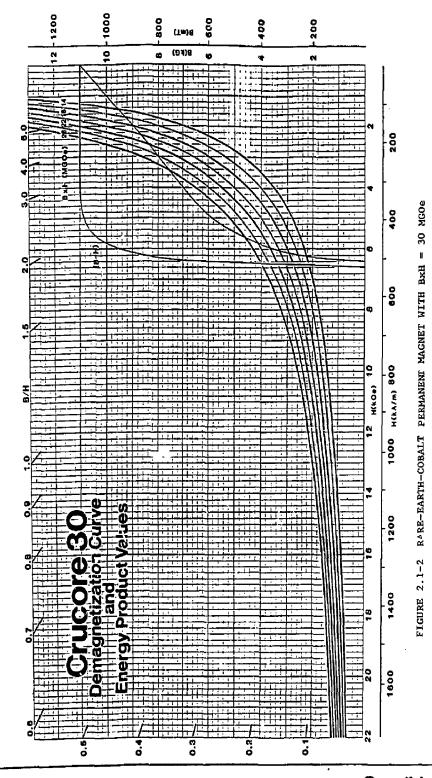
Figures 2.1-2, 2.1-3, and 2.1-4 show demagnitization curves for some rare-earth-cobalt candidate material.\* Of these, the Crucore 30 has the highest BxH product which is conventionally used as a figure-of-merit for permanent magnets. However, the demagnitization curve is not linear over the entire quadrant. The intrinsic magnetization (B-H) remains nearly constant for a while but it drops off rather sharply above 5 kOe. The Crucore 26 has a lower BxH product but has much better linearity than the Crucore 30. There are other rare-earth-cobalt materials such as Crucore 18 which have excellent linearity with a high residual induction B.

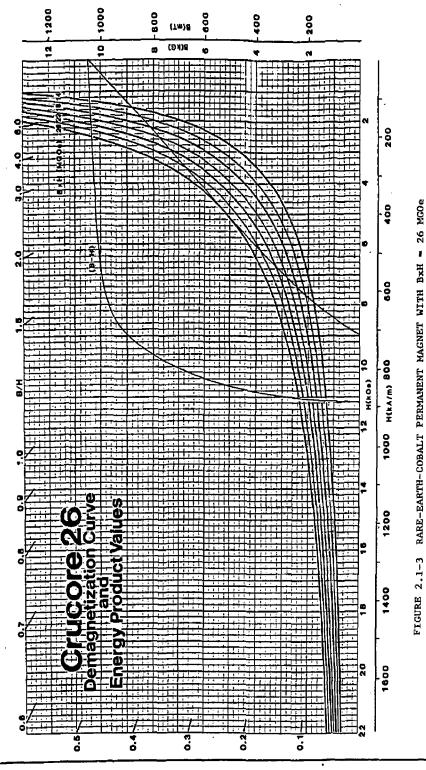
Figure 2.1-5 shows the demagnetization curve for an oriented ferrite material, Ferrimag 7B, which has very good linearity making it a good candidate for an ironless dipole or quadrupole of the style analyzed by Halbach. The ferrites have much lower residual induction than the rare-earth-cobalt materials but they are much less expensive and they have lower density. For an electron beam with an energy less than 200 MeV, this Ferrite material would be a very good candidate.

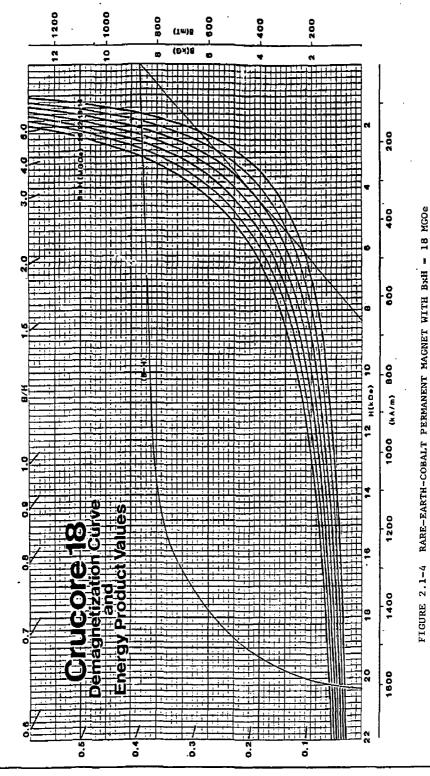
The ironless design concept for the quads and dipoles use 16 trapazoidal pieces arranged as shown in Figure 2.1-6. Each piece is magnetized in the direction shown with an arrow. The magnetic field in the gap is given by Halbach as follows:

Dipole
$$B = .974 B_{r} \ln \left(\frac{r_{2}}{r_{1}}\right)$$
Quadrupole
$$B(r_{1}) = 1.875 B_{r} \left(1 - \frac{r_{1}}{r_{2}}\right)$$

<sup>\*</sup>The three materials shown here are given merely as examples of the kinds of properties available. Sin 2 new and stronger materials are continuously being developed, there is no doubt that stronger permanent magnet materials will be available in the future.











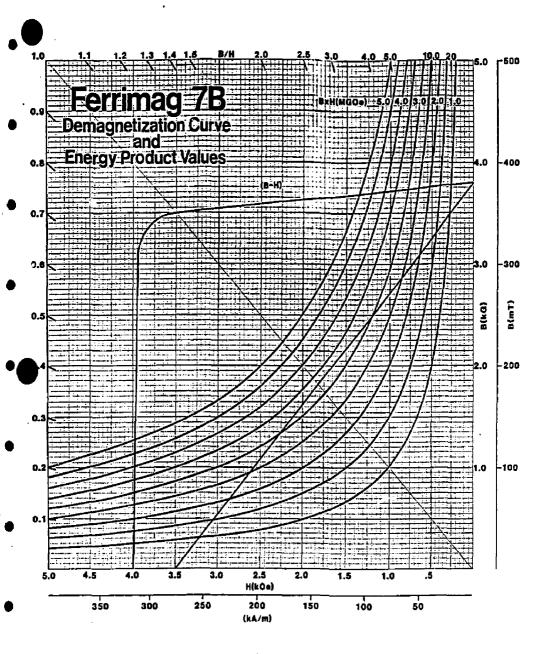


FIGURE 2.1-5 ORIENTED FERRITE PERMANENT MAGNET WITH BxH = 3.3 MGOe

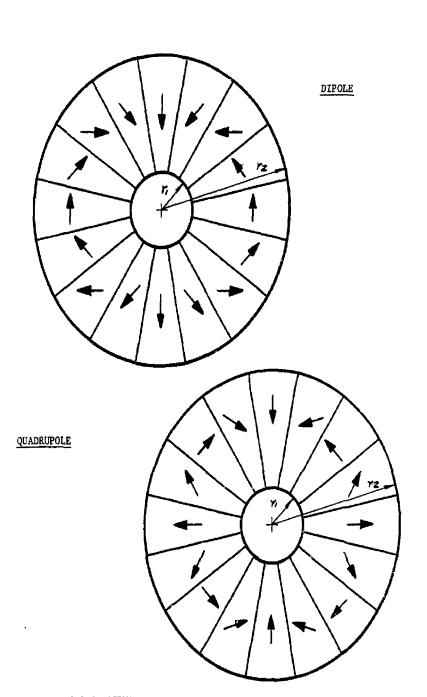


FIGURE 2.1-6 PERMANENT MAGNET DIPOLE AND QUADRUPOLES
16 TRAPEZOIDAL PIECES MAGNETIZED IN DIRECTION
OF ARROWS

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Where B, = residual induction (from demagnetization curve)

r<sub>1</sub> = radii shown in Figure 2.1-6

Using these equations for dipoles and quadrupoles of the baseline lattice structure having an inside radius  $r_1 = 11$  mm and using Crucore 26,\* the outside radii and weights were found as follows:

#### Dipole

 $r_1 = 11.0 \text{ mm}$   $r_2 = 56.13 \text{ mm}$   $r_3 = 65.44 \text{ mm}$   $r_4 = 5.17 \text{ kg}$ 

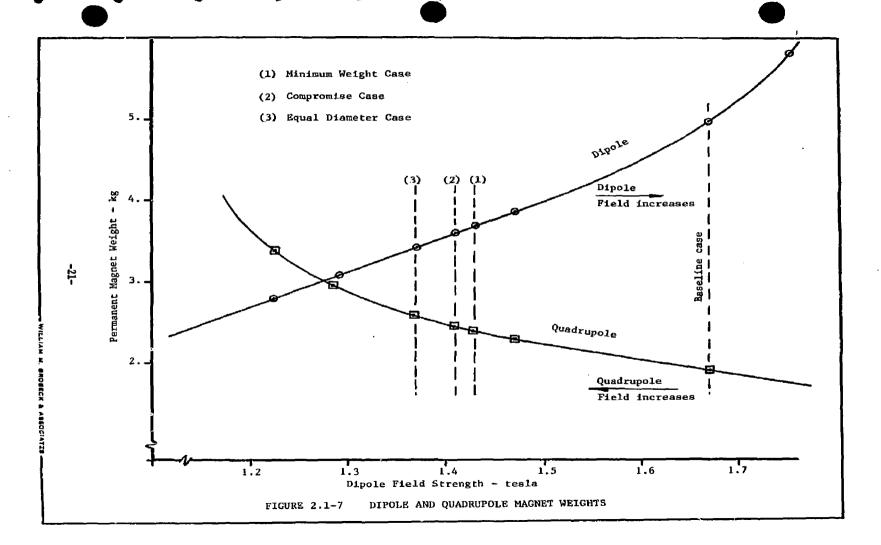
#### Quadrupole

 $r_1 = 11.0$  mm  $r_2 = 35.48$  mm 1 = 65.44 mm  $W_1 = 1.94$  kg

Ways of decreasing the weight of the baseline case were explored. It was clear from the Halbach equations for ironless permanent magnet dipoles and quadrupoles, that the weight of these elements depend upon their field strengths and upon the properties of the material used. Since the material selected for the baseline case is nearly the optimum available material, the only practical way to reduce the weight is to lower the magnetic fields. Lowering the field requires an increase in the length of the bending elements. This can be done without increasing the total length of the system if the quadrupoles are shortened while the dipoles are lengthened.

A variety of cases were calculated to assure that suitable beam transport properties were retained as the dipole lengths were increased. Figure 2.1-7 shows the decrease in dipole weight associated with decreasing

<sup>\*</sup>Crucore 26 with  $B_r$  = 10.5 kG,  $H_C$  = 9.0 kOe,  $BH_{m\hat{a}_X}$  = 26 MGOe and  $\rho$  = 8.3 g/cm<sup>3</sup> is used as an illustrative example. Clearly, alternatives with greater linearity are available.



its field. To retain proper focussing, the quadrupole strengths had to be increased which required an increase in the quadrupole weights. These increases are also shown. By comparing total weights and component diameters, a compromise case was selected. The compromise case is nearly at the minimum weight condition, but has a more favorable diameter ratio than does the minimum weight case. Table 2.1-1 shows the various properties of the calculated cases.

The values shown are for a 500 MeV system. Obviously, these would not be the proper specific values of a diverter for an electron beam of different energy. However, the method of calculation and the general design concept is valid and can be applied to other energy levels. For lower energy, it would be possible to use systems which are shorter and lighter in weight.

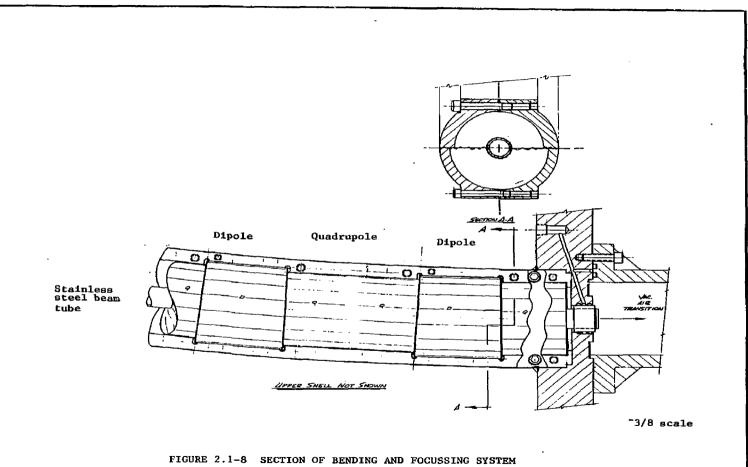
At 50 MeV (ATA, for example), a beam diverter using ferrite appears to be practical. Such a system could use a peak field in the dipole of about .141 tesla and have an overall length of each 30° bend of about 1.57 meters.

The bending system using permanent magnet material requires sufficient structural strength and rigidity to accurately hold the permanent magnet wedges. A suitable concept for assembly of system and for support of the evacuated beam tube is also required. Figure 2.1-8 shows a conceptual design for this support. It consists of two curved stainless steel shell pieces bolted together at the midplane. This concept allows the bending system to be assembled in two halves which are assembled around the beam tube. This outer shell is then attached to larger frame type structure which transmits the dynamic loads associated with rapid slewing of the system. An evacuated stainless steel inner tube of about 1 mm thickness carries the return current.

Сая	se No.	t <sub>q</sub>	2 <sub>d</sub>	G <sub>q</sub> G/cm	В <sub>О</sub> <u>G</u>	Wt <sub>q</sub> kg (each)	Wrd kg (each)	Wt total**
	2	5.366	8.9	14000	12260	3.44	2.81	77.43
	4	5.60	8.432	13660	12937	2.98	3.07	72.19
Equal dia.	5*	5.841	7.950	13269	13721	2.57	3.42	68.48
Compromise	6	5.95	7.732	13110	14107	2.44	3.61	67.82
Min. Wt.	3	6.00	7.632	13044	14293	2.38	3.70	67.74
	7	6.10	7.432	12920	14675	2.30	3.90	67.94
Baseline	1	6.544	6.544	12350	16667	1.94	5.17	72.42

<sup>\*</sup>Case 5 gives equal diameters for quadrupoles and dipoles.

\*\*This is the weight of permanent magnet material. A stainless steel shell for support and alignment will add about 45 kg.



#### 2.2 Vacuum Rotary Joints

The bending systems for the electron director must be rotated about their respective inlet axes in order to alter the direction of the exit beam. There are two bending systems in the conceptual design. Each of these must be provided with a support structure and a means for rotating these two structures about their axes. A rotary joint is required for each of these systems. These joints must provide accurate alignment and must be nearly vacuum tight. It is believed that it will be impossible to provide an absolutely vacuum tight seal, so some provision for minimizing leakage and for vacuum pumping must be provided.

In detail, the requirements for the rotary vacuum joints are the following:

- 1. Permit 360° rotation.
- Provide a good vacuum seal with a very low leakage rate.
- Provide adequate vacuum pumping ports for rough vacuum pumping and for high vacuum pumping.
- 4. Maintain accurate alignment, concentricity, and angularity.
- Provide sufficient strength and rigidity to withstand the dynamic loads due to 180° slewing in .3 seconds.
- 6. Provide electrical current path for beam tube counter current.
- Provide support for the drive mechanism with strength for the rotational torque reaction and for the overturning torque.

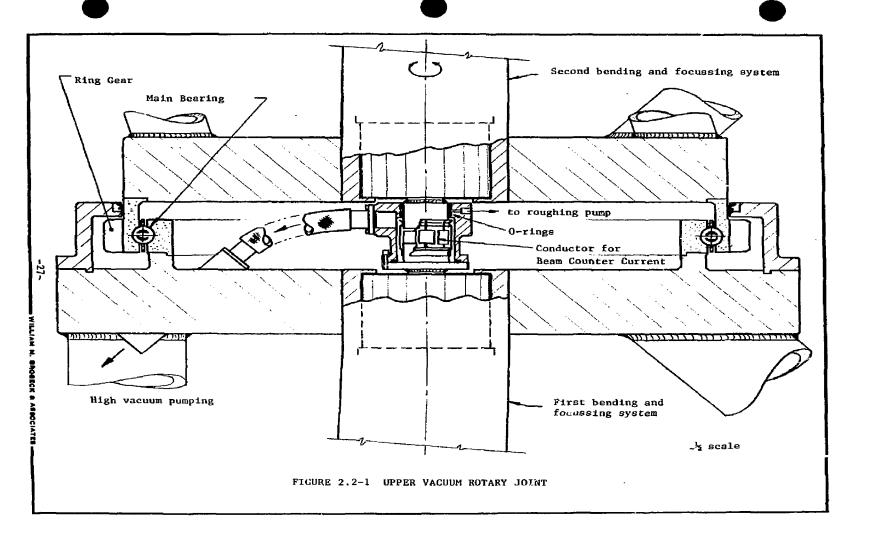
The rotary vacuum joint for the upper bending section must carry all the dynamic loads of the upper structure. These loads include the dynamic force associated with rotation about Axis 2 (See Figure 2.0-1) and also those associated with rotation about Axis 1. The rotational load due

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to turning about Axis 2 can be nearly balanced. However, the rotation about Axis 1 produces dynamic load that must be carried by this rotary joint. A discussion of these dynamic loads will be made in the section dealing with mechanical mounts and slewing system. Suffice it to say here that the dynamic loads on the upper joint are much lower than those on the lower joint because the loads on the upper joint superimpose upon those associated with rotation of the lower structure about axis 1.

A conceptual design for the upper rotary vacuum joint is shown in Figure 2.2-1. The lower joint will be similar but stronger. The vacuum seal and counter current flow paths are shown conceptually. The vacuum seal consists of 0-rings with an intermediate pump-out port. The double 0-ring is for two-stage pumping, but three-stage pumping may prove to be necessary in practice. These seals must be lubricated to minimize friction and vacuum leakage.

The counter current flow path is through a spring loaded contactor connected to a squirrel cage conductor. This open squirrel cage also permits vacuum pumping.



#### 2.3 Vacuum-to-Air Transition

The electron beam is transported in a high vacuum and must be brought out of the director into the air. An abrupt transition from vacuum-to-air is desired. A thin foil window strong enough to withstand the differential pressure would provide an ideal transition if it were sufficiently transparent to high energy electrons. Most potential foil materials will permit a very large percent of the electron beam to pass through; however, the very small percent of the beam energy that is lost in the foil will deposit a great amount of thermal energy into the foil. If the energy is concentrated by a small diameter beam, the local heating could be great enough to melt or otherwise destroy the foil through thermal shock and spallation.

To obtain a preliminary evaluation of potential foil materials and to illustrate the severity of the thermal problem, a simple calculation of the heating of a wide range of materials was made. For this calculation, the stopping range for 50 MeV electrons and the specific heats of the materials were assumed as constants, independent of temperature. These calculations were made for a one-centimeter diameter, 50 MeV beam having  $35 \times 10^3$  joules per pulse (based on ATA 70 ns pulse). Table 2.3-1 shows the results of these calculations.

As can be seen in this table, the temperature rise per pulse increases rapidly with an increase in atomic number. A single pulse passing through an aluminum foil would raise the temperature to a value more than three times its melting point.\* A simple pulse through a copper foil would raise its temperature to almost six times its melting point.\*

<sup>\*</sup>Non-linearity of the specific heat curve and latent heats of melting are ignored so this is not absolutely accurate!

