3/28/78
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[redacted]
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DIRECT NUMERICAL CONTROL
AT
BENDIX KANSAS CITY DIVISION

Between early 1970 and mid-1975, the Kansas City Division of the Bendix Corporation conducted an evaluation of Direct Numerical Control (DNC) to determine if the capability offered enough potential benefit to warrant implementation for production use.

To conduct this evaluation, a four-machine prototype system was constructed using a behind-the-tape-reader interface approach. An APT Source editing capability, which was previously deemed the most beneficial of the DNC advantages, was incorporated into this prototype system in January 1974.

MASTER

In this five-year evaluation period, the four prototype machines were operated under DNC control for a total of 18,700 hours to determine the reliability of the transmission system. And during the one and one-half year availability of the APT Source editing capability on these four machines, 77 part programs were revised from portable terminals located at the machine sites.

Based upon the results obtained from utilization of this prototype system, the decision was made in mid-1975 to implement a production system at Bendix Kansas City.

We now have 16 machines interfaced to our DNC computer, 15 of which are presently operational. Future plans include connection of over 40 existing or newly-purchased continuous-path NC machines to the DNC system.

3/20/78

DIRECT NUMERICAL CONTROL (DNC) AT BENDIX KANSAS CITY DIVISION

SLIDE 1

Good Morning:

What I would like to do this morning, is cover the background information concerning how and why we at Bendix Kansas City became interested in Direct Numerical Control, what our approach was in determining whether it would prove beneficial to us, our present status of implementation, and what our future plans are.

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When I refer to DNC. I am talking about the condition where a remotely located computer is used for the control of NC machines. This computer can be located next to or many miles away from the machine tool, depending on what type of a technique is used.

Back in the latter part of 1969 and early 1970, there was a lot of publicity appearing in the magazines and trade journals about DNC. Several machine tool, machine control unit and computer manufacturers were developing their own unique approaches to DNC and were making various claims about what it could do for the user. Bendix is a large user of multi-axis continuous path NC machines ranging from 2-Axis lathes to 5-Axis machining centers. With over 40 existing and planned continuous path NC machines that could take advantage of these stated benefits, we undertook an investigation through literature searches and personal contact to determine what these benefits really were so we could see if DNC should be pursued here and if so which of the various approaches would be best for Bendix.

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This initial investigation of DNC indicated that for Bendix there did exist a potential for cost avoidance through improved machine utilization and productivity, improved product quality and improved schedule performance.

The first real advantage we found to be gained from a DNC system, was the ability to make immediate changes to the information that directs the machine tool movements (this is referred to as EDITING). Under the method used at the time of the study, if an error was found in an NC tape, it would take anywhere from 24 to 72 hours to get it corrected and a new mylar back to the shop. This meant that either the machine had to set idle until the corrected tape was returned or the fixturing had to be removed and a new set-up made for a different part. Either of these alternatives involved lost machining time. In a DNC system, the NC programmmer has at his disposal a portable CRT located at the machine tool site with which he can make changes to the APT Source data in the APT processing computer and regenerate new tape data in a short time (generally somewhere between one and two hours). Thus eliminating a considerable amount of this lost machining time.

This immediate change capability also permits the NC programmer to optimize the machine movements to eliminate inefficient moves. Because of the long turn-around time for tape changes and the possibility of generation of new errors in the process, optimization was not then done to the extent that it could be with DNC. It was estimated, by industry people using DNC systems at that time, that on an average the reduction in machine cycle time should be approximately 20% due to optimization. This optimization and editing capability both directly affect machine utilization and productivity.

It would also be possible, through the use of editing, to "fine tune" programs in areas where parts are exhibiting marginal dimensional control because of machining variables not attributable to the tape information. This would result in an improvement to part quality.

Schedule performance could be improved by the immediate incorporation of changes to product configuration through the editing feature, and it would also be possible, through the use of the computer, to gather real-time data that was not then available, in areas related to machine utilization, departmental efficiencies, and machine downtime.

This latter activity is termed a Management Information System. The data can be compiled into reports from which Management would be able to gather information to help reduce machine downtime and increase utilization.

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At the completion of our initial investigation, the advantages of DNC appeared significant enough that it was decided that a further evaluation should be performed and we set about developing a 4-machine prototype system with which to perform this study. Since a behind-the-tape-reader interface approach appeared to best meet our needs and permitted us to use either tape or computer operation at our discretion, this approach was selected. You will notice that we chose machines at varying distances from the CDC 1700 DNC computer to check for any data transmission problems, and also provided a connection between the 1700 and CDC 6600 computers to provide for the APT Source editing capability.

SLIDE 5

This is the basic equipment associated with the 1700 Computer system. As you can see, it consists of the computer mainframe, magnetic tape drives, a disk, teletype and paper tape reader and punch. We have shown the 6600 Computer dotted in this slide since it is only used when the part programmer is making source level changes and for preparation of the MIS reports. The 1700 Computer is the one that contains the active tape library, provides data to the machines and to which initial contact is made from the CRT's at the machine site during editing.

These next few slides will show you some of the equipment that comprised our prototype system.

SLIDE 6

This is the 1700 Computer mainframe itself that is located out on the factory floor.

SLIDE 7

This is the first machine that was connected to the prototype system in April, 1971. It is an Ex-Cell-O 2-Axis mill equipped with a Bridgeport head that was located approximately 200 feet from the DNC Computer and was used for machining plastics. There are only two differences the operator noticed in the basic operation of his machine with our prototype DNC system. The interface box on the side of the MCU which he used to request the loading of the tape information he wished to use and feeds the computer information regarding machine status, and

SLIDE 8

this toggle switch located in the MCU which the operator uses to select either tape or computer operation. All the other operator controls remain the same.

SLIDE 9

This is the second machine that was connected to the system in August, 1971. It is an Ex-Cell-O 3-Axis mill that is located approximately 1200 feet from the computer and used for metal machining. Notice the portable CRT that is used for editing. The interface equipment for both of these original machines was specially designed hardware purchased for our specific application.

SLIDE 10

This is the third machine that was connected to the system in December, 1973. It is an Ex-Cell-O 3-Axis mill that was located approximately 800 feet from the computer, and

SLIDE 11

this is the fourth machine that was connected to the system in January, 1974. It is an American lathe that is located approximately 400 feet from the computer.

These latter two machines used different interface equipment from the first two. In the time that lasped between procurement of the initial interfaces and appropriation for the second set, our supplier had developed a communication system using standard hardware that could be adapted to our use. Using this standard equipment offered significant savings in cabling cost, design fees and purchase prices of the interface equipment for a production DNC system, so the decision was made to change approaches.

SLIDE 12

One of our major objectives for the prototype system was to operate it as much as possible to determine its reliability by checking for transmission errors. We operated these four prototype machines for a total of 18,700 hours under DNC control without any transmission errors, which indicated that the systems' transmission hardware, cabling and technique have been proven to be extremely reliable.

During the 5-year period the prototype system was in operation, we experienced a total of 34 days of computer downtime and 14 days of interface downtime. The majority of the computer downtime was due to inadequate temperature control in a temporary computer location that was corrected when a permanent location was obtained, and all of the interface problems occurred on the original units which were all specially designed hardware.

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I showed this slide to you earlier as being the anticipated advantages we saw for DNC. Our study verified that these were in fact the advantages of DNC. We found changes were also required to correct for cutting tool problems, creation of rework tapes, making process improvements and corrections for fixture problems. These are really special cases of 1, 3 and 4, but they show some of the additional advantages of being able to make real-time changes.

Our prototype system DNC machines were not devoted exclusively to developmental activities; they were production machine tools which were required to meet production schedules. Thus when the editing capability became available in January, 1974, it immediately was put into use. We had begun our preparation earlier by training all of our part programmers in the use of the system.

