UCRL--87756

DE83 002469

FAST PRESSURE MEASUREMENTS FOR THE TMX-U FUSION EXPERIMENT*

A.L. Hunt, F.E. Coffield, and W.L. Pickles
Lawrence Livermore National Laboratory
University of California
Livermore, CA 94550

ABSTRACT

The pressure on the boundary of the Lawrence Livermore National Laboratory's (LLNL) tandem mirror (TMX-U) plasma experiment is difficult to trace for several reasons: (1) the TMX-U boundary is in the high vacuum range (10^{-5} to 10^{-6} Pa) and requires an ionization gauge; (2) the boundary includes high-energy neutral particles and radiation, so the gauge must be optically baffled from the plasma; (3) the gauge must be shielded from the magnetic flux density of 0.03 T; (4) maximum conductance to the gauge must be preserved so that the time response remains about 1 ms; (5) a fast electrical circuit is required to measure the small ion-current changes at a rate consistent with the geometrical and experimental time constant of 1 ms. We have developed solutions to these limitations, including fast ionization gauge (FIG) circuitry for the remote gauge operation and the CAMAC system for recording the pressure-time history in the TMX-U computer data base. We also give some examples of actual fast pressure histories during plasma operation.

* Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under contract number W-7405-ENG-48.

INTRODUCTION

Pressure measurement in high-temperature plasma physics and fusion research has recently been reviewed.[1] In the tandem mirror plasma experiment (TMX-U)[2] at LLNL, measuring changes in pressure on the plasma boundary during plasma fluctuations requires an instrument with a more rapid control circuit than those now available. We have constructed an ionization gauge system with a 1-ms response time over a pressure range of 10^{-3} to 10^{-6} Pa that we believe to be of general interest and application to similar experiments.

We installed three shielded pressure-sensing assemblies on TMX-U as indicated in Fig. 1: one on each end fan and one on the central cell. This arrangement is called FIG, for fast ion gauge assembly.

The standard Bayard-Alpert (B-A) ionization gauge provides adequate time response if it is shielded from the experimental magnetic fields. Because of the unacceptable delays inherent in switching ranges, the control circuit incorporates a high-gain, low-noise current-to-voltage amplifier that covers the complete ion current range of interest. To complement the fast electrical response, the gauge is placed inside a chamber that has a small volume-to-conductance ratio so that the pumping, or filling, time is also on the order of 1 ms. The magnetic field shield surrounding this chamber is adequate in a flux density more than 3×10^{-2} T and in a rate of change of flux density of 10^{-1} T per second. Because access to the experimental area is denied, the gauge controller is remotely operated at a distance of 50 m. The ion and emission currents are also recorded at that remote location.

ION GAUGE PRINCIPLES

The collected ion current is directly related to the electron emission and the pressure by $i^+ = S P i^-$. The constant S, which is called gauge sensitivity, is a function of the gauge geometry. S is furnished by the gauge manufacturer, but large gauge-to-gauge variations are caused by small differences in the location of elements. Therefore, each gauge must be calibrated if accurate pressure measurements are required.[3] The B-A gauges used are the nude design with a nominal sensitivity S of 18.8 x 10^{-2} Pa^{-1} (25 $Torr^{-1}$) for nitrogen gas. If the gas is not nitrogen, the change in gauge sensitivity is usually applied separately.[4] (To determine gas composition, each shielded pressure gauge has a mass spectrometer.) There is no assurance that the gas composition in the gauge volume remains unchanged during the plasma density changes. Because nitrogen sensitivity is 18.8 x 10^{-2} Pa^{-1} and hydrogen or deuterium sensitivity relative to nitrogen is 0.4, the resulting sensitivity for deuterium is 7.52 x 10^{-2} Pa^{-1} (10 $Torr^{-1}$). Because of our present limited knowledge of the gas composition during the experiment and the difficulty in processing these data in the computer, we have found it convenient to record the electron and ion currents as a function of time. A gas sensitivity factor can be obtained later by manually analyzing the mass spectra and machine computation of the true pressure-time display.