Melting Point OC		: יי	2.5	1778	1300	3500		<b>5</b> C	י פ	ט פ	86	679	099	1410	77	119	ტ	9	99	839	1541	1660	1890	1857	1224	1535	1495	1453	1084	419	2620	196	231	3387	207.2 6.362 .0307 14 24763 327
Temperature Rise at (oc)	310	207	127	0 C G	1631	2734	2190	2771	2973	1966	1861	2121	2379	2862	2863	2733	4471	4481	2880	3081	4212	6387	5141	5092	5474	5187	5741	2068	6427	6023	10576	11879	12228	17083	24763
Stopping ** Range for 50 MeV Electrons gr/cm <sup>2</sup>	10	21	26.5	26.5	25	22.5	20 20	<b>50</b>	70	22	20	21	21	22	21	22	50	19	21	22	19	19	18	19	81 138	19	27	70	18	19	17	16	16	14	14
Specific Heat @ 20°C Cp (CAL/gr °C)	3.428	1.243	858	. 445	. 261	ह. न	.243	.192	.179	.246	.286	.239	.213	.169	.177	.177	.119	.125	.176	.157	.133	.0877	.115	0110	. 108	801.	.103	.105	.092	.093	.0592	.0560	.0544	.0445	7080
Specific Heat @ 20°C Cp (CAL/°C Atom)	3,428	4.97	5,954	4.014	2,829	2.078	3.397	3.079	3.397	4.97	6.580	5.800	5.743	4.744	5.50	5.67	4.222	4.97	6.866	6.285	5.99	4.200	5.854	3.704	7.748	200	0.000	6.135	3,868	6.04	5.655	6.040	6.456	8.187	6.362
Atomic Weight	-	•	6.94	9.02	10.82	12.01	14.0	16.0	19.0	20.2	23.0	24.3	27.0	28.1	31.0	32.1	35.5	99.68	39.1	40.1	45.1	7.7	0.00	7 7 7	ָר ה ה ה	0.0	, ,	28.7	03.0	4.00	95.6	107.9	118.7	183.9	207.2
Symbol	I	He	Ľ	Вe	ø	ပ	z	0	ĵs,	Ne	g	X X	4	S	Д, (	so (		Ar ::	<b>×</b> ; (	ຮູ	ט ק מ	11	> د	ž	G A	y (	3 3	F .	3 8	97 7	or .	Ag.	us:	ja į	2
Atomic Number	н	2	m	4	'n	9	7	Φ,	σ	01	11	12	13	51	4;	9 :	7 .	9 7	6	3 6	7 T	7 6	5.5	25	7 6	27	à	07	67	2 5	2 ·	*	2:	47	Z Q

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Partie William M. Brobeck & Absociates

Specific Heats from Table 3-173 Perry's Chem. Eng. Handbook Melting Points from D-190 CRC Handbook of Chem. Physics 61st Edit.

Range Data from UCRL-2426 Vol. II (1966 Rev.)

The only materials which appear to have any practical value as foil windows are those using elements with low atomic numbers. Pure elements such as beryllium of carbon are obviously attractive, although beryllium may present some special radiation problems. The high scrength of beryllium and its light weight make it especially attractive. Combinations such as siliconcarbide or boron-carbide are also reasonable candidates.

The values in the table are for heating by a one centimeter diameter 70 ns beam pulse with 10 kA of current at 50 MeV. These are the values expected for ATA. For higher beam energy, the thermal deposition will not change significantly. A shorter beam pulse, say 10 ns will have a very significant reduction in the heating per pulse. A 10 ns pulse at 10 km at 11 cause one-seventh of the temperature rise of a 70 ns pulse. Reduction the diameter will also have a significant thermal effect. Changing the diameter from one centimeter to one-half centimeter will cause the temperature rise to increase by a factor of four (ignoring non-linearity of the specific heat function).

Taking into account the non-linearities of the specific heats and assuming that ATA pulses can be chopped to 10 ns and focussed to 4mm diameter, the single pulse temperature rise for carbon and beryllium are calculated to be the following:

For beryllium  $\Delta T = 654^{\circ}C$ For carbon  $\Delta T = 1164^{\circ}C$ 

For any case requiring a multitude of pulses closely spaced in time, the temperature rise would be excessive unless the material in the path of the electron beam is somehow renewed or cooled. The scheme considered for the

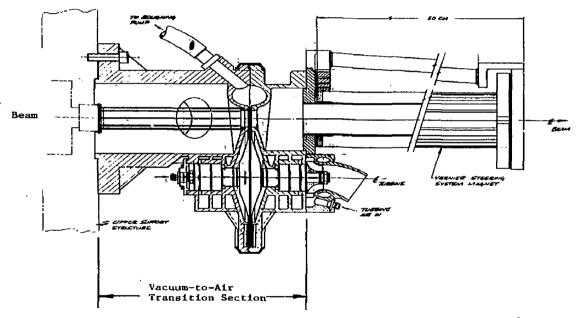
<sup>\*</sup>Taking into account the non-linearities of the specific heat results in a lower temperature rise than would otherwise result.

conceptual design is one in which the foil is rotated at a high speed to bring a new portion of the foil into the path of the beam for each pulse. Figure 2.3-1 shows the conceptual design for the Vacuum-to-Air Transition Section. A rotating disk is shown in the path of the beam. For a beam having a diameter of less than 5mm and pulsing in the frequency range from 1 to 33 kHz, a tangential speed of the disk at the beam spot of 150 meters per sec assures that the disk has travelled the full width of the beam between pulses. This speed is subsonic and will not cause excessive stress in a lightweight disk made of beryllium.

The high rotational speed of the disk can be used to aid in purging air from the space around the disk. By suitable design, the rotating disk can be made to function as a turbo-molecular pump. A suitable roughing pump and pumping ports will be required.

Of course, there are other possible schemes for a Vacuum-to-Air Transition Section. A larger diameter beam can be brought through a non-rotating foil. Such a beam can result from defocusing in the vacuum upstream of the foil and then be refocussed after passing through the foil. Refocussing the beam in air or other gas at atmospheric pressure has potential problems which need to be studied.

At this time, the rotating foil concept appears to be a viable one which will add very little to the system moment of inertia.



-¹₂ scale

FIGURE 2.3-1 VACUUM-TO-AIR TRANSITION WITH HIGH SPEED ROTATING DISK.

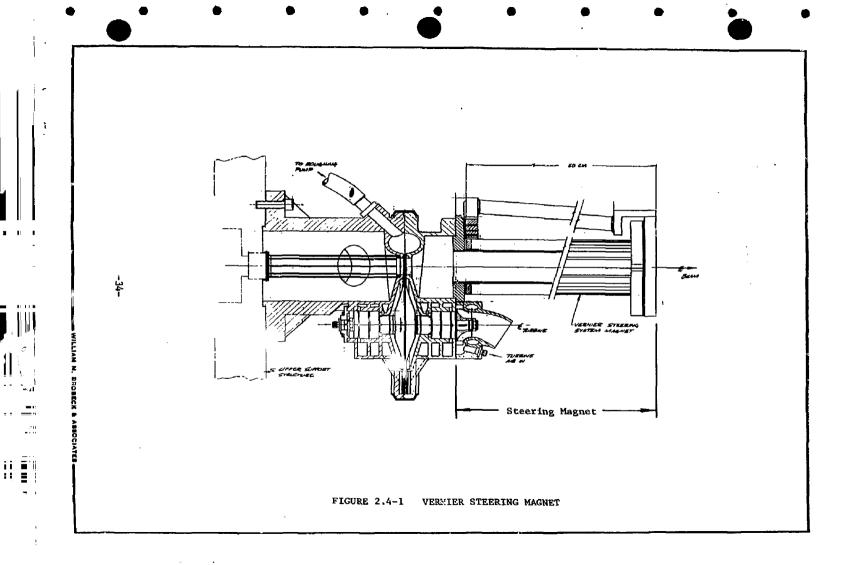
#### 2.4 Vernier Steering System

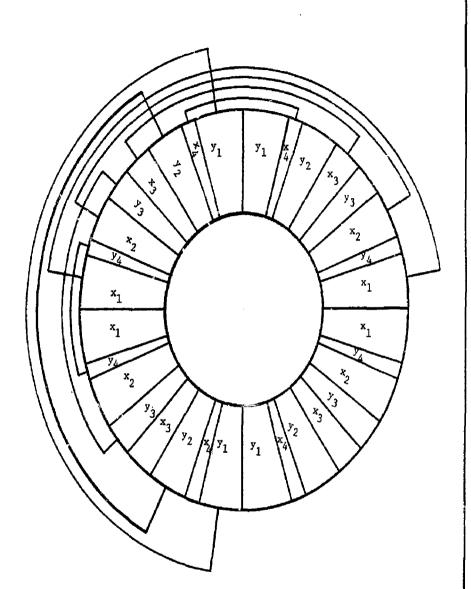
A Vernier Steering System to provide electro-magnetic steering of the beam after it has traversed the Vacuum-to-Air Transition Section is desired. This steering system will provide "fine tuning" of the beam director to correct for vibration and small aiming errors. The total correction to be provided is one degree. This one degree bend can be in any direction. Thus, two sets of mutually perpendicular coils are required. Figure 2.4-1 shows the Vernier Steering System mounted downstream of the Vacuum-to-Air Transition Section.

This system would be 500mm long for a 500 MeV beam and would be capable of giving a one degree bend. This bend will require a very modest magnetic field of 58.2 mT. A bend of one degree in a length of 500mm will take the beam off the axis of the steering magnets a distance of 4.3mm.

Thus, the magnetic field in the steering system must be fairly uniform. It was at first thought that a four-wire system could be used for the Vernier Steering System, but it does not now appear that such a simple system will provide a magnetic field of sufficient uniformity.

The system shown in the figure uses two sets of coils which are interwound. Each provide a nearly cosine variation in amp-turns. Such a variation will give good field uniformity. Figure 2.4-2 shows the coil cross section. The coils labeled, X, operate on one power supply to give a very uniform vertical field. The coils labeled, Y, operate on a separate power supply to give a very uniform horizontal field. By adjusting the current in each set of coils, a resultant field of any direction and magnitude (within limits) can be obtained. The steering magnet contains no magnetic iron and can be operated at high frequency with very little hysteretic or eddy current losses.





Horizontal deflection soils  $x_1$ ,  $x_2$ ,  $x_3$ , and  $x_4$  require one power supply and vertical deflection soils  $y_1$ ,  $y_2$ ,  $y_3$ , and  $y_4$  another

~2 x scale

FIGURE 2.4-2 STEERING MAGNET COIL CROSS SECTION

#### 2.5 Mechanical Mounts and Slewing System

The "slewing system" refers to the structures and drive systems needed to point the beam. It's design and structural characteristics are discussed here. Gyrodynamic loading calculations and structural response calculations are illustrated and described.

The prinicpal beam director mechanical subassemblies are the two (2) 30° bending magnet arrays used to point the beam, together with the necessary supporting structures, vacuum system elements, and drive system elements. Hereafter, these will be discussed as the "Axis 1 System" and the "Axis 2 System." Also, in referring to the location of components along the beam line, "upstream" means towards the accelerator and "downstream" means towards the beam exit.

System (BTS) and rotates about the BTS beam line which is coincident with "Axis 1." The downstream beam line out of the Axis 1 System is rotated 30° with respect to Axis 1, and is coincident with "Axis 2." The upstream beam line of the Axis 2 System coincides with the downstream beam line of the Axis 1 System. The downstream beam line of the Axis 2 System is rotated 30° with respect to Axis 2. This general arrangement is illustrated on Figure 2.0-1. Axis 1, coincident with the BTS beam line, is a fixed datum axis. Axis 2, coincident with the Axis 1 System downstream beam line, is tilted 30° with respect to Axis 1 and rotates about it. The Axis 2 System "spins" about Axis 2 which in turns "whirls" about Axis 1. The Axis 1 System "whirls" about Axis 1.

The Axis 2 System is supported on a multi-load bearing normal to and centered on Axis 2, located at the downstream beam line exit from the Axis 1 System. The Axis 2 System is to be both dynamically and statically balanced for rotation about Axis 2. The distribution of mass and flexibility along Axis 2 in the vicinity of the transition section attachment may be selected to reduce scructural rotation at the beam line exit. The Axis 2 System includes the transition section, means to pump the transition section, drive gear and support bearing, plus associated structure and balance weight.

The Axis 1 System is supported on a multi-load bearing normal to and centered on Axis 1, located at the downstream beam line exit from the BTS. This sytem may be "over balanced," to support the Axis 2 System in a way that compensates for both structural rotation and translation of the exit beam line at the transition section. Such sechanical "tuning" is not free; it is associated with increased system weight and drive power. The Axis 1 System includes the Axis 2 System drive, means to pump the rotating vacuum joint, drive gear and support bearing, plus associated structure and balance weight.

#### Description of Calculation Strategy

Sketch DN132-165-1 (Appendix A) illustrates "pipe truss" representations for both the Axis 1 and Axis 2 Systems. Sketch DN132-165-1B (Appendix B) is a full-scale schematic of the rotary vacuum joint that supports the Axis 2 System. It shows a full sized multi-load support bearing and a general arrangement for a vacuum seal and electrical feed through.

Neither drawing represents a recommended mechanical design; it is too early in the design process for that. Both drawings were used as a basis for weight

estimates, gyrodynamic loading calculations, and structural response calculations. So far, only a "beam bending" type structural response has been estimated. Each supporting truss is comprised of a circular pattern of eight (8) pipes that surround the 30° bending magnet arrays. These pipes terminate in welded housings. Two sets of calculations were performed for assumed steel trusses and for assumed aluminum trusses. The axis 2 System used 3 inch diameter tubes with .094" wall thickness. The Axis i System used 6 inch diameter tubes with .094 wall thickness.

Tables 2.5-1 and 2.5-2 summarize the components and weights used for both the Axis 1 and Axis 2 Systems. In this study, the cargo component weights were not varied. The structure component weights, initially for steel, were then reduced by a factor of three to represent an aluminum structure. The Axis 1 System category titled "Balance, Vacuum System, Plus Other" was varied to illustrate how the balance of the Axis 1 System affects the translation and rotation of the transition section, and the associated trade off with drive power.

A three (3) step process was followed in estimating dynamic structural response.

- The non-axisymmetric structures of DN132-165-1, 1B and Tables 2.5-1, 2 were divided into several mass stations for calculation of gyrodynamic loads versus time. For this, the structures are assumed to be rigid.
- Then, the peak value gyrodynamic loads were applied to simplified, flexible beam model representations to calculate static structural deflections. The first mode vibration frequency was estimated from these static structural deflections and the model distribution of mass and inertia.

## TABLE 2.5-1 WEIGHT SUMMARY FOR AXIS 2 SYSTEM

	St'2	AL
CARGO	(lbs)	(1bs)
Transition Section Roughing Pump Vacuum Pump #1 Vacuum Pump #2 Bearing Ring and Gear Magnet Assembly	11. 50. 50. 50. 73. 250.8	11. 50. 50. 50. 73. 250.8
Subtotal	484.8	484.8
STRUCTURE		
Transition Plate	42.4	14 13
Structural Tubes and Stiffeners	158.12	52,61
Base	<u>138.0</u> 0	<u>46.0</u> 0
Subtotal	338.52	112.84
TOTAL	823.32	597.54

## TABLE 2.5-2 WEIGHT SUMMARY FOR AXIS 1 SYSTEM

	.St'L	A£
CARGO	(1bs)	(lbs)
Magnet Assembly Hydraulic Drive and Motor Axis 2 Brg Inner Pace Base Gear	250.8 125. 75. 753.	250.8 125. 75. 753.
	1203.8	1203.8
STRUCTURE		
Upper Brg Support Center L Strut Support Plate Tubes and Upper Structure Tubes and Lower Structure	138. 82.5 218.35 1253.05	
BALANCE, VACUUM SYSTEM, PLUS OTHER	1691.9	563.96
Case (1) Case (2) Case (3)	-0- (1129.0) (2258.0)	
AXIS 2 SYSTEM	823.32	597.54
Total Case (1) Case (2) Case (3)		2365.30 (3141.30) (3917.30)

 The static responses were then multiplied by a dynamic multiplier based on the gyrodynamic load signature as a function of time, and the natural periods of the flexible beam model representations.

#### Calculation of Gyrodynamic Loads

For the non-axisymmetric structures considered here, it proved convenient to approach the computation of gyrodynamic loads in a very primitive way, i.e., many mass stations were set up, each identified by axis position, radius normal to the axis, and angular orientation about the axis. The rigid body, absolute accelerations of these mass stations were then calculated as functions of spin and whirl kinematics. The associated gee loadings were then combined to find cross-section forces and moments, bearing loads, and drive torques.

The calculation model for station acceleration is illustrated on Figure 2.5-1. The associated component acceleration equations are tabulated on Table 2.5-3. The derivation leading to these equations followed the format of a similar derivation involving constant whirl and spin velocities.

General integral equations for spin and whirl kinematics are included on Table 2.5-3. For the calculated results here, it was assumed that spin and whirl velocities started at zero, increased at a constant rate, and then decreased at the same negative constant rate until the velocities were again zero. This scheduling is built into the equations stated on Table 2.5-4. The numerical results of this study assume a 180° total angle change in 300 ms for each axis. The peak angular velocity is 200 rpm. The angular accelerations are ± 139.6 rad per sec per sec.

In calculating Axis 2 System loads, the tilt angle,  $\theta$ , was set at  $30^{\circ}$ . The calculation input for this system is listed on Table 2.5-5.

<sup>\*</sup>Arnold & Mander, "Gyrodynamics and Its Engineering Applications," Academic Press, 1961, pp 60-64.

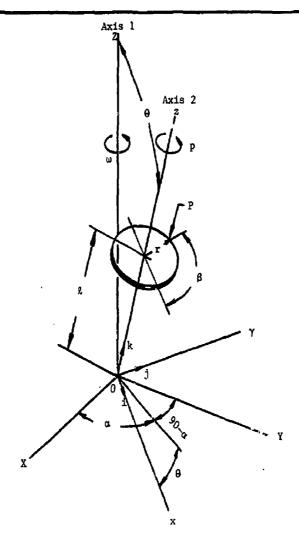


FIGURE 2.5-1 GYRODYNAMIC LOAD CALCULATION SCHEMATIC DIAGRAM

- X, Y, Z Fixed coordinate system
- x, y, z Whirling coordinate system; Plane 20z (20x) Whirls about Axis 1 with angular velocity  $\omega$ .

   is the whirl angle.  $\theta$  is the tilt angle between Axis 1 and 2.
- i, j, k Unit vectors along x, y, z
- £, r,  $\beta$  Coordinates of point P that spins about Axis 2 with angular velocity p.  $\beta$  is the spin angle with respect to whirling plane z0x.

