RADIATION HARDENED PROTON METER FOR FERMILAB EXTERNAL BEAM LINES

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Summary

A beam line current and charge monitor has been in use for several months with the following characteristics: (1) beam toroid in high radiation area 200 feet from electronics, and within 30 feet of the 140,000 ampere pulsed neutrino horn, (2) response time adequate to permit accurate (1%) measurement of 1 turn fast-extracted beam, (3) digital and analogue readouts for full scale ranges of 2×10^{12}, 1×10^{13}, and 5×10^{13} protons per pulse, (4) computer readout and standardization via CAMAC, (5) pulse-to-pulse repeatability is 1 in 1000 on test pulses. There is no interference from the horn, which pulses at the same time as the beam.

Introduction

The beam current measuring system described here is a further development of a device previously described.[1] The central task of the present design was to reduce to a minimum all radiation-sensitive components in the beam pickup "head." It has been found practical to completely separate the electronics chassis from the beam toroid and still maintain good immunity from electrical noise. The resulting device consists of a well-shielded current transformer to be mounted in a beam line, a triaxial cable about 200 feet long, and a rack-mounted signal-processing chassis.

In Fig. 1, the pickup "head" is shown at the left of its electronics chassis, which is normally several hundred feet away. Standing vertically in the background is the cylindrical multilayer magnetic shield that fits over the pickup "head."

An additional task was to insure minimum interference from neighboring powerful electrical apparatus, e.g., the 140,000 ampere pulsed neutrino horn (paper I-6, Fermilab Neutrino-Horn Focusing System, F. A. Nezrick, this conference) which device is within 30 feet of the beam transformer, in the same beam line.

Description of the Beam Transformer

Adequate shielding of the transformer is required because the beam spill current must be accurately monitored during the high-current pulse to the horn. Gating out "interference" from the electrical noise of the horn and its power supply is not possible because it would eliminate the desired signal.

Figure 1 along with Fig. 2 show some of the pieces that make up the beam current "head." The essential parts are the toroid transformer core, a close-fitting internal magnetic shield, a ceramic seal which provides an electrical gap in the vacuum pipe, and the gaussian shield. The winding on the core is wound in a cross-back fashion which provides maximum cancellation to magnetic fields that are not confined to the path of the toroidal core, i.e., it reduces pickup from stray fields but gives exactly the pickup to true signals generated by currents threading the core.

The selection of the toroidal core and its winding involved several considerations, very much the same as those of Ref. 1:

1) Low frequency response (pulse droop) and high-frequency response (pulse rise time) must be adequate to observe accurately the 21 μsec pulse of the beam. Since the high frequency response does not depend on the core, the core of highest permeability should be selected.

2) Stray parameters such as winding distributed capacitance should be controlled, and the winding should lend itself to direct connection to a 50 ohm transmission line.

A 150 turn winding of #20 wire on a 4 mil tape-wound Supermalloy core of 1 inch^2 cross section resulted in a beam current transformer with the following properties (low level):

1) Shunt L = 1.6 Hy.
2) Shunt R (reflected core loss) = 12.6 ohms.
3) Pulse droop = 7 parts in 10,000.
4) Pulse rise time = 25 nsec.

In place, the wound core is nested inside the internal magnetic shielding. Note the small gap on the inner-circumference of this magnetic shield as seen in Fig. 3. This is necessary of course, to prevent a shorted turn around the core. The construction of the shield is such that the two halves press together around the core.

Figure 3 is an assembly drawing showing how the various pieces fit together. From Fig. 1 it is seen that the gaussian shield is two "halves" which clamp together. The enclosure so formed contains the magnetically shielded toroid within and serves as a coaxial path around the outside of the core and along the vacuum beam pipe. Thus electrical shielding as well as mechanical rigidity is provided by this enclosure. Note that although the gaussian shield is grounded to the beam pipe, the core and its magnetic

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shielding are not. There are no active devices in the head. Probably the wire insulation is the only appreciably radiation-sensitive material present.

