PREPRINT UCRL- 79680

CONF-771029--6

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FAST-SCAN, BEAM-PROFILE MONITOR

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September 29, 1977

This paper was prepared for submittal to the Seventh Symposium on Engineering Problems of Fusion Research, Knoxville, Tennessee October 25-28, 1977.

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FAST-SCAN, BEAM-PROFILE MONITOR*

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Summary

A minimodular, data-acquisition system can be used to rapidly interrogate a 45-point matrix of beam-current sampling targets over the 3- × 12-in. rectangular, output beam cross section of a 50-A, neutral-beam ion source. This system, operating at a throughput rate of 12 μs per channel, can make several complete scans during the 10- to 25-ms-duration beam pulse. Data obtained are available in both analog and digital form. The analog signal is used to create an immediately interpretable CRT display of the beam-current density profile that shows how well the source is aimed. The digital data are held in buffer memory until transfer to a minicomputer for software processing and plotting.

Ion-Source Injector System

Twelve 50-A, neutral-beam ion sources inject 10-ms-duration beams into the magnetic confinement field of Lawrence Livermore Laboratory's (LLL's) 2XIIB experiment. Another 24 of these ion sources will inject 25-ms-duration beams into the confinement field of the TMX machine under construction at LLL. Developed by Lawrence Berkeley Laboratory, these ion sources produce a beam that is 3 × 12 in. in rectangular cross section.

Two of the basic measurements needed to ascertain performance quality of the ion-source injector system are: total beam current into a beam-stopping target, and total energy per pulse deposited in the same target. The latter, a calorimetric measurement, is made by observing the temperature rise of the known thermal mass of a beam-stopping target.

We have also found it helpful, if not necessary, to monitor beam-current density at a matrix of points over the beam cross section for optimizing source system output. This provides a profile of relative beam density that indicates hot spots and shows if the source is properly aimed.

Calorimeter Plate

The beam-stopper, calorimeter plate is 1/4 in. thick, made of copper, and cooled on the edges by water. It was designed with 45 beam-sampling holes through it to allow sampled beam currents to be monitored by an array of minitargets. These forty-five 1/16-in.-diam. beam-sampling holes are arranged in five horizontal rows of nine holes each. The rows are 1/2 in. apart, and the distance between adjacent horizontal holes is 1-3/8 in. The arrangement of this five-by-nine matrix of beam-sampling holes is such that one horizontal and one vertical row pass through the geometric center of the calorimeter plate with one hole at the center point. The 2- × 11-in. central area in which the sampling points lie comprises about 60% of the total 3- × 12-in. rectangular, output beam cross section.

Targets

The beam-sampling minitargets are 4-40 stainless steel machine screws. They are mounted on a custom-designed, printed circuit (pc) board that is insulated from and about 1/4 in. behind the beam-stopper, calorimeter plate. The pc board positions targets directly behind the 1/16-in.-diam. beam-sampling holes in the plate. Leads on the back (away from the beam) of the pc board connect the conductive pad around each screw hole to a tab of either of two 22-pin edge connectors mounted on the upper edge of the pc board. Figure 1

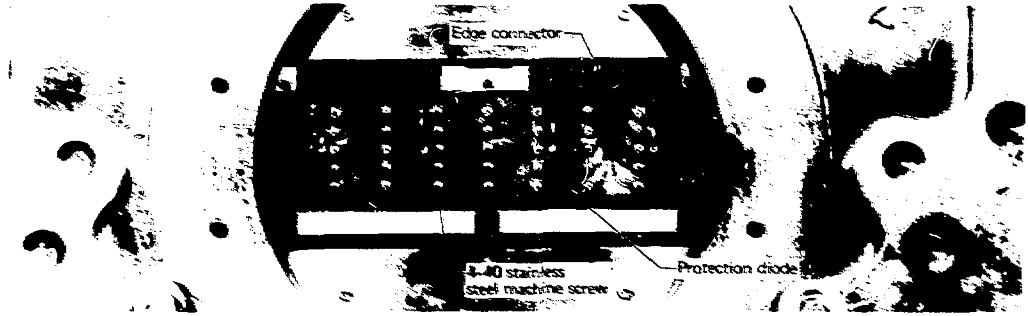

Fig. 1. Back view of beam-profile-monitor pc board in beam-target assembly.

