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**FILAMENT POWER REGULATOR FOR THERMAL IONIZATION
MASS SPECTROMETRY**

E. R. Rogers
J. R. Ferguson

September 1977

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OAK RIDGE Y-12 PLANT
OAK RIDGE, TENNESSEE

*prepared for the U.S. ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
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ABSTRACT

A device has been developed that will control the filament temperature in a thermal ionization mass spectrometer. The arrangement is superior to past methods to control this critical parameter. The operating principle lies in the feature of filament power control as contrasted with the formerly used voltage or current controls. Reproducibility and stability of ion beams showed great improvement.

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SUMMARY

A power-regulating module has been designed and fabricated for controlling the wattage of the ionizing filament in a mass spectrometer. Power regulation is used instead of voltage or current regulation because of the ability of power regulation to reproduce more consistently a required temperature of the filament.

The following differences are noted between the three methods of filament control:

1. Using voltage control, the voltage drop across the filament is maintained constant.
2. Current control is a method of keeping the current flow through the filament constant.
3. Wattage or power control is a combination of Methods 1 and 2. The voltage drop across the filament and the current flow through the filament are monitored, and the product of these two parameters is used for feedback control, thereby producing power regulation.

INTRODUCTION

A mass-spectrometric method to analyze for parts-per-billion concentrations of uranium in Uranium Resource Evaluation (URE) water samples has been previously described.^(a) For maximum precision and accuracy at this concentration level, a thermal-emission isotope-dilution method was developed at the Oak Ridge Y-12 Plant.^(b)

Experimental results indicated that reproduction of the ionizing filament temperature and control of the filament temperature are critical. The only methods that were available for filament control were voltage feedback control or current feedback control, but both methods proved to be inadequate. Measuring the temperature of the filament by optical means is impractical, if not impossible. The only viable alternative found was to control the temperature by controlling the power dissipated by the filament. A module has been designed, fabricated, and installed that controls the filament power. With the use of this module, there was a definite improvement in results by reproducing the ionization efficiency at a given power level. Furthermore, the intensity of the ion beam remains more stable during the data-taking period.

(a) Ferguson, J. R., Caylor, J. D., Rogers, E. R., and Cole, S. H.; *Rapid Determination of Uranium in Natural Waters by Thermal Emission Mass Spectrometry*, Y-2073; Union Carbide Corporation-Nuclear Division, Oak Ridge Y-12 Plant, Oak Ridge, Tennessee; March 28, 1977.

(b) Operated by the Union Carbide Corporation's Nuclear Division for the US Energy Research and Development Administration.

FILAMENT POWER REGULATOR

SPECIFICATIONS

Electrical Characteristics

Input:	115 VAC, nominal 50 - 60 Hz at 5 A.
Output:	Continuously adjustable from 0 - 25 W.
Load Resistance Range:	From $0.4 \times 10^{-3} \Omega$ to 1Ω at 25 W.
Readout:	Front-panel analog meter calibrated full scale at 25 W.
Line Regulation:	0.12% at $\pm 10\%$ of nominal (115-V line).
Load Regulation:	0.15% with 50% change in load resistance.
Isolation:	2500-VDC isolation from ground.

Mechanical Characteristics

Dimensions: NIM standard triple-wide module (4.05 x 8.714 in) per Document TID 20893.(c)

Weight: 12 lbs.

EXPERIMENTAL WORK

Preliminary Considerations

In experiments to determine the isotopic quantities of uranium at the parts-per-billion level, using a thermal ionization mass spectrometer modified for ion counting, it was noted that, for different ionizing filaments, the element being analyzed seemed to boil off the filament at different rates. It was theorized that each of the filaments were producing different temperatures at a given current setting on the current-regulated filament controller.

Rather than monitor the temperature of the filament, it was decided to attempt to monitor the current through the filament and the voltage drop across the filament to electrically control the power to the filament.

Design

A power-regulated filament controller was designed to replace the current-regulated filament controller which was being used in the power supply to the ionization filament of a thermal ionization mass spectrometer. In designing the new regulator, the primary consideration was that the ionizing filament to be controlled is operated at a high-voltage ion-accelerating

(c) *Standard Nuclear Instrument Modules*, USAEC, Revision 3; December 1969.

potential which, in this case, is approximately 2500 VDC positive with respect to ground. To cope with this situation, the circuitry for the controller is isolated from ground and referenced to the high-voltage power supply.

By using a differential input amplifier, with the inputs of the amplifier connected in parallel to the filament, it is possible to derive a voltage drop across the filament. The output of this amplifier is applied to the "X" input of a multiplying amplifier, while the "Y" input to the multiplying amplifier is derived by monitoring the voltage drop across a fixed resistor which is in series with the filament. This voltage is an analog of the current flow through the filament. What is applied to the input of the multiplying amplifier is the voltage drop (E) across the filament and the current flow (I) through the filament. The multiplying amplifier, as its name implies, multiplies the X input times the Y input, ($E \times I$), thereby producing, as its output, a voltage analog of the power dissipated in the filament.

This output is used as feedback to the error amplifier which controls the power dissipated in the filament.

Figure 1 provides views of the front and rear sides of the filament control.

