An intensity regulation system for a monochromator

David A. Wayne

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AN INTENSITY REGULATION SYSTEM
FOR A MONOCHROMATOR

BY

DAVID A. WAYNE

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A

THESIS

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Approved by

Norman Hillman (advisor)  Robert J. Bell

Ralph Carson
ABSTRACT

In the investigation of phenomena involving both optical intensity and wavelength, an instrument is often desired which allows one of these quantities to be held constant while the other is varied. A relatively inexpensive system is described which utilizes a commercial grating monochromator and external feedback electronics to regulate the output intensity as the wavelength is varied. In this system, a sample of the output intensity is taken by a photosensor with known spectral response. The output of the photosensor is then compared electronically with that of a pre-programmed function generator which cancels nonlinearities in the photosensor. The resulting signal is used to regulate the monochromator light source. System output intensity has been observed to be constant to within five per cent from 475 millimicrons to 800 millimicrons.
ACKNOWLEDGMENTS

The author wishes to express appreciation to his advisor, Dr. Norman G. Dillman, for his guidance and encouragement in this thesis effort.

The thoughtful suggestions and helpful discussions of three friends, Wallace DeShon, Arthur Reckinger and Donald Watke are also gratefully acknowledged.
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I. INTRODUCTION

Research on phenomena depending nonlinearly upon both light intensity and wavelength can often be considerably simplified by using a source of light in which wavelength can be changed while holding intensity constant. However, the output intensity of most commercial monochromators varies greatly with wavelength due to the spectral response of the grating or prism and the light source. A simple and relatively inexpensive feedback system is described that may be used with a commercial monochromator to regulate the output over a wide spectrum.

The design discussed here was developed with the intent of avoiding complexity in the operation of the device, while providing versatility in that a number of different photosensors may be used. Another feature of the design was an analog voltage proportional to output wavelength to drive an x-y recorder or other data acquisition systems. Because the corrections for intensity variations are made electronically, the system could be used with a hybrid computer to take advantage of sophisticated real-time computation and computer control of experiments.

One alternative solution to this problem is to calibrate the monochromator using an accurate photosensor and then provide a chart of settings for each wavelength of interest. The procedure for using the instrument then would be to set the wavelength and adjust the intensity according to the chart.
The advantages of this method are apparent: no external equipment is required and it is very inexpensive. However, an accurate device is required for the original calibration, and changes in optics, light source output, or power line voltage will result in errors in the level of intensity. The method is also troublesome for the experimenter, and the possibility of chart-reading error exists. Moreover, an analog output is not available, decreasing the flexibility of the instrument.

Another approach would be to electronically control the lamp voltage (and hence the output) according to a pre-set electrical program. This method would be considerably easier to use than the previous one, and an analog output could easily be provided. However, a change in line voltage, optics, light source, or any other parameter would adversely affect the output because it would not be regulated.

Commercial units are available in the configurations discussed, but are often not acceptable because they are too expensive and do not make use of the equipment presently available in a laboratory.

II. SYSTEM DESCRIPTION

A block diagram of the overall system is shown in Figure 1. The monochromator is the heart of the system, providing monochromatic light over a range of wavelengths of 350 millimicrons to 1600 millimicrons. A gear placed on the shaft controlling wavelength was coupled by a "no-slip"
Figure 1. Block Diagram of Light Intensity Regulating System.
belt to a precision 3-turn potentiometer. The gears and belt used were of special construction to avoid slippage or belt stretch.* The potentiometer provides an analog output voltage proportional to wavelength. The voltage across the entire winding of the potentiometer may be adjusted to obtain a desired wavelength/voltage scale factor.

The function generator develops a voltage which may be adjusted to simulate the spectral response of a photosensor over a wide spectral range. This voltage is a controlled function of the analog wavelength voltage from the potentiometer and, therefore, supplies a reference voltage at every wavelength.

A composite photodetector was used consisting of a silicon photodiode** with a spectral response of 300 to 1000 millimicrons and a germanium photodiode*** with a spectral range of 800 - 1700 millimicrons. The dc output of the two photodiodes are added and amplified by a differential amplifier. A dc input voltage to the silicon controlled rectifier (SCR) lamp driver circuit controls the light source intensity. This voltage is an error signal obtained by subtracting the output of the photodiodes from that of the function generator or reference.