The training required to provide the programmers with the knowledge required to use the editing capability consisted of four hours of formal "INTERCOM" language training, two more hours of classroom training on additional commands needed from the shop floor, plus two hours of individual instruction on the floor working with practice jobs.

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Between January 1974 and October 1975, we performed 77 editing operations from the machine site. Of these 77, 8 were mylar image type which used just the 1700 Computer; and 69 were done in APT Source using the 6600 Computer. During these changes, we saw jobs take from as little as an hour to as long as $2\frac{1}{2}$ days of shop time. This would have translated into approximately one-half day for the one hour job to a week or more for the $2\frac{1}{2}$ day job, using the existing change system, since on the $2\frac{1}{2}$ day job the programmer made nine different cycles through APT.

We found it very convenient for the part programmer to go out to the machine when there was a tape error or something that needed changing, watch the machine run and see what it was doing and then, using the portable CRT, correct it and have the machine operating again very quickly.

Also, when there is a tape with some extra time in it, the programmer can do a much more thorough job of removing all this excess time by making several changes at the machine and watching them run until he has removed all the non-productive time, than he can by watching the machine run and then going back up to his desk and trying to remember where all of the changes were required on one tape change, which is the way they had to do it without DNC.

SLIDE 15

We made 14 productive optimization changes during the editing capability evaluation. As you can see, we removed an average of about 46% of the cycle time and standard hour time on these parts which has resulted in a savings in direct production labor costs of approximately $71,000.

I would like to point out that we did not just go looking for the long running tapes to see how much time we could cut out. These jobs were taken just as they came across the production machines and you will note that even on a short job with an initial time of about 5 minutes, we were able to remove 19% of the cycle time.

Based on costs incurred during these optimizations, the average cost to Bendix for part programmer time, process engineer time and computer time to perform an optimization was $125.

SLIDE 16

I pointed out the $71,000 savings we realized from the optimizations of the 14 tape operations; had we done the same thing when these parts were first brought into production, an additional savings of $21,000 would have resulted, making a total saving from initial issue tape of $92,000.

Using the relationships we established in our evaluation and assuming instantaneous connection of 33 existing machines, there existed a potential savings of over $200,000 on the 455 active jobs scheduled on these machines and over $400,000 potential savings that would be generated yearly for the projected 440 new tapes that would be made for these machines each year.

SLIDE 17

Another benefit that is offered by the connection of a computer to the machine tools is a Management Information System (MIS) for collection of data associated with machine usage and downtime. The data can be collected both automatically and through operator inputs, and then can be used in the preparation of reports which can be analyzed to improve machine utilization.

A sample of some of the information that can be collected via operator input, is shown on this slide. As you can see, we can have him tell us what kind of operation he is running and numerous reasons for being down, and then using this data, we can get more accurate information for the improvement of both machine utilization and downtime.

Our final evaluation of hardware with the prototype system consisted of purchasing and using a mini-computer as the interface and a CRT as the operator input medium instead of the designed units. This was done in an attempt to reduce the overall system cost for a production system. This evaluation proved that a mini-computer was a viable alternative for the previous system, would reduce system costs and would add some additional capabilities and capacity to the system with its internal storage capabilities.

SLIDE 18

You saw in some of the earlier slides what our original system looked like, here is a couple of pictures of the mini-computer hook-up on a 5-Axis K & T Moduline, showing computer and operator CRT placement and the editing CRT.

SLIDE 19

We were really gratified with the acceptance of the system being displayed by the part programmers, machine operators, foremen and process engineers. This was a tool that we were offering which these people saw a use for, they are enthusiastic about and most important, they are willing to use it.

SLIDE 20

Based on the results we found during our prototype evaluation, the decision was made in the fall of 1975 to implement a production DNC system at Bendix using a behind-the-tape-reader interface approach with mini-computers as the interfaces. All existing and planned continuous path NC machines are considered as candidates for connection to this system.

We have purchased equipment for the connection of 16 machines to the system and now have 15 machines in operation with the 16th in work. This system is minus the Management Information System capability which is planned for incorporation at a later date.

Our original plans for implementation were to start with the multi-axis tool changer machines first and then work our way through the rest of the existing candidate machines, continually re-evaluating results for the determination of future expansions. We made an attempt to follow our original planning, but deviated in some areas where utilization was a determining factor. The 16 machines connected with this first set of equipment include five 5-axis mills, three 4-axis mills, six 3-axis mills and two lathes.

Since the production system was put into operation the week of November 28, 1977, the editing capability has been utilized 29 times. Included in these changes are 15 optimizations that have reduced cycle times by an average of 37% and resulted in standard hour savings of over 11,000 hours. These optimizations have already removed enough machining time to pay for over half the hardware costs for hook-up of these first 16 machines.

SLIDE 21

We presently are in the process of preparing appropriation packages to order six additional interfaces for new machines that are being purchased for specific programs and have budgeted for FY 1978 funding, enough equipment to connect an additional 20 of the in-house machines to the system.

To make sure that we have enough central computer capacity to handle these 42 machines, we have obtained from surplus, an additional CDC SC 1700 Computer and three more disk drives, so that our final computer complement will consist of two computers and four disk drives.

The FY 1978 package for 20 additional interfaces will complete the connection of all existing in-house DNC candidates, with the exception of eight older machines which are equipped with straight binary MCU's. Present planning calls for replacement of these MCU's and connection of the machines to the DNC system in FY 1982.

From now on, our present plans are to include the DNC interface equipment in the same appropriation package with new machine tools so that all new continuous path NC machine tools can be connected to the DNC system during their initial installation.

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Now let us summarize what I have discussed. When DNC became available, it appeared to offer a potential savings to Bendix Kansas City because we had 30 machines in-house and 15 more planned that were applicable to the concept. We developed a prototype system using a behind-the-tape-reader interface approach to study DNC. We found significant actual and potential savings due to the editing and management information system capabilities. Based on the information we obtained from our study, we felt like the behind-the-tape-reader interface approach we selected originally was the best for Bendix and we recommended implementation of a production DNC system. Upon approval of this recommendation we purchased equipment for an initial complement of 16 machines, 15 of which are in operation now. Present planning calls for the addition of another 26 machines to the system by the end of FY 1979 with additional machines to be added as they are purchased.

As you can see, Bendix Kansas City is prepared to invest significant capital in our DNC system, but we are not doing so blindly. We spent considerable time evaluating its benefits and we know that there is a pay-off to be gained.

DIRECT NUMERICAL CONTROL

BY
G. L. FINLAY

Bendix Kansas City Division

INITIAL INTEREST

STARTED IN 1969

VARIOUS SYSTEMS APPROACHES

INVESTIGATED FEASIBILITY
- LITERATURE SEARCHES
- PERSONAL CONTACT

ANTICIPATED ADVANTAGES OF DNC

POTENTIAL FOR COST AVOIDANCE

IMPROVED MACHINE UTILIZATION AND PRODUCTIVITY
IMPROVED PRODUCT QUALITY
IMPROVED SCHEDULE PERFORMANCE

HOW WILL DNC CONTRIBUTE TO THESE IMPROVEMENTS?