ION GAUGE MAGNETIC SHIELDING

The shielding chamber includes two gauges and a quadrupole-type mass spectrometer. One gauge is connected to a commercial controller for general pressure monitoring. Figure 2 is a photograph of the 304 stainless steel vacuum enclosure. The magnetic shielding is external and consists of a wrap of Co-Netic A-A alloy covered by a 1.6-cm-thick iron pipe with an end cap 1.3 cm thick.[5] The axis of the pipe enclosing the vacuum chamber (also shown in Fig. 2) is arranged perpendicular to the magnetic field direction for maximum effectiveness. The electron emission current is recorded on the same time scale as the ion current, so any evidence of magnetic field penetration can be detected.

The pulsed field of several seconds does not influence the gauge readings or the electron emission. The more sensitive electron multiplier on the mass spectrometer has also shown no indication of magnetic field penetration past the shielding. Both the ion gauges and the mass spectrometer are shadowed from the plasma charge-exchange neutrals, titanium gettering deposits, and plasma photons by an array of three small stainless steel disks and dividers bolted into the bottom of the vacuum enclosure (shown in Fig. 2). The dividers prevent the intermixing of electric fields and allow the gauges and mass spectrometer to operate independently.

FAST ION GAUGE CIRCUIT

A block diagram of the circuit is shown in Fig. 3. The proximity of the control circuit to the shielded gauge is shown in Fig. 4 and the remote controller and CAMAC crate installation are displayed in Fig. 5. The collected ion current-to-voltage converter has a 0.1-ms time response and a linear relationship between current and output voltage over three decades corresponding to 10^{-3} to 10^{-6} Pa. Two separate amplifier/line-driver circuits provide this large range without switching between amplifiers. The lower pressure amplifier is allowed to saturate as the higher pressure amplifier enters its operable range.

Rapid electron emission regulation is desirable because the work function and therefore the electron emission may change at a rate comparable to the rate of change in the surface coverage of absorbed gas on the filament surface. It is difficult to maintain constant emission during the 1-ms gauge response time because the thermal capacity of the filament and the available power restrict response times to the order of 10 Hz. The emission current is recorded on the same time scale as the ion current, and the ratio of ion-to-electron current may be computed to correct apparent pressure fluctuations caused solely by emission changes. Two emission ranges are provided, 0.4 ma and 4 ma.

Over-pressure protection is provided for the ion gauge. The amplified ion current trips relays that interrupt the filament supply. Degas logic and control relays connect the collector to the grid for degassing by electron bombardment. During degassing the potential difference between the grid collector and the filament is 300 Vdc. The emission current is limited to 50 ma and therefore the power is restricted to 15 W in the degas mode. A novel feature protects the gauge in the degas mode. If the pressure rises too rapidly and an arc develops between the grid collector and the filament, an arc detection circuit returns the circuit to the pressure-sensing mode where the over-pressure trip can operate.

The data acquisition system is designed with CAMAC standard components that are selected for overall TMX-U operational convenience.[6] The amplifier/line-drivers feed the digital system through two LeCroy Model 8100 dual-programmable differential amplifiers with optional local and remotely set gains. The output from these amplifiers is digitized by a LeCroy CAMAC Model 8210 quad 10-bit transient digitizer. The A/D converter has an analog-signal-out that is convenient for monitoring gauge operation. It can also be used on an oscilloscope as a good pressure-time display. The memory module used is a single LeCroy Model 8800/10 because the clock rate for digitizing is low and the required memory capacity is small. After each 100-ms plasma experiment, the TMX-U computer reads the memory of the CAMAC system, stores it on disks, and eventually transfers it to tape.