* Available from PIC Design Corp., East Rockaway, New York
** Type 626, Electro-nuclear Laboratories, Inc., Menlo Park, California
*** Type 653, Electro-nuclear Laboratories, Inc., Menlo Park, California
A. FUNCTION GENERATOR CIRCUIT

The function generator makes use of a circuit used in many analog computers to generate complex waveforms. A schematic diagram of this circuit is shown in Figure 2. The input voltage $e_i$ is the analog voltage representing wavelength. As $e_i$ increases, the voltage $\alpha E$ is eventually achieved, and the diode becomes forward biased. As $e_i$ increases further, either $V_1$ or $V_2$ will increase more rapidly depending upon the position of the wiper arm of $R_3$. These voltages are subtracted in the differential amplifier yielding a voltage which increases in a positive or negative direction at a rate (slope) depending on the setting of $R_3$. Each block in Figure 2 will produce one break point and slope. In the system described here, eight of these blocks were used.

The circuit was built on a plug-in printed circuit board so that additional function generators might be calibrated for use with other photosensors.

The potentiometers are set so that the output voltage is the same as that which would be produced by the photosensor were it to be illuminated by light of constant intensity over the range of wavelengths involved. To change the light intensity it is only necessary to adjust the signal level at the output of the function generator (by means of a potentiometer), or vary the monochromator slit width.

---

Figure 2. Schematic Diagram of Function Generator.
B. SILICON CONTROLLED RECTIFIER LAMP DRIVER CIRCUIT

The schematic diagram of the SCR lamp driver circuit is shown in Figure 3. The input, or error, signal is amplified by transistors Q₁ and Q₂, and controls the collector current of transistor Q₃. This current is quite constant with changing collector-emitter voltage and is used to charge capacitor C. This capacitor charges at a rate determined by the input and upon reaching the peak point voltage of the unijunction transistor (UJT), discharges through resistor R creating a pulse. The pulse initiates conduction in the SCR. Thus, load current flows for only a portion of the input power cycle; proportional to the input voltage. An SCR was used in this circuit for its efficiency and circuit simplicity as compared to, for example, a power transistor.

C. D C AMPLIFIER CIRCUIT

Matched transistors in single TO-5 containers were used in the dc amplifiers to eliminate problems with thermal drift. The schematic diagram is given in Figure 4.

III. PHOTOSensor SELECTION

A number of types of photosensors were considered for use in this system. A composite device made up of two semiconductor photodiodes was finally chosen. The photodiodes--when operated in the photovoltaic region--require no external power supply, thus eliminating a number of components. They are less expensive than some other photosensors and have
Figure 3. Schematic Diagram of Silicon Controlled Rectifier Lamp Driver Circuit.
Figure 4. Schematic Diagram of DC Amplifier.
a wider spectral response in the composite form. In addition, the types chosen were small in size, being housed in TO-18 size transistor packages which are approximately 0.200" in diameter and 0.270" long. The final choice was one silicon photodiode and one germanium photodiode.

In a semiconductor photodiode, the open-circuit voltage is a logarithmic function of light intensity and depends on temperature, whereas the short-circuit current is independent of temperature and is a linear function of light intensity.\(^2,3\) A low value of load resistance, therefore, would approximate the short-circuit condition and would be desirable. A load resistor of 1000 ohms was found to be a good compromise between output sensitivity and temperature stability.

The germanium and silicon photodiodes, each with parallel load resistors, are connected in series so that the voltage developed across the resistors will add. This output voltage is amplified by a differential dc amplifier as shown in Figure 5.

To calibrate the system, a detector with constant or known spectral response is required. A vacuum thermopile is such a device. The monochromator is connected to the system.

---


Figure 5. Photodiode Connection for Composite Photodetector.
Figure 6. Schematic Diagram of Regulated Power Supply.

Three supplies are used for isolation.
but power is supplied to it from a "Variac" variable auto-transformer connected to the 110 volt power line. The function generator is removed from the circuit, and a meter is placed across the input to the SCR circuit. The photo detector is used with another meter to determine optical output.

