MASTER MASTER

Conf 790410--2

A MICROCOMPUTER SYSTEM FOR CONTROLLING FUEL ROD LENGTH*

E. R. Meyer,† D. W. Bouldin,† and B. J. Bolfing‡

†Department of Electrical Engineering
The University of Tennessee
Knoxville, Tennessee 37916 U.S.A.

‡Instrumentation and Controls Division
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37830 U.S.A.

Send correspondence to:

B. J. Bolfing
Bldg. 3500
Oak Ridge National Laboratory
P.O. Box X
Oak Ridge, TN 37830

Send page charge to:

Union Carbide Corporation
Purchasing Division
P.O. Box M
Oak Ridge, TN 37830

Attn: D. M. McCammon

*Research sponsored by the U.S. Department of Energy under contract W-7405-eng-26 with the Union Carbide Corporation and subcontract to the University of Tennessee.

OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37830
operated by
UNION CARBIDE CORPORATION
for the
U.S. DEPARTMENT OF ENERGY

A MICROCOMPUTER SYSTEM FOR CONTROLLING FUEL ROD LENGTH*

E. R. Meyer,† D. W. Bouldin,† and B. J. Bolfing‡

†Department of Electrical Engineering
The University of Tennessee
Knoxville, Tennessee 37916 U.S.A.

‡Instrumentation and Controls Division
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37830 U.S.A.

Abstract

A system is being developed at the Oak Ridge National Laboratory (ORNL) to automatically measure and control the length of fuel rods for use in a high temperature gas-cooled reactor (HTGR). The system utilizes an LSI-11 microcomputer for monitoring fuel rod length and for adjusting the primary factor affecting length. Preliminary results indicate that the automated system can maintain fuel rod length within the specified limits of 1.940 ± 0.040 in. This system provides quality control documentation and eliminates the dependence of the current fuel rod molding process on manual length control. In addition, the microcomputer system is compatible with planned efforts to extend control to fuel rod fissile and fertile material contents.

Introduction

Equipment and processes are being developed at ORNL for refabrication of HTGR fuel. The HTGR fuel rods contain three types of particles: thorium (fertile) and uranium (fissile) as coated fuel particles, and shim, an inert graphite material.[1] The use of ^{232}Th in the fuel cycle provides a substantial gain in fuel material because a significant portion of the ^{232}Th is converted into the fissionable isotope ^{233}U. The graphite shim content is adjusted to maintain fuel rod length within specified limits. The three types of particles are bound together in fuel rod form by a carbonaceous matrix. Fuel rod fabrication consists of dispensing, blending, and loading the thorium, uranium, and graphite particles into a mold, followed by injection of matrix material into the void volume of the particles to form a fuel rod. The rod is then carbonized and heat treated into its final form.

An engineering-scale rod molding machine (Fig. 1) was designed and built at ORNL to develop a fuel rod fabrication process for the HTGR. This machine is a demonstration model for a planned facility which will permit high yield production of HTGR fuel rods. The machine is controlled by a programmable logic controller which dispenses the particles, indexes a turn-table holding 24 fuel rod molds, actuates the high pressure injection ram, and ejects the fuel rods.

Eight operations are involved in rod fabrication (Fig. 2). A bottom punch is placed in a cylindrical mold, and particles from three dispensers are blended and fed into the mold. A binding matrix slug is loaded, and a top punch is positioned to hold the mixture in the mold (Fig. 3). As a mold is indexed around the table, it is heated, the matrix material is injected into the void volume of the particle bed (Fig. 3), and the mold is cooled to form a fuel rod ~2 in. long.

Length Control

The dimensions and fuel content of the rods must be within specified limits to maintain the required power level and temperature of an HTGR. The fabrication process factors that affect rod length include the quantity of material introduced by each of the three dispensers, the heating time and temperature of the mixed materials in the mold, the injection pressure and time, and the cooling time and temperature of the fuel rods. The heating, injection, and cooling process conditions remain constant during fabrication. It is possible to control length by adjusting the quantity of any of the three particles. However, it is planned to control fissile and fertile contents by controlling the quantity of ^{232}Th and ^{233}U. The amount of graphite shim material thus remains the only variable available for control.

The length of an individual fuel rod must be 1.940 ± 0.040 in. in order to meet operating requirements.[2]

Manual control of rod length is possible, but the true rod length cannot be obtained until the rod has been ejected from the mold. However, the molds in intermediate positions must be filled to utilize the full capacity of the machine (Fig. 2). Hence, 18 rods will have passed the particle feed

*Research sponsored by the United States Department of Energy under contract W-7405-eng-26 with the Union Carbide Corporation and subcontract to the University of Tennessee.

station before variations in length are detected and correction initiatd. Automated measurement of rod length at the injection station can provide length information, with only eight intermediate molds between it and the fuel particle loading station.

Manual prediction of when the lengths of the rods may no longer be in the desired range requires the operator to perform a trend calculation and then adjust the setting of the shim dispenser at the particle feed station. Since he is already burdened with other tasks, the operator is restricted from systematically exercising continuous control over fuel rod length. This situation will be further compounded when operating a planned fuel rod molding machine of higher production capacity. The microcomputer system can continuously perform the trend calculation and adjust the shim dispenser accordingly. Thus, automatic control of fuel rod length is highly desirable at present and will become essential in the future.

