Conf-920842--7

ANL/CP--76107

DE93 001855

Charged-Particle Beam Diagnostics for the Advanced Photon Source (APS)*

by

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*Work supported by the U.S. Department of Energy, Office of Basic Energy Sciences, under Contract No. W-31-109-ENG-38.

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Abstract

Plans, prototypes, and initial test results for the charged-particle beam (e^-,e^+) diagnostic systems on the injector rings, their transport lines, and the storage ring for the Advanced Photon Source (APS) are presented. The APS will be a synchrotron radiation user facility with one of the world's brightest x-ray sources in the 10-keV to 100-keV regime. Its 200-MeV electron linac, 450-MeV positron linac, positron accumulator ring, 7-GeV booster synchrotron, 7-GeV storage ring, and undulator test lines will also demand the development and demonstration of key particle-beam characterization techniques over a wide range of parameter space. Some of these parameter values overlap or approach those projected for fourth generation light sources (linac-driven FELs and high brightness storage rings) as described at a recent workshop. Initial results from the diagnostics prototypes on the linac test stand operating at 45-MeV include current monitor data, beam loss monitor data, and video digitization using VME architecture.

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1. Introduction

The Advanced Photon Source (APS) will be a synchrotron radiation user facility with one of the world's brightest x-ray sources in the 10-keV to 100-keV regime [1]. Its 200-MeV electron linac, 450-MeV positron linac, positron accumulator ring (PAR), 7-GeV booster synchrotron, 7-GeV storage ring, and undulator test lines will also provide the opportunity for development and demonstration of key particle beam characterization techniques over a wide range of parameter space. Some of these values overlap or approach those projected for fourth generation light sources as described at a recent workshop [2]. The Accelerator Systems Division (ASD) Diagnostics Group is responsible for the design, procurement, testing, and operation of all the diagnostic systems on the injector rings, their transport lines, the storage ring, and the undulator test lines. A description of these plans using electrical conversion and optical conversion techniques and initial results from some prototypes tested on the linac test stand operating at 45-MeV are presented. A brief outline of the undulator test line parameters and diagnostics are also presented.

2. Background

Space precludes providing a complete description of the accelerator facilities for the APS but some background information is needed. The baseline electron source is a thermionic gun followed by a 200-MeV linac operating at a RF frequency of 2.8 GHz and a maximum macropulse repetition rate of 60 Hz. The base injector (gun, bunchers, and 45-MeV accelerating structure) was operated April through June 1992 as the injector linac test stand [3]. The design goals include 14-ps long micropulses, separated by 350 ps in a 30-ns macropulse with a total macropulse charge of 50 nC. The 200-MeV linac beam will be focused to a 3-mm spot at the positron-production target. The target yield is about 0.0083 positrons per incident electron with a solid angle of 0.15 sr and an energy range of 8$\pm$ 1.5 MeV. The positrons will then be focused by a pulsed solenoid and about 60% of them will be accelerated to 450 MeV. Commissioning of these two linacs is to be completed by December 1993. The 450-MeV positrons are injected into the horizontal phase space of the PAR at a 60-Hz rate. As many as 24 macropulses can be accumulated as a single bunch during each 0.5-s cycle of the injector synchrotron. The injector (or booster) synchrotron accelerates the positrons to 7 GeV at which energy they can be extracted and injected into the designated RF bucket of the storage ring. Figure 1 shows a schematic of the APS accelerators and lists the number of diagnostic stations. Several features of the subsystems are provided in Table I. The peak current, bunch length, and charge per pulse are given for the low energy transport (LET) lines between the linac and the PAR and the PAR and synchrotron, respectively. The high energy transport (HET) parameters are also provided. The revolution time, bunch length, and average currents are provided for the rings.

3. Procedures and Results

The basic charged-particle parameters such as beam position, profile, current, bunch length, energy, and beam loss are to be addressed. Both intercepting and nonintercepting techniques are combined. Some of these have initial prototype results from the linac test stand this spring. Some will be tested at other operating storage ring facilities around the country in the next year.

