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Publication Date

1965-06-22

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88-INCH CYCLOTRON

Berkeley, California

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Submitted to Control Engineering

UCRL-16210

UNIVERSITY OF CALIFORNIA

Lawrence Radiation Laboratory
Berkeley, California

AEC Contract No. W-7405-eng-48

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ABSTRACT

The automatic-control requirements of the 88-inch cyclotron at the Lawrence Radiation Laboratory are analogous to the requirements of many process controls in industry. The system being designed will reduce setup time from twenty to five minutes and will be capable of being overridden manually. Although the system is primarily analog, the input is on punched tape or IBM cards in order to make it compatible with eventual beam optimization when digital-computer techniques will be used.

INTRODUCTION

Looking at an operating cyclotron from a systems point of view reveals that the cyclotron beam is a product and the many parameters—such as radio-frequency dee voltage and frequency, main magnetic-field strength, trimming-field strength, and deflector position and voltage—are the controllable inputs that determine the type of output product; that is, the energy of the particles, the intensity of the beam, and other properties such as focus.

There is an ever-growing list of parameter setpoints that determine beams of different energies; presently these parameter values are set manually by an operator. An average of one particle or energy change occurs per eight-hour shift, and the resulting setup change takes about thirty minutes. Any automatic control system to be considered must cut this setup time to about five minutes (a figure determined by the length of time required for the slowest device to become stable) as well as monitor and maintain these setpoints throughout the following shift. The saving of twenty to twenty-five minutes per shift, at \$200 per hour for cyclotron time, would amount to an annual saving of about \$75,000.

Interested readers are directed to Reference 1 for general information about the 88-inch cyclotron.

SYSTEM APPROACHES

Each of the above-mentioned parameters is controlled to 0.1% or better, short term, by a regulator. Figure 1 is a simplified block diagram of a typical single-parameter regulating system. Regardless of the units of the parameter (i. e., volts, amperes, inches), the system starts as a potentiometer, which determines the value of the reference. The potentiometer is adjusted manually when the parameter value is to be set or changed. It is important to the operation

of the cyclotron, and to further development of beams, that this means of direct operator control not be sacrificed. The output, which may be voltage, current, probe position, or other, is converted by the feedback loop to the units and magnitude of the reference. The feedback loop may be a voltage divider, shunt, transducer, or some other device. The difference (error) between the reference and the feedback-loop output is amplified by the regulator amplifier so as to cause the output to change until the error is reduced to zero.

A simple method of automatic control involves the setting of a series of input reference levels (e. g. , potentiometer settings) from a known correspondence between reference setting and output. That is, the potentiometer readings from previous experiments are just reproduced automatically for a like experiment. A serious disadvantage is that over a long period this correspondence changes due to aging of parts, and changes again immediately upon replacement of parts. A better approach is to design a single, highly precise reference that will supervise the existing series of references sequentially. While the references are being sampled, the corresponding actual parameter values are compared with the desired parameter values, and the result of the comparison is used to reset the existing set of references as necessary to correct the actual parameter values.

A typical existing reference is a regulated dc power supply whose output voltage may be continuously varied over the desired range by the aforementioned potentiometers, which are operated manually. For automatic digital operation, all the existing references would either have to be redesigned so as to be operated by relays or solid-state switches, or the potentiometers would have to be driven by stepping motors. Then the actual parameter values would have to be converted from their analog form (voltage, current) to a corresponding

digital representation so that they could be compared with the supervisory reference (either punched tape or IBM card). On the other hand, analog operation, which involves working directly with voltages and currents within the automatic-control system, would require either an analog supervisory reference (i. e. , voltage) or a digital-to-analog conversion of a punched-tape or IBM-card supervisory reference. Use of a digital supervisory reference is advantageous in that it provides greater information density than an analog reference, and would be more usable in future computer studies.

A summary, then, of the most appealing automatic-control system for an operating cyclotron is:

1. Supervisory - the individual references are supervised sequentially so as to maintain a required output;
2. Analog - all operations within the supervisory loop, as well as within the parameter-regulating systems, are analog--that is, all operands are voltage representations of the voltage, current, or probe position involved;
3. Digital input - the supervisory reference is on either punched tape or IBM cards, with digital-to-analog conversion.

SYSTEM DESIGN

The specifications for this system are:

1. The approximately 80 machine parameters necessary may be controlled in parallel systems, as dictated by time and accuracy requirements;
2. In about five minutes at the beginning of an experiment the 80 devices must be set up to within 0.1% of the desired output value;
3. Each device must be maintained to within 0.1% of the desired output, long term;
4. An operator must be able to manually override the system, either partially or entirely, at any time during a run;

5. The system must provide, upon command, a permanent record of the values of the controlled devices;

6. The system must be compatible with future computer-directed optimization.

Programming considerations show that 40 devices is a convenient number to control with a single system. Considerations of device time constants and output-reading instruments indicate that 0.2 second is a reasonable sampling period.

With the above specifications in mind, we can derive a suitable block diagram as shown in Fig. 2. In this figure, for the 40 devices being controlled, the sampling period is 0.2 second and the sampling rate is therefore 5/sec.

Figure 3 is a block diagram of the complete automatic-control system supervising channel J, a typical member of the sequence of 40 single-parameter regulating systems to be controlled. While channel J is being sampled, the voltage output signal from the Output Sensing Device (a shunt, for example) is fed through the Input Multiplexer and Signal Conditioner to the Comparator and Motor Drive. At the same time the programmed value of channel J is fed through the Program Multiplexer, converted to a voltage, and compared in the Comparator and Motor Drive with the voltage output signal. The difference is amplified by the Motor Drive and is fed through the Output Multiplexer to change the channel J reference as required. A multiplexer can be any device (such as a group of relays, solid-state switches, or selector switch) whose output is a predetermined sequence of a group of inputs. While the other 39 channels are being sampled, the output of power supply J is maintained constant to 0.1% by the existing channel J regulator. A provision is made in the system for printing out the program, the error, and the actual output values of the 40 channels.

The hardware selected for the individual blocks in the system, although not described here will be discussed in a future article.

BEAM OPTIMIZATION

One of the long-term goals of the automation system is to provide optimization of the cyclotron-beam properties (such as focus and energy distribution) for a given particle, particle energy, and beam current. This optimization must be deferred until: (1) the cyclotron is capable of very stable high-precision operation, (2) suitable measurements of, and indices for, cyclotron-beam qualities are available, and (3) analytical relationships between the machine parameters and the cyclotron-beam qualities are derived. Figure 4 is a simplified block diagram of one possible digital-computer optimization loop.

ACKNOWLEDGMENT

P. F. Pellissier, engineering group leader, provided guidance through many discussions and made several contributions to the system concept.

FOOTNOTE AND REFERENCE

* Work performed under the auspices of the U. S. Atomic Energy Commission.

E. L. Kelley, General Description and Operating Characteristics of the
Berkeley 88-Inch Cyclotron, Nuclear Instruments and Methods 18,
19 (1962).

FIGURE CAPTIONS

- Fig. 1. Typical single-parameter regulating system.
- Fig. 2. Simplified 40-channel supervisory control system.
- Fig. 3. Automatic-control system.
- Fig. 4. Computer-directed optimization loop.

MUB-6806

Fig. 1

MUB-6745

Fig. 2

Fig. 3

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MUB-6740

Fig. 4

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