# TABLE 2.5-3 ABSOLUTE ACCELERATION OF POINT P IN WHIRLING xyz COORDINATE SYSTEM See Figure 2.5-1

$$a = a_1 i + a_2 j + a_3 k$$

$$a_1 = -r (p+w\cos\theta)^2 \cos \beta - kw^2 \sin\theta \cos\theta - r (p+w\cos\theta) \sin \beta$$

$$a_2 = -r(p+\omega\cos\theta)^2 \sin \beta - r\omega^2 \sin^2\theta \sin\beta + r(p + \omega\cos\theta)\cos \beta + k\omega\sin\theta$$

$$a_3 \approx -r \left(2p_\omega + \omega^2 \cos\theta\right) \sin\theta \cos\beta - 2\omega^2 \sin^2\theta - r\omega \sin\theta \sin\beta$$

Where

$$\omega = {}_{0}\int^{t} \dot{\omega} dt$$
  $p = {}_{0}\int^{t} \dot{p} dt$ 

$$\alpha = \alpha_0 + \int_0^t \omega dt$$
  $\beta = \beta_0 + \int_0^t \rho dt$ 

For the present estimates, equal constant values were assumed for both whirl and spin angular accelerations.

### TABLE 2.5-4 WHIRL AND SPIN KINEMATICS

WHIRL

A = 
$$|\dot{\omega}|$$

For  $0 < t < \frac{\tau}{2}$ 
 $\dot{\omega} = A$ 
 $\phi = At$ 
			1,	
No	Length	Radius	Orient.	Weight.
1 .	97.67	17.80	+0.00	11.00
- 2	92.59	14.90	+0.00	131.28
3	66.39	15.40	+0.00	5.95
4	69.89	14.29	+24.50	6.15
5	68.19	11.19	+48.55	<b>6.5</b> 5
6	69.09	6.18	+73,40	6.95
7	69.59	0.55	+180.00	7.10
8	69 <b>, 09</b>	6.18	+286.60	6.95
9	68.19	11.19	+311.45	6.55
10	66 <b>. 89</b>	14.29	+335.50	6.15
11	65.69	0.00	+0.00	30.00
12	39.69	0.00	+0.00	226.87
13	83.89	1.97	+180.00	10.90
14	64.19	16.80	+180.00	6.00
15	49.59	12.70	+180.00	4.40
16	70.07	10.85	+180.00	2.12
17	31.15	0.00	+0.00	73.00
18	70.19	20.80	+180.00	50.00
19	59.69	22.40	+180.00	50.00
20	63.89	11.50	+180.00	50.00
21	65.26	4.04	+0.00	125.40
				·
				823_32 lbs
	ALUM	INUM STRUC	TURE	
No.	Length	Radius	Orient.	Weight
î	97.67	17.80		11.00
2-	92.59	14.90	+0.00	85.46
3	66.39	15. 40	+0.00	1.9B
4	69.89	14.29	+24.50	2.05
5	6B.19	11.19	+48.55	2.18
6	69.09	6.18	+73.40	2.32
7	69.59	0.55	+180.00	2.37
8	69.09	6.18	+284.60	2.32
9	6B.19	11.19	+311,45	2.18

2 92.59 14.90 +0.00 85 3 66.39 15.40 +0.00 5 4 69.89 14.29 +24.50 5 5 68.19 11.19 +48.55 6 69.09 6.18 +73.40 7 69.59 0.55 +180.00 8 69.09 6.18 +286.60 2 9 68.19 11.19 +311.45 2 10 66.89 14.29 +335.50 2 11 65.69 0.00 +0.00 10 12 39.69 0.00 +0.00 11 13 83.89 1.97 +180.00	
2 92.59 14.90 +0.00 85 3 66.39 15.40 +0.00 1 4 69.89 14.29 +24.50 2 5 68.19 11.19 +48.55 6 69.09 6.18 +73.40 2 7 69.59 0.55 +180.00 2 8 69.09 6.18 +286.60 2 9 68.19 11.19 +311.45 2 10 66.89 14.29 +335.50 2 11 65.69 0.00 +0.00 10 12 39.69 0.00 +0.00 17 13 83.89 1.97 +180.00	jht
2 92.59 14.90 +0.00 85 3 66.39 15.40 +0.00 5 4 69.89 14.29 +24.50 5 5 68.19 11.19 +48.55 6 6 69.09 6.18 +73.40 7 7 69.59 0.55 +180.00 8 8 69.09 6.18 +286.60 2 9 68.19 11.19 +311.45 2 10 66.89 14.29 +335.50 2 11 65.69 0.00 +0.00 10 12 39.69 0.00 +0.00 11 13 83.89 1.97 +180.00	.00
4 69.89 14.29 +24.50 2 5 68.19 11.19 +48.55 2 6 69.09 6.18 +73.40 2 7 69.59 0.55 +180.00 8 69.09 6.18 +286.60 2 9 68.19 11.19 +311.45 2 10 66.89 14.29 +335.50 2 11 65.69 0.00 +0.00 10 12 39.69 0.00 +0.00 117 13 83.89 1.97 +180.00	5.46
4 69.89 14.29 +24.50 2 5 68.19 11.19 +48.55 2 6 69.09 6.18 +73.40 2 7 69.59 0.55 +180.00 2 8 69.09 6.18 +286.60 2 9 68.19 11.19 +311.45 2 10 66.89 14.29 +335.50 2 11 65.69 0.00 +0.00 10 12 39.69 0.00 +0.00 117 13 83.89 1.97 +180.00	1.9B
6 69.09 6.18 +73.40 2 7 69.59 0.55 +180.00 2 8 69.09 6.18 +286.60 2 9 68.19 11.19 +311.45 2 10 66.89 14.29 +335.50 2 11 65.69 0.00 +0.00 16 12 39.69 0.00 +0.00 17 13 83.89 1.97 +180.00 3	. 05
7 69.59 0.55 +180.00 2 6 69.09 6.18 +286.60 2 7 68.19 11.19 +311.45 2 7 68.89 14.29 +335.50 2 7 69.69 0.00 +0.00 10 7 69.69 0.00 +0.00 11 7 69.69 1.97 +180.00 3	2.18
8 69.09 6.18 +286.60 2 9 68.19 11.19 +311.45 2 10 66.89 14.29 +335.50 2 11 65.69 0.00 +0.00 10 -12 39.69 0.00 +0.00 117 13 83.89 1.97 +180.00 3	2.32
8 69.09 6.18 +286.60 2 9 68.19 11.19 +311.45 2 10 66.89 14.29 +335.50 2 11 65.69 0.00 +0.00 10 12 39.69 0.00 +0.00 117 13 83.89 1.97 +180.00 3	. 37
10 66.89 14.29 +335.50 2 11 65.69 0.00 +0.00 10 12 39.69 0.00 +0.00 117 13 83.89 1.97 +180.00 3	. 32
10 66.89 14.29 +335.50 2 11 65.69 0.00 +0.00 16 12 39.69 0.00 +0.00 117 13 83.89 1.97 +180.00 3	. 18
11 65.69 0.00 +0.00 10 12 39.69 0.00 +0.00 117 13 83.89 1.97 +180.00 3	. 05
13 B3.89 1.97 +180.00 3	.00
	. 42
48 48 40 44 44 44	. 63
14 64.19 16.80 +180.00 2	.00
15 49.59 12.70 +180.00 1	. 47
16 70.07 10.85 +180.00 0	.71
	. 00
46 74 45 45 45 45	.00
19 59.69 17.40 +180.00 50	.00
<b>.</b>	.00
<b></b>	. 40

For the Axis 1 System, the tilt angle, 0, was set at 0°. Since the Axis 2 System is both dynamically and statically balanced, it is represented by a single mass station in the Axis 1 System computations. The calculation input for the Axis 1 System is listed on Table 2.5-6.

#### Static Structural Response Calculations

Figure 2.5-2 illustrates the model used to estimate flexible static load response for the entire system. The forces  $T_1$ ,  $V_1$ , and  $M_1$ , are in the Axis 2 System which is considered here to be a straight beam-like structure tilted at  $30^{\circ}$  along Axis 2. The actual Axis 2 structure on one side tilts off Axis 2 and is balanced both statically and dynamically by additional structure that is oppositely located. The forces  $T_2$ ,  $V_2$ , and  $M_2$  are in the Axis 1 System pipe truss which is considered to be a curved beam-like structure. The balance weight,  $W_B$ , exerts a tension on the mass station located where the Axis 2 System attaches to the Axis 1 System at the location of the Axis 2 support bearing. The equations that correspond to this representation are illustrated on Figure 2.5-3.

The lengths listed in Table 2.5-5, for the Axis 2 gyrodynamic calculation, are measured from the intersection of Axis 2 and Axis 1. The CG of the Axis 2 System was computed to be at 60 ins. All items located at a length greater than 60 ins were lumped to produce end loads  $T_{SO}$ ,  $V_{SO}$ , and  $M_{SO}$ . All items located at less than 60 ins. were lumped into the station at the Axis 2 support bearing.

The lengths listed in Table 2.5-6, for the Axis 1 gyrodynamic calculations, are measured from the bottom support bearing illustrated on DN132-165-1. In terms of this list, the heavy base Items 12 to 19 are

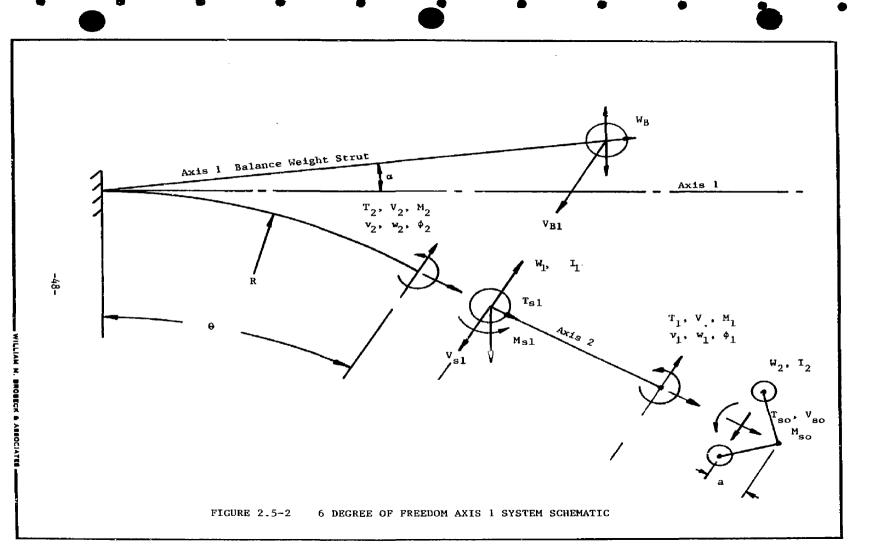
### TABLE 2.5-6 AXIS 1 GYRODYNAMIC CALCULATION STATION INPUT

#### STEEL STRUCTURE

No.	Length	Radius	Orient.	Weight
1	69.50		+0.00	75.00
2	66.43	13.80	+0.00	200.70
3	<b>65.30</b>		+180.00	28.63
4	63.00		+10B.36	28.20
5	56.00			27.22
6	49.00	23,99	+68.58 +33.54	26.28
7	46.70	24.20	+0.00	25.92
8	49.00	, 23.99	+326.46	26.28
9 .	56.00		+291.42	27. 22
10	63.00	13.97	+251.64	26.20
11	29.50	4.80	+0.00	B2.50
12	4.30		+180.00	254.92
13	4.30		+135.00	253.63
14	4.30		+90.00	250.69
15	4.30	24.20	+45.00	247.87
16	4.30	24.20	+0.00	246.79
17	4.30		+315.00	247.87
18	4.30		+270.00	
19	4.30		+225.00	253.63
20	33.50	4.50	+0.00	188.10
21	77.00		+180.00	125.00
22	98.50		+180.00	0.00 No balance weight
23	98.50	30.50	+0.00	823.00
				0710 2/ 11 -
	T. TA	MINUM STRU	יבטוער	3718.34 1bs
	1100	-	CIDILL	
No.	toneth	Radius	Oriont	Weight
1	69.50	15.60	+0.00	75.00
2	66.43	13.80	+0.00	108.70
3.	65.30	8.40	+180.00	9.54
4	63.00	13.97		9.40
5	56.00	20.39	+68.58	9.07
6.		23.99		8.76
7	46.70	24.20		a.54
8	49.00	23.99		8.76
9	56.00	20.39		9.07
10	63.00	13.57		9.40
11	. 29.50	4.80	+0.00	27.50
12	4.30	24.20	+180.00	147.72
13	4.30	24.20	+135.00	147.29
14	4.30	24.20	+90.00	146.31
15	4.30	24.20	+45.00	145,37
16	4.30	24.20	+0.00	145.01
17	4.30	24.20	+315.00	145.37
18	. 4.30	24.20	+270.00	146.31
19	4.30	24.20	+225.00	147.29
20	33.50	4.50	+0.00	188.10
21	77.00	12.50	+180.00	125.00
22				
	98.50	30.37	+180.00	0.00 No balance weight
23	98.50 98.50	30.37 30.50	+120.00 +0.00	0.00 → No balance weight 598.00

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2365.51 1bs



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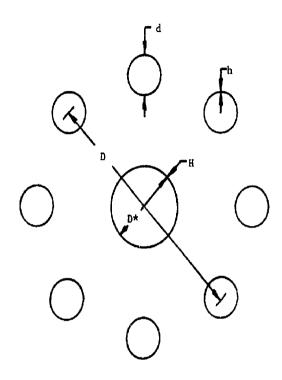
FIGURE 2.5-3 6 DEGREE OF FREEDOM, AXIS 1 SYSTEM EQUATION MATRIX

ignored and Item 22 representing 3/4 of the magnet array mess also is ignored. These items are very heavy, mostly centered about Axis 1, and are located at the base of the cantilever system in very stiff structure. They will not load the Figure 2.5-2 flexible cantiliver beam system to a significant degree. All the other items are lumped at the Axis 2 support bearing.

The flexible length of the Axis 2 straight beam representation is 61.44 ins. The flexible length of the Axis 1 curved beam representation corresponds to a radius of 300cm (118 ins) swept over a 30° arc. The beam crossection properties correspond to the sections illustrated on Figure 2.5-4. The dimensions were scaled from the intermediate circular tube truss patterns illustrated on DN132-165-1. All influence coefficient computations include terms for transverse shear in addition to beam bending.

The coefficient matrices and loading vectors for input to the equations illustrated on Figure 2.5-3 are listed on Table 2.5-7 for the steel structure, and on Table 2.5-8 for the aluminum structure. Loading vectors are illustrated for three difference Axis I balance weights. The loading level corresponds to 44 gees at the Axis 2 mass station at the tip and 19 gees at the Axis 2 support bearing.

A prior preliminary study was made of the Axis 2 System as a 3-station, 6-degree of freedom cantilever beam. That model is illustrated on Figure 2.5-5, and the associated equation matrix is illustrated on Figure 2.5-6. These early calculations are of interest only insofar as they illustrate considerable stiffness in the Axis 2 System when it is cantilevered from a datum plane. Much larger deflections are calculated when the Axis 2 System is cantilevered off the Axis 1 System because the combined



	ַ ַ ַ ַ	đ	h	D*	H
Axis 2	16	3	.094	3.54	.094
Axis l	41.5	6	.094	3.54	.094

Dimensions are in inches

FIGURE 2.5-4 STRUCTURAL CROSS SECTIONS FOR ESTIMATION OF BEAM LIKE FLEXIBILITIES

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# TABLE 2.5-7 STEEL STRUCTURE MATRIX COEFFICIENTS AND LOAD VECTORS

έ ψ α β γ All	61.44 2.890 E-07 1.217 E-05 2.604 E-07 8.477 E-07 2.318 E-07	Matrix Coefficients
A12 A13 A22 A23 A33	-3.037 E-07 -3.575 E-09 1.500 E-06 1.995 E-08 6.603 E-10	1 set

# TABLE 2.5-8 ALUMINUM STRUCTURE MATRIX COEFFICIENTS AND LOAD VECTORS

£ ψ α β Υ All Al2 Al3 A22 A23 A33	61.44 8.670 E-07 3.651 E-05 7.812 E-07 2.543 E-06 6.954 E-07 -9.111 E-07 -1.055 E-08 4.500 E-06 5.985 E-08 1.981 E-09	Matrix Coefficients l set
---	---	---------------------------

T <sub>SO</sub> 7832	7832	7832	
-V <sub>SO</sub> -13552	-13552	-13552	
M <sub>so</sub> +aV <sub>so</sub> 15896	15896	15896 }	
T <sub>s1</sub> 6072	6072	6072	Load Vectors
-V <sub>s1</sub> +V <sub>B1</sub> -10516	29876	70268	3 sets
M <sub>s1</sub> 28160	28160	28160	·

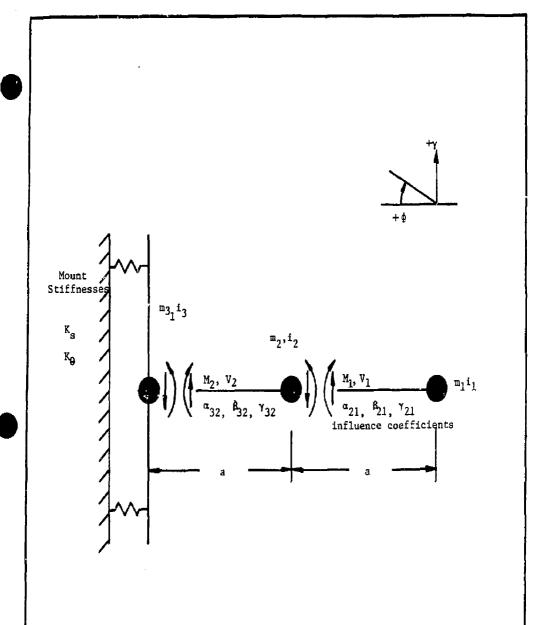


FIGURE 2.5-5 6 DEGREE OF FREEDOM,
PRELIMITARY AXIS 2 SYSTEM MODEL

[	1 y <sub>1</sub>	φ <sub>1</sub> <sup>2</sup>	y <sub>2</sub>	φ <sub>2</sub> ·	у <sub>3</sub>	6 \$3	v <sub>1</sub>	в м <sub>1</sub>	v <sub>2</sub>	10 M <sub>2</sub>		
1							1					<sup>ш</sup> 1 <sup>ў</sup> 1
2							a	1				<sup>1</sup> 1 <sup><math>\dot{\phi}1</math></sup>
3							~1		1			<sup>™</sup> 2 <sup>ÿ</sup> 2
4								-1	a	1		12 <sup>\$\vec{\phi}</sup> 2
5					-K <sub>8</sub>				-1		-	<sup>™</sup> 3 <sup>ÿ</sup> 3
6						-ĸ <sub>e</sub>				-1		±3 <sup>∳</sup> 3
7	1	а	-1				α <sub>21</sub>	β <sub>21</sub>				-0-
á		1		-1			β <sub>21</sub>	Y <sub>21</sub>				-0-
9			1	a	-1				α <sub>32</sub>	ß32		-0-
10				1		-1			β <sub>.j2</sub>	Y32		-0-

FIGURE 2.5-6 6 DEGREE OF FREEDOM, PRELIMINARY AXIS 2 SYSTEM MODEL

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system is much longer and much heavier. The Axis 1 System illustrated on DN132-165-1 does not achieve the values for "foundation stiffness," i.e.,  $K_{\rm g}$  and  $K_{\rm g}$ , necessary to limit the deflections to those previously estimated for the Figure 2.5-5 System.