A strong component of the beam position monitoring (BPM) involves RF BPM pickup elements and their electronics. The prototype button feedthrough for the storage ring is shown in Fig. 2; over 1800 have been received and electrically tested. In addition to these, there will be intercepting beam profile screens and the use of synchrotron radiation from at least one bending magnet in each of the rings. Gated, intensified cameras will supplement standard television viewing cameras to provide individual bunch and/or single pass capability.

Because the pulse structures of the electron linac will be representative of beam in the linac-to-par (LTP) transport line, the prototype current monitor system based on a fast current transformer manufactured by Bergoz and in-house electronics was tested on the linac test stand. Its installed position with a shield at the end of the beamline just before a Faraday cup is shown in Fig. 3. Test results are shown in Fig. 4. The 30-ns macropulse and the 100 mA current level are indicated.

The loss monitor system which will cover the entire extent of beamlines and accelerators was tested as a prototype. A gas-filled coaxial cable acting as an ionization chamber was installed along the length of the linac test stand. Preliminary tests showed the effects of applied high voltage to the cable, gas mix, gas pressure, cable diameter, and cable impedance. The rise time of the system is less than 15 ns when the high voltage is set to 500 volts so axial location determination by signal arrival time analysis is under investigation. Position resolution of 7 feet or less may be practical. Sample data are shown in Fig. 5 where applied voltage polarity flips the observed signal polarity. The system also picked up a noticeable amount of noise from the RF modulator tank located a few meters away beyond the radiation shielding wall.

The imaging techniques can be applied to several aspects of the diagnostics problems. Initial tests included a VME-architecture-based video digitizing system linked to a Sun workstation. The beam image digitized was one of the first in the startup tests on the linac test stand. Background subtraction, pseudo-color intensity, pseudo-3D display, and beam profiles are demonstrated in the composite image of Fig. 6. The digitizing scheme can be applied to particle energy spectra (images from an energy-dispersive region) and particle bunch length (video readout of a streak camera).

4. Undulator Test Lines

The undulator test lines are being considered at 650 MeV and 7 GeV. In the first case, the tungsten positron conversion target will be retracted and the 450-MeV linac rephased to accelerate the electrons to 650 MeV. A key point here would be the switch to the RF thermionic gun which is projected to provide normalized, edge emittance of about 10 π mm rad, a few orders of magnitude colder than the standard thermionic gun [4]. This gun also may allow micropulse bunch lengths of less than 1 ps to be attained via filtering and magnetic compression techniques. The emittance at 200 to 650 MeV will be measured in a straight 10-m long section that bypasses the PAR. Cross-comparison of several techniques including three-screen, two-screen, optical transition radiation (OTR) interferometry, and quadrupole field scan is planned. Bunch length will be determined by a streak camera using either OTR or some other prompt mechanism. As shown in Table II, many of the critical beam parameters identified in the 4th Generation Light Source Workshop [2] will be approached by the proposed undulator test line e^- beam.

5. Summary

In summary, key charged particle beam parameter characterizations are being addressed at the APS. Due to the diverse parameter space involved, a number of complementary intercepting and nonintercepting beam techniques are being employed. In the rings, of course, nonintercepting techniques are dominant. The undulator test line initiative will address transport of high brightness beams to undulators at energies that happen to be of interest to the next generation of light sources, including short-wavelength, linac-driven FELs.

Acknowledgments

The authors are indebted to George Mavrogenes and John Galayda for their support, to the linac test stand operations crew including Ray Fuja, Bill Berg, and Bill Wesolowski for beam time, and to Ned Arnold and Eric Ko of the Controls Group for data acquisition and analysis support.

References

[1] D.E. Moncton, E. Crosbie and G.K. Shenoy, "Overview of the Advanced Photon Source," Rev. Sci. Instrum., 60, (7), July 1989.

[2] Proceedings of the Fourth Generation Light Source Workshop, Feb. 24-27, 1992, Stanford, California, SSRL 92-02.

[3] G. Mavrogenes et al., Proceedings of the Linac Conference, Ottawa, Canada, August 24-28, 1992.