Description of the Triaxial Signal Cable

Figure 4 shows a cut-away view of the cable. The outer most shield connects the gaussian enclosure to the signal-processing chassis. The middle shield goes to the internal magnetic shield structure. The intermost conductor and shield form a transmission line of 50 Ω impedance and connect the toroid core winding to the input amplifier. In this configuration, (1) the signal cable is electrically terminated at the receiving end, and (2) the signal ground of the beam current transformer comes from the electronics chassis. The outermost shield of the triax cable serves as a guard to intercept all external electrostatic flux and direct any resulting displacement current so that no noise current flows on the ground shield of the signal cable.

Further, to attenuate noise currents external to the triaxial cable, the cable is loaded externally with 200 each 0-5 ferrite cores (manganese-zinc).

The cable triax connector problem was solved by duplicating the connector already in use by the accelerator r. f. systems.

See Fig. 5 which shows an opened connector and its connection technique to the triax cable.

A second cable, carrying a much higher level signal for test pulsing, follows the same path as the triax cable from chassis to head.

The Signal-Processing Chassis

The functions of this chassis are:

1) Provide the "ground" to the remote beam transformer as previously discussed.
2) Terminate the signal cable in 50 ohms, process the signal for direct view and as an integrated signal (charge), and digitize the charge.
3) Provide test, monitoring, and calibration features.

To meet the specification that the device response time be fast enough to permit measuring beam current during fast spill of one main-ring turn ("fast-spill" consists of a ~ 21 μsec duration train of 53 MHz bunches) to ±1% necessitated impedance-matching the toroid to a 50 ohm cable and matching the cable to a wide-band input op-amp.

Referring to Fig. 6, one sees the timing sequence and signal processing diagram.

The main amplifier is provided with remotely switchable input and feedback resistors to provide digital and analogue outputs over charge full-scale ranges of 5×10^{13}, 1×10^{13}, and 2×10^{12} protons.

To remove non-constant noise effects such as amplifier offset and drift, the integrator first negatively integrates for 150 μsec then positively for 300 μsec and again negatively for 150 μsec. The entire beam spill must occur within the 300 μsec of positive integration. Thus any signal (noise) common to both the negative and positive integration periods is subtracted out.

For fast spill (21 μsec duration), it is convenient to center the spill in the 300 μsec interval by triggering the device with a machine clock pulse which occurs 300 μsec before fast spill.

After the integration process is completed, the value of the output of the integrator is converted to a digital signal. The switch across the integrating capacitor is closed removing the analogue information, now digitally stored, and readies the integrator for the next fast beam spill cycle.

Display

The digital signal is displayed on the front panel via decimally decoded seven segment LEDS and is outputted through a 23-pin connector. This output, along with a LAM signal is read by the MAC-16 computer system. The device then can be controlled and read remotely during the experimental run.

Built-In Calibrate/Test Feature

A known charge

$$\left(Q = \int_{T1}^{T2} I(T)\, dt \right)$$

is passed through the toroid by means of a single turn test winding to provide both a level of confidence in total system operation and a numerical calibration. This calibration can be done locally, or remotely, via computer (MAC-16/CAMAC system). Figure 6 shows the essential parts of a test charge calibrator circuit which is in the signal processing chassis. In operation, all the transistors are normally saturated sinking the current from the resistors in their respective channel, biasing off all the diodes. When any one of the inputs (A, B, or C) is set to a logic "1" and the 100 μsec one shot is operated, the resistor current is switched from its associated transistor and "ORed" into the 50 ohm coax line. The pulse thus formed is terminated in the characteristic impedance of the coax line after passing through the one turn winding of the toroid.

Good long-term stability in this circuit is achieved for the following reasons:

1) Wire-wound current-determining resistors, adequately heat-sinked, are maintained in thermal equilibrium because current (very nearly the actual required current) is maintained at all times.
2) The switching transistors do not determine the current, they only switch it on and off, (i.e., current switching is employed).

3) Hot-carrier diodes perform the current switching, with low forward drop together with the fast turn-on and turn-off required of the current pulse to achieve accurate total charge within the 100 μsec interval.

