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WIDE-RANGE MONITOR FOR PULSED X-RAY SOURCES

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WIDE-RANGE MONITOR FOR PULSED X-RAY SOURCES

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A monitoring instrument based on a high-pressure ionization chamber has been developed that measures average dose rates as low as 0.1 mR/h and responds linearly to short pulses at dose rates up to 1.2×10^{10} R/h. Its sensitivity can be remotely changed by a factor of 10^4, to enable accurate measurement of both background radiation and very high intensities such as can be expected from accelerator beam-spills. The instrument's detector-electrometer pulse response was measured using a dose-calibrated field-emission accelerator having a 30-ns pulse width.

Introduction

We have developed a radiation-monitoring instrument that is sufficiently sensitive to monitor the 40-h work environment in the control area of a pulsed x-ray accelerator; its sensitivity can also be changed by a factor of 10^4. It measures average levels as low as 0.1 mR/h and responds linearly to short pulses at dose rates up to 1.2×10^{10} R/h. When placed adjacent to the accelerator, it can perform beam diagnostics as well as, after shutdown, measure the activation products formed.

The instrument uses a Reuter-Stokes high pressure ionization chamber with specified steady-state range of 10^{-4} to 10^5 R/h, sensitivity of 5×10^{-10} A/(R/h), and leakage of 10^{-14} A at 1500 V. The electrometer circuit[1] was developed at DOE Environmental Measurements Laboratory (EML) and has a stability of 3×10^{-15} A at temperatures from -20° to 40°C.

The initial application of this instrument will be for the FXR (Flash X-Ray) Accelerator, which has a pulse width of 60 ns occurring every three seconds during tune-up pro dures. It will also be used to monitor other pulse machines, both new and existing.

Electrometer Circuit

The electrometer circuit (shown in Fig. 1) acts as a current amplifier for steady-state ionization chamber currents and as a charge-sensitive amplifier with 0.3-s decay time constant for fast current pulses. The P-channel enhancement mode MOSFET, HDIG 1030, is cleaned, temperature-aged,[1] and tested for low (≤5 × 10^{-15} A) leakage. Then the optimum drain current (~400 µA) is found for the minimum temperature coefficient of the operating point. The circuit acts to keep zero volts on both the gate and drain. The drain current is set by adjusting the I_D potentiometer when the selected MOSFET is put in the circuit. The zero potentiometer is used to zero the electrometer circuit output without affecting I_D.

Since we operate down to 0.1 mR/h, corresponding to 0.5 mV from the electrometer, the +7.5 V and -7.5 V power supplies and the bias resistors must be very stable. Unlike the negligible effect of power supply voltages on operational amplifiers, a 0.1-mV change in the +7.5 V results in a 0.1-mV change in the electrometer output. The sensitivity to changes in the -7.5 V is scaled down slightly by the MOSFET G_m. Both the voltage sources are the AD584, which are stable to 10 ppm/°C, and the resistors are stable to ±25 ppm/°C.

The 301A operational amplifier has adequate temperature stability and band width and is frequency-stable with the 0.30-µF feedback capacitor used in the

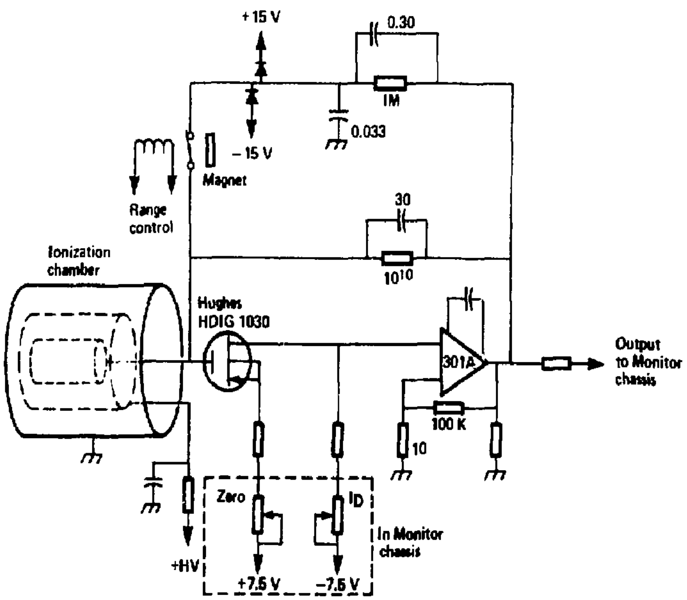

FIG. 1. Simplified schematic of electrometer circuit.

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high range.

A reed switch is used to change range by a factor of 10^4. A permanent magnet is used to hold the switch in the closed position, thus making the switch less sensitive to stray magnetic fields. Regardless of which range has been selected, when the unit is turned on, a one-minute one-shot delays the switch opening. The amplifier is thus kept in its less sensitive range to protect the MOSFET from HV transients and to allow quiescent operation of the following circuits to be more quickly reached. The reed switch also closes and allows for circuit protection if power is lost. The diodes offer additional protection for the MOSFET during transient conditions.