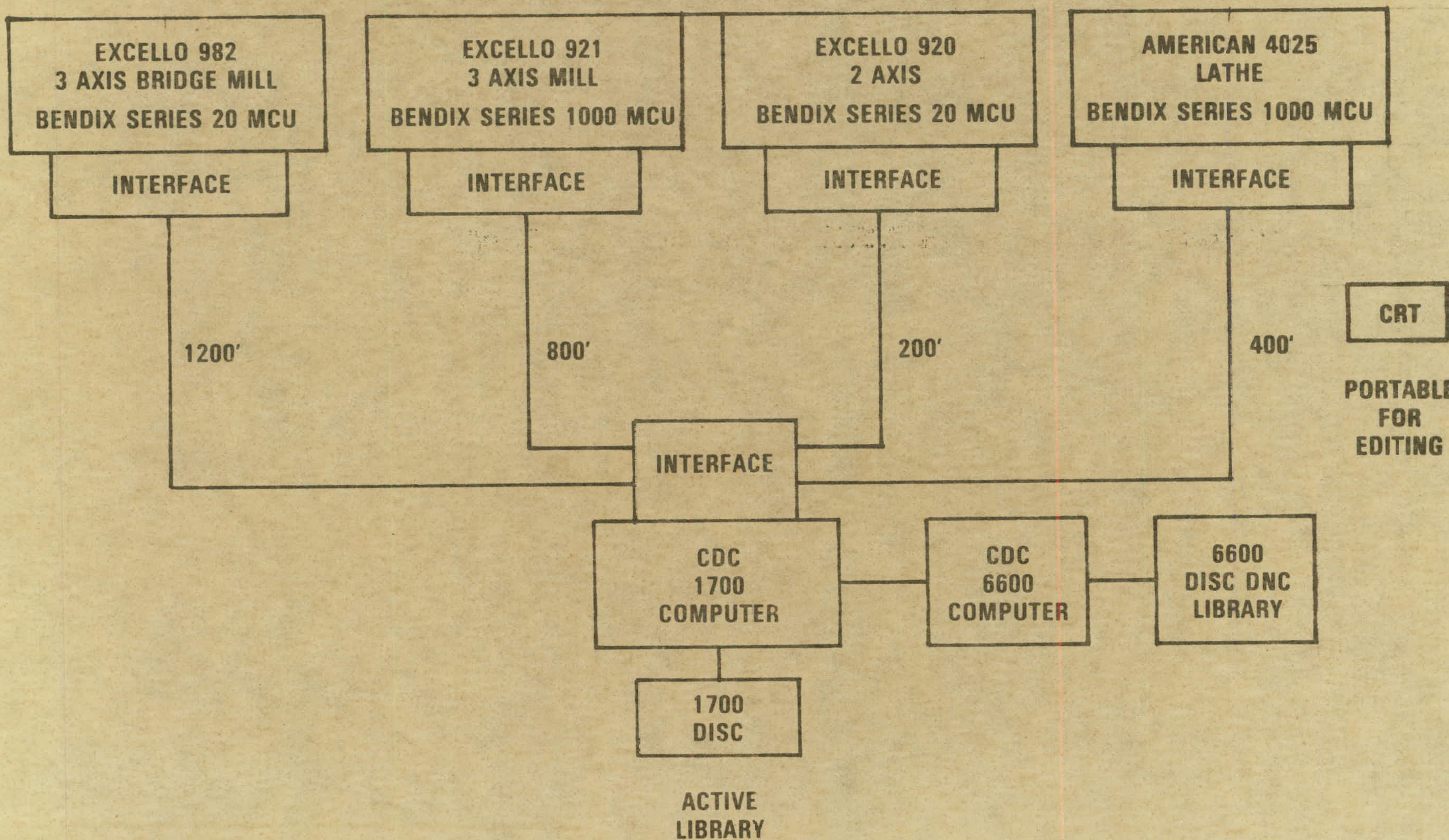
SHOP FLOOR EDITING OF NC TAPE DATA

1. IMMEDIATE CORRECTION OF ERRORS
   a. REDUCE LOST MACHINING TIME
2. OPTIMIZATION TO REDUCE MACHINE RUN TIME
3. ABILITY TO "FINE TUNE" DATA FOR AREAS OF MARGINAL DIMENSIONAL CONTROL
4. IMMEDIATE INCORPORATION OF PRODUCT DESIGN CHANGES