#### Dynamic Multiplier Estimate

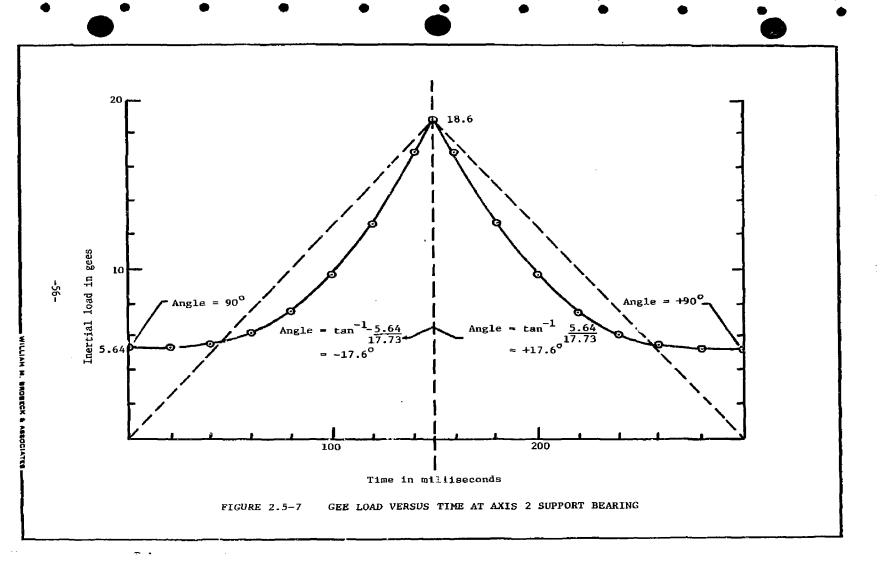
Figure 2.5-7 illustrates gee load versus time at the location of the Axis 2 support bearing. Note that the orientation of the load relative to the structure shifts a total of 180° as the structure rotates, with a sudden 35° shift when the angular acceleration goes from plus to minus when angular velocity is at its maximum value. Such a sudden angle shift would lead to a mechanical impact. This means that an acceleration schedule different from that assumed here probably will be selected. The selected schedule will reflect a trade off where higher absolute values of angular acceleration mitigate the intermediate angle shift impact.

Figure 2.5-8 illustrates triangular pulse dynamic multipliers for single degree of freedom undamped vibration systems as a function of the ratio between pulse time and response period. Table 2.5-9 tabulates dynamic multipliers for the structural cases studied here.

A real system will have many flexible modes. Also, the values tabulated in Table 2.5-9 do not consider any variation in load orientation. Therefore, we choose to apply a dynamic multiplier of 1.75 to all static responses calculated in this preliminary study.

#### Calculated Results

The results plotted and tabulated here indicate that slewing system mechanical deflections can be maintained within a range that can be



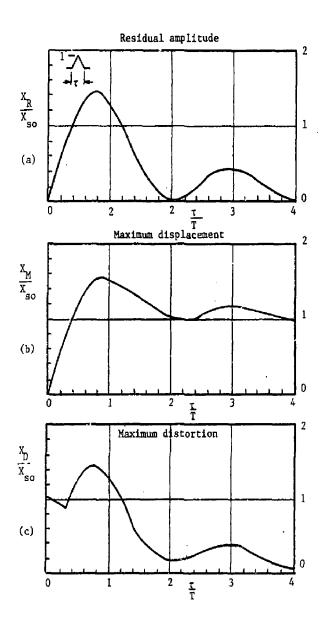


FIGURE 2.5-8 DYNAMIC MULTIPLIERS FOR TRIANGULAR PULSE VERSUS RATIO OF PULSE TIME TO NATURAL PERIOD

### TABLE 2.5-9 TABULATION OF DYNAMIC MULTIPLIER DATA

	Dynami	c Kultipli	ers	TI	iangular F	ulse
ω(Hz)	T(ms)	τ(ms)	τ/ <sub>T</sub>	x <sub>R</sub> /x <sub>s</sub>	x <sub>M</sub> /x <sub>s</sub>	x <sub>D</sub> /x <sub>s</sub>
1.29	775	300	.387	1.	1.	1.
1.57	637	300	.471	1.25	1.25	1,25
2.49	402	300	.746	1,5	1.5	1.5
.9	1111	300	. 270	1.	1.	1.
1.05	952	300	.315	1.	1.	1.
1.75	571	300	.525	1.3	1.3	1.3

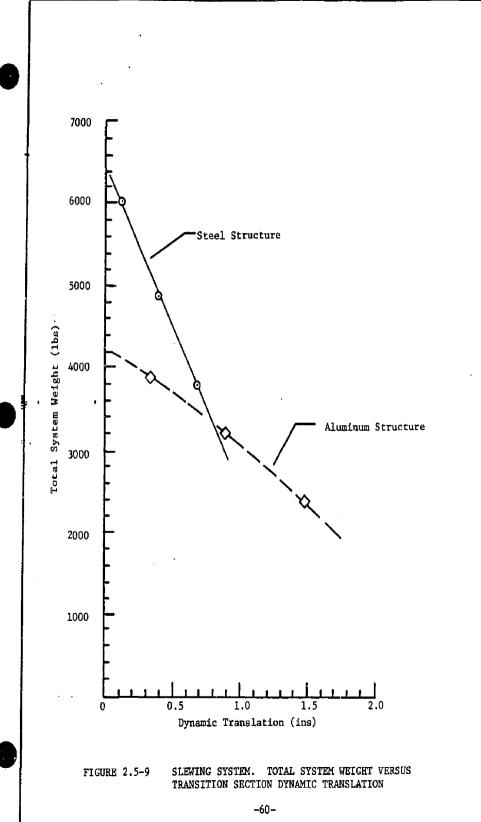
TABLE 2.5-9 TABULATION OF DYNAMIC MULTIPLIER DATA

compensated by the Vernier Steering System. Both the Axis 1 System and Axis 2 System can be "tuned" mechanically to limit deflection translation and rotation at the transition section exit, because the magnitudes of the tangential, radial, and axial gyrodynamic load components directly depend upon mass distribution. The mechanical designer has considerable control over the distribution of mass and structural flexibility.

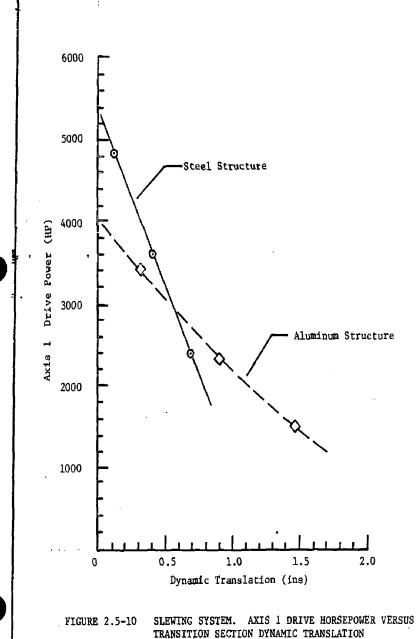
System response computations.  $v_1$ ,  $w_1$ , and  $\phi_1$  represent deflections at the transition section. Figures 2.5-9 and 2.5-10 show how variation in the Axis 1 balance weight,  $W_B$ , affects the system. Overbalancing the system can eliminate transition section translation at a cost in system weight and drive power. Figure 2.5-11 shows a quite flat variation for transition section angle with the transition section translation. This means that a balance weight structure acting at the transition section could be positioned to significantly reduce the absolute level of transition section rotation.

Table 2.5-10 summarizes calculated mechanical loadings for the cases studied here. The Axis 2 bearing load is consistent with the size of the selected bearings. The large Axis 1 support bearing is oversized by a factor of 2 for the highest load case. Structural stiffness, not bearing load, is the reason for the large diameter base of the Axis 1 System. The tabulated structural loads, stresses, and deflections all assume a dynamic multiplier of 1.75.

Structural models with many mass degrees of freedom and flexible connections, tend to have higher calculated frequencies and lower stresses than the very simple two and three mass representations calculated here.



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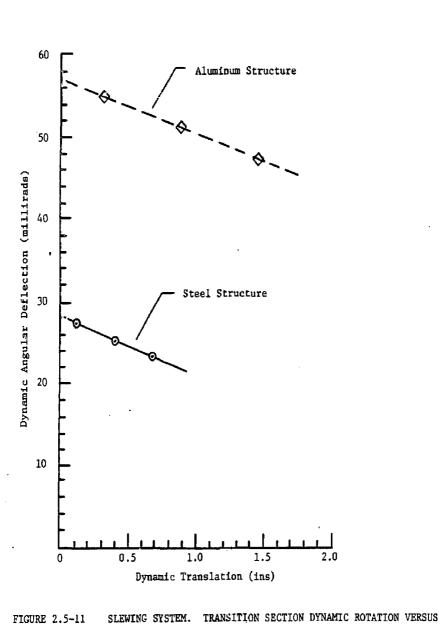


TABLE 2.5-10 SUPMARY OF ESTIMATED PEAK MECHANICAL RESPONSES

Structure Type	Aris 2	Axia i	Total	Axis 2	Axis i Pask Power hp	Amia 2	Axis 1 Brg Hom 1b - 1nm	Amis 2 Stress psi		Transition Section		lat
	Sys Wt 1bs	Bal. WE	Sys WE Lbs	Peak Power hp		Brg Nom			Axis l Strees psi	Tranolation ios	Rotation Rad	Bending Frequency H <sub>2</sub>
Steel	823	-0-	7719	111	2414	1404841	5031528	55243	30277	0.670	0.023	1,29
Steel	823	1129	4848	un	3610	1404841	(35614)	55243	10318	0.390	0.025	1.57
Steal	823	2258	5977	211	4806	1404841	8405642	55243	63945	0.112	0.027	2.49
		-	-	<del>                                     </del>					<del> </del>	<del> </del>	<b></b>	-
Aluminum	598	-0-	2365	71	1529	1175654	3992081	46231	30370	1.479	0.047	0.9
Aluminum	598	776	3141	71	2351	1175654	853279	46231	6491	0.898	0.051	1.05
Aluminum	598	1552	3911	71	3172	1175654	5698641	46231	43352	0.324	0.055	1.75

On the other hand, the pumps, motors, transition section, gear drives, and other components have increased in size since being initially selected. The pipe truss bending model may or may not possess enough structural weight to limit deflection modes that have not yet been calculated, such as torsional modes. Clearly, these numerical results can only be used as a rough guide for understanding the mechanical nature of the slewing system.

Refer now to Tables 2.5-1, 2 and Table 2.5-10. Overall stiffness varies with structural weight and overall loading varies with the sum of structural plus cargo and balance weights. If loading geometry and time signature does not change, then additional calculated responses can be estimated by ratioing the values in Table 2.5-10.

$$\Delta_{\text{new}} = \frac{\left[1 + \frac{W_{c} + W_{B}}{W_{S}}\right]_{\text{new}}}{\left[1 + \frac{W_{c} + W_{B}}{W_{S}}\right]_{\text{old}}} \times \Delta_{\text{old}}$$

Where  $W_c$ ,  $W_B$ , and  $W_s$  are cargo, balance, and structure weights from Tables 2.5-1 and 2. In the case of 2.5-2 for the Axis 1 System, the items for "tubes and lower structure" should be left out of the above calculation.

The additional power requirement will also vary with the above weight ratio equation.

CONCLUSIONS: The structural weight and stiffness will determine the vibrational frequencies and, dependent on the slewing rates, these will also determine the dynamic deflection.

Adequate structural rigidity can be provided to limit the deflection of structure to a tolerable amount as determined by the following two primcipal limiting criteria for tolerable deflection:

- (1) Maximum aiming error that can be compensated for by the vernier steering magnet and
- (2) maximum structural misalignment of the magnetic components of the achromat.

Since the achromat can accommodate a significant (1%) variation in energy, it will also be able to accommodate a limited (1%) structural deflection.

Increasing the stiffness of the structure requires an increase in its weight and drive power. Since all of these increases very rapidly with increasing energy, the weight and power will become so large that it will be very difficult to achieve useful slewing rates for beam energy in excess of 1000 MeV.

#### 2.6 Radiation Effects

The main radiation effects are those associated with collisions of the high energy electrons with the wall, exit foil and gas molecules.

There will also be some synchrotron radiation due to bending the beam in a magnetic field. The synchrotron radiation is given by the following equation:

$$U = 8.85 \times 10^{-32} \frac{(W/e)^4}{r}$$

Where U = energy loss ev/rev

W/e = energy of electron in ev

r = bending radius in meters

For a 500 MeV electron beam being bent through a 60 degree angle with a bend radius of curvature of 1 meter, the energy loss is only 922 ev.

This is a very small fraction of the total beam energy. For the very high beam currents contemplated for the electron beam director, the total radiation from the source may amount to only a few joules for a:multi-pulse burst. The peak radiation would be in the far ultraviolet region and would be mostly tangential to the beam path.

The radiation due to gas scattering in the vacuum chamber 's expected to be extremely small if a high vacuum is maintained in the beam tube. At a pressure of  $10^{-3}$  torr, the beam loss due to gas scattering will be insignificant.

Radiation due to collisons with the wall of the vacuum chamber will be extremely high if the beam is not well behaved in its transmission through the beam director. Collisions with the wall by even a small fraction of the beam must be avoided because an excessive amount of radiation would be produced. It will be necessary to "trim" the beam upstream of the beam

director to limit its size (in phase space) to assume that it does not spread out far enough to scrape the walls. The limiting beam radius is 5mm.

The radiation due to the beam passing through the exit foil will be unavoidably large. It will consist of high energy x-rays with a very strong forward distribution due to momentum conservation in the electron-electron impacts. The x-rays will have a continuous spectrum characteristic of bremsstrahlung with a maximum energy equal to the energy of the electron. The half-angle in the forward direction which includes all but 1/e of the intensity is given by

$$\theta_{i_2} = .65 \left(\frac{Wo}{W}\right) \quad \text{In } \left(\frac{W}{Wo}\right)$$

Where Wo = rest mass of electron

W ≈ energy of beam

For a 500 MeV electron beam, the half angle is about one quarter of a degree, for a low emittance beam. High emittance will increase the spread.

The total amount of radiation due to passing the beam through the exit foil will depend upon the foil thickness and its density. A very thin foil of low density will minimize the radiation effects. For a carbon or beryllium foil one millimeter thick, the beam loss is expected to be less than .5% of the total beam energy but it does represent a large amount of radiation.\*

Figure 2.6-1 shows the radiation loss for the beam passing through an exit foil of either beryllium or carbon and the loss in air. This figure shows the loss for collisions and for radiation. Clearly, the radiation loss increases with energy. The loss due to collision is a very weak function of energy.

<sup>\*</sup>The essential point is that strong forward distribution assures that the bulk of the radiation from the foil does not intersect the coils of the vernier steering magnet, and that this must be confirmed in any actual design.

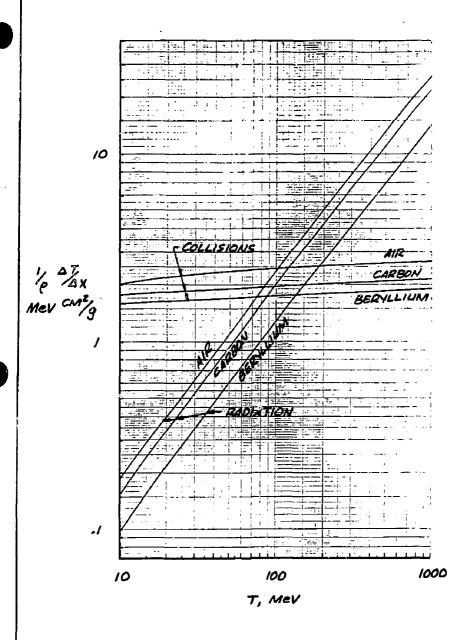


FIGURE 2.6-1

BEAM LOSS DUE TO RADIATION AND COLLISIONS
FOR BERYLLIUM AND CARMON FOILS AND FOR AIR
(Reference: Berger & Seltzer)

#### 2.7 Size, Weight and Cost Estimate

The size, weight and cost of a 500 MeV electro beam director were calculated. All these values are dependent upon the beam energy. A range of energies from 10 to 1000 MeV were considered for the conceptual design and the concepts presented are considered to be applicable to any energy within that range. Some simple scaling law would be desirable. For example, it would be nice to be able to say that doubling the energy would double the length of the bending systems and that this, in turn, would cause some easily extrapolated increase in weight and cost. Within narrow limits, some sort of extrapolation based on energy ratios is reasonable because the same permanent magnet material would be used for a limited range of energies. For beams with very high energies, a rare-earth-cobalt with a high residual induction would be used. For low energies, oriented ferrites would probably be selected and, for intermediate energies, rare-earth-cobalts of intermediate residual induction may be selected.

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For a given permanent magnet, material, an increase in energy will require a proportional increase in length and weight of the bending system. The weight of the support system will increase approximately with the cube of the energy as it must not only increase in length but also in the transverse directions. The moments of inertia will not only increase with weight but also with the square of the offset dimension. The moment of inertia has a strong influence upon the design of the mounting and slewing system. From the increase in dimensions and weight associated with increasing beam energy, it appears that the moment of inertia will increase by at least the 4th power of the energy ratio.\* Thus, the required drive power for a given slewing rate will also increase by at least the 4th power.

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<sup>\*</sup>The exponent probably approaches the 5th power at high energy.

The values given below for the 500 MeV beam director are based on an unproven conceptual design. As stated above, within limits, these values may be scaled up or down for different beam energies.

The results of the size, weight and cost analysis are summarized in Table 2.7-1. The costs are the unit costs in production and do not include development costs.

TABLE 2.7-1 SUMMARY OF SIZE, WEIGHT AND COST

ITEM	Dimension Meters	Weight Kg_	Cost K\$
Beam Bending System	3.14 length	227	152
Support Structure	3.14 x 2.9W 10E	2700 <sup>*</sup>	154
Drive System		4000**	501
Vacuum System			81
Vacuum/Air Transition	.25	25	105
Vernier Steering	.5	50	40
Sensors and Control			100
Total	3.89 x 2.9 Wide	7000	\$1133

Weight of rotating structures (5900 lbs) includes upper drive motor.
 Weight of stationary portion of the drive system includes lower

drive motor, hydraulic pumps, accumulations and foundation structure (8800 lbs).

#### 3.0 RECOMMENDED RESEARCH AND DEVELOPMENT

The conceptual design of an electron beam director contains elements which require developmental effort. To support the development will require research to provide basic data on behaviour of material and interactions of the beam. There is need for a design and development effort associated with many elements of the system, but some elements are more critical than others.

Single quadrupoles and dipoles using permanent magnets in an ironless configuration have been designed and built. A long string of such elements as shown in the conceptual design has not yet been built and tested.