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*Work performed under the auspices of the U.S. Energy Research and Development Administration, contact No. W-7405-Eng-48.

shows the back of the beam-profile-monitor pc board as installed in the beam-target assembly.

Target Assembly

The beam-target assembly is located about 1 m from the exit grid of the ion source and near the exit port of the beam-neutralizer chamber. It is mounted in such a way that it can be moved vertically out of the beam line for beam injection into the experiment or lowered into place for source performance monitoring. Figure 2 shows the front (beam side) of a beam-stopper, calorimeter plate mounted in the beam-target assembly. When this photograph was taken, the right beam-edge-skimmer paddle was pushed into about 1 in. from the beam center line. The 1/16-in.-diam, beam-sampling holes in the copper calorimeter plate are barely discernable.

The beam at target location should be composed entirely of energetic neutral particles. The actual current monitored at the beam-sampling minitargets is that running up from ground to replace secondary electrons produced at the surface of the screw heads by incident atoms. A small (5- to 10-V) negative bias is needed to ensure all emitted secondary electrons are driven away and do not fall back on the screw heads. Should the beam no longer be neutralized and positive beam current terminate on the target elements, thus connecting them electrically to the 20- to 40-kV accel potential of the ion source, the monitoring system would be damaged. To prevent this, each target element is connected by a small, solid-state protection diode to a ground bus on the pc board. This diode would be forward biased if the target tended to go positive, thus clamping the target to a 0.8-V, forward-diode drop above ground. Each beam-sampling current passing through the 1/16-in.-diam holes in the calorimeter plate has a range of 1 to 10 mA. The negative bias, needed on target elements to drive away secondary electrons, also back biases the protection diodes so they appear as open circuits to the monitoring system.

Wire leads from the pc-board edge connectors carry beam-current signals from the beam-line vacuum tank to the outside via a multipin, hermetically-sealed connector. The beam currents are passed through current-monitoring resistors and the common negative bias to ground. Voltages produced across the 45 resistors must be rapidly scanned, in a time short compared to the 10- to 25-ms-duration beam pulse, and the output produced must be useful to and interpretable by a knowledgeable operator. About the time we became aware of this need, we also became aware of the existence of a commercially available, minimodular, data-acquisition system that is ideally suited to this and similar fast scanning applications. Although the unit we selected was one of the first on the market, essentially identical models are now available from six or eight data processing component manufacturers.

Data-Acquisition System

Our minimodular, data-acquisition system contains the following interconnected elements: a 16-channel, single-ended multiplexer (also available as 8-channel differential inputs), a signal-conditioning, differential amplifier, a high-speed sample and hold, a fast, 12-bit, analog-to-digital convertor, and all control and programming logic to make the unit readily usable. These elements are contained in a 3- × 5- × 3/8-in. package with a multipin edge connector. We also purchased an auxiliary module of the same size that contains 48 single-ended channels of multiplexer input. The two units together provide 64 channels of multiplexer input. Fortunately, the differential amplifier in the auxiliary module treats negative target bias as a common mode signal and only amplifies the voltage drops across the current-monitoring resistors.

The data-acquisition system has a nominal throughput rate of 50 kHz, or 20 μs per input channel. Newer units have throughput rates up to 100 and 200 kHz (10 and 5 μs per input channel). Control points brought out and made available to the user increase clock rate and shorten digital output word length to 8 bits. This allows the modules to operate at a throughput rate of about 80 kHz, or about 12 μs per input channel. We normally use this 12-μs rate to scan all 64 input channels in about 770 μs.

The analog signal is conveniently available from a point at the output of the differential amplifier and the input of sample and hold. This signal is used to create a useful and immediately interpretable CRT display. This vertical bar-graph display is created by committing the 64 input channels as follows: The first channel has no signal; the module is set to dwell on it until triggered to start scan. The second channel is connected to a 10-V level for use as a scope-sweep trigger, and the third channel has no signal. Channels 4 through 12 are connected (in order) to current-monitoring resistors in the first row of the beam-profile pc board. Three "no-signal" channels are left