4) Mica timing capacitors and metal film resistors maintain the timing accuracy of the one-shot.

Results of several months of operation of the charge calibrator have proved it reproducible to within 1 part in 1000.

Conclusions

The system described here has operated under the following conditions:

1) Beam toroid located 200 feet from the amplifier/logic circuitry and in a radiation environment where the typical beam halo through the material of the toroid is 10^9 particles per pulse. Residual radiation measured at the toroid one-half hour after turn-off of a beam of 2×10^{12} particles per pulse for several shifts was 100 mrad/hr.

2) Beam toroid located 30 feet from the 140,000 ampere pulsed neutrino horn. The system has been in use for several months, there is no detectable interference from the neutrino horn pulse. Pulse to pulse stability of the charge measurement is ~/part in 1000.

Acknowledgments

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References

[1] C. R. Kerns, Proton Meter for NAL External Beam Lines, IEEE Trans. Nucl. Sci., NS-20 (1) 204 (1973).

Figure Captions

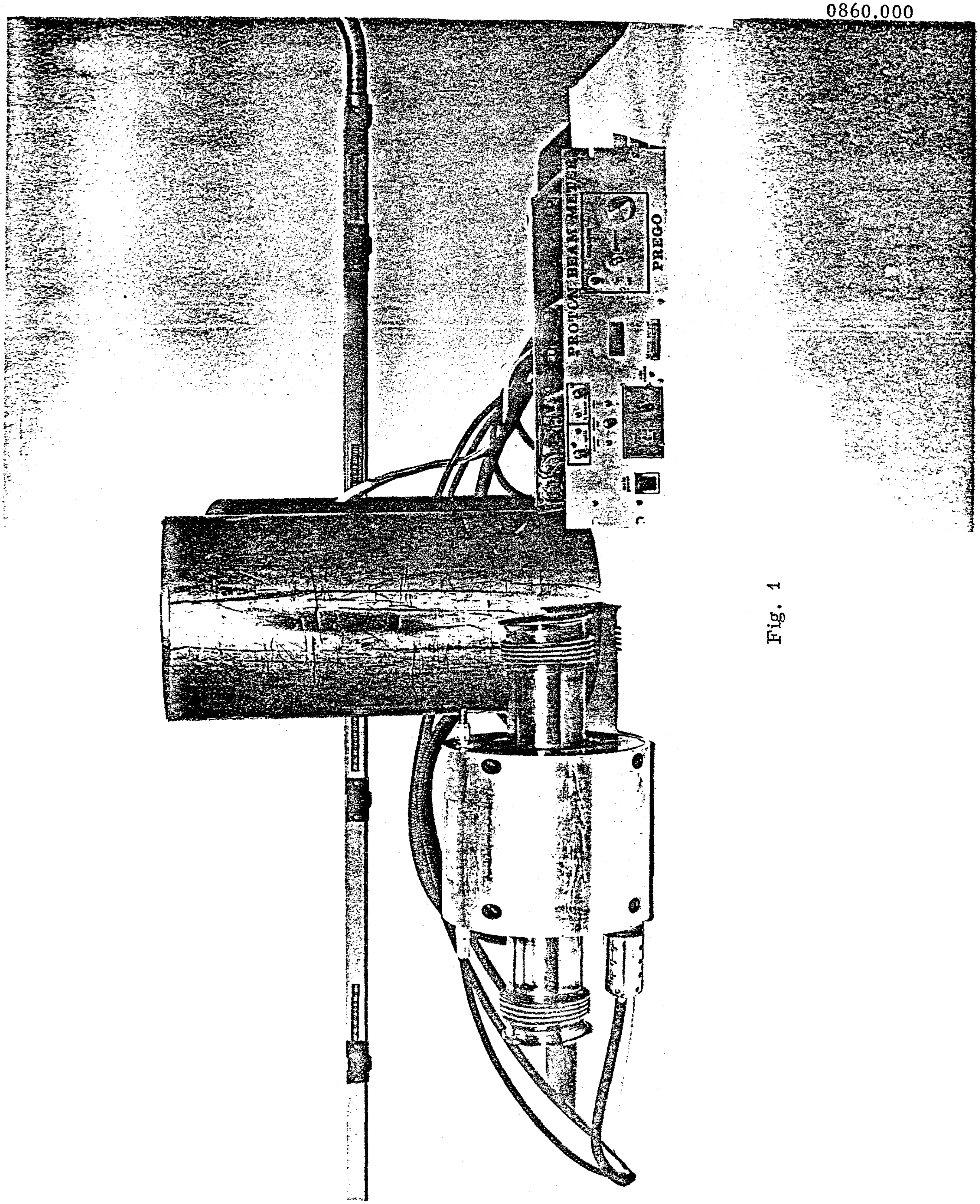


Fig. 1

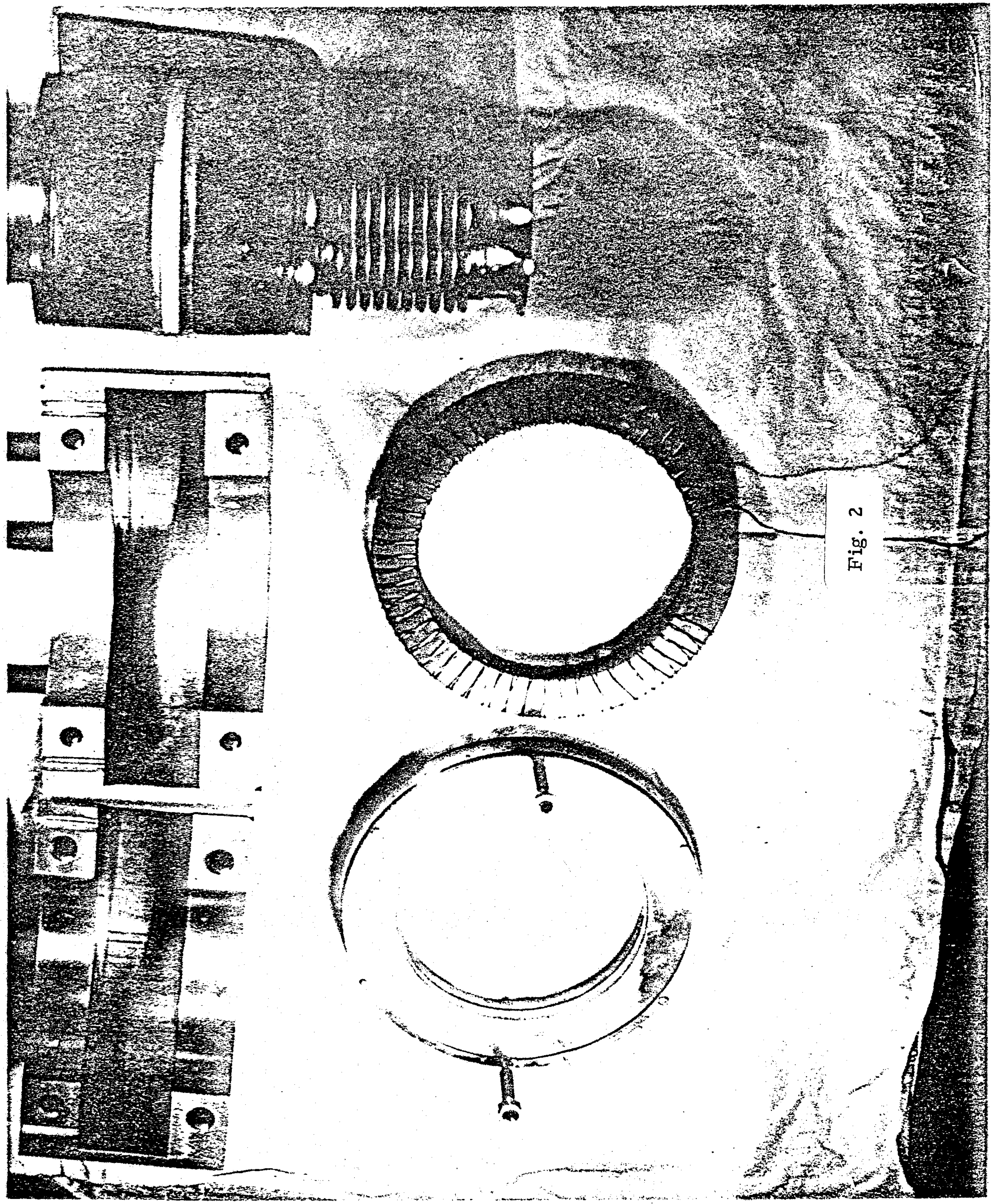
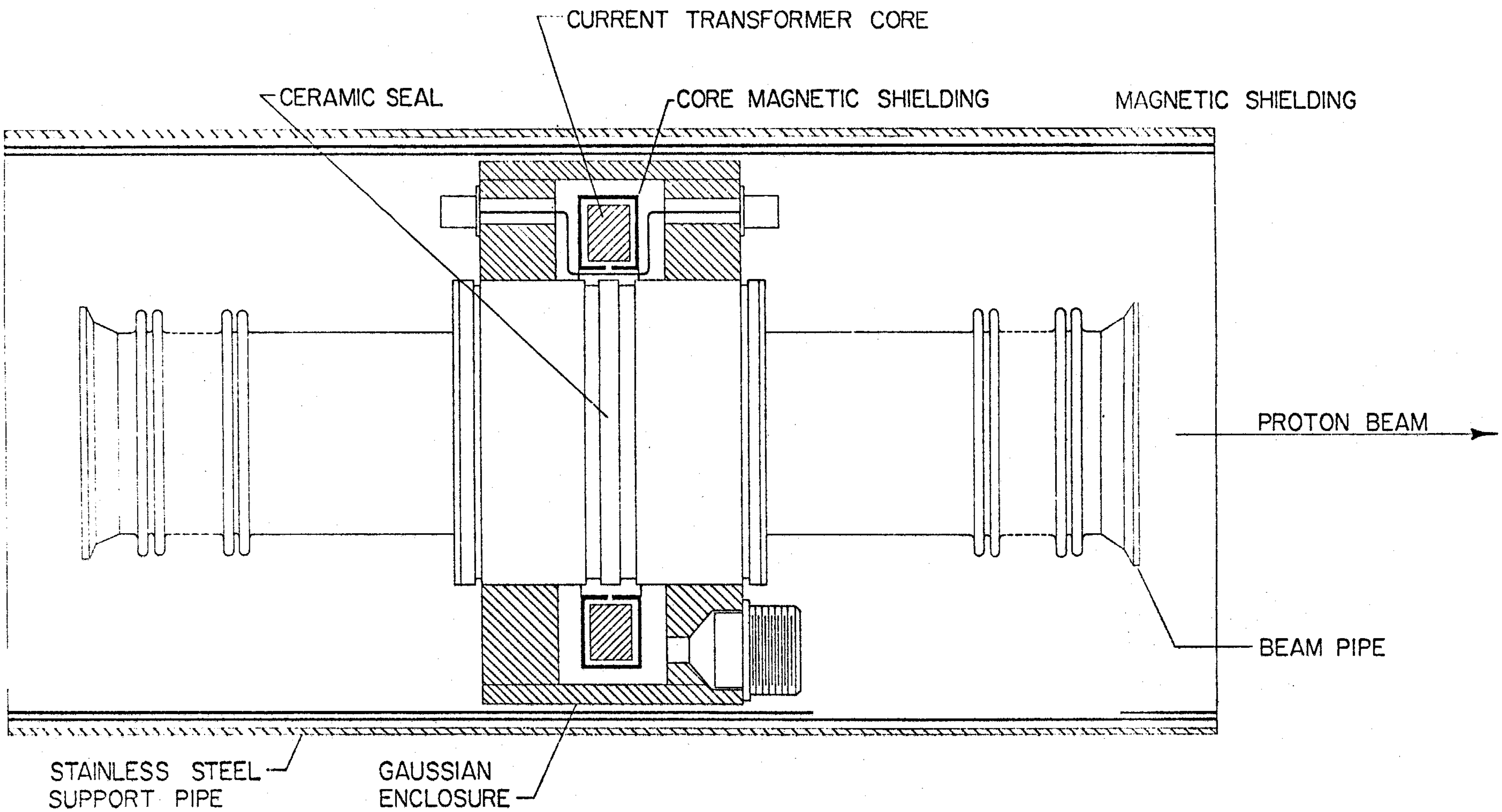