Circuit Description

Figure 2 presents the electrical schematic for the regulator. Following is a circuit description: A potential of 110 VAC is applied to the module via the NIM bin connector. Pin 33 is at AC phase and Pin 34 is at AC neutral. The AC phase is fused with a 5-A fuse and is applied to Transformers T1, T2, T3, the fan motor, and the pilot light. The three transformers each have an insulation breakdown voltage specification of 2500 VDC. The 110-VAC secondary voltage of T1 is applied to the ± 15 -VDC power supply module. This DC voltage is used to power the operational amplifiers and supply the reference voltage to the error amplifier. The secondaries of Transformers T2 and T3 are connected in series to supply 15 VAC at 8 A to the full-wave bridge (D1). The minus side of D1 is connected to the floating common, while the plus side is filtered by Capacitor C3 and applied to the collector of Q1 and to R5. This rectified and filtered voltage is the drive voltage for the filament. D1 and Q1 are mounted on heat-sink material directly above the cooling fan. The ionizing filament is connected to the module through J21. J22 is used to connect the high voltage into the regulator through R15 and R16. The differential input to Amplifier A1 is connected in parallel with the ionizing filament. This arrangement allows the voltage drop across the filament to be monitored. R8 is the trim adjust for Amplifier A1. The inverting input (PIN 2) of A1 is connected through R11 to the more positive side of the filament, while the feedback for A1 is from the output (PIN 6) through R7 to the summing junction (PIN 2). The voltage divider network of R9 and R10 connects the more negative side of the filament to the noninverting input (PIN 3). This voltage divider is used to equalize the gain of the two inputs, since the noninverting input has a higher gain than the inverting input. The output of A1 is PIN 6, which is equivalent to the voltage drop across the filament and is applied to PIN 6 (the X input) of the multiplying amplifier (A2). The Y input (PIN 1) of A2 is coupled to the arm of R12 which is used, along with R13, as a gain-calibration adjustment.

(a) Front View.

173392 (b) Rear View.

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Figure 1. VIEWS OF THE FILAMENT CONTROL.

for the multiplying amplifier. Resistors R12 and R13 have a voltage drop across them that is equivalent to the voltage drop across R14. R14 is a selected length of manganin wire in series with the filament. (Manganin wire is used because of its low temperature coefficient.)

The voltage drop measured across R14 is directly related to the current flow through the filament. Amplifier A2 multiplies the X input by the Y input with the output (PIN 4) being the product of X (the voltage across the filament) and Y (the current through the filament), yielding an output voltage analogous to the power dissipated at the filament. Potentiometers R17, R18, and R19 are used to calibrate the multiplier. The output of A2 is used as the feedback voltage to the error amplifier (A3) and to the readout buffer amplifier (A4).

Resistors R20 and R21 set up the gain of A4 as slightly greater than one. Potentiometer R22 is used to calibrate the wattage readout meter (M1). Error amplifier A3 is used in the inverting mode with its gain limited by resistor R3.

The reference voltage is obtained at the voltage divider (R1) and R23. R23 is used to bias the CCW position of the wattage adjust potentiometer (R1) to a slightly negative value so as to turn off the filament current. R2 is the summing resistor for the reference voltage. As the wattage adjust potentiometer is turned "CW", the arm becomes more positive, producing a more negative signal at the output of Amplifier A3. Current from this signal flows through Resistor R4 into the base of Q2, causing Q2 to conduct less; which, in turn, raises the voltage drop across Q2 and allows current to flow into the base of Q1. Q1 begins to conduct, allowing current to flow through the filament to produce a voltage drop to be used by Amplifier A1. The current flow through the filament also conducts through the current-sensing resistor (R14) and terminates at the negative side of the drive voltage power supply. Amplifier A1 senses the voltage drop across the filament and produces a negative output equivalent to the voltage drop across the filament times two. This output is applied to the X input of A2 while, at the same time, the Y input senses the current flow through the filament. PIN 4 of A2 is equal to $V_{XY}/10$.

This output serves two purposes: (1) to supply current through Summing Resistor R6 to the summing input of A3, completing the feedback and satisfying Amplifier A3; (2) to supply current through R20 into the summing input of A4, the output of which is used to drive M1, the wattage readout meter.

CONCLUSIONS

It was found that different filaments reached their optimum ion producing efficiency at different current settings, depending on age and mechanical differences. The bulk of the filaments reached optimum at current values between 3.5 to 5.0 A. This range represents a difference in power dissipated for an individual filament by a factor of two, based on I^2 alone. This difference is even more when the positive thermal coefficient of resistivity of rhenium is considered.

With the extremely light filament loadings of uranium involved in the URE program (1 to 150 pg of uranium on the filament), optimizing filament temperatures is extremely critical. Determining optimum current settings for individual filaments is a time-consuming and imprecise trial-and-error process which is neither economical nor practical for a routine procedure. As an example of the difficulties involved, three filaments which had predetermined optimum current values were found to give accumulated counts from a given standard that differed by more than an order of magnitude. With power regulation, all filaments began to create uranium ions at 8 W and reached optimum between 12 and 14 W. This consistency enables the operator to control the ionization rates as desired, depending on sample concentration. Also, the problem of temperature "overshoot", resulting in complete loss of the sample with no data acquired, has been completely eliminated.

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