Air-to-Vacuum Transition devices as shown in the conceptual design utilize known technologies but these have not been proven in the specific application shown in the conceptual design.

Procedure for analyzing the dynamic response of structures to various types of loads are well known, but specific structures to support a beam director have not been sufficiently well defined nor has a complete slewing system been designed. The brief examination of a support and a slewing system concept indicates that a great amount of design and optimization will be required in order to achieve a practical design. A light weight structure with high rigidity is required if high slewing rates are to be achieved.

The steering magnets for the Vernier Steering System are of a conventional design, but the tracking and control system needed to assure that the required accuracy and vibration compensation is achieved is yet to be developed. An additional problem associated with the design of the steering magnet is the potentially high radiation which may occur just downstream of the Vacuum-to-Air Transition Section. The radiation problem is

treated conceptually by simply providing enough operture to permit the radiation which is directed strongly forward, to pass through without great interaction with the material of the steering magnet. Some critical experiments of the beam/air interaction will be required to verify this approach.

Probably, the most critical items in the conceptual design are the Vacuum-to-Air Transition Section and the permanent magnet bending system.

Design and development work on these two items should be started soon. Both systems can be tested using the electron beam from ATA (Advanced Test Accelerator) at Lawrence Livermore National Laboratory.

The rotating foil approach to the Vacuum-to-Air Transition could be built, tested and refined using presently available technologies. The development of such a device would permit the running of many critical experiments dealing with beam/air interaction. The development of this rotary foil device will require the development of a well-balanced rotor, a suitable vacuum pumping system and a suitable bearing system. In the final configuration, the gyrodynamic behaviour of the device must be suitably accounted for, but, for the initial developmental device, the gyroscopic loading of the disk and bearings can be avoided by simply testing in a static configuration.

A permanent magnet bending and focussing system should be built for tescing at ATA. This should be designed so that it can be rotated to direct the beam in various directions. A continuous rotation may be desirable but not absolutely necessary. Discrete steps should be all right. The main thing to explore in this design and development is the characteristics of the permanent magnet bending system. The problems of accuracy of

mechanical and magnetic alignment needs study. How reliable are the magnetic property projections? What are unique fabrication problems? What sort of optical aberations will occur? What are the consequences of vibration and misalignment? Building and testing a system will provide answers to these questions.

For the beam energy at ATA (50 MeV), a bending and focussing system using an oriented ferrite such as Ferrimag 7B should be built. This material will give a lower field than that obtainable with rare-earth-cobalt. The lower field is desirable for a 50 MeV electron beam because it gives a greater length of the system.

#### 4.0 CONCLUSIONS

In the engineering effort on the conceptual design of an electron beam director, a variety of components and concepts were examined, and found to be promising. There were no technical reasons for believing that a suitable design could not be devised for handling high intensity pulsed electron beams in the 10 to 1000 MeV energy range. Of course, there are problems which must be solved, and there are limits imposed by material properties which must be recognized.

Achieving high slewing rates will be difficult but not impossible. Special design efforts will be required to produce a sufficiently  ${\rm light}$  weight support structure having adequate rigidity.

The most critical elements of the design appear to be the Vacuum-to-Air Transition, the permanent magnet bending and focussing system, and the support structure. The design of the first two of these items has a strong influence on the design of the support structure, because the weights and alignment requirements of these components determine the key design criteria for the rest of the system.

Presently, available permanent magnet materials appear to have suitable magnetic properties to satisfy the design requirements for bending and focussing of the beam. Whether these materials have the required physical strength and uniformity is not certain, but there are no fundamental reasons why good quality control procedures cannot assure adequate uniformity nor why existing physical properties cannot be utilized by careful design of the magnet support and containment assembly.

The aperture of the beam tubes can be made sufficiently large to insure that the beam loss by collisions with the wall will be insignificant and that adequate vacuum pumping will be possible to prevent excessive beam loss due to gas scattering. This will be necessary to minimize radiation.

The vacuum rotary points will have some leakage but, by proper design with at least two stages of pumping, the leakage rate can be made tolerably low. The joints can be made sufficiently strong to provide adequate rigidity and alignment.

Radiation effects can be minimized by good design and suitable suitelding. The radiation from the beam passing through the Vacuum-to-Air Transition Section will be unavoidably large but, at this point, the electron beam/air interaction may be so great that other radiation effects may seem insignificant.

The calculated size of the total structure does not appear excessively large although the weight of seven tons does seem high for a 500 MeV beam. It is believed that this weight may be significantly reduced after design optimization for a specific set of beam requirements. It seems premature to begin detailed design until a specific value of beam energy has been selected.

Using a value of 50 MeV would permit the use of a much lighter structure than would be needed for a 500 MeV beam because the weight is expected to increase by about the third power of energy. Thus, a factor increase in energy would require about 1000 fold increase in the weight of the support structure.

<sup>\*</sup>The rotary vacuum joints were initially thought to present serious design problem, but do not now appear to be excessively difficult. It appears that lubricated vacuum seals with intermediate pump-out ports are viable.

5.0 APPENDIX

DESIGN STUDY SKETCHES

DN132-165-1A

DN132-165-1B

#### CHANGES MADE ON

#### "CONCEPTUAL DESIGN OF AN ' ECTRON BEAM DEFLECTOR"

#### BY LBL PRIOR TO DISTRIBUTION

- Added to bottom of Title page: Lawrence Berkeley Laboratory Contract No. 4522410.
- 2. Page ii: Removed "5.0 Appendix"
- 3. Page 7: Replaced bracket on equations.

Changed equation to: 
$$\theta = \frac{\pi}{2} - \sin^{-1}\left((1 - \sin^2 \gamma (1 + \cos \alpha_2))\right)$$

Changed equation to: 
$$\phi = \alpha_1 + \tan^{-1} \left( \frac{2}{3} \frac{(\sin \alpha 2)}{\cos \alpha_2 + 1} \right)$$

- 4. Page 9: Replaced brackets on equation
- 5. Page 14: Replaced parenthesis on equations
- 6. Page 23: Changed  $Wr_d$  with  $Wt_d$  in column 7
- 7. Page 37: Removed reference to Appendix--replaced with "(not included)" two times
- 8. Page 38: Added "\*" after sketch no. and included footnote at bottom
- 9. Page 46: Added "\*" after sketch no. and included footnote at bottom
- 10. Page 50: Added "\*" after sketch no. and included footnote at bottom
- 11. Page 65: Fourth line from bottom, changed "increases" to "increase"



APPENDIX H. BEAM DIRECTOR COMPONENTS FOR ATA TESTS (FINAL REPORT)

#### BEAM DIRECTOR COMPONENTS

FOR

ATA TESTS

Prepared for

LAWRENCE LIVERMORE NATIONAL LABORATORY

LIVERMORE, CALIFORNIA

Prepared by

BROBECK CORPORATION 1235 Tenth Street Berkeley, California 94710 (415) 524-8664

DECEMBER 1985

Report No. 4500-300/301-R1

This work was done under Subcontract No. 6551805 with Lawrence Livermore National Laboratory, Livermore, California.

This work was sponsored by PM3-405 Naval Sea Systems Command, Washington, D.C. 20362, under Contract No. W-7405-ENG-48 with the United States Government, represented by the Department of Energy.

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**APPROVALS** 

Issue

Contents

Original v + 35 pgs.

Prepared by

Approved by

Francis C. Younger

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## BEAM DIRECTOR COMPONENTS FOR ATA TESTS

A system for directing a high-energy electron beam had been studied earlier and a conceptual design had been developed. Several key components of this design were identified and targeted for verification tests using the high intensity electron beam from ATA. This report covers two of these components—the achromat and the vernier steering magnet which were built for testing at ATA.

The achromat is a major beam transport element of the beam director. It is designed to provide a 30 degree achromatic bend of a 45 MeV electron beam using a combination of permanent magnet dipoles and quadrupoles. The dipoles provide the beam bending and the quadrupoles provide focusing to assure achromaticity to a first order. Since higher order chromatic aberration may be present, a system of trim coils is provided to permit adjustments in the quadrupole gradients to compensate for beam energy variations. The permanent magnet elements are made from a relatively weak oriented grain ferrite magnetic material. As a beam bending and focusing device, its most unique feature is its light weight, which is required to permit the rapid slew rates needed for a beam director. Testing at ATA is expected to show the extent to which the achromat is sensitive to the space charge associated with high intensity beams and to permit an evaluation of the vacuum requirements for successful steering and focusing a high intensity beam.

The vernier steering magnet is an electromagnetic device for producing a finely controlled angle of bend for the electron beam. The device has two sets of coils for bending the beam. One set bends the beam in the horizontal

plane and the other bends the beam in the vertical plane. By suitably energizing both sets of coils, the direction and magnitude of the bend can be controlled. The device is designed to produce a maximum bend of two degrees in any direction. The peak magnetic field required in fairly low so that iron is not required to provide a flux return path. A major requirement of the design is that it be light weight so that high slew rates may be achieved. For the tests at ATA, the vernier steering magnet is installed in a vacuum tank so that the environment can be controlled. The tests at ATA should provide answers to critical questions on the suitability of this type of vernier steering element operating with a high space charge beam and/or with ionized gases in the magnetic aperture.

#### REQUIREMENTS

The vernier steering magnet is designed to produce a 2 degree hend of a 45 MeV electron beam using two orthogonal sets of coils which can be separately energized to control the direction and magnitude of the bend angle. Table 1 lists the target specifications and shows as-built values based on magnetic measurements. As may be seen, the required current is somewhat lower than targeted because the effective magnetic length is longer than initially projected. The coil resistance is slightly higher; consequently, the required voltage is only slightly higher than the design objective.

The achromat is designed to produce a 30 degree bend of a 45 MeV electron beam using permanent magnet dipoles and quadrupoles in a lattice structure designed to give a 360 degree phase advance. The target characteristics for the design are listed in Table 2. The arrangement of the dipoles and quadrupoles are shown in Figure 1 and the arrangement of permanent magnet elements required to produce dipole and quadrupole fields are shown in Figures 2 and 3. The focusing characteristics are shown in Table 3.

The magnetic strength of the permanent magnet sectors varies slightly from element to element. Also, the alignment of the magnetic easy axis may vary slightly from the exact location desired. To account for the variations in alignment and magnetic strength and to minimize any adverse effect these may have upon the achromat, each segment was separately measured for magnetic moment and orientation of magnetic axis by the Magnetic Measurement Group at Lawrence Berkeley Laboratory (LBL). Using these measurements, the elements were sorted prior to the assembly in dipoles and quadrupoles.

## TABLE 1. VERNIER STEERING MAGNET CHARACTERISTICS

40 cm

COIL LENGTH

MAXIMUM FIELD	147 gauss ± .5%	
MAXIMUM BEND	± 2 degrees ± .5%	
DIRECTION	X or Y	
PROJECTED VALUE	X - COILS	Y - COILS
COIL RADIUS - inches	1,5	1.25
NUMBER OF COIL TURNS	78	78
COIL RESISTANCE - ohm	.766	.736
CURRENT FOR 2° BEND - amp	22.8	19.0
VOLTAGE - volts	17.5	14.0
INDUCTANCE - mH	1,26	1.05
MATERIAL	ALUM	ALtiM
WEICHT - pounds	1.6	1.5
AS BUILT VALUES FOR 45 MeV		
CURRENT FOR 2° BEND - amp	18.3	15.25
RESIST	1.00	.95
VOLTAGE	18.3	14.5
EFFECTIVE MAGNETIC LENGTH - cm	46	45

# TABLE 2 ACHROMAT CHARACTERISTICS

FNERGY

45 MEV ELECTRONS

LATTICE

(QF B QD QD B QF) X 4

MAGNET DEVICES

PERMANENT MAG. DIPOLES
PERMANENT MAG. QUADRUPOLES

BEAM TUBE APERTURE

2.84 cm

MAGNET APERTURE

3.24 cm

QUADRUPOLE CHARACTERISTICS (16 QUADS)

GRADIENT 1281 G/cm
LENGTH 5.315 cm
R1 1.62 cm
R2 2.36 cm
MAGNET WT 8.85 KG

DIPOLE CHARACTERISTICS (8 DIPOLE)

B 1104 G LENGTH 9.00 cm R1 1.62 cm R2 2.23 cm MAGNET WT 2.60 KG

PERMANENT MAGNET MATERIAL

FERRIMAG 7B

RR 3800 G

HC 3500 0E

W 4.8 G/CM<sup>3</sup>

MREV 1.05 - 1.07

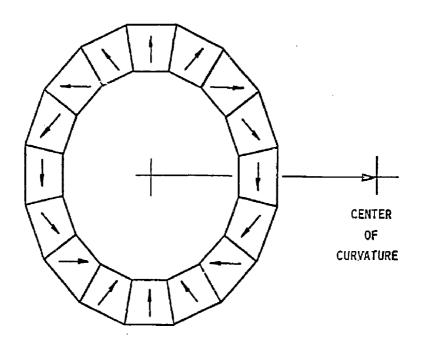
TRIM COIL CHARACTERISTICS

△ GRADIENT 25.6 G/cm (2%)
CURRENT 10.8 AMP
VOLTAGE 105 VOLT
POWER 1134 WATT
INDUCTANCE 1.5 MH

COOLING

WATER COOLED FLOW REQUIRED 0.7 GPM

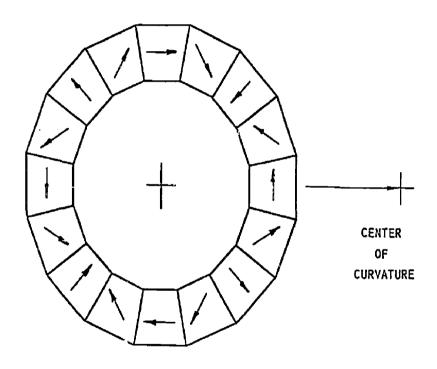
# FIGURE 2. PERMANENT MAGNET DIPOLE



16 PERMANENT MAGNET SEGMENTS

ARROWS SHOW DIRECTION OF MAGNETIZATION

# FIGURE 3. PERMANENT MAGNET QUADRUPOLE



16 PERMANENT MAGNET SEGMENTS

ARROWS SHOW DIRECTION OF MAGNETIZATION

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2	
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The assembled dipoles and quadrupoles were also measured at LBL. The measured dipole fields were all slightly higher than the desired 1107 gauss. The maximum value was 1126 and the minimum was 1115 gauss. On the average, the fields were about 1% high; however, the effective magnetic length was, on the average, about 3.5% longer than desired. As a consequence, the optimum energy for transmission through the achromat is 46 MeV rather than 45 MeV.

The measurements of the quadrupoles showed that the integration of their gradients over their length gives an effective B' x leff from 1.379 to 1.400 Tesla. This compares with a design objective of 1.362 Tesla. Thus, the achieved gradient x length products are about 2% high on the average. This is consistent with the error in the dipoles. The trim coils will provide about 4.5% adjustment in effective gradient.

The dipoles and quadrupoles were located within the achromat assembly in such a way to distribute the magnetic errors to minimize their influence.

## DESIGN DRAWING

The drawings for the vernier and achromat are listed in the Appendix.

## MEASUREMENT AND SORTING OF P.M. SEGMENTS

Permanent magnet segments were measured for magnetic moment and direction of magnetic axis at LBL. An example of data from these measurements is shown in Table 4. The MAGID numbers identify the segment and indicate its type and position by the first three digits. For this example, the first whree digits of MAGID indicates that these segments are for the short quadrupoles and for positions 1 and 2. These positions are shown on the design drawings. At these positions, the angles THTAXY should be 180 and 135 respectively. As may be seen from the table, the angles deviate significantly from the desired values. It is also clear that there is a significant variation to the magnetic moments MXY and MZ.\* Ideally, MZ should be zero. It was anticipated that there would be significant variation inspite of steps taken to minimize the scatter in magnetic properties and orientation of magnetic axes. Because of these expected variations, extra segments were obtained so that, through a selection process, the best arrangement of segments could be made. Segments with large deviations would be rejected. Values of MZ were generally ignored, even though a large value would indicate some fabrication error.

Using a rather simple algorithm, the segments were assigned to a specific quadrupole or dipole in such a way as to minimize the variation in total magnetic moments for each type of element and to minimize the summation of vertical and horizontal components of the magnetic moments.

<sup>\*</sup>The table shows some values from early measurements which should be ignored.

The additional digit in front of the MXY value indicates data that has been updated.

## TABLE 4

DATA PRINTED FROM SCRTED DATA FILE: ADZ-081400.SRT

	MAGNETIC	MEASUREMENT:	S ENGINEERING	G=
	MAGNETIC	C MOMENT SOR	TING	PAGE 1
MAGNETS	2.093 INC	CHES FING MI.	TH EASY AXIS	OF 160.0 DESREES
MAGID	YXE	THTAXY	MZ	. DATE TIME
	[Max-Cm]	[Degrees]	[Max-Cm]	
101009	11251.	-·179.9	177.	4-AUG-95 7:52:15
101017	11264.	-179.7	-213.	14-AUG-65 10:59:48
101041	11279.	-179.1	-48.	14-AUG-85 13:11:30
101033	11285.	177.7	-157.	16-AUG-85 11:44:51
101025	11258.	178.7	110.	14-AUG-85 11:34:49
101201	11705.	-175.7	524.	20-JUN-85 14:48:34
101009	211342.	-179.7	193.	21-JUN-95 14:49:17
101017	211342.	-179.5	-219.	19-JUN-85 13:17:59
101041	211343.	-179.1	-45.	20-JUN-85 11:13:44
101041	211346.	-179.1	-56.	21-JUN-85 07:25:46
101033	211351.	179.7	-153.	20-JUN-85 11:05:50
101025	211356.	178.7	116.	20-JUN-85 14:55:17
101033	211361.	179.8	-125.	21-JUN-85 07:17:19

	[max-Cm]	[Degrees]	[Max-Cm]		
102026	11290.	134.5	-128.	14-AUG-85	11:44:03
132034	11267.	134.3	337.	16-AUG-85	11:47:38
102013	11327.	137.1	-231.	19-JUN-85	13:26:27
122202	11331.	:35.2	-256.	14-AUG-85	09:29:31
102010	11387.	132.9	593.	21-JUN-85	JB:11.54
102042	11413.	132.4	-48t.	.5-AUG-85	13:16:39

ΉZ

MAGNETS 2.093 INCHES LONG WITH EASY AXIS OF

THTAXY

132.4

.33.0

134.2

132.8

MXY

11419.

111372.

211543.

MAGID

122042

100017

102274

102042

211331. 134.1 354. 20-JUN-85 08:43:59 132234 134.6 ~123. 102026 211369. 17-JUN-95 13:31:12 211400. 135.3 -257. 11:29:47 102202 20-JUN-85 132.7 -482. 17-JUN-85 14:11:33 192942 211542.

-487.

533.

354.

-467.

135.0 DEGREES

16-AUG-65

20-JUN-35

17-JUN-85

19-JUN-85

DATE

TIME

13:20:49

11:27:57

14:04:23

14:17:15

Ideally, the summation of horizontal and vertical components should be zero. Because the angular orientations deviate from the ideal values and the magratic moments are not uniform, the vector summations do not yield zero values.