GAUGE SYSTEM UTILITY

Figure 6 illustrates the fast pressure histories at the plasma boundaries (shown in Fig. 1) during two separate TMX-U experiments, labeled as shots 20 and 21 on August 6, 1982. These pressure traces give comparative histories for two methods of generating the initial plasmas. In each case, after the initial target plasma is generated in the magnetic field, it is increased in energy and density by subsequent ionization and trapping of the high-energy neutral beams over a period of about 65 ms. In the first method, a high-density, low-energy plasma is injected axially along the magnetic flux lines to generate a "stream" plasma. In the second method, high-powered electromagnetic radiation at the electron-cyclotron resonant frequency of 28 GHz interacts with deuterium gas to generate a high-density, low-energy target plasma. This second method is called electron-cyclotron resonance heating (ECRH).

In Fig. 6 the top pair of traces is the pressure history of the FIG with the mnemonic FCCS1 located at axial coordinate $Z = 0$. The middle pair of traces is from the gauge at $Z = 10$ m with the mnemonic FEFS1. Similarly, for the lower pair of traces the mnemonic is FWFS1, which is located 10 m on the west side of the central cell. The ordinates of Fig. 6 are corrected for gas composition, which the mass spectrometers indicate to be mostly deuterium.

There is no significant difference in the power introduced into the target plasma after either method of start-up plasma generation. The ECRH is on from 5 to 25 ms at a power of 55 kW. The neutral beams inject about 615 A at an average energy of 10 keV, or about 6 MW. The quantity of gas introduced by the beams at the rate of 8.2×10^3 Pa•liter/sec is

5.3×10^2 Pa•liter over the 65-ms beam-on time. In both experiments the gas boxes introduced deuterium at the inner mirrors at the rate of 7.3×10^3 Pa•liter/sec for a period of 60 ms, or a quantity of 4.4×10^2 Pa•liter. The beams and gas boxes introduced a total of 9.7×10^2 Pa•liter in each experiment. The higher pressure on the boundary for all FIG locations appears to be caused by the 4×10^2 Pa•liter of cold gas introduced during the generation of the start-up plasma by the injection of the "stream plasma." These pressure studies show ECRH to be the superior method for generating the start-up plasma if later, more extensive investigations indicate that the resulting plasma is of equivalent high quality.

ACKNOWLEDGMENTS

We wish to acknowledge our debt to all in the TMX group and we especially wish to thank Thomas P. Stack for arranging the ion gauges and mass spectrometer within the vacuum chamber and testing the magnetic field shields during the early phases of this work.

REFERENCES

1. H.F. Dylla, J. Vac. Sci. Tech. 20, 119, 1166 (1982).
2. F.H. Coensgen, T.C. Simonen, A.K. Chargin, and B.G. Logan, TMX Upgrade Major Project Proposal, Lawrence Livermore National Laboratory, Livermore, CA, LLL-PROP-172 (1980)
3. K.E. McCulloh and C.R. Tilford, J. Vac. Sci. Tech. 18, 994 (1981); C.R. Tilford and K.E. McCulloh, J. Vac. Sci. Tech. 20, 1140 (1982).
4. D.R. Denison, Methods of Experimental Physics, 14, 73 (1979), Ed. by G.L. Weissler and R.W. Carlson.
5. Co-Netic, A.A. Alloy, made by Perfection Mica Co.
6. LeCroy Research Systems of California, 1806 Embarcadero Rd., Palo Alto, CA 94303.

MD/kt
MFE/PC/82-100
3473w/0420w

FIGURE CAPTIONS

Fig. 1. FIG measurement positions on the boundary of the TMX-U plasma. The flow of information from the gauges to the computer and data storage system is indicated.