[4] M. Borland, Private Communication (July 1992), APS, Argonne National Laboratory.

TABLE I
APS PARAMETERS FOR BEAM DIAGNOSTICS

	LET 1	LET 2	HET
PEAK CURRENT	8 mA	11.9 A	28.9 A
BUNCH LENGTH	30 ns	0.29 ns	122 ps
INTENSITY PER PULSE	1.5×10^{9} positrons	2.2×10^{10}	2.2×10^{10}
CHARGE PER PULSE	240 pC	3.5 nC	3.5 nC
PULSE RATE	60 Hz	2 Hz	2 Hz

	PAR	IS	SR
RF FREQUENCY	9.77 or 117 MHz	351.93 MHz	351.93 MHz
REVOLUTION TIME	102.3 ns	1.228 us	3.68 us
NUMBER OF BUNCHES	1	1	1 to 60
MIN BUNCH SPACING	—	—	20 ns
BUNCH LENGTH	30 ns → 0.29 ns / 0.92 ns	122 ps	35 to 100 ps
MIN AVE BEAM CURRENT	1.4 mA 1 linac pulse injected	—	0.22 mA for single bunch
MAX AVE BEAM CURRENT	33.4 mA 24 linac pulses injected	4.7 mA	5 mA for single bunch
MAX INTENSITY	3.6×10^{10} 24 linac pulses injected	3.6×10^{10}	2.2×10^{10} per bunch per mA

TABLE II Beam parameters for the undulator test line at APS as compared to 4th Generation Workshop values (ref. 2)

Parameter	APS	4th Generation Workshop (Linac)
Emittance (Π mm mrad) (rms, normalized)	2	1.5
Peak Current (kA)	1/2 to 1	1
Bunch Length (ps)	<1 to 15	~1
Energy (MeV)	200-650	100-1000
Energy Spread	0.1 %	0.05 %
Macropulse Bunch Length	30 ns	--

Figure Captions

Fig. 1 A schematic layout of the APS accelerator and diagnostics.

Fig. 2 Photograph of the RF button feedthrough for the storage ring beam position monitor.

Fig. 3 Photograph of the fast current monitor as installed on the linac test stand.

Fig. 4 Initial test results of the fast current monitor system.

Fig. 5 Initial beam loss monitor data from the gas-filled coaxial cable ionization chamber.

Fig. 6 Composite image of an initial beamspot recorded at a position just after the accelerator. VME-based hardware, a Sun workstation, and PV-wave display software platform were used.