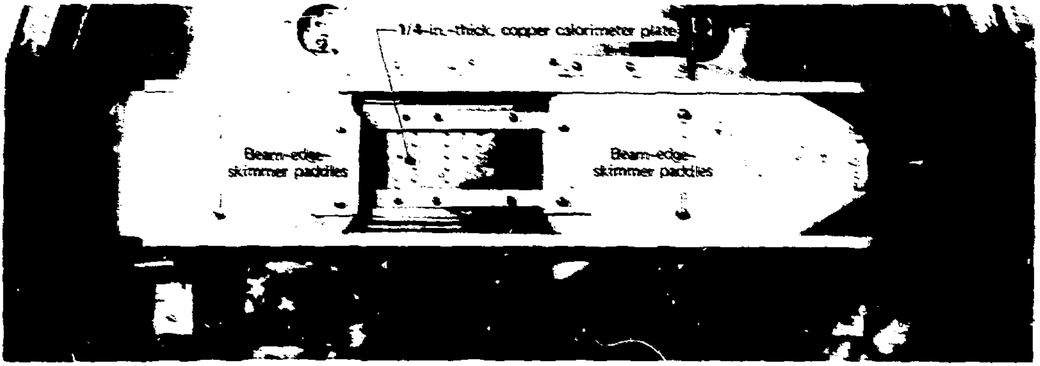

Fig. 2. Front view of beam-stopper, calorimeter plate mounted in beam-target assembly.

between every nine inputs from the remaining four rows. The "no-signal" inputs are terminated in the same resistors as the current-monitoring channels to prevent noise pickup, but no signal is connected to them. Thus 5 channels are left after all 45 targets have been interrogated. This fortunately provides about a 60-μs interval for the oscilloscope sweep circuit to recover enough to respond to the next sweep trigger when in multiple-sweep mode. If we were to look at the beam-input side of the target assembly, we would see that each horizontal line is scanned, in turn, from the upper left to the lower right corner.

Monitored voltage levels rise and fall very fast when the scanner is used at a 12-μs-per-channel throughput rate. The pulse train produced by the voltage fluctuation is amplified by a line-driver, operational amplifier before it is transmitted to the oscilloscope. Whenever a "start-scan" trigger from the ion-source control system enters the scanner chassis, the multiplexer switch sequentially scans the 64 input channels. The length of this scan period is set by an adjustable "scan-duration" timer that has a 1- to 20-ms-duration range. (Actually, the trigger first goes to a "start-scan-delay" timer with a 1- to 20-ms-duration range so the operator can preselect the portion of the beam pulse he wishes to investigate.) A 10-V, scope-sweep trigger appears at the output each time the multiplexer switch step to the second channel. The operator can select a built-in, dummy, test-voltage pattern to appear across the input resistors. The dummy pattern resembles an actual target pattern, and this built-in feature enables the operator to adjust oscilloscope sweep speed so the 45-line, vertical bar-graph pattern is spread across the full face of the CRT. The height of each voltage pedestal is directly proportional to the beam current going to its corresponding minitarget. Since display always starts with the left end of the first row of current-monitoring resistors, and there are three dead channels between each row, it is easy to identify the pattern associated with a particular row.

Overlapping and illegible repetitive display sweeps can be prevented by use of a switch-selected, linear-ramp signal. This signal, which can be made to appear at the input summing point of the line-driver, operational amplifier, superimposes the data pulse train on the linear ramp. Vertically displaced repetitive sweeps will then appear on the face of the CRT. This linear-ramp signal is obtained from one terminal of the 555 "scan-duration" timer chip, so the ramp always starts from zero and exactly coincides with the duration of the scan. The ramp signal is taken through a buffer