At this time a wavelength is selected and adjusted on the monochromator. The output light intensity reading is noted as is the voltage at the SCR circuit input terminals. This process is repeated for a range of wavelengths, adjusting the Variac to maintain the optical output at a constant value.

A plot of the values obtained by this procedure is actually the output of the photodiodes (and dc amplifier) under stimulation by light of constant intensity.

For part two of the calibration, the monochromator is disconnected from the power source and the function generator is reconnected to the system. The potentiometers in the function generator are adjusted to produce the negative of the curve found above. This is most easily accomplished with an x-y plotter. The x axis input is connected to the analog wavelength voltage terminals, while the y input is placed across the input to the SCR circuit.

The third part of the calibration consists of plugging the monochromator into the regulator and measuring the output with the thermopile or other "known" photodetector. The function generator potentiometers are adjusted very carefully until the output is made most constant with respect to wavelength. This operation is also made much easier by using the x-y recorder.
IV. PERFORMANCE

The methods outlined above were used to calibrate the monochromator-regulator system, first for a grating assembly which covers a range of 350 millimicrons to 800 millimicrons, then for one covering 700 to 1600 millimicrons. These results are shown in Figures 7 and 8. The output of the system with the 350-800 millimicron grating was found to be constant to within five per cent from 475 millimicrons to 800 millimicrons. With the 700-1600 millimicron grating installed, the output intensity was constant to within five per cent over a range of 750 to 1200 millimicrons. Variations are apparently caused by the piecewise-linear character of the output of the function generator.

V. REMARKS

The system described is an inexpensive and simple means of obtaining monochromatic light of constant intensity over a considerable range of wavelengths. It operates on the principle of negative feedback, so that variations in the optics of the monochromator, changes in line voltage, or aging of the lamp will have a negligible effect on the output light intensity. The device was packaged (except for the photosensor units) in an enclosure measuring 5" x 5" x 11-1/2". A photograph of the monochromator and regulating system is shown in Figure 9.
Figure 7. Relative Spectral Output of System with 350 - 800 Millimicron Grating. (1.0 equals approximately 3.5 milliwatts.)
Figure 8. Relative Spectral Output of System with 700 - 1600 Millimicron Grating. (1.0 equals approximately 14 milliwatts.)
Figure 9. Regulating System with Monochromator.
BIBLIOGRAPHY


5. SCR Designers Handbook (Westinghouse Electric Corporation, Semiconductor Division, Youngwood, Pennsylvania, 1964)
APPENDIX A - MANUAL OF OPERATION

1. Introduction

The purpose of this appendix is to provide instructions pertaining to the operations of the monochromator-regulator system. Suggestions are contained herein for maintenance and servicing of the system as well. It is best to first read through the instruction steps before performing them.

2. Preliminary Set-up

a. Place the regulator housing to the right of the monochromator so that the rubber bumpers rest against the monochromator housing. Slide the housing forward so that the front surfaces are in line. (See Figure 9.)

b. Adjust the wavelength dial on the monochromator to the triangular mark.

c. Turn the large knob on the regulator housing to the counter-clockwise extreme.

d. Loosen, with a 1/2" wrench, the nut below the large knob, so that it slides easily in the slot.

e. Loop the "no-slip" belt around the gear under the large knob and then over the large gear on the monochromator housing. Pull back on the knob to make the belt taut. The counter-clockwise limit on the pot should occur as the
wavelength dial reaches the dark triangle. Move the belt appropriately, a tooth at a time, until this condition is achieved.
f. Tighten the nut below the large knob while holding the belt tight.
g. Place the switch in the correct position.
h. Make the photosensor connection by means of the short cable with plugs on each end and the blue jacks in the front of both monochromator and regulator. (Do not overtighten.)
i. Plug the monochromator power cord into the socket at the rear of the regulator.
j. Apply power to both units by plugging the regulator power cord into a grounded receptacle. CAUTION: Do not attempt to separate the monochromator-regulator combination without first loosening the belt and removing it. Attempting to lift both units at once may damage the "no-slip" belt.