PROPOSED LAYOUT OF BEAM DIAGNOSTICS IN THE APS

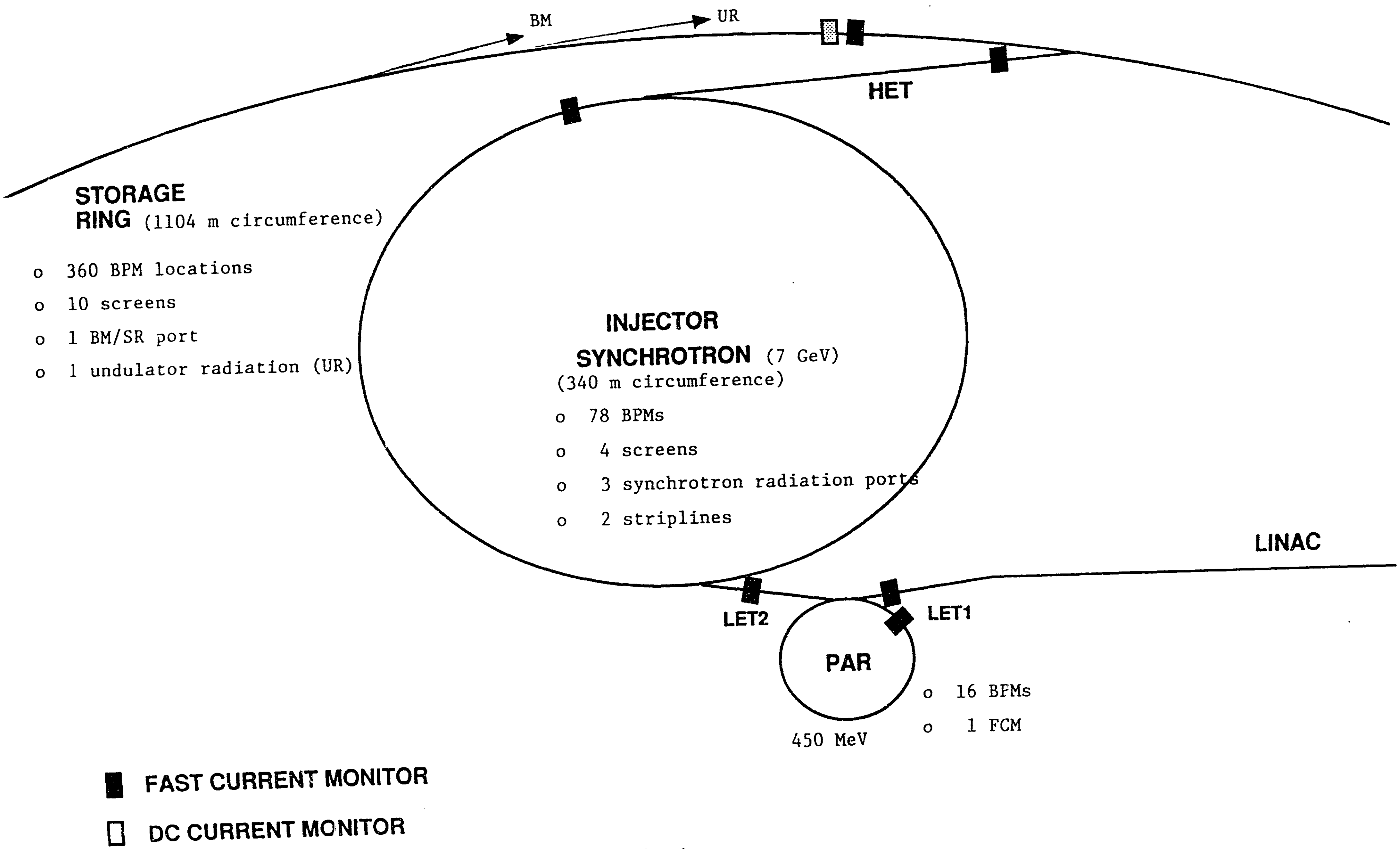