Since we are operating at times with small signal currents (0.1 mR/h corresponds to 5×10^{-14} A), the HV power supply must have very low noise. Noise voltages result in noise currents through the 100-pF HV-electrode-to-signal-electrode capacitance. For a resulting current of $\leq 10^{-14}$ A, the voltage drift rate must be ≤ 0.1 mV/s. A multiple-section filter is used, mostly located in the monitor chassis, that has a time constant of 1 s. The power supply chosen is the Bertan PMT-20A-P; it does not have the lowest noise of those tested, but it is adequate and a very convenient size.

Monitor System

The monitor system (Fig. 2) is designed to read out both the dose rate and dose/pulse. The gains of the amplifiers in the two channels are adjusted so that the digital voltmeters (DVMs) read out directly in physical units. (For the low dose-rate range, 0.5 mV/(0.1 mR/h) × 20 = 10 mV/(0.1 mR/h).) As shown, the low dose-rate range reads from less than 0.10 mR/h to 99.99 mR/h, which should be more than adequate in a normally manned area. For the low dose/pulse range, if a level of 0.1 mR/h was all due to accelerator pulses, in the FXR case this would be

$$\frac{0.1 \text{ mR/h}}{1200 \text{ pulses/h}} = 0.083 \text{ µR/pulse},$$

and the dose/pulse DVM would read 0.08 µR/pulse.

Differential outputs of 0 to ±5 V are supplied for a remote data acquisition system.

There can be an error in the dose/pulse reading, depending on the level of steady-state radiation. The steady level is added to the actual dose/pulse. If the dose rates contributed by each component are equal, the error in indicated dose/pulse is 10%.

A formula to calculate the true dose/pulse as a function of the DVM readings can be derived from the

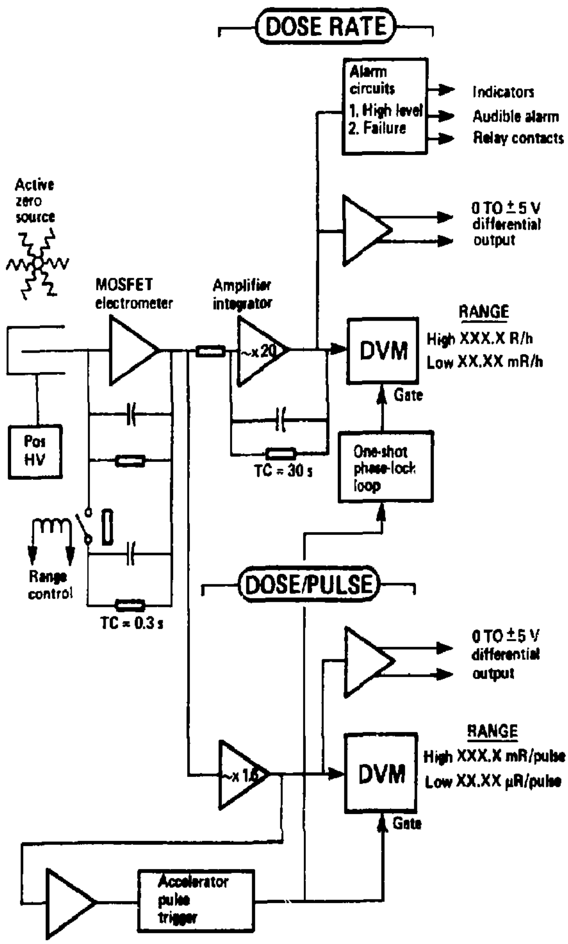

FIG. 2. Block diagram of monitor system.

following equations:

$$D_{PI} = V_{dc}G_P + V_PG_P \quad ,$$

$$D_R = V_{dc}G_R + \frac{V_P}{10}\,G_R \quad ,$$

and

$$D_{PT} = V_PG_P \quad ,$$

where

D_{PI} = dose/pulse indicated on DVM, μR/pulse or mR/pulse,
D_{PT} = dose/pulse, true, μR/pulse or mR/pulse,
D_R = dose rate indicated on DVM, mR/h or R/h,
V_{dc} = dc component from electrometer,
V_P = peak amplitude of pulse component from electrometer,
G_P = dose/pulse amplifier gain,
G_R = dose-rate amplifier gain.

Solving the above equations gives:

$$D_{PT} = 1.11\left(D_{PI} - \frac{G_P}{G_R}\,D_R\right).$$

The DVMs are operated in gated mode. When the accelerator is off, a free-running one-shot triggers the dose rate DVM every 3 s, and the dose/pulse DVM holds its last reading. When the accelerator is on, the dose/pulse DVM is triggered by the accelerator pulse, and the dose rate DVM is phase-locked to the accelerator pulse.