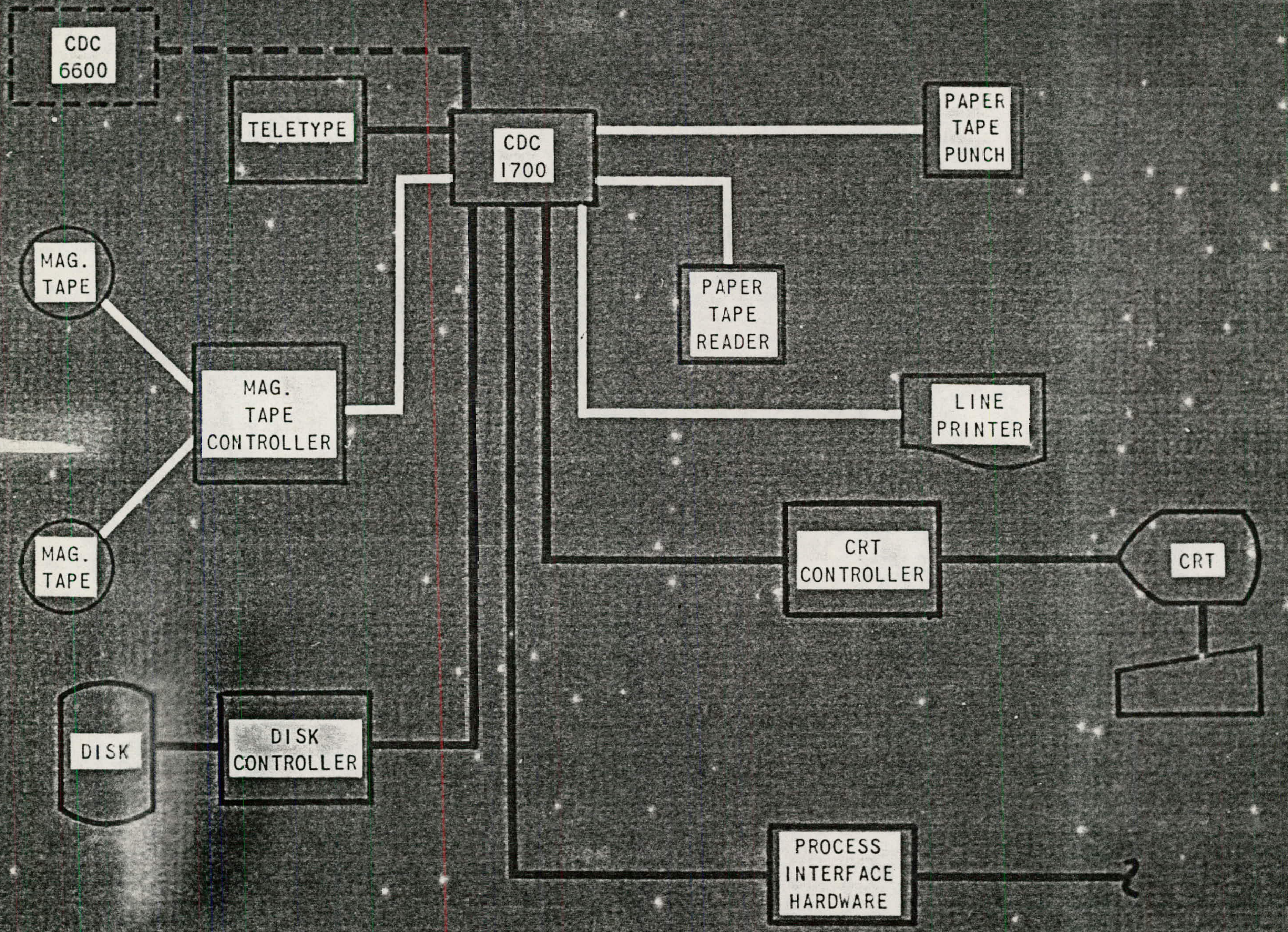
MANAGEMENT INFORMATION SYSTEM

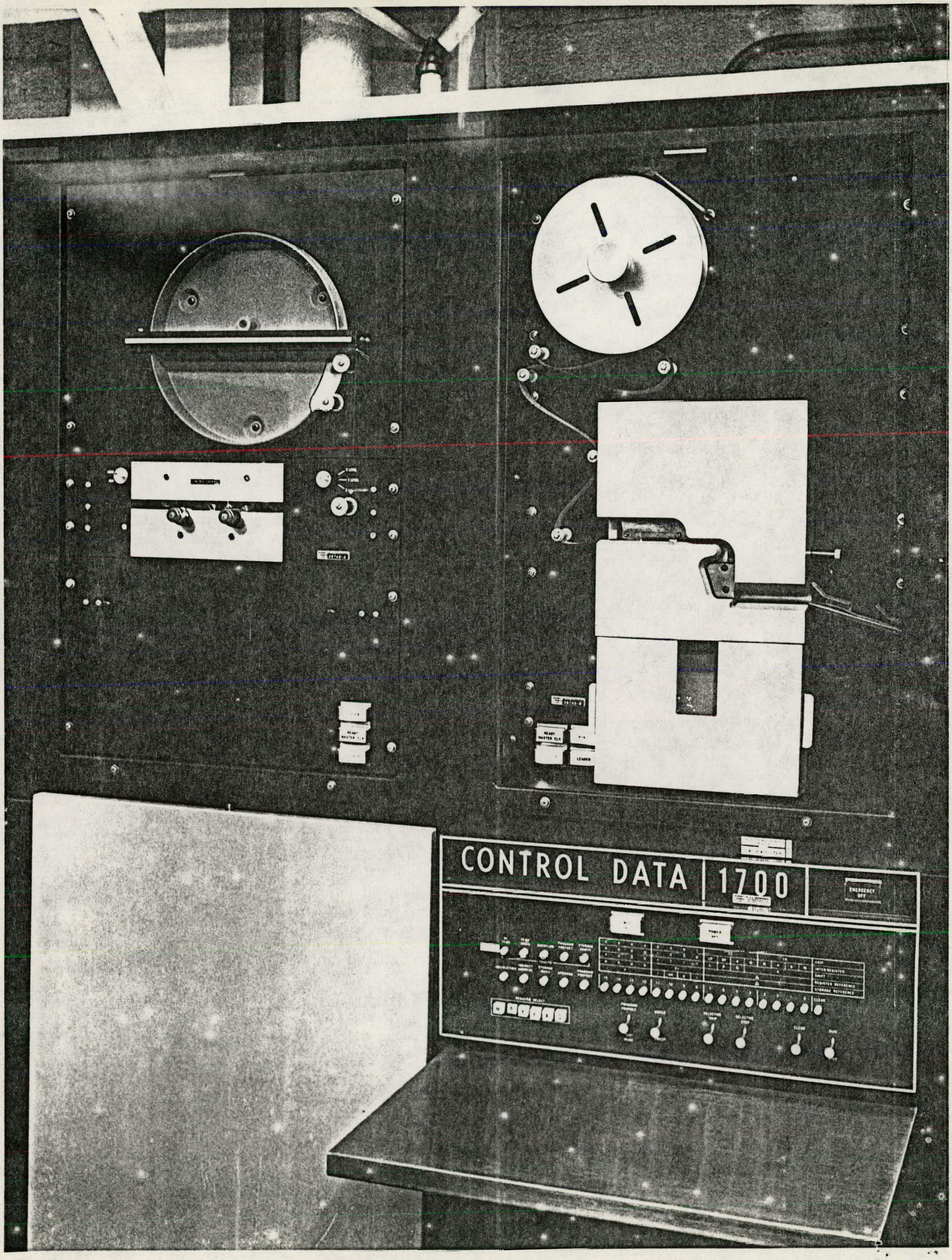
1. REDUCE MACHINE DOWNTIME

PROTOTYPE SYSTEM



BASIC COMPUTER HARDWARE (CDC 1700)