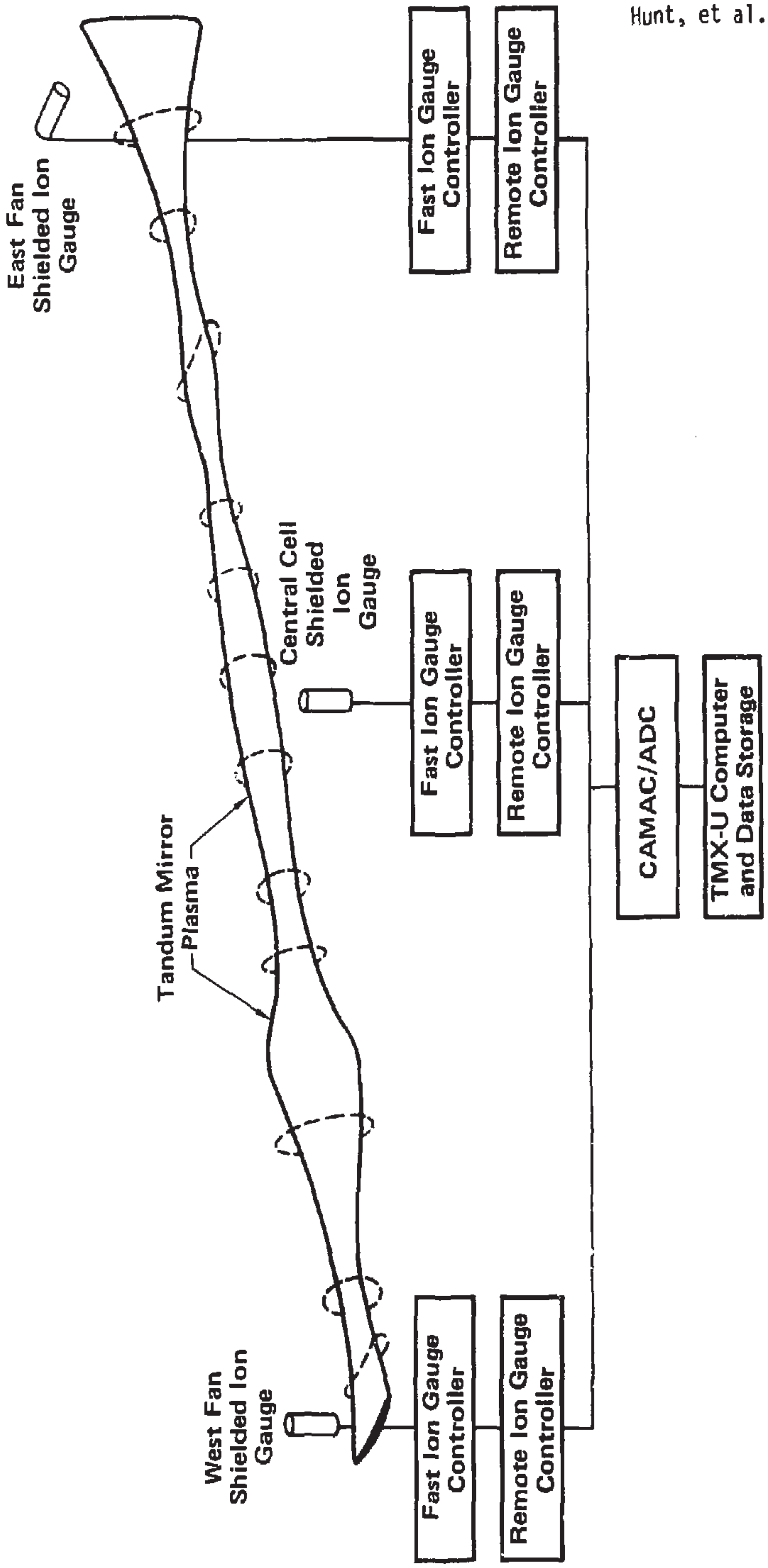
Fig. 2. The 304 stainless steel vacuum chamber for two ionization gauges and a quadrupole mass spectrometer. This chamber is protected from the magnetic field by external shields.

Fig. 3. Block diagram of the FIG controller circuit.

Fig. 4. Shielded ionization gauges and mass spectrometer mounted on the west-end fan of TMX-U with the axis of the shield perpendicular to the magnetic field. The shielding box attached to the cylinder protects the mass spectrometer high-frequency electronics. The FIG controller for the shielded gauge is unshielded but mounted to minimize the effect of the field.