The final assignments for segments for the short quadrupoles is shown in Table 5. The segments for this table were presorted to eliminate those with the greatest deviation in angle or moment. The segments selected have an average magnetic moment, MXY, of 11311.9 with a standard deviation of 52.97. This is less than 0.5%. Each segment can be used in any of two places and in either quadrupole (S1 or S2). The ideal positions for the segments are those which give the lowest average vertical and horizontal component. The segments are systematically moved from position-to-position to bring these averages to their lowest values.

The assignments of segments for the long quadrupoles are shown in Tables 6 through 9. The method for selection is the same as that for the short quadrupoles explained above.

ABLE 5

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_	SE6. NO.		10103		102002		102026				103035	103043	?	104044		106012	•	•	105029	10501		104014	•	106044			107040	10701			109024	CYUBUI	
!	HOR17.	-11265.8		11277.40		4706.886		-4555.62	8028.093	-8001, 11			-10501.3		10371.54		-98.3393	19.48730			-(049B.0		10415, 49		-7763.44	8092.010			1730 400	-4636.36			11.64987 0.805688 49.15774
_ !	VERT.	-1/7,7 -38.7//B -11265.B		-359.1 -177.162 11277.60		-65.4 -10280,7 4706,88		13.8 10328.97 -4555.62	44.6 7916.775 8028.093	-135.2 -7945,45 -8001,11			157.9 4304,758 -10601.3		-23.4 -4488.16 10371.54		-90.5 -11248.5 -98.3393	89.9 11279.98 19.68730			-157,5 -4348,43 -1049B.O		24.2 4680.911 10415.49		33.2 6267.233 -7763.44	-44.8 -8025.7g 8082.616			67.5 10452 77 4730 400	-113 -10451.4 -4636.36			11.64987
E # 511	GLDB.ANG	-1/3'		-129.1		-65.4		113.8	44.6	-135.2			157.9		-23.4		-90.5	6.68			-157.5		24.2		133.2	- A.B.			87.3	77			
ᇘ		11704		11279		11307		11289	11275	11276			11442		11301		11259	11280			11343		11419		11341	11390			11314	11354			11372.68
	SEC. 118.	10101		101041		102018		102034	103003	103011			104036		104020		105037	105013			.04022		106038		107031	107007			108014	108048			0.004683 52.97544 54.44115 11322.68
	DEL BIT	10 00 10 TO	23.90625		135,2 -19,0937	4,90625	31,90625	136.3 22.90625	36.90625	89.8 35.90625	54, 90625	89.4 -17.0937	45.4 -130.093	44.1 62.90625	44.1 10.90625	-78.0937	-0.5 42,99525	31.90625	-0.4 -20.0937	0.90625	-45.0 -51.0937	-43.0 14.90625	-43.3 -107.093	-45.7 123.9062	-91.8 -29.0937	-89.8 -78.0937	-90.7 27.90625	-89.6 43.90625	135.0 -2.09373	135.5 -42.0937	135.8 -41,0937	-134.4 -64.0937	52.97544
17	1707	7.07.	178.7	-179.1	135,2	137.1	134.5	136.3	89.6	84.8	40.4	89.4	45.4	7.7	-:	14.0	9.5	1.0-	÷.0,	0.3	-45.0	-63.0	-43.3	-45.7	-91.8	-89.8	-90.7	-89.0	-135.6	-135.5	-135.8	-134.4	6.004683
100	7	649	9 5	-48	-250	-231	-128	334	139	#	200	-548	709	292	++-	356	846	-733	-316	749	133	123	179	-74	-41	135	-488	-61	-316	17	-305	323	
SERJES=	11764	11285	11288	11279	11331	11307	11280	11289	11275	11276	11257	11329	11412	11249	11301	11290	11269	11280	11332	11211	11363	11297	11419	11188	11341	11390	11284	11268	11314	11354	11353	11376	11311.90
SEGNENTS	101017	10103	101025	101041	102002	10201	102026	102034	103003	102011	103035	103043	104036	104044	104020	104012	105037	105013	105029	105021	106022	10901	104039	106046	107031	107007	107039	107015	¥10801	108048	108024	N	AVERABE

TABLE 6

	KORIZ.		-357.1 1153.468 22769.80	1.08/77	115.2 20485.30 -9204.44		-68.2 -20917.8 B346.545				44.2 15438.02 15875 24	7 2023 - 15524 4 - 1570 T		-26.9 -7994 14 20014 58	7	158 1 8414 481 -20001 A	5.7007		ACTO 011 4 CATCC - F 00-	01 1 22847 OF 123 002	711.770	-157.4 -8540 65 -20542 1		22. 7 8517. 690 20020 G2			14. 1 15247 74 -15040 F	-41.8 -1525A 9 140A0 74			A7 20482 15 8494 158	-111 -21062.5 -8085.1X	5.92033 -20.8840
	VERT.		153.468		20485, 30		-20917.8				5438.02	15524		1007		1474 98T			A 50555	20 2782		20 075G		1917 490			47. 74.74	1575A B			6187 15	21062.5	. 920333
₱ 5(5-D)	SLOB, ANG		-357.1		115.2		-68.7	!			44.2			-20 9		158.1			- 60			-157.4		22.7			174				A7 7	=	
#		,	22799		22459		22529				22144	22149		22469		22620			22703	22854		22251		22594			219B4	22043			22251	22561	22446.5
_	į		8 5	:	2	!	99	ŀ			23	6		9	1	95	:		-	. 2		2	1	72			ĸ	! ≈			=	9	9
	Z. 535		201105	•	202050		202066				203123	203107		204059		204060		•	205117	205109		206070		204126			207005	707127			208104	208088	271,86
	<b>FD913</b>	-22770.9		72822.77		9245.418		-8409, 25	15953.72	-15240.8			-20906.7		20988, 05		-397.897	476.2725	1		-20924.4		20942.20		-15558.1	15420.31			7546.037	9447.31			2.897137 -16.4021 271.8660
	VERT.	-174.4 -39.7428		-0.8 319.6867 22822.77		-65.9 -20668.3 9245.41		21024.63 -8409.25	43.9 15352.40 15953.72	-133.5 -16060,5 -15240,8			158.2 8362,089		-22.8 -8822.56		-91 -22795.5 -397.897	88.8 22737.01 476.2725			-157,4 -8710,82 -20926,4		22.5 8674.668 20942.50		134.9 15612:51 -15558.1	-45.7 -15801.7 15420.31	!		70.5 21309.35 7546.037	-114, B -20445, B -9447, 3)			. 897137
DUADRUPULE # 3(B-D)	5L08.ANS			-0.8		65.9		111.8	43.9	-133.5			158.2		-22.8	!	-16-	89.9			-157.4		22.5		134.9	-45.7			70.5	-114.8			.,
<b>QUADRUPUL</b>		1777		22825		22942		22644	22141	22141			22517		22767		22799	22742			22667		22669		22041	22079			22605	22523			22535.81
	ř	*/0107		201065		202122		202058	203115	203083			204100		204052		205101	205125			206054		209094		207119	207079			208128	208120			272.6571 266.0533 22535.81
1	UEL MAS	-7/4, 843	-306,843	-333.843	32, 15625	-150,843	-37.8437	-152,843	350, 1562	350, 1562	347.1562	342.1562	-25.8137	82,15625	44.7 -275.843	45.6 -128.843	-307.843	-1.2 -250.843	0.3 -211.843	-362,843	-44.9 -175.843	-44.9 240.1562	-45 -176.843	-45.3 -104.843	450, 1562	412, 1562	507.1562	443.1562	-114.B43	137.3 -31.8437	240.1562	-69.8437	272.6571
200	1814	7,7,7	-178.7	179.2	136.7	136.6	134,3	134.3	88.9	91.5	89.2	69.5	5.7	46.6	44.7	45.6	•	-1.2	0.3	1:7	-44.9	-4.9	7	- 5.3	-90.1	- 60.7	-68.9	-88.8	-132	-137.3	-133.5	-133.5	0.012122
200	10	777	-286	-324	-1	17	<b>∓</b>	'n	-32	40	- 53	<b></b>	-175	â	-324	•9	300	241	Ç	7.	-113	-	151	-120	-156	=	152	190	-130	75	-101	7	_
 SERIES=	1100	1//77	22792	22825	22459	22842	22529	22644	22141	22141	22144	22149	22517	22409	22767	22620	22799	22742	22703	22854	22667	22251	22668	22596	22041	22079	21984	22043	22606	22523	22251	22561	22491.15
SEGNENTS	30102	20102	201081	20105	202020	202122	202056	202058	203115	203083	203123	203107	204100	204069	204052	204060	205101	205125	205117	205109	204054	204070	20904	206126	207119	207079	207095	207127	20B12B	208120	208104	208088	AVERAGE

	HDR12.	22830.31	-22854.6		-8839.72		824X A2X				CY #1551	-15188 7		2087B 44		-21017.7			7056 275	A101 101	A175 LAB	-20017 0		74 64605			-15977.4	1594R. 31			7907.356	-8652.47	0.693257
	VER1.	-3.7 -1476.37 22830.31	177.2 1117.780 -22854.6		112.9 20926.56 -8839.72		-6B.7 -21143.8 8243.423				45. A 15841 AT 15518 A2	-131.2 -14174.1 -15188 7		-23.8 -9788.50 20878 AA		156.6 9108.189 -21047.7			-88. 6 -23047 1 547 2594	88.5 24078 DB		-156.4 -9147 17 -20077 0		24.3 9481.290 20998.73			134.1 15487.46 -15977.4	-45.7 -16342.8 1594B.XI			69.6 21262.24 7907.356	-112.5 -20886.9 -8652.47	-6. SC126 0.693257
DUASRUPOLE # 9(6-D)	GLOB. AND	-3.7	177.2	!	112.9		-6B.7	Ì			45.6	-111		-23.8		156.6			-88	8	;	156.4		24.3			1.54.1	45.7	į		9.69	-112.5	
QUASRUPOL	MIY	22878	22882		22717		22694				22203	22188		22819		22934			23054	23086		27848		23040			22959	22835			22685	22610	11121
	SEB. ND.	201097	201089		202082		202098				203067	203051		204116		204092		•	205085	205077		204062		204110			207087	207103			208080	208056	254.4351
				22872, 67		7907.265		-8833.11	15862.95	-16417.4			-20839.1		20974.56		-1119.44	39.94707			-20984.0		21018, 33		-16229.3	16240.14			9926.320	-7856.88			-1.16661 -16.E108 25ú.4351
_	139.7 119 5475 - 2281 A			-2.9 1158,679 22872,67		-69.9 -21607.6 7907.265		12.9 20910.90 -8B33.11	46.1 16484.04 15862.95	-136 -15854.1 -16417.			156.2 9191,147 -20839.		-23,3 -9033,07 20974,54		-92.8 -22888.6 -1119.44	69.9 22887.96 39.94707			-157.3 -6777.81 -20984.0		22 8491.956 21018.33		137.2 15028.56 -16229.3	-42.7 -14985.9 16240.14			64.1 20442.45 9926.320	-110 -21586.6 -7856.86			-1.16661
E # 7(7-D	64.08, A116	•		-2.9		6.69-		112.9	46.1	-136			156.2		-23.3		-92.8	69.6			-157.3		22		137.2	-42.7			64.1	-			
OUADRUPOLE # 7(7-D)	MXY 22832			22902		23009		22700	22877	22823			22776		22837		22916	22888			22746		22669		22119	2209B			22725	22972			22743.06
	SEG. NO. 201113			201121		202105		202090	203059	203075			204076		204108		205053	20202			204078		204084		207055	207111			208072	208064			011302 257.2506 256.7456 22743.06
	DEL NYY SEB, NO71,9487 201113	-117.968	-121,968	-141.968	43,03125	-24B, 968	46,03125	40.03125	-116.968	89.0 -62.9687	557,0312	572.0312	-15.9687	-5B.96B7	14.2 -76.9687	-173,948	-2.B -155.94B	-127,968	-293.968	-1.5 -325.968	44.8 14.03125	-43.9 -87.9687	-45.5 91.03125	-43.2 -279.968	-87.8 641.0312	-87.7 662.0312	-90.9 -198,968	-90.7 -74.9697	-138.4 35.03125	-132.3 -211.968	-132.9 75.03125	-135.0 150.0312	257, 2506
	Thiriy 179.7			177.1	135.4	132.6	133.8	135.4	91.1	89.0	90.6	91.9	13,7	13.7	4.2	#	-2.8	-0.1	=	-1.5	-44.8	-43.9	-45.5	-43.2	-67.8	-67.7	- 6.06-	-40.7	-138.4	-132.3	-132,9	-135.0	0.011302
206	N1 325	230	728	113	-142	-596	12	9	-1106	423	Ħ	ņ	1	458	98	-1126	88	166	383	<b>†</b> 0†-	-132	-112	-160	-183	183	÷-	212	-5	ņ	290	7	<u>6</u>	
SER1ES=	#KY 22832	22878	22382	22402	22717	23009	22694	22700	22877	22823	22203	22189	22776	22819	22837	22934	22916	22868	23054	23086	22746	22848	22669	23040	22119	22098	22959	22835	22725	22972	22685	22610	22760.03
GMENTS	EK MG. 201113	201097	2010B9	201121	20202	202106	202098	202090	203059	203075	203067	203051	204076	204116	204108	204092	205053	205093	205085	205077	20407B	208062	20 <b>6086</b>	204110	207055	207111	207087	207103	208072	208064	208080		EKRDE

TABLE 8

	T. HDK12.		-0.8 -319.492 22880.46	178.4 641.3349 -22960.1		98.829.80 -8828.89		-69.2 -21357.7 8113.057				45.5 15712.24 16552.25	-130.7 -1744R.R -15075.5		-21 -8143,12 21213.5A		159, 9 7942, 387 -21201, 4			-41.3 -22930.5 -520.38B	88.25 23214.26 209.2600		-155.A -8984.27 -207At.4		26.4 10235.05 20418.38			161 14442 21 -13211 1	-41 -14989 7 17243 47			240 1670 CD 4011C RA	113 -1107 C COTIC- CIT-	103.928 -24.4258
_	VEAT.		-319.	641.3		20730		-2135				15712	-1764	:	-8143	:	7947			-2293	72.7		- ROA4		10235			14.412	1408			40410	210	-103.
BUADHUFULE # 415-F	GLOB. ARG		9.0-	178.4		113.5		-69.2	!			45.5	-130.7		-21	i	159.9			-41.3	88, 25							1	7	•		87		:
BUALMUFÚI	HIY		22882.7	22969.1		22571.6		22846.8				22825.8	23041.9		22722. ₿		23111.2			22936. 5	23225.1		22622		23019			22340	27848. I			4 CATC	27077	22890.45
	SEG. HD.		301137	301161		302176		302162				303171	303187		304164		304180			305173	305145		304192		306166			307175	307147			308174	308192	
		-22654.8			23061.60		8471.316		-10943.9	16264.33	-16495.2			-20139.4		21330.54		-39,5363	-1152.88			-20417.4		21409.52	-	-15383.0	15985.27	i		9692.775	-8729.49			-45, 9359 14, 94984 172, 8116
_	VERT.	-179.5 -197.705 -22654.8			-358.4 -444.168 23061.60		-68 -20967.2 8471.31		118.48 20209.94 -10963.9	44.2 15816 37 16264.33	-136.4 -15708.2 -16495.2			152.7 10394,23 -20138.		-21.2 -8273.57 21330.54		-90,1 -22452,6 -39,5363	92.9 22758.31 -1152.88			-155.1 -9477.47 -20417.4		19.45 7560.138 21408.52		131.4 16267.13 -15383.0	-45,3 -16153,5 15985,2)			64,7 20505,22 9692,775	-112.6 -20971.7 -8729.49			.45, 9359
14-514-11	GLOB.ANS	-176.5			-358.4		99		118.48	44.2	-13b.4			152.7		-21.2		-40.1	92.9			-155.1		19.45		131.4	-13.3			64.7	-112.6			•
WUADRUPOLE # 2(4-F)		22655.7			23070.6		22613.9		22992.4	22686.7	22778.1			22662.7		22678.9		22652.7	22787.5			22509,9		22704.2		22388.B	22725.9			22680.7	22716.1			22719.05
	DEL MXY SEG. NO.	301169			301185		302186		302170	303163	303179			304172		304188		305189	305181			306174		304190		307191	307183			308168	308184			U. UOBZ15 187. 3452 160. 1330 22719, 05
	DEL MXY	-179.5 149.0531	179.2 -77.9468	176.4 -164.346	178.4 -265.846	135.8 233, 1531	134.5 190.8531	133.3 -42.0468	40.98 -187.646	89.2 118.0531	26.65312	68.5 -21.046B	94.3 -237.146	40.2 142,0531	81.95312	46.3 -74.1468	47.4 -306.446	-0.1 152.0531	2.9 17.25312	-1.3 -131.746	-1.75 -420,346	-42.6 294.8531	-44.1 182.7531	48.05 100.5531	-41.1 -214,246	-91.6 415.9531	-90.3 7B.B5312	-B4 14.75312	-86 -43.3468	137.8 124.0531	-135.1 88.65312	-134.5 42,35312	-134.5 -267.546	187.3452
	THIANY	-179.5	179.2	176.4	-178.4	135.8	134.5	133.3	140.98	69.2	9.89	68.3	94.3	40.2	46.5	46.3	₹.4	÷	5.4		١	-	-+:	-48.05	7	-41.6	-90.3	<b>\$</b>	-97	-137.8	-135.1	-134.5	-134.5	U. UOB215
UÚ¢	7	1.6/1	-271.1	386.8	1100.7	-106.9	-126.1	8.4.8	-48.4	4.04	-69.1	-229.8	107.2	309.3	96.1	-155.4	-1144.3	164.8		-915.3	-1213.3	73	-146.6	-186.3	-770.3	-113,B	-18.1	-63.6	102.8	142,5	71.6	-55.5	-078.9	
SERIES	HAY.	22055.7	22882./	22969.1	23670.6	22571.6	22613.9	22846.6	22992.4	22686.7	22778.1	22625. a	23041.9	22662.7	22722.8	22878.9	23111.2	22652.7	22787.5	22936.5	23225.1	22509.9	7297	22704.2	23019	2238B.8	22725.9	22790	22848.1	2,7680.7	22716.1	22762.4	23072.3	22804.75
SESTENIS	TEN NO.	201169	2011/	301161	301185	302178	302186	302162	302170	303163	303179	303171	303187	304172	304164	304188	304180	305189	305191	305173	305165	306174	306182	306190	306166	307191	307183	307175	307167	306169	308184	308176	308192	AVERAGE

