SERVO SYSTEM FOR AUTOMATIC DOSE CONTROL

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Summary

Circuitry has been designed and constructed such that conveyor motion past a scanned Linear Accelerator beam is automatically regulated as a function of average beam current. Using this, the ratio of average current to conveyor speed can be held constant, thereby eliminating beam current variation as a source of error in irradiation processing. In the system, the ratio of current to conveyor speed is computed, multiplied by a factor inversely proportional to the scan height, and displayed on a digital voltmeter. The current signal is derived from a secondary emission monitor within the accelerator, while the conveyor speed is sensed by a tachometer coupled with the conveyor drive assembly. The beam scan is detected by a pair of adjustable sensor bars which are perpendicular to the plane of scan.

Introduction

Due to the continuous nature of the conveyor-scanned beam method of processing food and other bulk commodities, an automatic control loop between the independent variables of accelerator beam current and conveyor velocity is desirable. In approaching the dose control problem, the beam current and conveyor velocity were designed to be as constant as possible, but small changes still occurred in beam current due to various causes, some external to the accelerator. Since the dose received is proportional to beam current, I, and inversely proportional to conveyor velocity, S, it is only necessary to hold constant the ratio of I to S. This is essentially what the Dose Control System does, dose being proportional to the constant (I/S). In addition to this, the system is designed to compute the ratio of I/S, multiply this ratio by a factor inversely proportional to scan height (since dose is inversely proportional to scan height) and display the results in suitable dose units on a digital voltmeter.

Circuit Logic & Features

A signal proportional to beam current from a secondary emission type current sensor is averaged in an R-C circuit with a 5-second time constant. As seen in Figure 1, this average current signal is applied to a d.c. servo-voltmeter (V-1). Geared to this voltmeter is a double element rotary potentiometer (R_1 & R_2) adjusted so that the wiper of each potentiometer moves along its resistance element in direct proportion to the voltmeter reading. A constant voltage, selectable by the operator, is applied across R_1. The voltage appearing between the wiper and the lower tap is now directly proportional to average beam current and is used as a reference voltage for the conveyor speed control circuit.

The conveyor speed control in its original configuration consisted of a reference voltage supply and potentiometer and a differential amplifier. The potentiometer selected reference voltage was compared with a voltage from a d.c. tachometer coupled to the conveyor drive motor and the difference between these signals was amplified and used as an error signal to change the conveyor velocity in a direction which caused the difference to approach zero. In the modification for the automatic system, the reference supply and potentiometer were disconnected from the conveyor control circuitry and the voltage between the lower tap and wiper of R_1 was substituted as the control voltage. Thus we have a system where any change in beam current causes a proportional change in position of the servo voltmeter mechanism, in the voltage from potentiometer R_1, and therefore in the voltage the conveyor sees as a reference. The conveyor velocity changes, reducing the difference voltage between the reference and the tachometer signal towards zero, and proportional control is achieved.

The readout portion of the system calculates the ratio I/S, multiplies this ratio by a factor inversely proportional to scan height, converts to dose units and displays the result on a digital voltmeter.

The conveyor tachometer signal is applied to a servo-voltmeter (V-2) identical to that used in the conveyor control loop. Geared to this unit is a single element rotary potentiometer, R_3, which is utilized as a resistance directly proportional to conveyor velocity. The remaining resistance element on the servo voltmeter in the conveyor loop, R_2, is utilized as a variable resistance proportional to beam current. A power supply (PS-2) was procured with programming features which include the ability to program its output voltage proportional to an external voltage or resistance, and at the same time, inversely proportional to another resistance. By connecting R_2 to the directly proportional input and R_3 to the inversely proportional input, the power supply output was made proportional to the ratio R_2/R_3 and therefore to the ratio I/S.

After calculation of the ratio I/S there remain two calculations to be made, inserting the scan height factor and converting to suitable dose units. These calculations are performed with an additional power supply (PS-3) of the same type used in the I/S calculation. However, this application is even more demanding of the power supply's programming capabilities. The output of the power supply calculating I/S is first fed to a decade divider which inserts 1:1, 10:1, or 100:1 attenuation factors corresponding to conveyor system gearbox settings of 1:1, 10:1, or 100:1. This factor is inserted automatically by the conveyor gear selector switch. The output of this attenuator is applied to the voltage programming input of the power supply, while a resistance proportional to the scan height is applied to the inverse resistance programming input. Finally, a system calibration resistor is applied to the direct resistance programming input. At this point the signal proportional to the ratio of beam current to conveyor velocity has been multiplied by a factor inversely proportional to scan height and, finally, has been converted to suitable dose units. This signal is displayed on a digital voltmeter.

Component and Sensor Details

This section will present some details of the components of the automatic dosimetry system. Sensors to be discussed are the secondary emission beam monitors, the conveyor tachometer, and the scan height sensing bars. In addition, pertinent specifications will be given on the d.c. servo voltmeters, rotary potentiometers, and the programmable power supplies.

The secondary emission monitor presents an output signal of 10 volts per amp across a 100 ohm resistive load. However, since the Linear Accelerator is a pulsed source, this instantaneous current signal must be averaged in an R-C circuit. A five-second time constant was chosen for this circuit to eliminate an undesirable modulation effect in the signal caused by the scan frequency of approximately 0.5 cps. However, since the current fluctuations to be compensated for have time constants measured in minutes, the filtering effect of a five-second time constant does not degrade necessary system response. Moreover, the conveyor shows considerable phase lag at frequencies above 0.5 cps and should not be allowed to experience any such rapid current fluctuations.