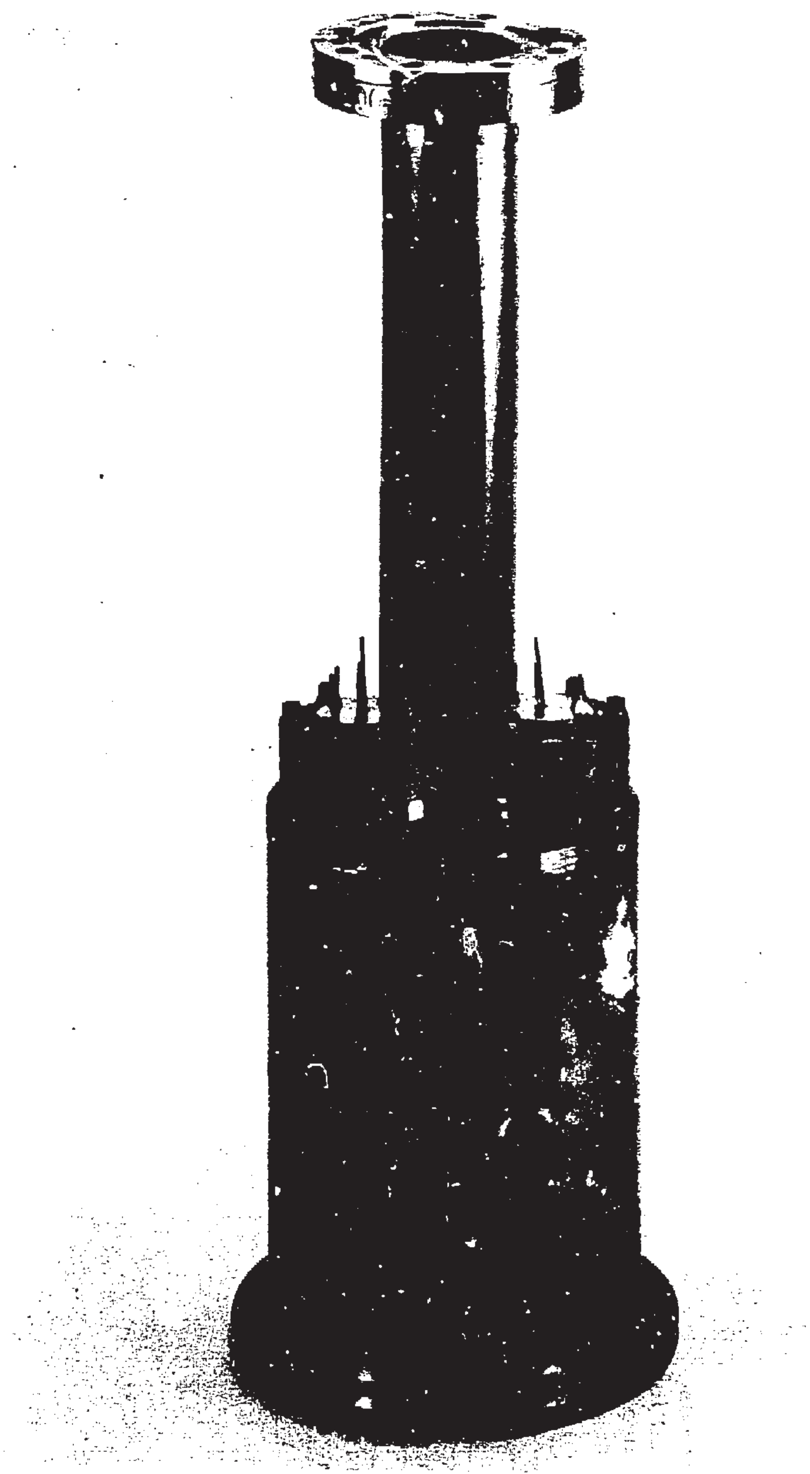
Fig. 5. Remote FIG controller and CAMAC crate installation. The oscilloscope is a convenient monitor of the analog signal from the A/D converter.