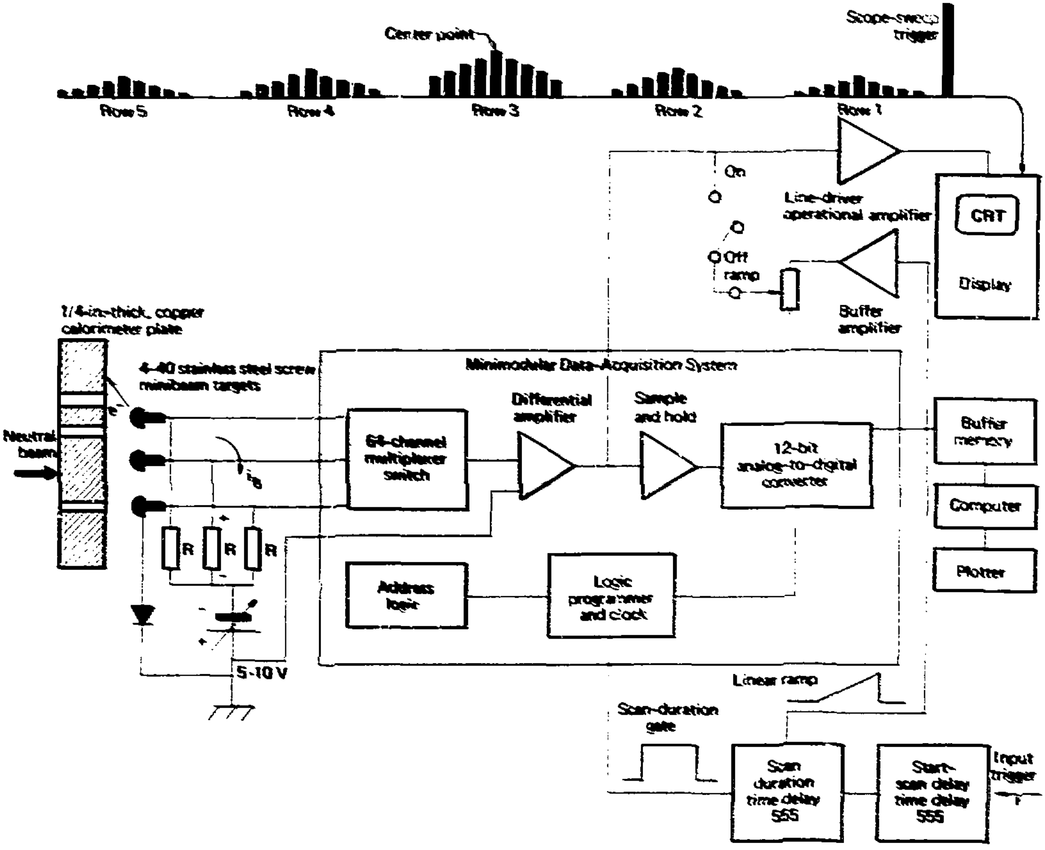

Fig. 3. Block diagram of ion-beam diagnostic system.

amplifier with an output amplitude adjust so the operator can preferentially adjust vertical displacement in the CRT display.

Beam-current monitoring resistors are located on pc cards in the scanner chassis. They are socket-mounted, 16-pin-DIP, film-resistor chips with 15 resistors per chip. Although we find 1-kΩ resistors (which develop 1 V per milliamp) about right for our application, input sensitivity can be changed by plugging in different ohmic-value resistor chips. A companion buffer-memory chassis stores the output of the analog-to-digital converter in the data-acquisition module. The digital data can then be transferred to a minicomputer where they can be software processed to produce equidensity contour plots, or whatever the investigator deems most useful.

The simplified block diagram of Fig. 3 shows how the elements that compose this ion-beam diagnostic system are connected. Figures 4 and 5 are typical oscilloscope traces of single- and multiple-sweep, beam-density profile patterns. Figure 6 shows the front of the scanner chassis and the various controls.

Our minimodular, data-acquistion systems prove excellent for fast-scan, beam-profile monitoring. Although this paper describes only the simplest mode of operation, that of continuous sequential scanning, these systems are able to random input address and to single step on command. The systems collect data in both analog and digital form and are ideal for any application requiring rapid interrogation of multipoint signal sources.

Fig. 4. Oscilloscope trace of single-sweep, beam-density profile pattern.

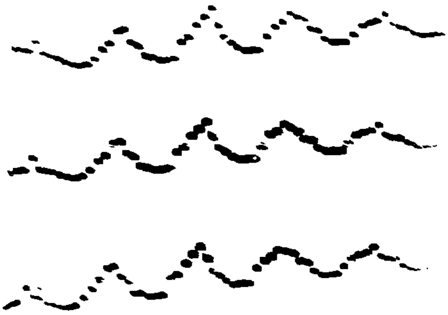

Fig. 5. Oscilloscope trace of multiple-sweep, beam-density profile pattern.

Fig. 6. Front view of scanner chassis and controls.

Acknowledgements

I wish to thank Charles C. Damm and John E. Osher who encouraged development of this ion-beam diagnostic system, and Michael J. Wilson who offered helpful suggestions and did an excellent job of constructing the prototype scanner chassis with its myriad of intricate connections.