3. Change of Monochromator Grating

a. Disconnect power by removing regulator power plug from receptacle.
b. Loosen the 1/2" nut beneath the large knob.
c. Slide the knob forward in the slot and remove the belt.
d. Remove the four screws in the top of the
grating housing and lift out grating.
e. Install the other grating assembly and insert four screws.
f. Repeat steps b. through j. of Section 2 as required.
g. Remove side panel and install proper function generator circuit board.

4. Operation

After the installation of the proper grating and calibration (see Appendix B), the regulated system is ready for use.

The output intensity is adjusted by means of the small knob on the regulator housing. The range of regulated wavelengths for different settings of the intensity control is shown in Figures 7 and 8. As this figure shows, a smaller range of regulated wavelengths is available for higher output intensities.

A pair of terminals located toward the rear of the regulator housing provides a voltage approximately proportional to wavelength. The scale factor is 1 volt per 100 millimicrons; hence, 0.350 microns is represented by roughly 3.5 volts. This voltage may be used to drive recording instruments or other data acquisition equipment. This voltage corresponds to the wavelength dial with an accuracy of roughly five per cent.

CAUTION: The "low" side is not connected to the metal chassis and should not be connected to power line grounds.
The output of the monochromator is focused on the subject to be illuminated and the wavelength is selected by means of the dial. Higher spectral purity (at the expense of intensity) may be obtained by narrowing the exit slits of the monochromator. Narrowing the inlet slits is not recommended, as it adversely affects the regulation.

After a wavelength is selected, a fraction of a second is required for the lamp filament to reach the new operating temperature. Therefore, a slow rate of change should be used when recording an optically activated response as a function of wavelength using the x-y recorder.
APPENDIX B - CALIBRATION PROCEDURE

1. Introduction

This appendix is for the purpose of providing instructions and suggestions for the proper calibration of the system. The adjustments to be made are listed in the recommended order.

2. Equipment Required

A. Vacuum Thermopile (or other optical standard)
B. Hewlett-Packard 425A DC Microvoltmeter or equivalent
C. x-y plotter

3. Calibration Procedure I

a. Connect the equipment in the manner shown in Figure B-1.
b. Remove the function generator circuit board.
c. Apply power to all instruments.
d. Using an accurate voltmeter, set the proper voltages at the power supply terminals.
e. Adjust the x-y recorder for the proper scale factors.
f. Adjust the "V variac" for a constant intensity as read on the meter connected to the thermopile, as the wavelength is varied.
Note: the thermopile has a long time constant.
g. Activate the pen control each time the wavelength is changed and the Variac is properly adjusted. This will plot a series of points representing constant optical output intensity.
Figure B-1. Equipment Connection for Calibration Procedure I.
h. Connect the points with not more than eight straight line segments.
i. Remove power from the monochromator light source by turning its power switch "off".
j. Reverse the terminals to the y input to the x-y plotter.
k. Re-insert the function generator circuit board.
l. Adjust the potentiometers on the function generator board until the curve is matched accurately.
m. Remove the leads from the y input of the x-y plotter.
n. Plug the power cord of the monochromator light source into the socket at the rear of the regulator housing.

4. Calibration Procedure II
   (To follow Procedure I)
   a. Connect the equipment in the manner shown in Figure B-2.
b. Apply power to all instruments.
c. Adjust the x-y plotter for the proper scale factors.
d. Varying the wavelength very slowly, record the output of the thermopile as a function of wavelength.
Figure B-2. Equipment Connection for Calibration Procedure II.
e. Carefully adjust each potentiometer in the function generator as required for maximum "flatness" of the curve.

5. Calibration Procedure III
(If no optical standard is available)
   a. Connect the equipment as shown in Figure B-3.
   b. Apply power to all instruments except monochromator light source.
   c. Carefully adjust each potentiometer in the function generator until the curves shown in Figures B-4 and B-5 are matched.

6. Service and Maintenance
   Refer to Appendix C for schematic diagrams and interconnection charts.
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VITA

David A. Wayne was born on January 6, 1944, in St. Louis, Missouri. He received his primary and secondary education in St. Louis. In September of 1961, he entered the University of Missouri - Rolla (formerly the University of Missouri School of Mines and Metallurgy), from which he received the degree of Bachelor of Science in Electrical Engineering in August, 1966.

The author has been enrolled in the Graduate School of the University of Missouri - Rolla since September, 1966.