Fig. 6. Fast pressure histories at the plasma boundaries shown in Fig. 1 for the stream and ECRH methods of generating the initial target plasmas in TMX-U.

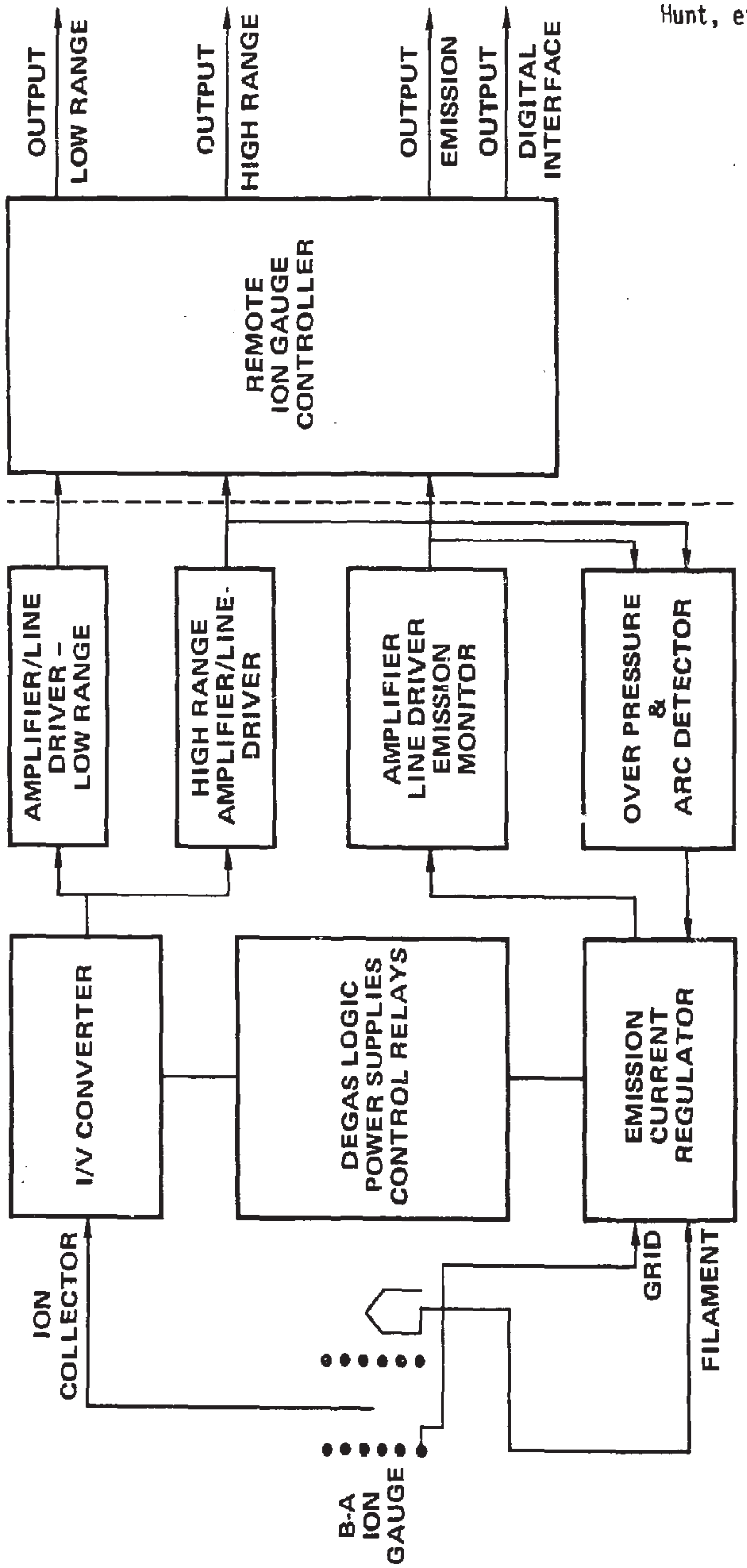


Hunt, et al. Fig. 1

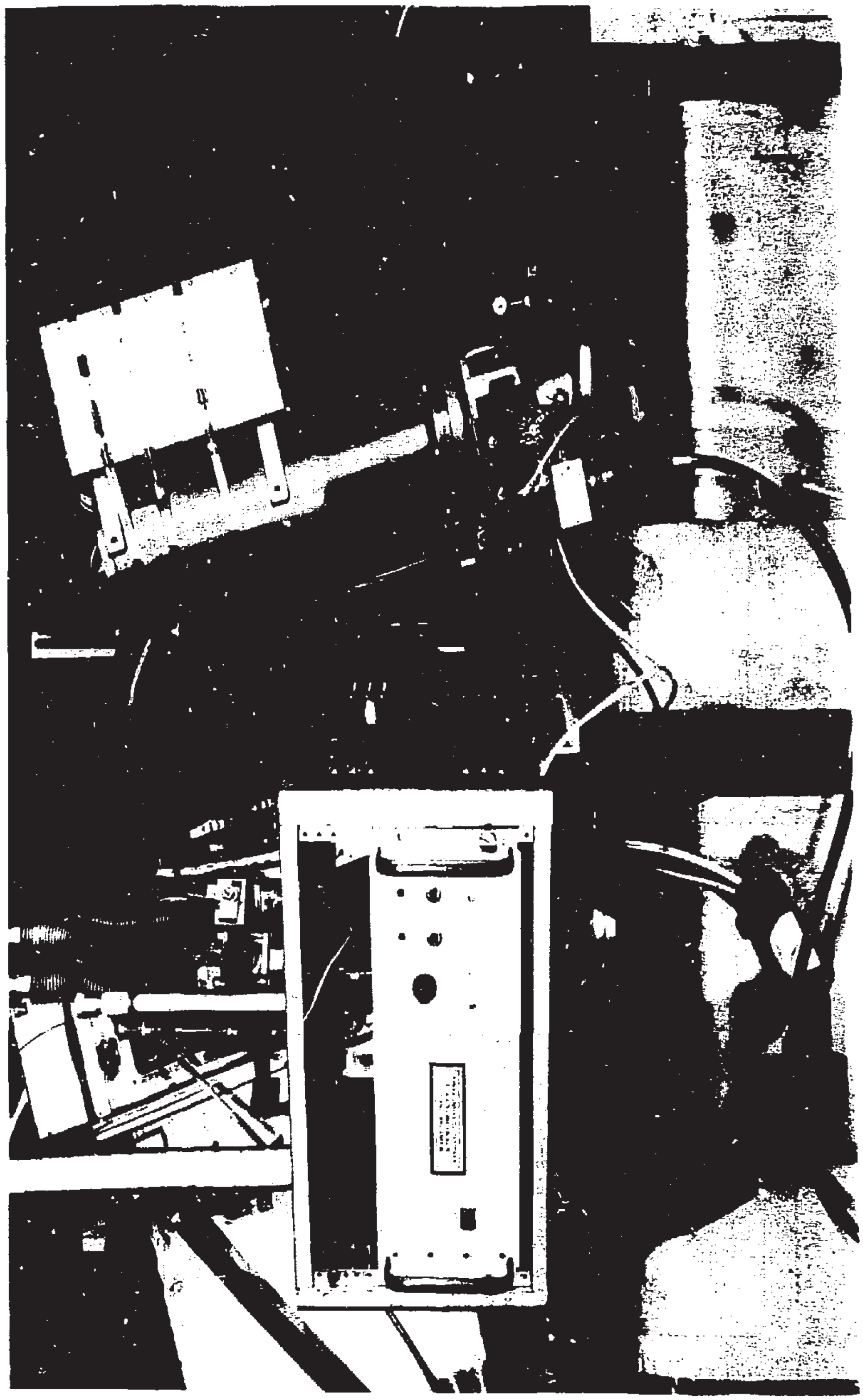
Hunt, et al. Fig. 2