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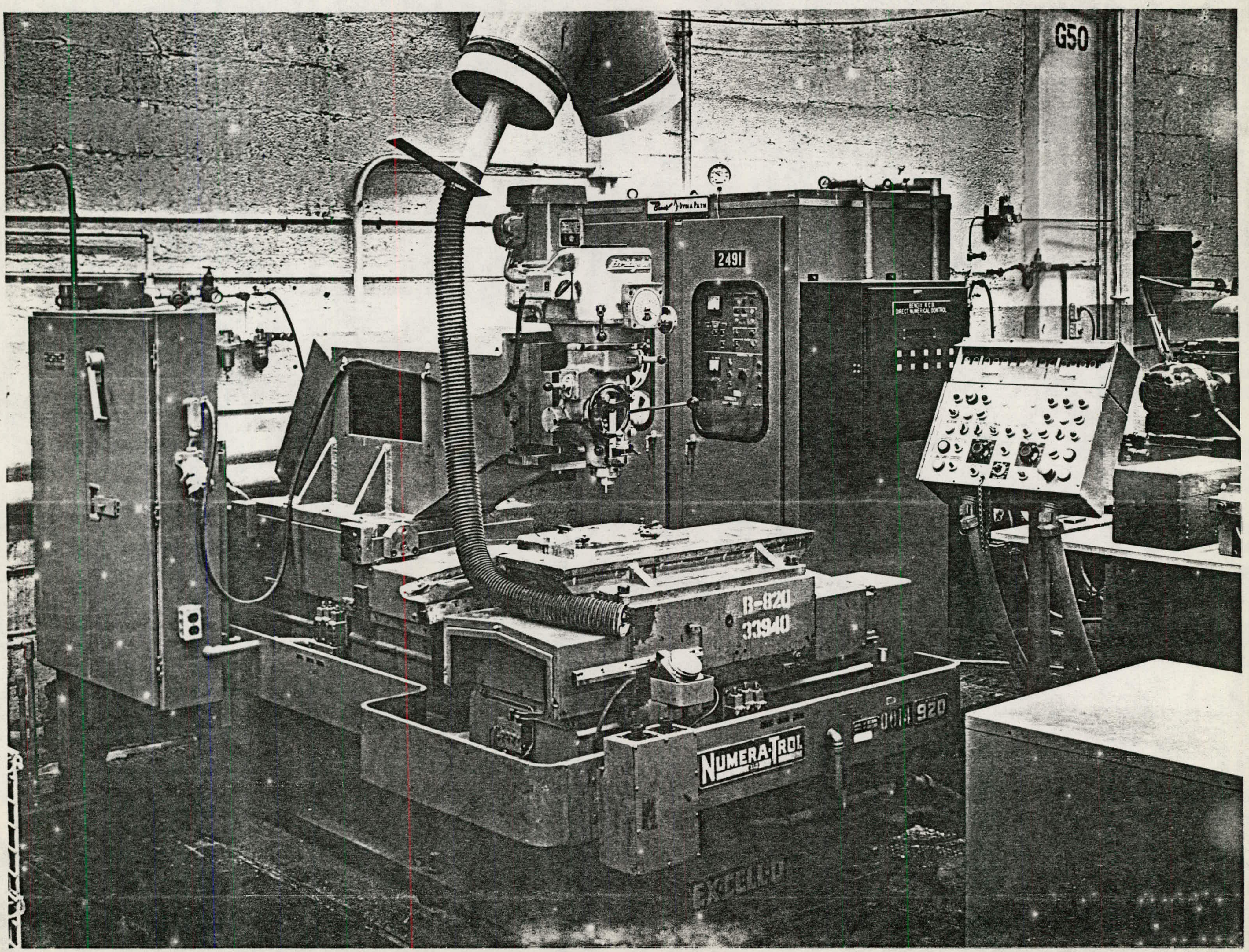
1700
EMERGENCY OFF
READY
MASTER CLR
LEADER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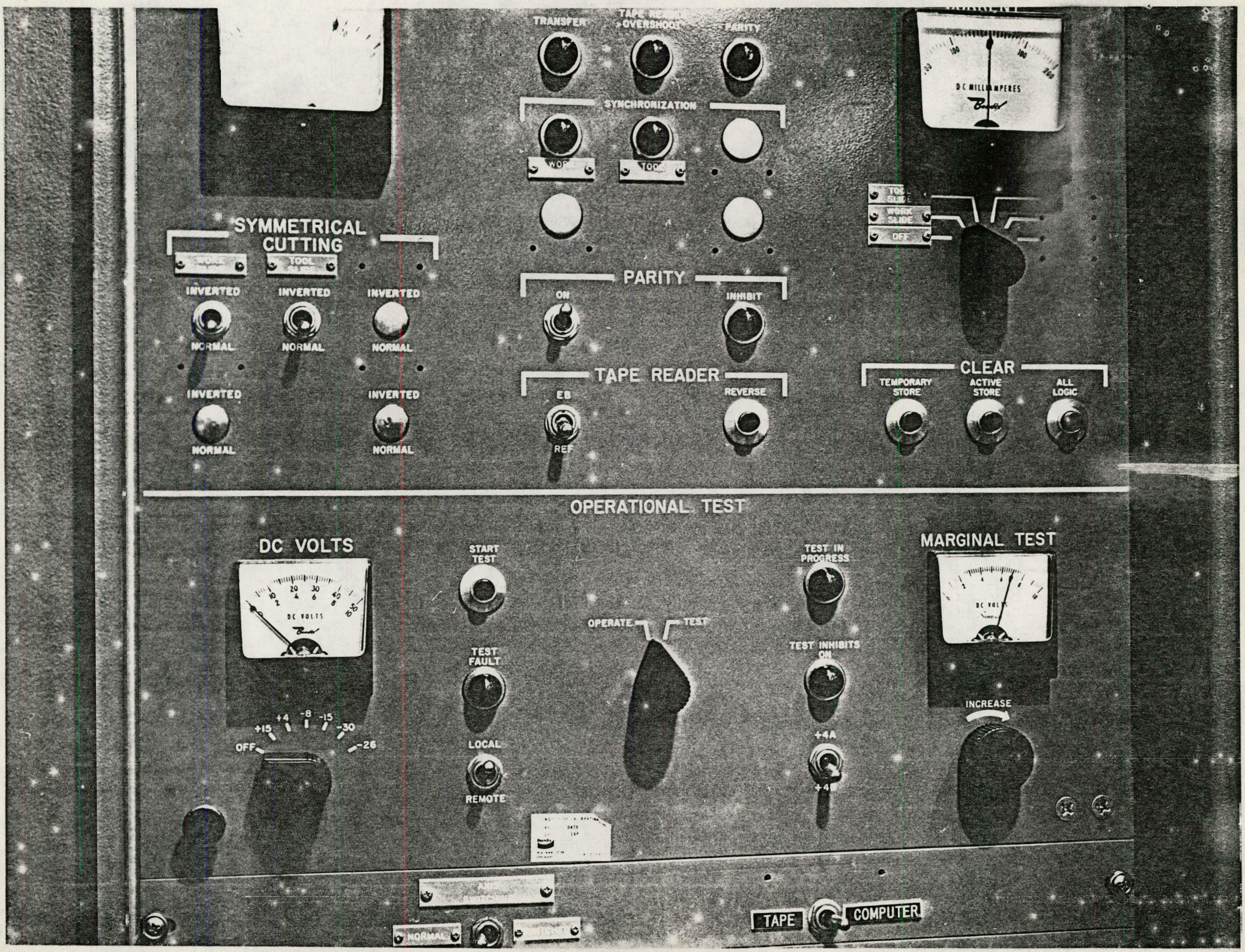
B-820
33940
NUMERA-TROL
920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OVERSHOOT
PARITY
SYNCHRONIZATION
WORK
TOOL
SYMMETRICAL CUTTING
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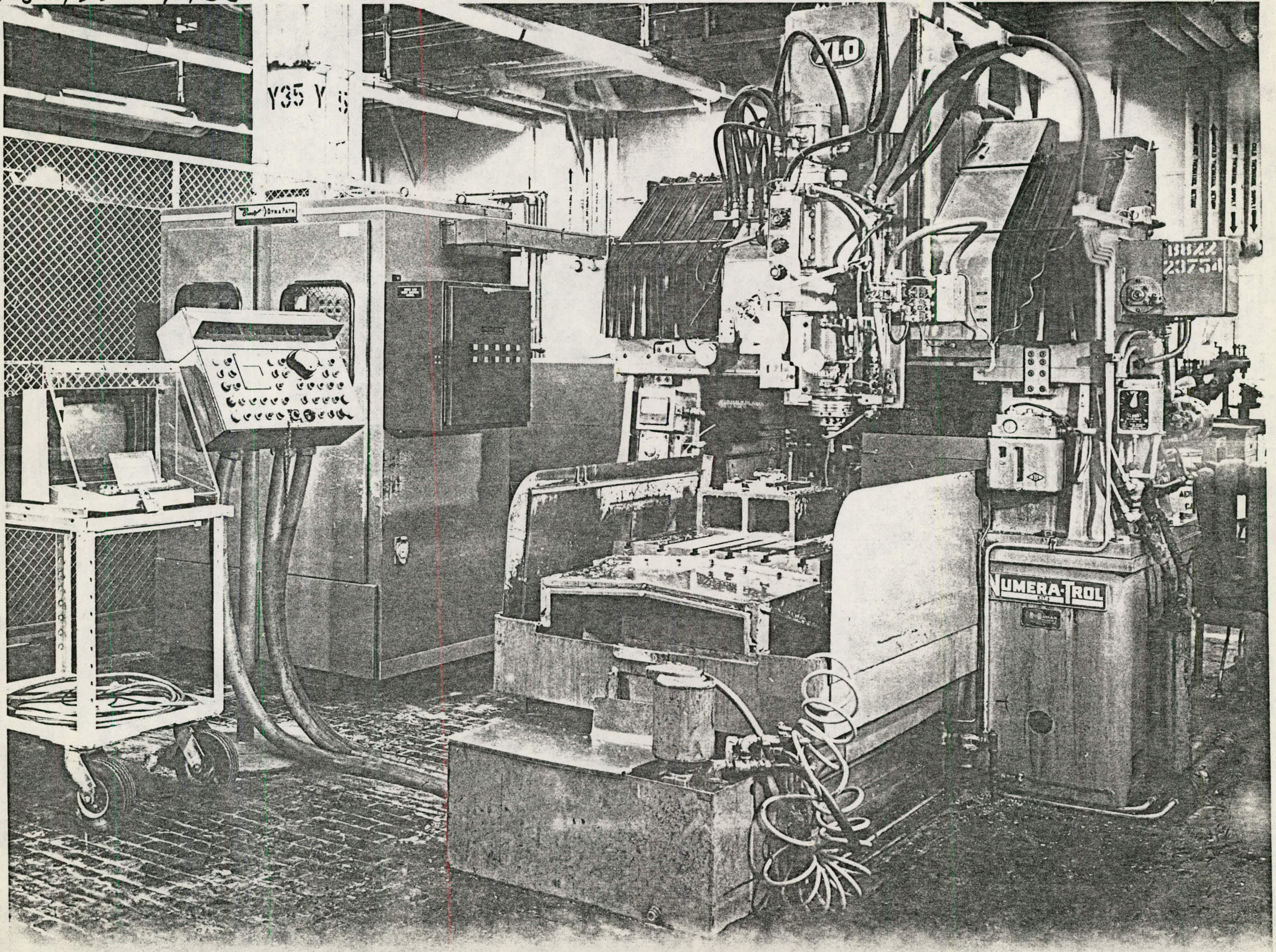
TOOL
INVERTED
NORMAL
INVERTED
NORMAL
INVERTED
NORMAL
INVERTED
NORMAL
INVERTED
NORMAL
PARITY
ON
INHIBIT
TAPE READER
EB
REF
REVERSE
DC MILLIAMPERES
TOOL SLIDE
WORK SLIDE
OFF
CLEAR
TEMPORARY STORE
ACTIVE STORE
ALL LOGIC
OPERATIONAL TEST
DC VOLTS
+15
+4
-8
-15
-30
-26
OFF
START TEST
TEST FAULT
LOCAL
REMOTE
OPERATE
TEST
TEST IN PROGRESS
TEST INHIBITS ON
+4A
MARGINAL TEST
DC VOLTS
INCREASE
NORMAL
TAPE
COMPUTER