Fig. 2



BEAM METER
ENCLOSURE

Fig. 3

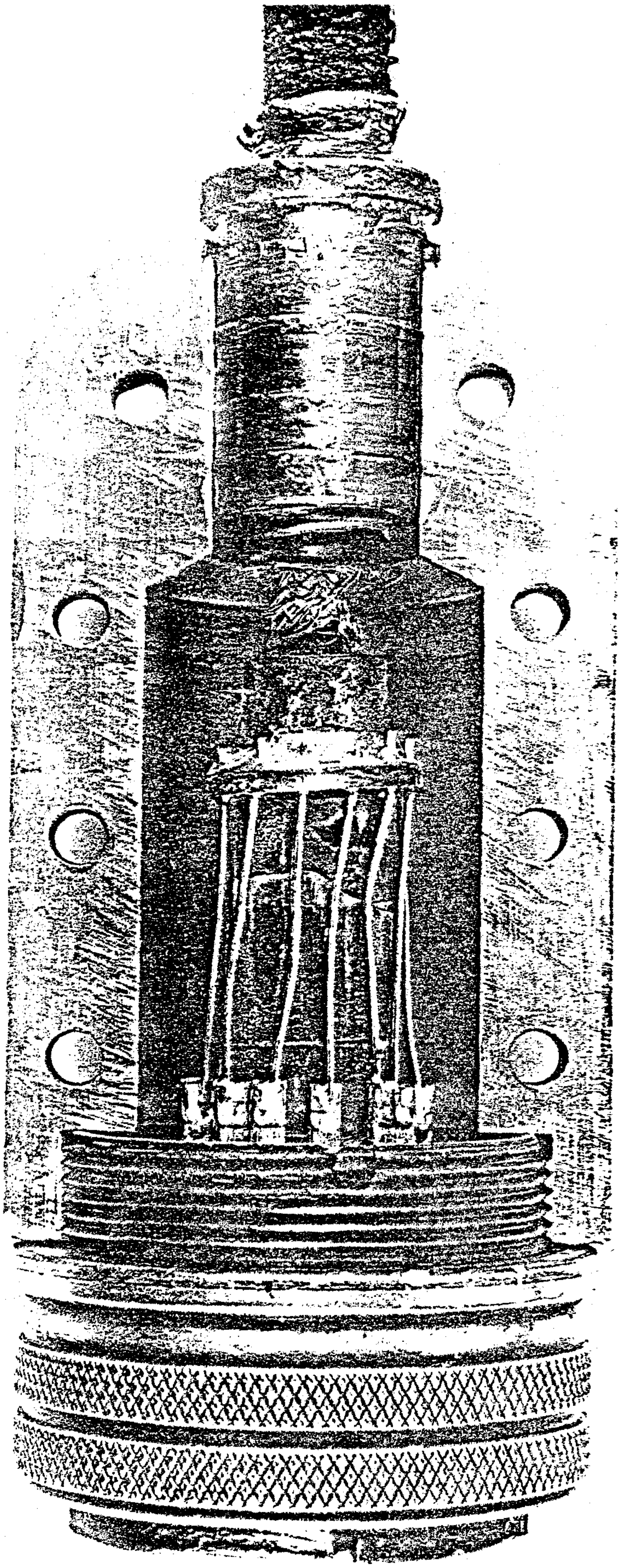


Fig. 4

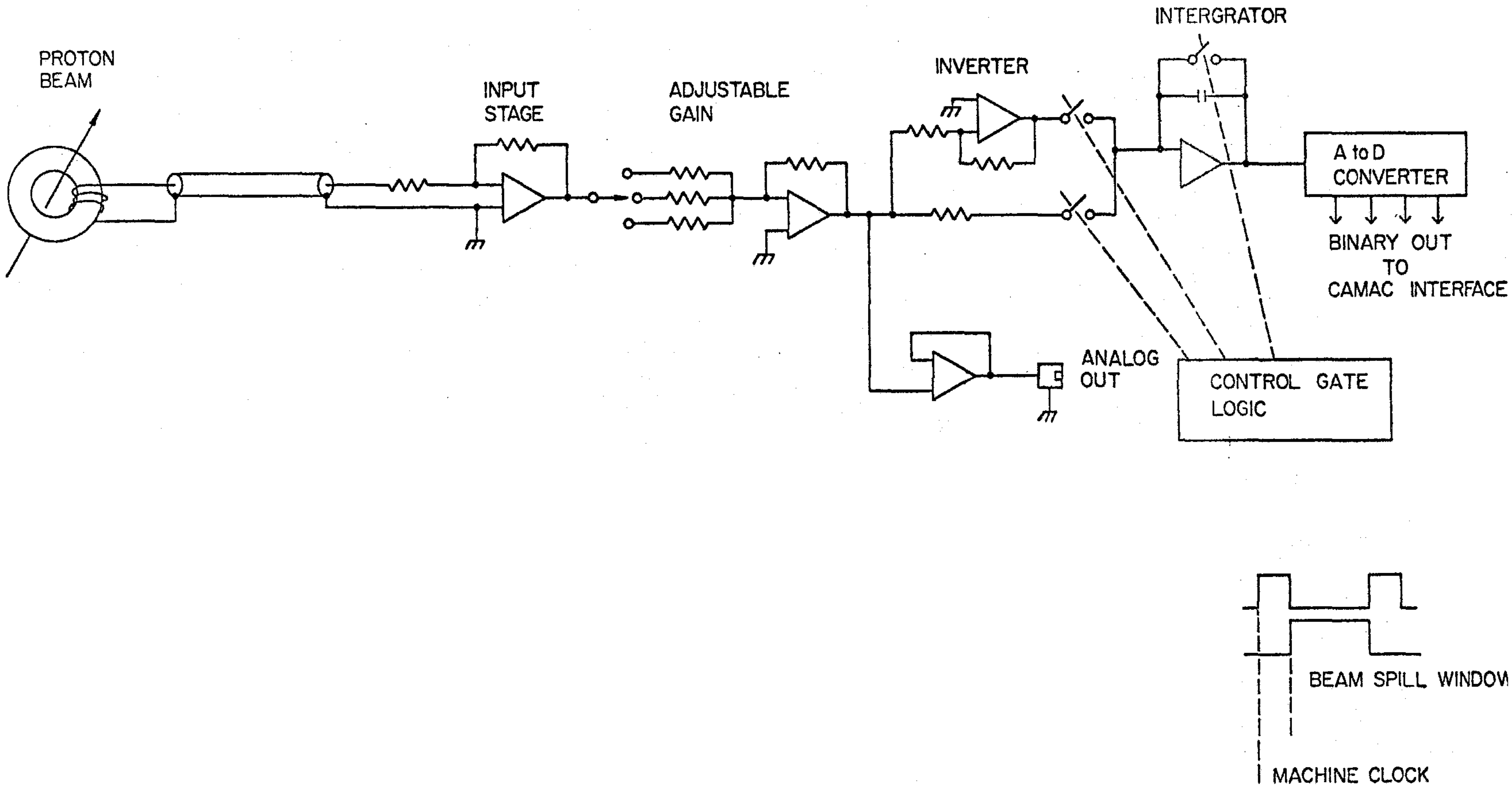