Fig. 1

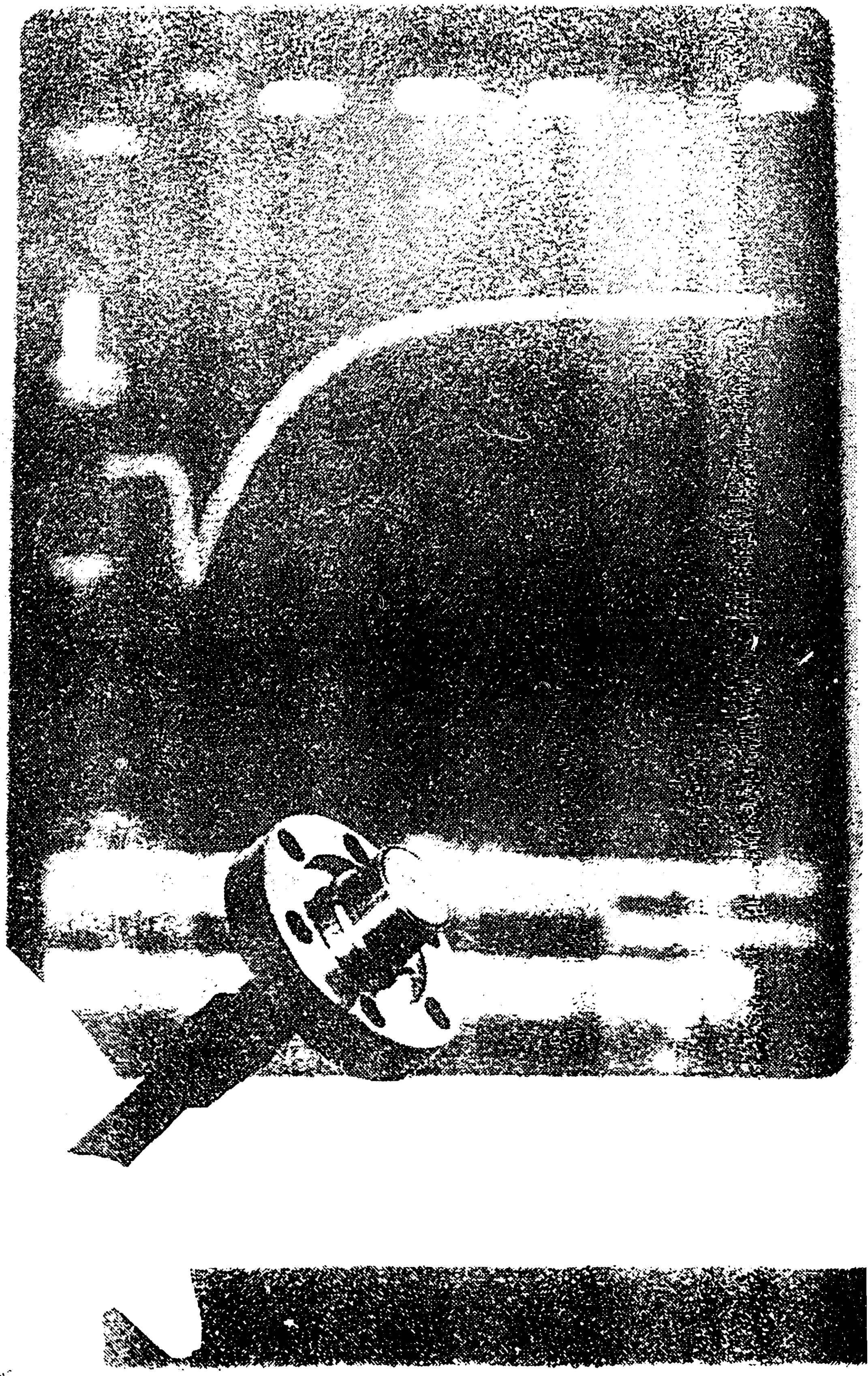
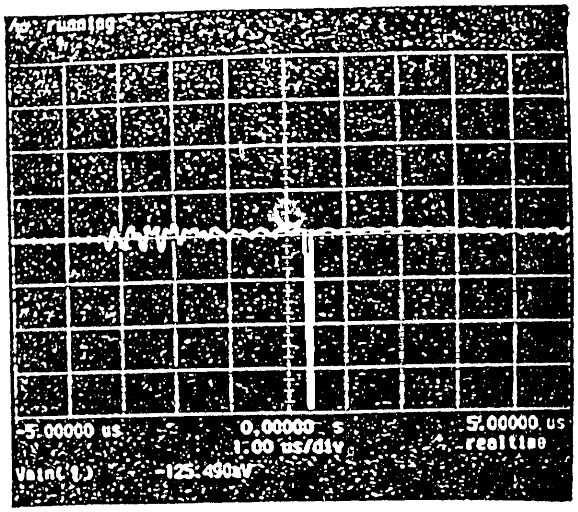