D80735 FILE



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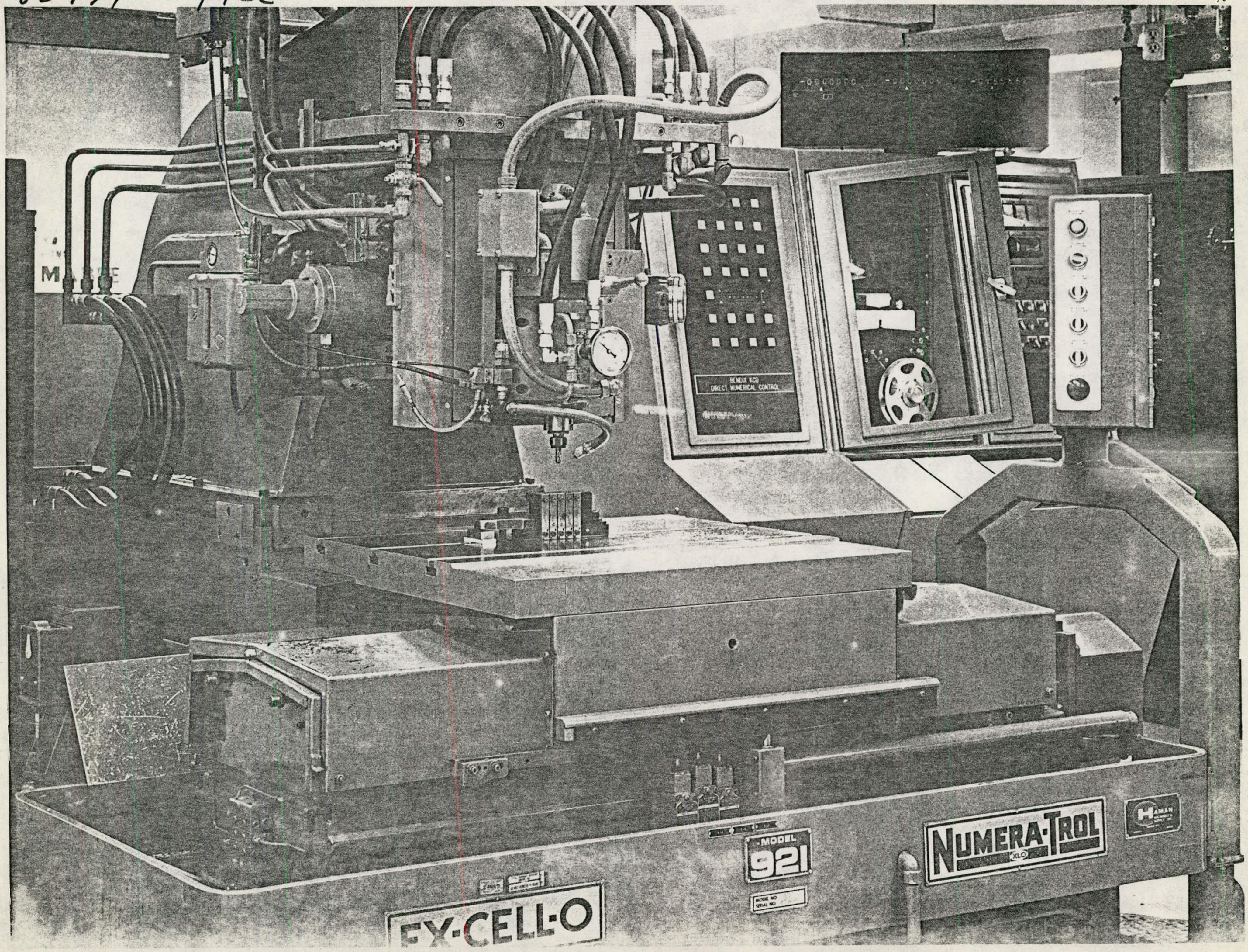
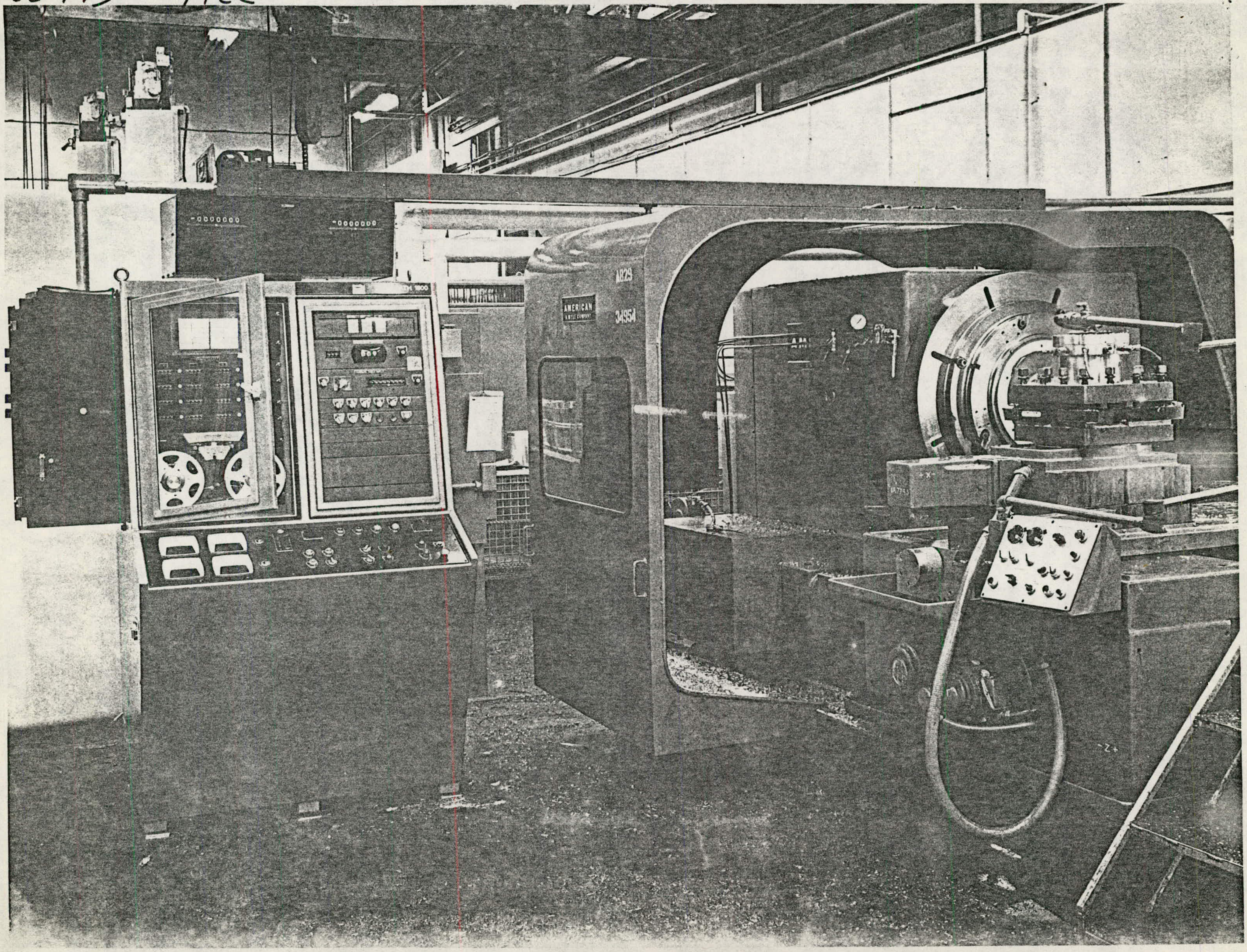