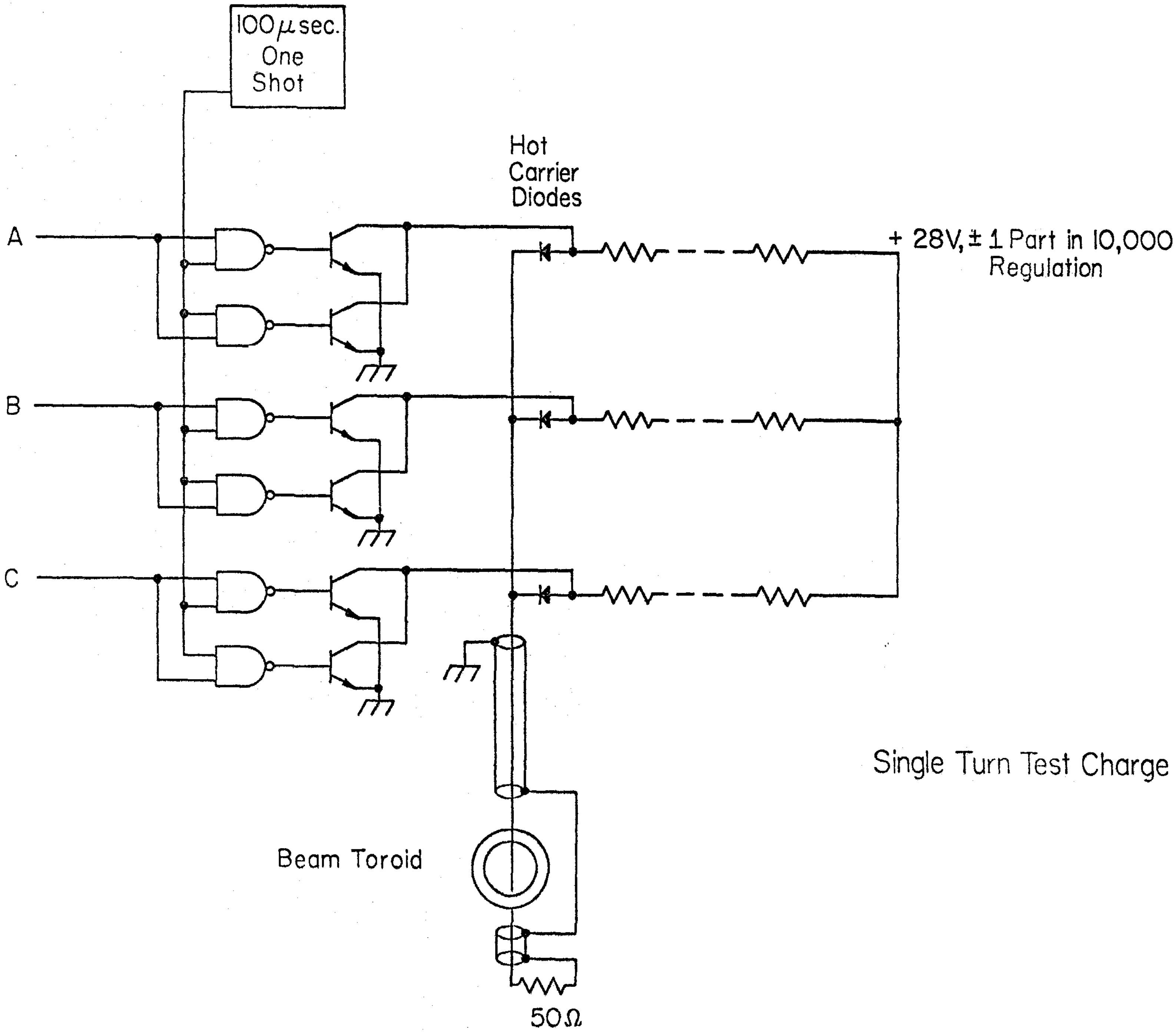

PROTON
BEAM
INPUT
STAGE
ADJUSTABLE
GAIN
INVERTER
INTERGRATOR
A to D
CONVERTER
BINARY OUT
TO
CAMAC INTERFACE
ANALOG
OUT
CONTROL GATE
LOGIC
BEAM SPILL WINDOW
MACHINE CLOCK

Fig. 5



Single Turn Test Charge Calibrator

Fig. 6