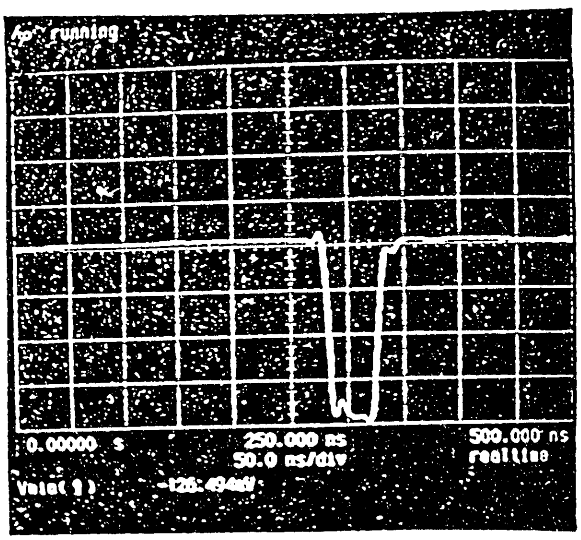
Fig. 2

THE INITIAL DATA FROM LET PROTOTYPE BEAM CURRENT MONITOR *



30mV/div
1us/div

I_b =101mA



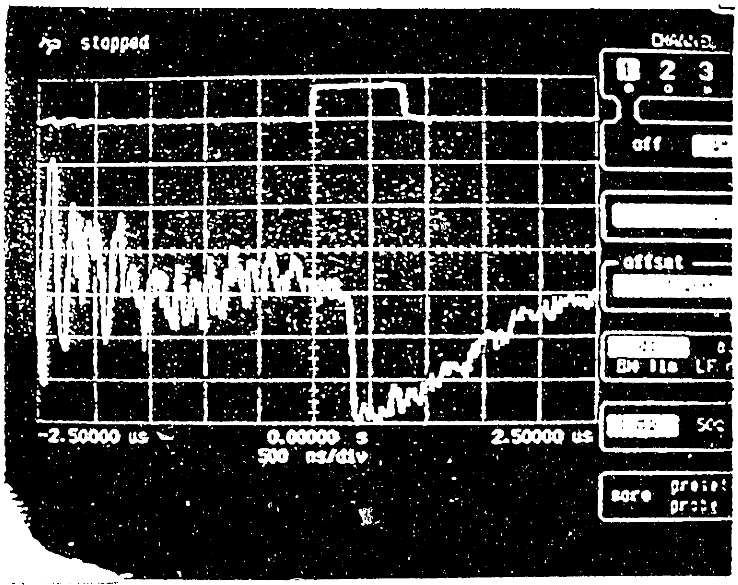
30mV/div
50ns/div

T_W=39ns

* Test performed on the LINAC teststand on April 16, 1992

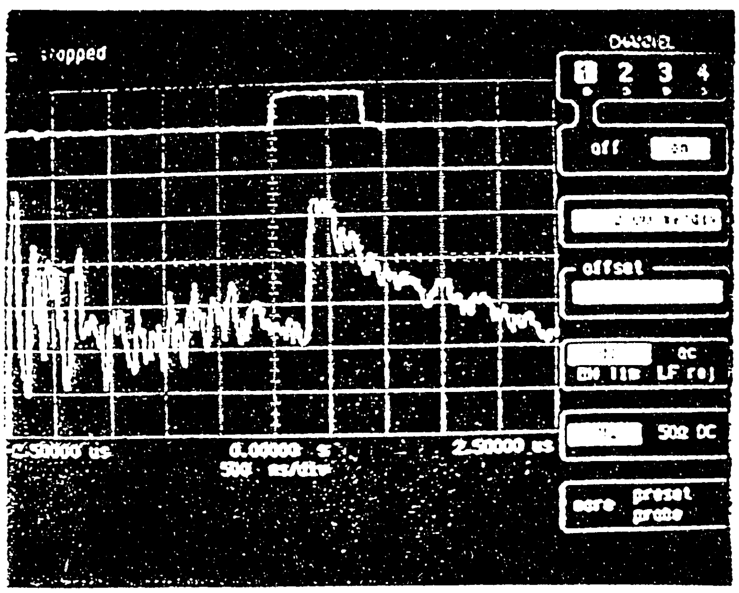
Fig. 4

Initial Data From the Loss Monitor Tests in the Linac Test Stand



High voltage = +100 V

2mV per div
500 nsec per div



High voltage = -100 V

Pulse rise time is about 50 nsec
1.7A peak beam current
50 Ohm, 7/8 inch coaxial cable ionization chamber