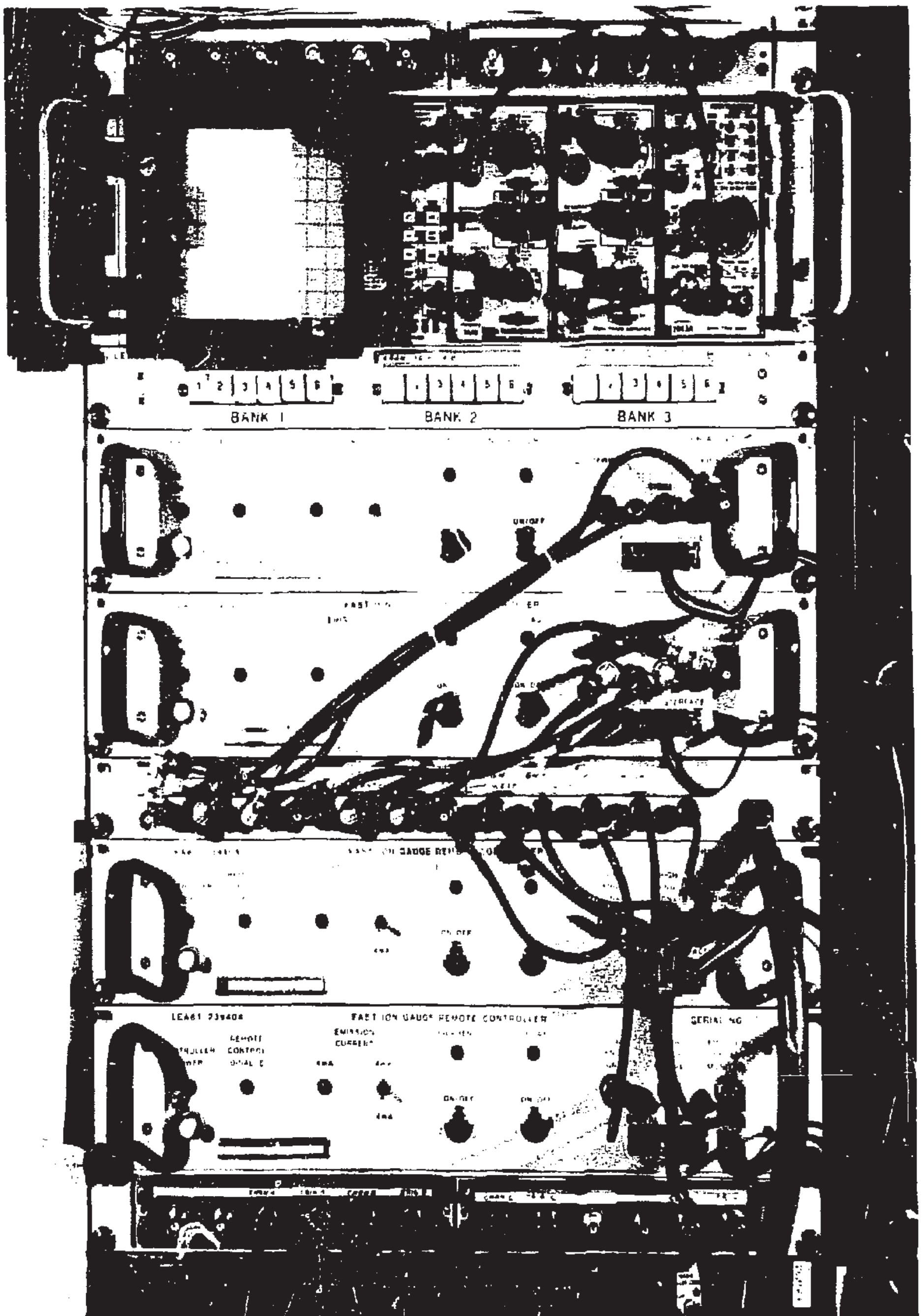
Hunt, et al. Fig. 3



Hunt, et al. Fig. 4



Hunt, et al. Fig. 5



Hunt, et al. Fig. 6