1.1

4.0

SEGMENTS	SER!ES=	300				<u>ODADRUPOL</u>	E # 6(3-F	1			QUADRUPO	E # 8(1-F	:)	
LTEN NO.	MIY	HI	THTAXY	DEL MIY	SE6. NO.	MXY	BLOD. AND	VERT.	HORIZ.	SEG. NO.	MXY	GLOB, ANG	VERT.	HORIZ.
301209	22933	-140	-178.9	-256.781	301209	22933	-178.9	-440.254	-22928.7					
301193	22707	416	-178.5	-230.781						301193	22907	-359.5	599.6353	22899.15
301217	22533	20	-179.6	143.2187			•			301217	22533	-179.6	-157.308	-22532.4
301129	22936	354	-178.8	-259.781	301129	22936	-358.8	-480.335	22930.94					
302146	22456	147	136.9	20.21875						302146	22656	114.4	20632.44	-9359.29
302138	22600	-393	137,7	76.21975	30213B	22600	-64.8	-20449.0	9622.611					
302210	22793	96	134.9	-116.781						302210	22793	-67.6	-21073.1	8685,737
302130	22951	80	135.R	-274.781	302130	22951	113.3	21079.26	-9078.15					
303219	22692	693	90.7	-15.7812	303219	22692	45.7	16240.49	15848.43					
202128	22469	469		207.2187	303139	22469	-136.8	-15381.0	-16379.1					
303211	22722	-65		-45.7812						303211	22722		15954.32	
303131	22417	-17		259.2187						303131	22417	-133.7	-16206.7	-15487.5
304148	22519	195		157.2187	304148	22519	157.2	8726.463	-20759.4					
304132	22581	-19B	45.5	95.21875						304132	225B1	-22	-B45B. 99	20936.73
304140	22629	-116	44.6	47.21675	304140	22629	-22.9	-8805.48	20845.50					
304204	22955	-244	44.6	-278. 781						304204	22955	157.3	6858.473	-21176.B
305221	22554	41	-0.5	122.2107	305221	22554	-90.5	-22553.1	-196.818					
305197	22504	-101	-0.7	172.2187	305197	22504	89.3	22502.32	274.9313					
305205	22590	60	-0.2	86.21875						305205	22590	-90.2	-22589.8	-70.0530
305213	22669	-327	-0.3	7.21875						305213	22669	89.7	22568.68	118.6940
308222	22597	-140	-45.1	79.21875	20755	22597	-157.6	-8411.04	-20891.9					
30615B	22430	-195	-43.4	46.21875						30515B	22630	-155.9	-9240.51	-20657.4
306142	226B7	162	-44.2	-10.7812	306142	22687	23.3	8973.740	20836.79					
306150	22747	-246	+44. i	-70.7812						306150	22747	23.4	9033.923	26876.16
307215	22763	534	-83.4	-86.7812	307215	22763	136.6	15640.17	-16539.0					
307151	22722	317	-90.7	-45.7812	307;51	22722	-45.7	-16261.9	15869.39					
307223	22764	-612	-91.6	-87.7812						307223	22764	133.9	16402.62	-15784.5
307175	22833	-138	-91.4	-156.781						307135	22833	-46.4	-14535.0	15746.08
308216	22545	22	-135.4	131.2197	308216	22545	67.1	20748.12	8772.799					
308200	22535	-104	-134,5	141.2197	308200	22535	-112	-20894.0	-8441,75					
308160	22577	109	-134.9	99.21875						30B140	22577	67.6	20373,47	8603.425
30B224	22629	57	-135.7	47.21875						308224	22629	-113.2	-20791 1	-8914.51
AVERAGE	22676.21		0.006454	146.3659	154.2208	22664.75		3.380111	-13.3558	137.1088	22687.68		-2.32187	3.320605

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BROBECK CORPORATIO

The assignment of segments for the dipoles are shown in Tables 10 through 14. The process for selection is similar to that explained for quadrupoles except that any segment can be used in only one position, but in any dipole. Thus, the allowable trade-offs are from dipole-to-dipole. Because the segments were received in batches sufficient for assembly of only a few dipoles, the extent of the trade-offs was limited. As was the case with the quadrupoles, segments with large deviation were eliminated early on and a batch of 32 segments were sorted into two dipoles each with about the same total magnetic moment.

karatangan digarah di paraman di paraman karatangan karatan karatan karatan karatan karatan karatan karatan ka

	HOR 17.		-15598.4	-11249.0		219, 3737		10782.13			1.1 295.5830 15394.16		10748.49		91.7 15278. 27 -451 449		-10851.7		-15249 4	0.4050	-11447.4		-698.907		-48.9 -11773.6 10270.83		15091.69		10907.94		300, 1520	-10837.6		86,07121 -167,159
	VERT.	:	179.2 217.8100 -15598.	-135.8 -10939.2 -11249.0		-69.2 -15710,4 219,3737		-45.7 -11048.8 10782.13			295, 5830		45.2 10823.79 10748.49		15278.27		133.9 11276.42 -10851.7		179. 6 106. 5549 -15262 A		-137.8 -10375.3 -11442.4		-92.4 -15391.1 -698.907		-11773.6		1,9 500,6431 15091,69		45.4 11041.37 10907.94		68.9 15632.11 300,1520	33.4 11455.17 -10832.6		86.07121
. B2( )	GLOB, ANG		179.2	-135.8		-89.2		-45.7			-:		45.7	!	91.7	•	133.9		179.6	:	-137.8		-92.6	•	4		1.9		45.4		68.9	133.4		
DIPOLE #			15600	15691		15712	!	15438			15397		15254		15285		15650		15243		15446		15407		15524		15100		15535		15635	15766		15487.68
	SEB. HO.		401233	402250		403251		404252			405253	•	406239		467239		408256		409257		1410258		411243		412260		413245		414262		415247	416248		-37.1775 -169.572 188.0839 15487.48
	HORIZ.	-15636.6			-11797.4		-790,362		10849.88	15415.84		10674.01		80.14689		-10463.3		-15411.5		-10757.4		-383.634		10522.91		15427.62		11016.86		-440.547			-11119.7	-169.572
	VERT.	-179.4 -109.165 -15636.6			-137.9 -10659.7 -11797.		-92.9 -15401.9 -790.362		-45.7 -11118.2 10849.88	0.7 188.3495 15415.84		45.3 10785,38 10674.01		89.7 15306.79 80.14689		132, 9 11259, 91 -10463, 3		182,5 -672,872 -15411.5		-134.9 -10795,0 -10757.		-91.4 -15697.3 -383.634		-46.1 -11039.B 10622.91		0.4 107.7068 15427.42		44.5 10826.24 11016.86	•	91.6 157784 -440.547			135.7 10851.27 -11119.7	-37.175
~ >19	61.08. ANG	-179.4			-137.9		-92.9		-45.7	0.7		45, 3		89.7		132.9		162.5		-134.9		\$.16-		-46.1		0.4		#.5		91.6			135.7	
DIPOLE # 610	Y.	Ν.			15900		15622		15535	15417		15175		15307		15371		15426		15240		15702		15320		15428		15446		15778			15537	15490.06
		401249			402234		403235		404236	405237		406254		407255		408240		192609		410242		<b>+11259</b>		412244		413261		414246		415263			416264	0.012285 190.2949 192.4732 15490.06
	DEL MAY SEG. NO	-179.6 -148.125	-111.125	-202, 125	-411.125	-223, 125	-133,125	50.875	-46.125	71.875	91.875	313.875	234.875	181.875	203.875	117.875	-161.125	62.875	225.875	248.875	42.875	-213, 125	81.875	168.875	-135.125	60.875	388.875	42,875	-46,125	-289.125	-133.9 -146.125	-155.9 -277.125	-48, 125	190.2949
	THIAIY	-179.4	179.2	158.3	160.4	134.2		113.2	113.2	89.3	88.9	67.2	67.3	45.3	43.3	24.6	23.6	-2.5	÷.	-22.4	-19.7	-43.6	-42.4	-66.4	-63.6	-90.4	-91.9	-112.0	-112.9	-136.6	-133.9	-155.9	-158.2	0.012285
004	74	56	2	236	-210	233	496	383	-743	-95	-2B	<u> </u>	115	ž	-313	832	-1202	28	-45	695	1161	8901	1296	79	801	ė	=	<b>₽</b>	-183	-B1	517	211		_
SEA1E5*	μχ	15437	15400	15691	15900	15712	15622	15438	15535	15417	15397	15175	15254	15307	15285	15371	15650	15426	15263	15240	15446	15702	15407	15330	15624	15428	12100	15446	15535	1577B	15635	15766	15537	15488.87
SEBRENTS	ITEN NO.	401249	401233	402250	402234	403251	403235	404252	104236	<b>405237</b>	405253	406254	406238	407255	407239	408240	408256	409241	409257	410242	410258	411259	411243	412244	412260	413261	413245	414246	414262	415263	415247	416248	•	AVERAGE

	HDR.C.2.		-15703.3	-10965.6		-487,463		11379.57			15593, 44		10990.73		-597, 055		-11479.5		-15209.1		-11090.9		-575, 306		10995,34		15171.90		11586.19		-191, 293	-11136.7		-94.6474
	VERT.		75.1 1346,256 -15703.3	-135 -10945.8 -10945.e		-91.8 -15511.3 -487.463		-43.1 -10448.B 11379.57			-3.2 -871,820 15593, A4		44.4 10762.92 10990.73		92, 7 15411, 63 -592, 055		137.8 10468.98 -11479.5		178.9 292.0314 -15209.1		-137 -10342.5 -11090.9		-92,1 -15689,4 -575,306		-45.1 -11073.8 10995.34		-5.5 -1480.14 (517).90		40.8 10359.24 11586.19		90.7 15656.83 -191.293	136.2 10629.76 -11136.7		-101.627 -94.6474
	GLOB. ANG		175.1	-135		-91.B	!	-43.1			-1.2	) :	44.4	•	92.7	•	137.8	:	178.9		-137	•	-92.1	•	-45,1		(*)	:	41.6		1.06	136.2		
DIPOLE # 84(	MIY		15761	15508		15519		15585			15613		15383		15423	!	15496		15212		15165		15700		15577		15443	!	13542		15658	15430		15501.25
	SE6. NG.		401281	402282		403283		404268			407 BS	!	406286		407287		408288		469289		410274		411275		412276		413293		41427E		415295	416280		-94.3729 -89.2678 155.1771 15501.25
	HORIZ.	-15664.4			-11077.7		-824.081		11391.99	15372.99		10909,26		-989.086		-10895, 1		-15239.1		-133.3 -11230.2 -10582.B		80.18355		10718.60		15355.62		10861.28		-217.419			-10528.3	-89.2678
	VERT.	-179.5 -136.701 -15664.			-133.8 -11551.7 -11077.7		-93 -15724.4 -824.08		-43.1 -10660.4 11391,99	-3.2 -859.483 15372.99		44.9 10771.60 10809.26		93.7 15295.05 -989.086		135.3 10781.63 -10895.1		180.9 -239,395 -15239.		-11230.2		-89.7 -15313.7 80.18355		-46.1 -11138.2 10718.60		0.4 107,2042 15355.62		45.5 11052.52 10861.28		90.8 15570,48 -217,419			131.9 11734.07 -10528.3	-94.3729
~	GLDE, ANG	-179.5			-133.8		-93		-43.1	-3.2		÷.9		93.7		135.3		180.9		-133.3		-B9.7		1.94-		0.4		45.5		90.B			131.9	
DIFULE # B34	HXY	15665			16005		15746		15602	15397		15260		15327		15328		15241		15431		15314		15450		15356		15496		15572			15765	15497.48
-	SEG. NO.	101265			402266		403267		404284	405269		406270		407271		408272		409273		410290		411291		412292		413277		414294		415279			416296	0.011800 132.9062 206.9374 15497.68
	DEL MIY SEG, NO.	-179.5 -165.531	-261,531	-8.53125	156.3 -505.531	136.8 -19.5312	13B.0 -246, 531	110.6 -85.5312	-102, 531	93.2 102.4687	-118.531	239.46B7	116.4687	172,4697	76.46875	171.4687	3,46875		287.4687	68.46875	334.4687	185.4687	-42.9 -200.531	41.46875	-67.4 -77.5312	-90.4 [43.4687	56.46875	3.46875	-109.3 -42.5312	-135.8 -72.5312	-135.7 -158.531	69.46875	-154.4 - 265.531	132.9062
	THIAIY	-179.5	175.1	157.5	156.3	136.8	138.0	110.6	9.011	93.2	93.2	67.6	.69	₩	42.8	22.2	19.7	6.0-	Ξ	-24.2	-20.5 3	-45.3	-42.9	-66.4	-67.4	-90-	-84.5	-113.0	-109.3	-135.8	-135.7	-158.	-15.4	0.011800
90	74	2	14	<b>÷</b>	-114	961	795	E02	-256	109	-583	-382	•	108	-1329	1313	961	₽	127	1035	-63	-79	-1176	¥	-1129	-143	-112	<del>-</del>	-483	753	255	<del>?</del>	669	
SERIES-	HKY	15665	15761	15508	14005	15519	15744	15585	15402	15397	15618	15260	15383	15327	15423	15328	15496	15241	15212	15431	15165	15314	15700	15458	15577	15356	15443	15496	15542	15572	15658	15430	15765	15499.46
SEPTEMIS	11Eh XD.	401265	401281	402282	402256	403283	403267	404268	404284	405269	405285	406270	406286	407271	407287	408272	408288	409273	409289	110290	<b>+10274</b>	411291	411275	112252	412276	113277	413293	414294	414278	415279	415295			AVERAGE

THE RESERVE OF THE STATE OF THE

	HORIZ.		864.3	870.8		1.830		4.222			51.17		94.22		73144		0.604		1.36.1		015.3		5.086		65.66		53.72		40.23		BC90	714.5	:	5.944
	2		÷	유		-79		666			153		Ξ	•	3,5	į	3.	:	-	:	7	:	7	:	105		155	ļ	Š		74	7	•	7
	VERT.		-179.5 -138.446 -15864.3	-133.3 -11482.7 -10820.B		-92.9 -15630.9 -791.830		-49,9 -11868,5 9994,222			-1.1 -294.757 15351.17		43.2 10513.95 11194.22		89.9 15315.97 24.73144		133.9 11024.43 -10609.0		181.1 -296.389 -15436.1		-135.8 -10711.9 -11015.3		-90.5 -15479.4 -135.086		-46.3 -11056.3 10565.66		3.8 1033.077 15553.72		66.6 11251.73 10840.23		89.4 15659.14 164.0928	35.3 11196-63 -11114-5		-59.6624 -155.944
1 78	GLUB. ANG		-179.5	-133.3		-92.9		6.64-			-1.1		43.2		6.6		133.9		181.1		-135.8		-90.5		-46.3		, F	:	46.6		89.4	135		
DIPOLE # 96(	***		15865	15778		15951		15516			15354		15359		15316		15300		15439	•	15345		15480		15293		15588		15486		15470	15918		15523.62
	SEG. NO.		401313	402314		403315		404300			405301		405318		407319		408304		409305		410322		411323		412308		4:3325		414310		415311	416328		196.2854
		-15665			-12064.1		771.0447		10145.02	15344.97		10897.73		-677,016		-10743.0		-15172.7		-10855.0		491, 4495		10468.46		15540.07		10940, 35		-381.874			-11545.0	-43.6131 -162.177 196.2854 15523.62
	VERT.	5, 36-15			-139.1 -10450.3 -12064.1		-87.2 -15765.1 771.0447		-49.5 -11878.3 10145.02	-0.1 -26.7820 15344.97		45.5 11089.41 10897.73		92.5 15506.22 -677.016		135 10743.07 -10743.0		178 529.8441 -15172.7		-135.2 -10779.4 -10855.0		-88.5 -15330,7 491,4495		-46.6 -11070.0 10468.44		-2.9 -787.226 15540.07		45 10940.35 10940.35		91.4 15625.33 -381.874			136.5 10955.85 -11545.0	-43.6131
55.	á	180			-139.1		-87.2		-49.5	-0.1		45.5		92.5		135		178		-135.2		-88.5		-46.6		-2.9		ŧ.		91.4			136.5	
DIPOLE # 551	AX.	15645			12961		15784		15621	15345		15548		15521		15193		15182		15298		15336		15236		15560		15472		15630			15916	15516.75
	SEB. ND.	401297			402258		403299		404316	405317		406302		407303		40B320		609321		410304		411307		412324		413309		414326		415327			416312	235,1107
	DEL MY SES. ND.	160.0 -144.812	-179.5 -344.812	218.76%- H.CCI	-440.812	137.9 -130.812	132.2 -263.812	4.1375	117.0 -100.812	50.1 175,1875	91.1 166.1875	67.0 -27.8125	69.3 161.1875	-0.8125					81.1875	222, 1875					227.1875	-39.8125	-93.8 -67.8125	48, 1875	34, 1875	-136.4 -109.812	-134.4 -149.912	-157.8 -397.812	-159.0 -395.812	0.013955 216.5971 235,1107 15516.75
	THIRIY	0.08	-179.5	H.CCI	161.6	137.9	132.2	17.4	117.0	50.1	91,1	67.0	69.3	42.5	45.1	22.5	23.6	2.0	-1:1	-22,3	-21.7	-46.5	-44.5	-65.9	-64.2	-87.1	-93.8	-112.5	-114.1	-136.4	-134.4	-157.8	-159.0	0.013955
400	711	Ş	7 ;	97/	557	-36	-818	-345	-667	22	-8€	12	20B	11.75	-284	1+3	-665	-120	-167	-263	145	-360	-893	-67	-431	-75	365	55	-36	194	165	-142	-1247	
SER1ES=	MIY	13065	15865	P//CI	12961	12921	15784	15516	15521	15345	15354	15548	15359	15521	15316	15193	15300	15182	15439	15298	15365	15336	15480	15236	15293	15560	15588	15472	15486	15630	15670	15918	15916	15520. 18
SEGMENTS	ITEM NO.	401247	401313	402314	40279B	403315	403299	464330	404316	405317	405301	406302	405318	407303	407319	408320	408204	409321	409305	410106	410322	411307	411323	412324	412308	413309	(13325	414326	414310	415327	415311	416328	416312	AVERABE