A source to give an active zero level of 0.3 mR/h is used to allow the failure alarm to be set with a margin to allow for the zero drift. The alarm is set at the equivalent of -0.15 mR/h or -15 mV.

Packaging

The detector-electrometer and monitor chassis are shown in Fig. 3. The electrometer is packaged within a housing that slides over the end of the detector and is sealed with an O-ring on the tube and a gasket on the cover. A spark plug desiccant cartridge is used to ensure a long-term dry environment for the electrometer.

On the front panel there are LEDs that indicate which ranges are being displayed on the DVMs. A ten-turn locking potentiometer is used to zero the electrometer output.

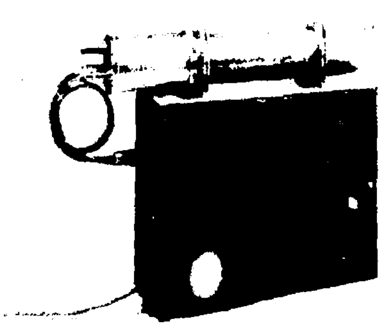

FIG. 3. The detector-electrometer and monitor chassis. The polyethylene equilibrium sleeve is not shown.

Calibration and Pulse Tests

The detector and electrometer were calibrated using ^{137}Cs and ^{60}Co sources in our calibration facility. The sensitivity of the first detector delivered was measured to be 4.1×10^{-10} A/(R/hr).

The detector and electrometer were then tested with the 30-ns-wide, 2-MeV maximum-energy x-ray pulse from the Febetron field emission accelerator. Thermoluminescent dosimeters mounted on the detector gave the dose calibration, and lead absorbers of various thicknesses were used to vary the beam intensity. The response of the detector and electrometer system (shown in Fig. 4) is linear up to 100 mR/pulse, which corresponds to a dose rate of 1.2×10^{10} R/h. The linear part of the curve follows the slope (shown as a dashed line) calculated from the source calibration and the electrometer circuit conversion gain using a feedback capacitance of 0.340 μF (a different value than used in the final design). The slope calculation is as follows:

$$\text{coulombs/roentgen} = \left[4.1 \times 10^{-10}\ \text{A/(R/h)}\right] 3600\ \text{s/h} = 1.48 \times 10^{-6}\ \text{C/R} \ ;$$

$$\text{volts/roentgen} = \frac{1}{C}\left(1.48 \times 10^{-6}\right) = \left(1.48 \times 10^{-6}\right)/\left(0.34 \times 10^{-6}\right) = 4.35\ \frac{\text{mV}}{\text{mR}} \ .$$

The electrometer amplifier linearity was measured with a pulser through a 0.030-μF test capacitor. The amplifier is linear up to 4 V, where the positive clamping diode conducts and causes a loss of charge before the loop is closed.

Conclusions

An instrument has been developed with a very wide range of steady-state and pulse response to x-ray radiation. Since the pulses detected are very short the charge-collection problem is reduced, and the

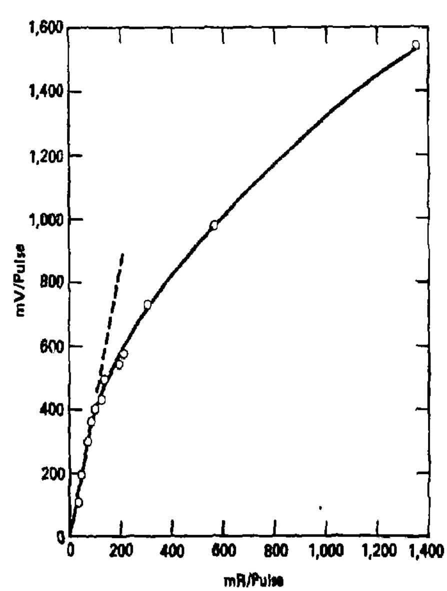

FIG. 4. Linearity of detector-electrometer (30-ns pulse from Febetron 705, C_{fb} = 0.340 μF).

detector performance for high-level pulses greatly exceeds the steady-state specification of 10^5 R/h.

Four monitors have been built, but at this time none have been installed in the field. The stability over 24 h with a 5°C temperature change is approximately 0.02 mR/h.

Energy response studies are presently underway (for up to 100-MeV x rays). Initially, FXR will operate at 25 MeV, and an approximately 5-cm-thick polyethylene sleeve will be used on the detector to approach electronic equilibrium.

Acknowledgments

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Reference

1. V. C. Negro, S. Watnick, and P. Raft, "A Temperature-Compensated Electrometer for Environmental Measurements," IEEE Trans. Nuc. Sci. NS-21, 805-811 (Feb. 1974).