BENDIX KCO
DIRECT NUMERICAL CONTROL
MODEL
921
NUMERA-TROL
XLO
EX-CELL-O

P85995 FILE



OPERATIONAL TIME UNDER DNC

	INSTALLED	OPERATING TIME-HOURS	AS OF
MACH #1	APRIL, 1971	967.0	DISCONNECTED JAN, 1973
MACH #2	AUGUST, 1971	4,859.0	AUGUST 11, 1976
MACH #3	DECEMBER, 1973	9,540.0	AUGUST 11, 1976
MACH #4	JANUARY, 1974	3,332.0	AUGUST 11, 1976

TOTAL OPERATING HOURS 18,698

2 MACHINE SIMULTANEOUS OPERATION - 3,907.0 HOURS
3 MACHINE SIMULTANEOUS OPERATION - 863.0 HOURS

ANTICIPATED ADVANTAGES OF DNC

POTENTIAL FOR COST AVOIDANCE

IMPROVED MACHINE UTILIZATION AND PRODUCTIVITY
IMPROVED PRODUCT QUALITY
IMPROVED SCHEDULE PERFORMANCE

HOW WILL DNC CONTRIBUTE TO THESE IMPROVEMENTS?

SHOP FLOOR EDITING OF NC TAPE DATA

1. IMMEDIATE CORRECTION OF ERRORS
   a. REDUCE LOST MACHINING TIME
2. OPTIMIZATION TO REDUCE MACHINE RUN TIME
3. ABILITY TO "FINE TUNE" DATA FOR AREAS OF MARGINAL DIMENSIONAL CONTROL
4. IMMEDIATE INCORPORATION OF PRODUCT DESIGN CHANGES

MANAGEMENT INFORMATION SYSTEM

1. REDUCE MACHINE DOWNTIME

APT SOURCE EDITS

6	CUTTING TOOL PROBLEMS
2	REWORK OR NEW TAPES CREATED
31	PROCESS CHANGES
1	FIXTURE PROBLEM
10	TAPE ERRORS
3	"FINE TUNE" DATA
1	PRODUCT DESIGN CHANGE
15	OPTIMIZATIONS (ONE HAD NO SCHEDULED PARTS)
69	

OPTIMIZATION RESULTS

TAPE NO.	CYCLE TIME	% CYCLE REDUCTION	% STAND. HOUR REDUCTION
A11500D	6.9	60.6	54.7
A11249C	3.8	19.1	38.8
A11486C	21.8	75.8	68.5
32041C	36.8	62.0	68.4
11034E	23.2	45.5	38.8
32017D	114.9	57.4	41.0
A11485C	13.6	79.1	75.0
32022C	16.9	74.7	67.0
32032B	23.1	41.2	52.4
32033D	68.8	17.6	43.5
A11606B	19.2	36.6	34.3
21302A	2.3	36.1	19.5
A11558C	7.1	33.6	28.0
A11471B	2.0	10.9	10.5
	AVERAGES	46.4%	45.7%

BASED ON $15 DIRECT PRODUCTION LABOR SAVINGS PER STANDARD HOUR REMOVED, ESCALATING AND PROJECTING OVER PRESENT SCHEDULING, THIS RESULTED IN SAVINGS OF $71,735 ON THESE 14 NC OPERATIONS

AVERAGE COST PER OPTIMIZATION WAS $125.65

POTENTIAL SAVINGS

PROJECTED SAVINGS - 14 PARTS	$71,735
MISSED SAVINGS - COMPLETED PARTS	20,712
PROJECTED TOTAL SAVINGS FROM "A" ISSUE	$92,447