	HORIZ.		-15714.7	-11993 9		54.39831		11159.48			15158 91		10971 TR		31-31 & 30151	77.7	-10846.4		a 45278 B	77710.0	-11120 7		BD. 43487		10578 95		15173, 45		11032.18		A 46-15	-11417.9		-45,9924 -107,456
	VERT.		-179,7 -62,2831 -15714.7	-138.7 -10536.9 -11993.9		-89.8 -15583.9 54.39831		-43.6 -10627.0 11159.48			-3.7 -993.216 15358.91		84.3 10895.05 10971.3B		15,105		134.1 11192.71 -10846.4		184 T - 1149 R2 - 1527R B	70.07	-135 A -10812 4 -11100 7		-89.7 -15361.7 BD. 43487		PP 81201 8 12901- AL-		1 248, 3487 15173, 45		44. 4 10842. AR 11032.1B		45,000	(36,2 10945,55 -11413,9		-45, 9924
1 )88	GL CB. ANG		-179.7	-138.7		-89.8		-43.6			-3.7	•	24.3	•	6	2	134.1		184		A 25 4		-89.7	i	97-	!	-	•	11.1	•	â	136.2		
DIPOLE # 88(	Ä		15715	15965		15584		15410	•		15391	<u>;</u>	15467		15,495		15384		5333	777.	15317		15362		15229		15374		15497	•	15020	12814		15528
	SEG. NO.		401329	402330	-	403331		404332			405349		406334		407351		408338		409353		410354		411355		417356		413357		414358		415159	416360	, ,	200,4192
		-16043.2			-11197.9		191.5992		11477,89	15443.37		10978.97		188.0562		-10705.A		-15499.8		-10759.4		-674.224		10011.24		15532,00		10879.59		-433,204			-11281.5	-26.8527 -118.268 200,4192
	VERT.	-178 -560.241 -16043.2			-135.3 -11081.2 -11197.9		-89.3 -15681.8 191.5992		-42.7 -10591,4 11477,89	4.1 1105.994 15443.37		43.7 10491.74 10978.97		89, 3 15391, 85 188, 0562		134.2 11008.87 -10705.A		179.3 189.3757 -15499.8		-134,4 -10987,1 -10759,4		-92.5 -15442.2 -674.224		-49.5 -11721.6 10011.24		1.3 352.4704 15532.00		45.1 10917.64 10879.59		91.6 15508.95 -433.20			135.6 10668.40 -11281.5	-26.8527
87( )	GLOB. ANG	-178			-135.3		-89.3		-42.7	₹		43.7		89.3		134.2		179.3		-134.4		-92.5		-49.5		1.3		45.1		91.6			136.6	
-		16053			15754		15683		15618	15483		15186		15393		15356		15501		15378		15457		15415		15536		15413		15515			15527	15516.75
	SEG. NO.	401345			402346		403347		404348	405333		406350		407335		408352		409337		410338		411339		412340		413341		414342		415343			416344	190.0817 15516.75
	DEL KIY SEG. NO.	-530.625	-192.625	-442.625	-231.625	-61.625	-160.625	112,375	-95.625	39.375	131,375	336.375	60.375	129.375	127.375	166.375	-63.625	21.375	200,375	144.375	10, 375	65.575	160.375	107.375				109.375			-305.625		-4.625	195, 3998
	THIAIY	-178.0	-179.7		157.8	134.8	134.5		110.2	85.9	43.7	8.89	67.7	45.7	45.0	23.3	23.4	0.7	7.7	-23.1	-21.7	-42.5	-45.3	-63.0	-66.5	-91.3	-41.0	-112.6	-111.9	-136.6	-135.0		-159.1	0.012588
00	¥	<b>9</b> €	-41	725	194	-22	-315	ķ	-224	-15	-117	ij	ç	-102	ž	127	-1042	S.	9	198	149	-246	-1129	797	-122	-284	-114	-139	-,	22	-945	113	ę,	
35	_	_	_	_	15754	15584	15683	15410	12618	15483	15381	15186	15462	15393	15395	15356	15584	15501	15322	15379	15512	15457	15362	15415	15229	15536	15376	15413	15497	15515	15828	15814	15527	15522.37
SEGNENTS	LTEM NO.	401345	401329	402330	402346	403331	403347	404332	404348	405333	405349	406350	406334	407335	407351	408352	408336	409337	409353	410338	410354	411339	411355	412340	412356	413341	413357	414342	414358	415343	415359	416360	416344	AVERABE

# TABLE 14

SESMENTS	927 185±	400				DIFOLE à	301 1		
ITEM NO.	317	#277 #2	THEAXY	NET MYV	SES. NO.		97( ) JLD8.ANS	VERT.	92311.
401361	15873	-236		-345.875	40:36:			83,11045	
4013450		706		-525. 875	701301	12012	61717	02:114-7	-133/44/
4023300		725		-437.875					
402362		-157		-259.875	402362	15787	-171 S	-11260.0	_11005 1
4033310		-22		-56.875	402-302	19,41	-124.3	-11200.0	-11403.1
403363		237		-185, 875	403363	15713	_01	-15703.4	_C (G T7C
4043320		-5		117.125	100000	13,13	-74	-12/03.7	-040.073
404354		37		- 29.125	404364	15498	-47 7	-10510.1	11T00 7A
405365		38	97.6		405365			-2033.57	
4053490	15376	-117	93.7		TVJJDJ	17310	-7+0	-5022-71	13240.73
106356	15477	327	59.6		406366	15477	42 0	10535.51	11777 61
4063500	15186	-33			100000	\$4TFF	744 î	10004401	1.3-1.30
407367	15518	870	43.8		407367	15518	91.7	15514.59	_172. 094
4073510	15395	584	45.0		707301	17012	71.4	14417047	-9641704
408368	15283	-15	71.4		408368	15283	171	10597.26	-11017 1
4083520	15356	721	23.3		***************************************	12542	130.1	1471110	TiaVitai
409369	15458	-315	3.0		409359	1545B	177	309.0092	_15471 0
1093530	15322	-40	-4.3		TVIJGI	13100	4,,,	207.0072	137.0.0
410370	:5513	253	-21.7		410370	15513	-135.8	-10815.1	-11171 4
4103540	15512	:49	-21.7		150417	19019	10410	140101	******
§11371	15273	487	-43.5		41:371	15273	-91 5	-15267.7	_100 300
4113550	15362	-1129	-45.3	185.125	121011	19214	7110	1340711	1177.000
412372	15458	-351	-71.4	69.125	412372	15458	-41.1	-10161.7	11449.59
4123E40	15229	-122		298.125		14.00	****		110-0150
413373	15457	167	-94.0	70.125	4!3373	15457	4	1078.225	15410.71
4123570	15276	-114		151.125			•		
414374	15498	-115	-110.7	-	414374	15498	43.2	10409.11	11097.55
4143580	15197	-77	-111.9					••••••	
415375	15779	-1123		-251.875	415375	:5779	87	15757.37	825, 3093
1153590	15828	-945		-300,375		••••	٠.		
4163440	15527	59	-159.1	9.125					
415376	15914	-204	-158.1	-386.ā75	115376	15914	135.8	11154.44	-11770.1
AVERAGE	15527.12	i	0.014130	217,4025	191.3093	15554.68		22.92794 (	
								-	- '

## MAGNETIC MEASUREMENT ON ASSEMBLIES

The dipole and quadrupole assemblies were measured at LBL. The data on the quadrupoles is summarized in Table 15. The values of R leff shown in the table should be compared to the design objective of 1.362 for the long quadrupoles and 0.681 for the short quadrupoles. All of the units show a slight offset of the SC axis. This offset translates to a superimposed dipole. Taking into account the direction and magnitude of this offset for each quadrupole, it was possible to arrange the distribution of quadrupoles to minimize the beam deflection due to this very small offset.

The data for the dipoles is summarized in Table 16. The values 8 leff should be compared with the design objective of 100996 (.1107 x .09). The maximum angular error is about 1 degree. The quadrupole content is small but the sextupole content is perhaps higher than desired. To minimize the influence of the sextupole content, the dipoles were arranged to distribute this component along the beam axis.

TABLE 15. QUADRUPOLE ASSEMBLIES MEASUREMENTS SUMMARIZATION

- 4									
•	DATASET	QUAD ID	ORIENT	SC AXIS	SC AXIS	B'Leff	QUAD ANGLE	ALPHA D	BLeff
				(mm)	(des)	(Tesla)		(des)	( g <sub>1</sub> T-N <sub>3</sub> )
	110600	ab	Hore	0.16	98.3	1.379	4.4	0.125	0.221
	1106C1	8D	Norm	0.16	97.9	1.379	4.4		
•	1106C2	8D	Rev	0.17	-111,9	1.379	-175.1		
-	1106C3	81	Rev	0.17	-111.9	1.380	-175.1		
	1125A0	1 F	Morm	0.06	27.2	1.387	5.3	0.100	0.083
	1125A1	1F	Norm	0.06	28.0	1.386	5.5		0.083
	1125A2	1 <b>F</b>	Rev	0.04	-147.6	1.388	-174.9		0.056
•	1125A3	1 F	Rev	0.04	-148.0	1.388	-175.0		0.056
	1106C8	20	Rev	0.09	-106.5	1.374	-176.0	-0.375	0.124
	110609	2D	Rev	0.09	-107.0	1.375	-176.0		
	110400	2B	Norm	0.10	67.7	1.376	5.5		
	1106D1	20	Norm	0.10	66.4	1.377	5.4		
	1106D2	3F	Norm	0.05	70.2	1.381	5.3	-0.250	0.069
	11061/3	3F	Rev	0.06	-174.7	1.386	-175.7		
	110880	4F	Могъ	0.20	43.2	1.388	5.7	-0.150	0.278
	1108B1	4F	Norm	0.19	42.8	1.388	5.6		0.264
	1108B2	4F	Rev	0.18	-35.1	1.389	-174.9		0.250
٦(	1108R3	4F	Rev	0.18	-35.0	1.390	-174.9		0.250
	110800	5F	Nora	0.01	153.8	1.398	5.7	-0.525	0.014
	110801	5F	Norm	0.01	168.0	1.397	5.7		0.014
	110802	SF	Rev	0.04	-178.8	1.399	-176.4		0.056
	11081/3	5F	Rev	0.03	174.8	1.398	-176.4		0,042
	112500	6 D	Norm	0.07	21.9	1.400	5.0	0.200	0.078
	112501	6D	Norm	0.07	22.0	1.400	5.0		0.09B
	112502	6 D	Rev	0.04	-141.3	1,402	-174.2		0.056
	112503	4D	Rev	0.04	-141.4	1.402	-174.2		0.056
D	1125R0	70	40 tm	0.11	95.5	1.400	4.8	0.413	0.154
	1125B1	71)	dorm	0.10	85.8	1.400	4.8		0.140
	1125B2	7 D	Rev	0.13	-123.0	1.400	-173.0		0.182
	112583	7 D	Rev	0.13	-123.8	1.401	-174.4		0.182
	1125D0	81	Norm	0.15	0.03	1.383	5.1	0.100	0.207
	1125D1	81)	Horm	0.15	79.7	1.383	5.1		0.207
	1125D2	8D	Rev	0.16	-115.6	1.384	-174.5		0.221
	1125D3	ПЗ	Rev	0.16	-115.2	1.383	-174.5		0.221
_	1106E4	<b>S1</b>	Могы	0.16	-64.4	0.696	4.6	0.300	0.111
	1106E5	51	Rev	0.10	98.1	0.696	-174.2	V.5VV	V + 2 4 4
4								_	
•	1106E6	S2	Noth	0.09	164.9	0.694	5.7	-0.025	0.062
	1106E7	<b>S</b> 2	Rev	0.14	-173.9	0.694	-174.4		

TABLE 16. BROBECK PERMANENT MAGNET DIPOLES 22 November 1985

<u>s/n</u>	8 leff (T-m)	B (T)	Dipole Dev. (degree)	Quad. Relative	Sextupole Relative
B1	0.01030	0.1120	-0,43	0.5	4.8
B2	0.01027	0.1117	-1.14	2.0	4.5
B3	0.01028	0.1117	+1.00	2.7	4.0
B <b>4</b>	0.01028	0.1115	+0.01	2.2	6.0
<b>B5</b>	0.01032	0.1119	-0.74	1.2	5.0
86	0.01033	0.1124	-0.93	1.0	4.1
B7	0.01034	0.1123	-0.32	2.4	4.5
B8	0.01030	0.1117	-0.46	0.6	3.4
B9	0.01035	0.1126	-1.01	1.0	2.7
81*	0.01029	0.1119	-0.96	0.5	4.8

<sup>\*</sup>Measurement redone.

## ARRANGEMENT OF ACHROMAT ELEMENTS

The dipoles and quadrupoles were arranged along the beam axis in such a way as to minimize the effects of magnetic errors.

The quadrupoles were arranged in the following order along the beam path:

The S2 and S1 quadrupoles were installed in the defocusing positions and the 8D was rotated 9D degrees in order to use it as a focusing unit. The 7D quadrupole was rotated 18D degrees to balance out its dipole content. Because the 4F quadrupole had the largest offset error, it was set aside as a spare.

The dipoles were arranged along the beam axis in the following order:

B1, B4, B8, B3, B9, B2, B6, B5

Because B7 had the highest combination of quadrupole and sextupole components, it was set aside as a spare.

The arrangement of the dipoles and quadrupoles to minimize the effects of errors in dipole, quadrupole, and sextupole content was based on a simplistic attempt to balance the dipole and quadrupole vectors. It was not rigorous, but the arrangement, in any case, needs to be documented and is, therefore, shown here.

## TESTS AT BROBECK CORPORATION

Prior to delivering the vernier and achromat to Lawrence Livermore National Laboratory (LLNL), the units were tested for vacuum leaks. In addition to leak testing, the vernier coils were operated at design current in vacuum for a short period of time. Calculations show that full current can be sustained for up to two minutes without cooling. Since heat transfer inside the vacuum chamber is difficult, operation times longer than two minutes at full current, even with the cooling water on, is not advised. At half current, operation should be limited to eight minutes.

Test on the achromat other than leak testing consisted of operating the trim coils at part load. No adverse heating occurred.

Since the polarity of permanent magnet devices is fixed and cannot be reversed by simply switching the coil leads, a polarity check using a compass and a current-carrying tensioned wire was used at the time of assembly to verify proper polarity for steering an electron beam.

## RECOMMENDATIONS FOR POWER SUPPLIES

The power supplies and expected field for the vernier coils and achromat trim coils are shown in Table 17. The trim coil current of 4.35 amp to produce a gradient of 64.3 G/cm corresponds to a 4.6% adjustment relative to the design point gradient.

## TABLE 17

## FOWER SUPFILIES AND EXHECTED FIELDS FOR BEAM DIRECTOR COMPONENTS

#### VERNIER STEERING MAGNET

### X-CJILS

CONDUCTOR LENGTH = 262 FEET COND. RESISTANCE = .356 94MS CURRENT @ 132 G = 20.83 A VOLTAGE @ 20.83A = 8.33 V

#### Y-COILS

CONDUCTOR LEMGTH = 252 FEET CCND. RESISTANCE = .246 0HMS CLRRENT @ 132 G = 17.14 A VOLTAGE @ 17.14A = 4.22 V

## POWER SUPPLY

TWO POWER SUPPLIES NEEDED

MAX. CURRENT = 25 A

MAX. VOLTAGE = B V

REGULATION = 0.01%

PREFER CURRENT REGULATION - PULSE BASIS

## ACHROMAT TRIM COILS

CONDUCTORS 18 GAGE. 56 TURNS/SLOT
CONDUCTOR LENGTH = 2400 FEET
COND. RESISTANCE = 15.0 OHMS TOTAL
CONNECTIONS ALL COILS IN SERIES
CURRENT @ 64.3 G/cm = 4.35 AMPS
MAX. CURRENT TOTAL = 4.5 AMPS
MAX. DC VOLTAGE = 67.5 V
INDUCTANCE = 6.0 m H
TIME CONSTANT = 0.40 m S

#### POWER SUPPLY

MAX. CURRENT = 6 AMPS
MAX. VOLTAGE = 100 V
REGULATION = 0.1%
PREFER CURRENT REGULATION - PULSE BASIS

## RECOMMENDED TEST PROGRAM

The beam director components require verification of their operating characteristics at high current density where space charge and ionization of residual gas may have significant influence on performance. The electron beam at ATA can provide sufficient current to permit meaningful tests to be performed. It is desired that the beam transport characteristics of the achromat and vernier steering magnet be measured over a range of beam current densities and residual gas densities.

Because a tightly focused beam at high current can produce a current density sufficiently great to cause physical damage to the components if the beam strikes the wall, it is advisable to make preliminary measurements at low current and small spot sizes. A collimator and beam scraper upstream of the components will be required to limit the beam diameter. It is also proposed that prior to testing on ATA, tests using a low current beam from the RF linac be performed to characterize the achromat and vernier steering magnet. Measured characterics for the low current tests should be compared with calculated characteristics based on the magnetic measurements and physical arrangement.

For all of these tests, it will be necessary to determine the phase space coordinates of the beam entering the component and to measure these coordinates on the beam exiting from the component. The beam leaving the component will be acted upon not only by the component but also will be acted upon by ionized residual gas and by its own space charge forces. It is desired that the component effects be separated from the ionization and

spare charge effects. Thus, the measurements on the exiting beam should be made in a vacuum to eliminate ionization effects. Careful planning of the test procedures will be necessary at each stage of the testing.

#### **ACKNOWLEDGEMENTS**

We wish to acknowledge the valuable assistance from the Magnet Measurement Group at LBL, especially the efforts of D. H. Nelson and M. I. Green, the valuable advice and encouragement of Dr. Edward P. Lee, and the support from Dr. Gene Nolting, Naval Surface Weapon Systems, White Caks Laboratory, Silver Springs, MD. Additional assistance in coordinating the design interfaces to match the requirements of ATA were received from Gil Cruz of LLNL. Assisting in the work at Brobeck Corporation was J. T. Gunn and J. E. Miller.

# APPENDIX

# ACHROMAT BEND MAGNET DRAWING LIST

Achromat	: Interface & Vacuum Test Assembly	9501781
	Vacuum Transition Flange	95C1774
	Adapter Plate	95C1775
	Bolt Ring	95C1776
	Diaphragm Plate	9 <b>5B</b> 1777
	Adapter Spool	95B1778
	Bearing	95 <b>8</b> 1779
	Alignment Bar	95B1780
	Downstream Mounting Plate	95B1782
	Spacer	95B1783
	Stud	95B1784
	Achromat Assembly	95J17 <b>4</b> 9
	Housing	95J1739
	Beam Tube	95C1752
	Quadrupole Assembly	95C1750
	Dipole Assembly	9501751
	Trim Coil Assembly	9501740
	Magnet Spacer	95B1738
	Water Manifold	95C1743
	Flange Ring	9501744
	Adjusting Sleeve	9501745
	Retaining Flange	95B1746
	Retaining Sleeve	9581747
	Barrier Ring	95B1748
	Focusing Quad	9501732
	Defocusing Quad	9501733
	Segment Carrier - Quad	9501736
	Dipole	95D1734
	Segment Carrier - Dipole	95C1737
	Manifold Fitting 1/2"	95B1741
	Manifold Fitting 1/4"	9581742

## VERNIER STEERING MAGNET DRAWING LIST

Vernier	Steering Magnet Installation	95J1728
	Coil Assembly	95E1708
	Lock Nut	95C1710
	Interface Flange	95E1714
	Downstream Mounting Plate	95E1716
	Manifold Clamp	95B1717
	Supply Manifold	9501720
	Return Manifold	9501721
	Magnet Power Input Flange	95C1723
	Magnet Cooling Input Flange	95C1724
	Water Supply Connector	95B1725
	Water Return Connector	95B1726
	Spreader	95B1727
	Magnet Power Terminal	9581729
	2-Port Exp. Tank	95D1769
	Pump-out Spool	9501771
	Tank Spool (50 cm)	9501770
	Cover (6" Port)	95C1772
	Coil Spool	95D1707
	Coil X12 X 5	95D1705
	Coil Y12 Y 5	9501706
	Cooling Coil	95C1709
	Y Coil Spacer	95C1712
	X Coil Spacer	95C1713
	Cover (12" Port)	95C1773
	Manifold Fitting 1/2"	95B1718
	Manifold Fitting 3/16"	95B1719
		2002112