Fig. 5

APS LINAC Test Stand First Accelerated Beam

April 15, 1992

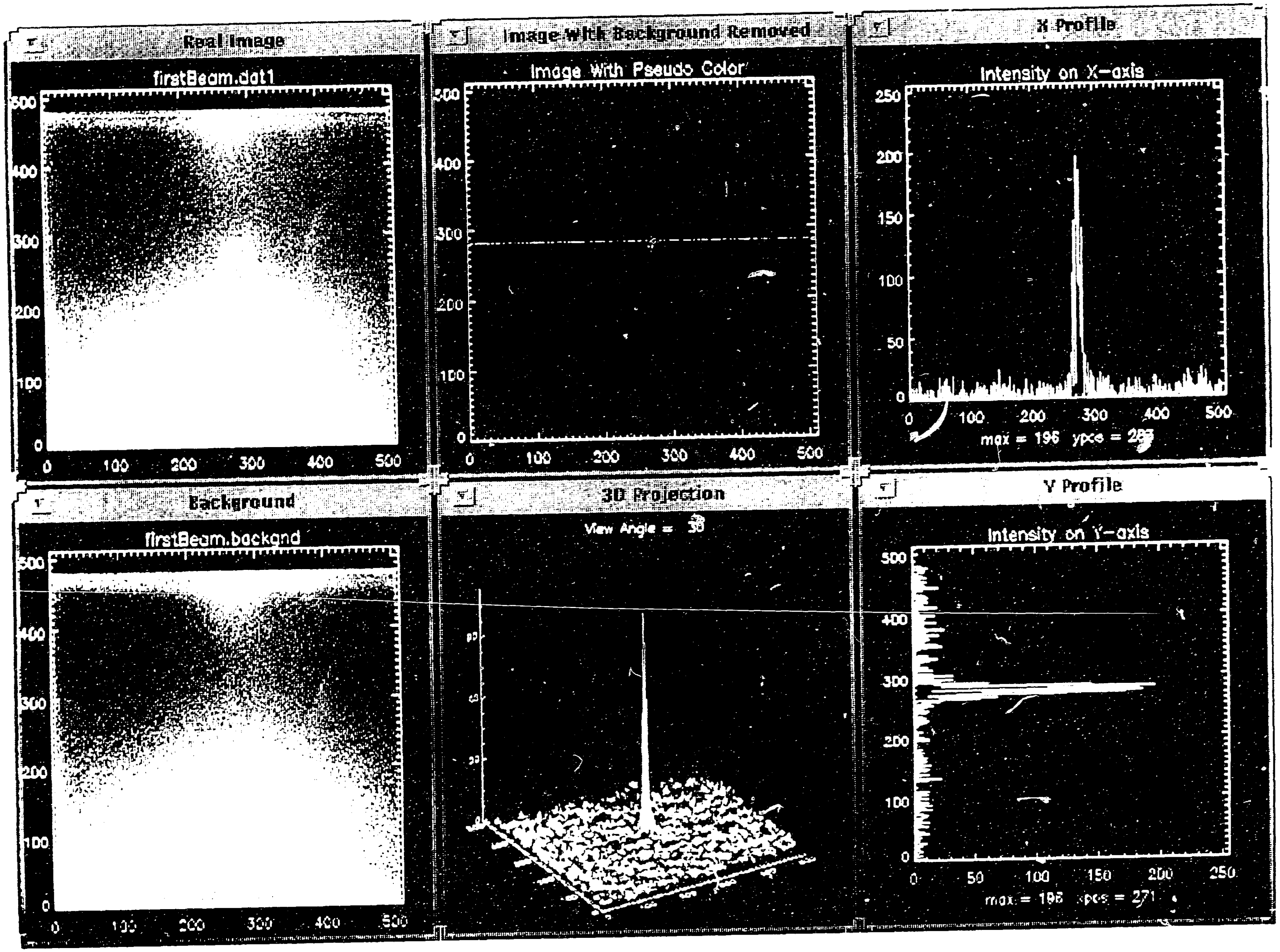


Fig. 6

END

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