The signal, now a measure of average current, is amplified in a Sanborn Model 1500 preamplifier (and recorded) and applied to a Moseley Model 22 d.c. voltmeter. This model voltmeter was selected to convert the beam current signal and the conveyor velocity signal from voltage to resistance functions at an accuracy within 0.2%. This is accomplished by means of follower potentiometers which are geared directly to the voltmeter servo system and which are furnished as an accessory to the instrument. The voltmeter to be used to monitor the beam was modified by the substitution of a dual element rotary potentiometer for the single element unit provided by the manufacturer.

To allow operator adjustment of conveyor velocity (with a given beam) a 0-36 volt resistance programmable power supply (PS-1) is used as a reference voltage supply, with the magnitude of the reference voltage selected by a 3-turn 50K ohm programming potentiometer on the control panel. This selected voltage is applied to R_1, a 200 ohm element of the dual potentiometer on the beam following voltmeter. This low resistance and the attendant high-power dissipation is necessary to reduce potentiometer loading effects in the conveyor control circuitry.

At this point, a description of the power supplies used in the system is in order. Three supplies are used: 0 - 36 volt, 300 ma for the programmable reference voltage; 0 - 72 volt, 150 ma for calculation of I/S ratio; and, 0 - 72 volt, 150 ma for insertion of scan height and unit conversion factors. The supplies used are of the Kepco, Inc., PAX series with line, load, and stability figures of less than 0.05%, and the ability to be programmed with voltage, resistance, and inverse resistance. The units fit nicely into the control console, six across in a standard relay panel adapter.

In programming by three separate functions at one time, one voltage and two resistances, the output follows the equation:

$$V_o = V_r \frac{R_x}{R_y}$$

where V_o is the output of the supply, V_r is the voltage programming function, and R_x and R_y are the resistance functions.

A conveyor velocity reference signal is obtained from a 0 - 25 volt linear d.c. tachometer furnished as a component part of the Servo-Tek, Inc., control system used on the conveyor. This voltage, in addition to being used in the conveyor control loop, is applied to a d.c. voltmeter of the same type used for beam following. Geared to this voltmeter is a single element, 3-turn, Spectrol potentiometer with resistance of 25K ohms. The potentiometer is wired as a resistance directly proportional to conveyor velocity into the inverse resistance programming terminals of a 0 - 72 volt PAX supply. Into the direct resistance programming terminals is connected the remaining resistance function on the beam follower voltmeter, R_2, a 50K ohm element.

The output voltage of this supply, after traversing the gear setting attenuator, is applied as the voltage reference to a similar 0 - 72 volt PAX supply.

Scan height, the remaining parameter to be included in the dose calculation, is measured by adjusting a pair of horizontal bars just far enough apart in front of the scanned beam such that the beam just hits the upper bar at the top of the scan, and just hits the lower bar at the lowest point on the scan. The separation of the bars is motor controlled from the control console, and attached to the bars is a 100K ohm rotary monitoring potentiometer which furnishes a resistance directly proportional to bar separation. Since dose is inversely proportional to scan height, this resistance is connected to the inverse resistance programming terminals of the last mentioned supply. Finally, a 100K ohm potentiometer is connected as an adjustable resistance to the direct resistance programming terminals of the same supply and is used to adjust system output voltage to suitable dose units. The result is displayed on a digital voltmeter.

Therefore, the system, in addition to controlling the conveyor velocity, performs the overall calculation:

$$\text{Dose(Megarads)} = K \frac{I}{SW}$$

where:

I is beam current

S is conveyor velocity

W is scan height

K is Megarads conversion factor

The use of the power supplies completely eliminates non-linearities and loading effects which would be present in a passive system.

Performance

The system, after assembly, was checked out as two separate systems, the conveyor control loop and the computing and display circuits.

The conveyor control loop was found to be linear within 0.5% and repeatable within 0.1% when approaching a set current value as slowly as 0.01 uamp/sec. When beam input was simulated by a sinusoid, the system 90° phase lag point was found to 1.3 cps. This performance was entirely satisfactory due to the highly filtered nature of the system's current input signal.

The computing and display circuits were then checked out by simulating zero to full scale excursions of each parameter in the system dose equation while holding the remaining three constant. The system was found to be accurate within 1% in all cases.

Acknowledgments

The authors wish to thank Mr. James Caspersen and Mr. Irwin Wertheim for their aid in the construction and calibration of the system.

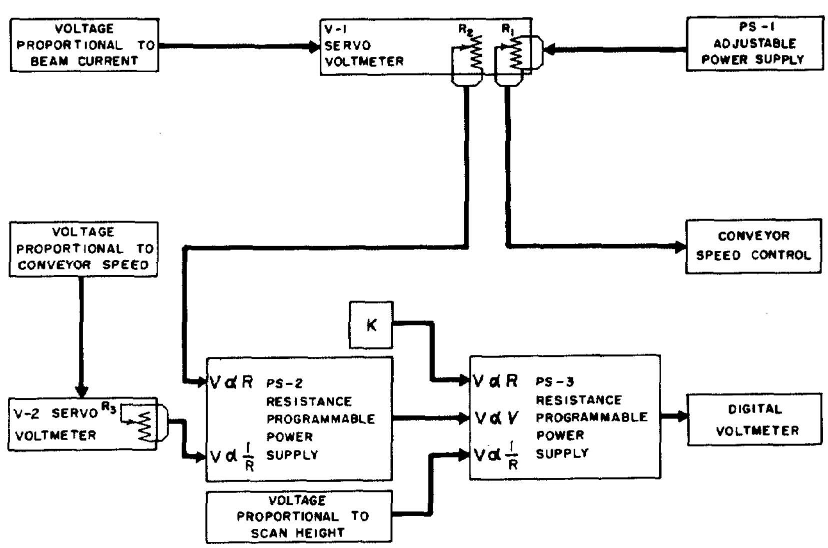

Fig. 1. Automatic dose control system.