455 ACTIVE JOBS ON 33 MACHINES
$215,000 POTENTIAL SAVINGS

440 NEW TAPES ON 33 MACHINES
$450,000 POTENTIAL SAVINGS GENERATED YEARLY

MANAGEMENT INFORMATION SYSTEM DATA

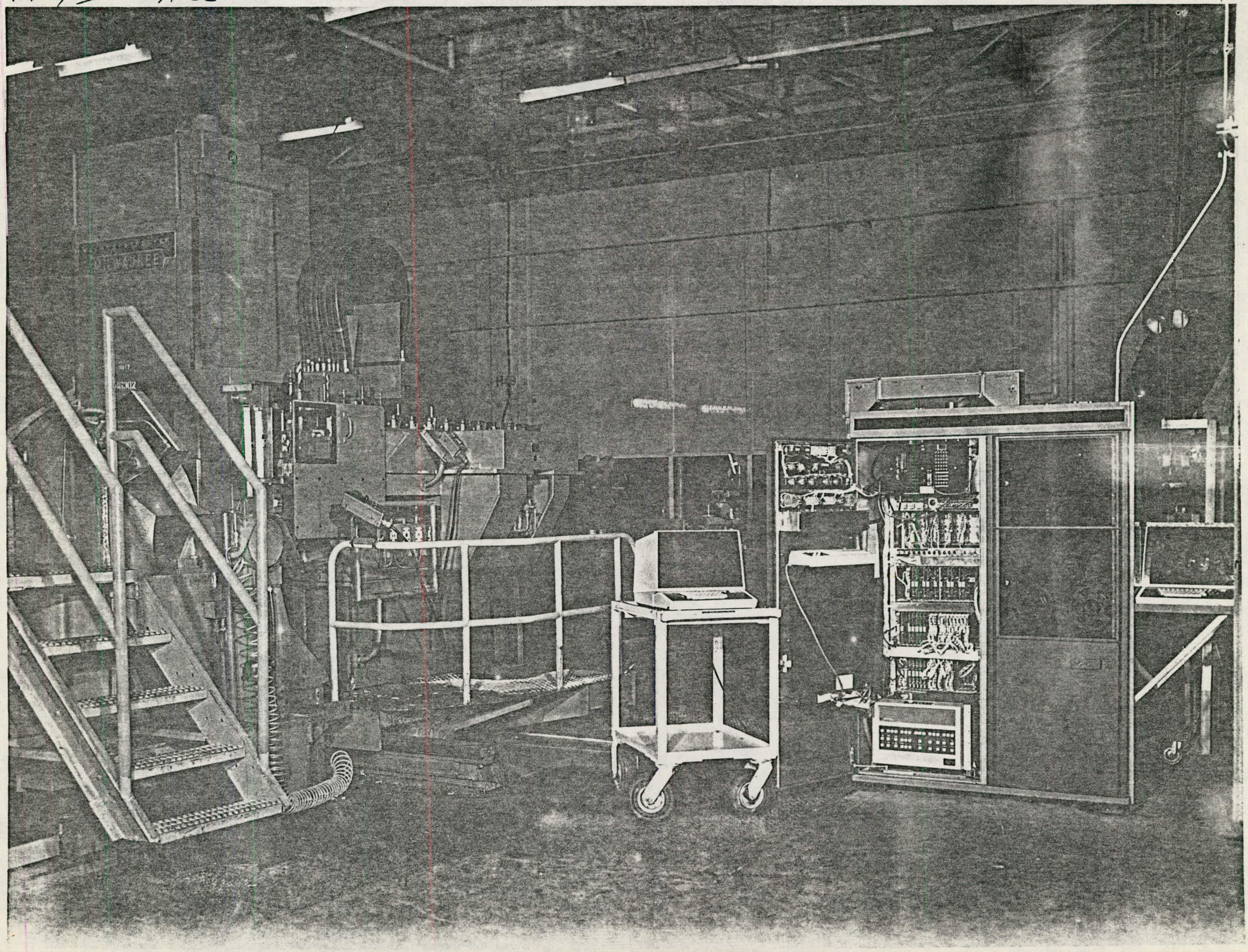
OPERATIONAL DATA

- PRODUCTION OPERATION
- DEVELOPMENT OPERATION
- OTHER TYPE OPERATION
- REWORK

DOWNTIME DATA

- ASSISTANCE RESPONSE TIME
- PROCESS ENGINEER
- MAINTENANCE
- PART PROGRAMMING
- SETUP
- TOOL CHANGE
- WAITING FOR EQUIPMENT
- NO OPERATOR/PARTS AVAILABLE
- DRY RUN
- IN PROCESS GAGING
- MACHINE WARMUP
- CLEANUP

P 990/5 FILE



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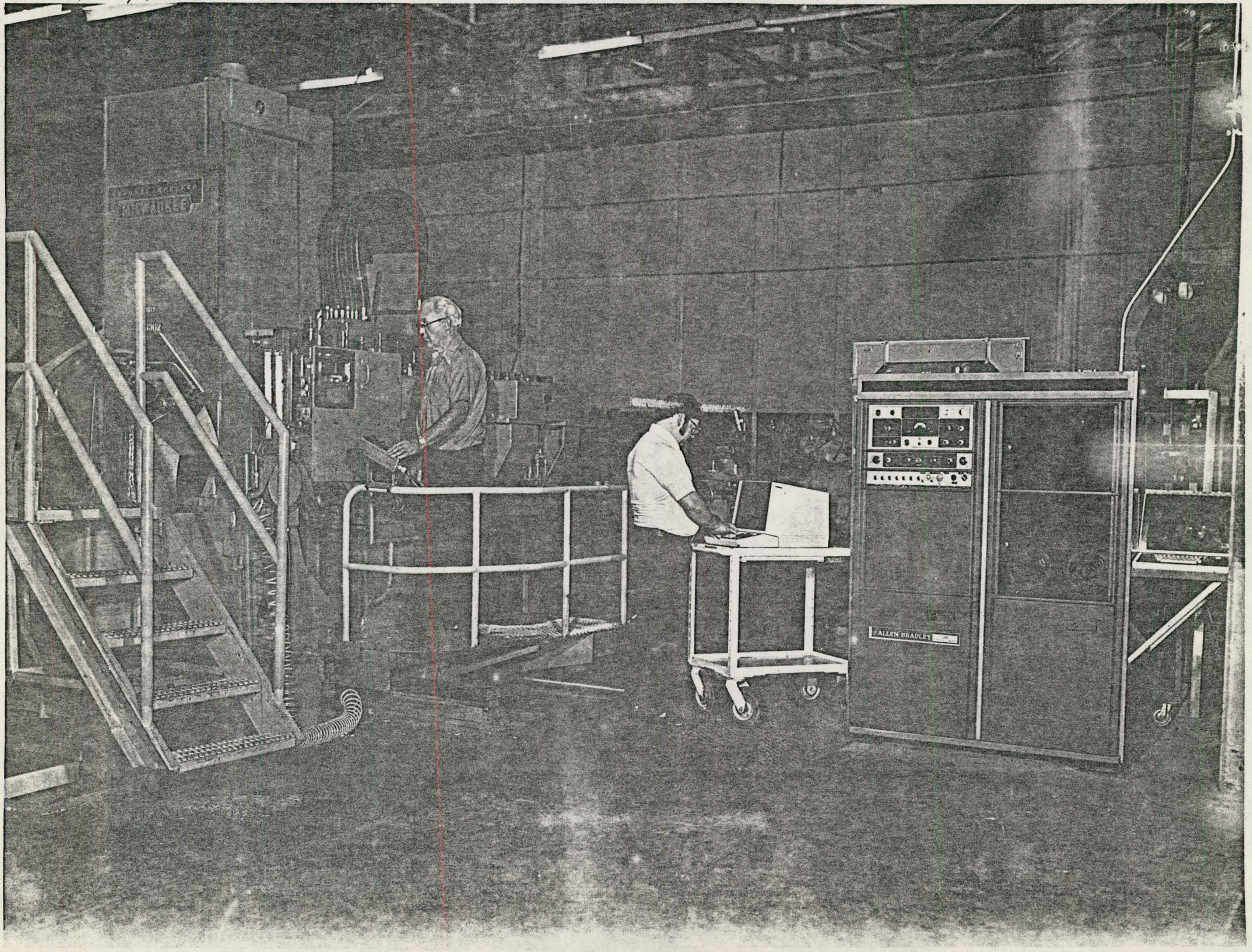

PRODUCTION SYSTEM IMPLEMENTATION

INITIAL APPROPRIATION PACKAGE SUBMITTED OCTOBER, 1975 FOR 16 INTERFACES

STARTED RECEIVING EQUIPMENT JANUARY, 1977

16 MACHINES INCLUDE:

- 5 FIVE - AXIS MACHINING CENTERS
- 3 FOUR - AXIS MACHINING CENTERS
- 1 THREE - AXIS MACHINING CENTER
- 5 THREE - AXIS MILLS
- 2 LATHES

FUTURE PLANNING

- PREPARING APPROPRIATIONS FOR 6 INTERFACES
- FY1978 BUDGET INCLUDES 20 ADDITIONAL INTERFACES
- FINAL EXISTING MACHINES BUDGETED IN FY1981
- DNC TO BE INCLUDED WITH NEW MACHINE PROCUREMENTS

SUMMARY

- DNC APPEARED TO OFFER BENEFITS TO BKC
- DEVELOPED PROTOTYPE SYSTEM TO PERFORM EVALUATION
- FOUND ACTUAL AND POTENTIAL SAVINGS DUE TO EDITING AND MANAGEMENT INFORMATION SYSTEM
- RECOMMENDED EXPANSION OF PROTOTYPE SYSTEM
- PURCHASED 16 INTERFACES
- ADDITIONAL PLANNING FOR 26 MORE

PROTOTYPE COSTS

CABLE INSTALLATION (5 MACHINES PLUS 1700-6600 LINK)	$24,833
#1 & 2 INTERFACES ($8,950 DESIGN FEES)	30,156
MODIFICATION TO #1 & 2 INTERFACES	3,345
#3 & 4 INTERFACES ($20,000 DESIGN FEES)	45,100
MINI-COMPUTER & TTY	7,029
CAPITAL EQUIPMENT COSTS	$110,463
D/744 SCIENTIFIC PROGRAMMING (SOFTWARE DEV. & MODS)	$77,531
FY 70 TO DATE - 6.0 MY'S	
D/743 NC COMPUTER PROGRAMMING (EDITING & OTHER DEV.)	$25,414
FY 70 TO DATE - 1.7 MY'S	
PDO EXPENDITURES FY 70 TO DATE	$123,267
TOTAL PROTOTYPE COSTS TO DATE	$336,675

INTERFACE COSTS PER MACHINE

MINI COMPUTER SYSTEM	$8,200
SERIAL I/O CARD	500
OPERATORS CRT	1,500
INSTALLATION	1,000
TOTAL	$11,200