Demonstration of Controllability

A prototypic refabrication facility will require assay and fuel homogeneity devices to monitor the fissile and fertile contents in rods. These data would then be utilized to control the dispensers of fissile and fertile materials. An experiment was performed to show that fuel rod length can indeed be maintained within the specified limits by adjusting only the setting of the shim dispenser (Fig. 4). With fertile and fissile dispenser settings fixed, the shim dispenser was set at an initial value and several rods were produced. After the rods were ejected from their molds, their lengths were measured manually with a micrometer, and a running average of the rod lengths was computed (1.962 in., Fig. 4). A conservative, manual change of the shim dispenser was made to reduce the length nearer to the desired 1.94 in. At this new setting the average length of about 50 rods was 1.953 in. The dispenser was reset, producing rods with an average length of 1.950 in. After a final dispenser setting, rods were produced with an average length of 1.94 in. as specified.

This experiment demonstrated that rod length is controllable by adjustment of only the shim particle dispenser. Because of scatter in the data, it was felt that a determination of a valid average rod length requires that at least 10 rods be used. Furthermore, it illustrates how tedious it is for a human operator to note each rod length, to determine an update on the trend calculation, and to make an adjustment immediately. The considerations involved in designing and implementing a system for automatically controlling rod length will be described next.

Design Considerations

The first consideration in controlling rod length is to obtain an accurate measurement; for our purposes an accuracy of ±0.004 in. (an order o. magnitude less than the rod length tolerance) was desired. A linear variable differential transformer (LVDT) was chosen to measure rod length because it provides an analog signal that maintains an accuracy of 0.0015 in. over its entire ±0.5 in. range. The LVDT allows connection to the microcomputer system as well as to a local indicator.

Since the operational sequence of the molding machine is under control of a programmable logic controller, we utilized a digital controller for maintaining proper rod length, since communication between the two digital devices can be readily performed. Therefore, the analog voltage from the LVDT must be converted into digital form. A 12-bit analog-to-digital converter was utilized since it was compatible with the chosen digital controller and preserved the accuracy of the LVDT.

For digital control of the amount of shim particles dispensed, a stepping motor was chosen to drive the micrometer slide valve on the shim dispenser (Fig. 5). As indicated in Fig. 5, the position of the slide valve controls the volume of particles dispensed into the mold. A synchro encoder enables slide valve position feedback to the microcomputer for adjustment of the quantity of particles dispensed.

The algorithm required for a control application is generally the critical factor in specifying the design of a digital controller. For computing a running average and communicating with the input/output devices, a simple logic controller would be appropriate. However, a major additional application for the controller is envisioned. This will involve controlling three dispensers: fissile, fertile, and shim. Thus, a programmable and flexible system is needed. Furthermore, the use of such a device allows alternative control schemes to be experimentally checked on-line for possible improvement in performance.

The tasks presently required of the digital controller consist primarily of communication with humans and other devices. The controller must accept 12-bit data from the LVDT, compute trends in rod length in accordance with the control algorithm, issue commands to the stepping motor for adjustment of the shim particle dispenser, check that the adjustment has been properly made by monitoring the feedback from the synchro encoder, synchronize its operations with the fuel rod molding machine by performing handshaking operations with the programmable logic controller, accept operator commands from the keyboard, and print data concerning rod length, trends, and controller status. In addition, it must request and receive software tasks from a PDP-11/40 minicomputer. The complexity of these tasks and the requirement for PDP-11 compatibility indicated that the powerful LSI-11 microcomputer was the best choice. These tasks have been coded in FORTRAN to hold software development time to a minimum and to provide for flexibility in making future revisions. A block diagram of the control system is shown in Fig. 6.

The manual demonstration experiment revealed that the scatter in rod length data dictates that at least 10 rods be utilized in computing a mean prior to making an adjustment to the shim dispenser. Consequently, the control algorithm implemented in the LSI-11 uses this procedure. Also, since it is apparent that the fabrication process changes over a period of time, only data from the most recent 25 rods are maintained in the computation of the mean. To initialize the controller with historical data for the shim dispenser setting, values obtained from the demonstration experiment are used. Then, during the course of operation, new data are obtained to reflect the current state of the fabrication process. If the fuel rod molding machine is not in use for a period of 5 min or more, the microcomputer automatically reverts to the data used for initialization. The inherent delay between the time that the particles are dispensed into the mold and the time when the length measurement of the corresponding rod is made forces a suspension in dispenser adjustments until a new trend (with a minimum of 10 rods) can be obtained.

Concluding Remarks

Control of the length of fuel rods produced by the fuel rod molding machine is required to assure that rods will be within the specified range. Implementation of automatic control was dictated by the complexity of the control task and because of planned extensions to fissile and fertile content control. A programmable digital controller was needed (1) to communicate with the fuel rod molding machine controller, (2) to provide flexibility for future revisions, and (3) to be prototypic of what would be used in a remote HTGR fuel refabrication facility. The LSI-11 was selected because of its capability and its compatibility with an existing PDP-11/40 computer. The primary contributions of the work described in this report have been to provide elementary control of fuel rod length and flexible facilities for future expansion.

Acknowledgment

The authors are indebted to P. Angelini of the Metals and Ceramics Division and to D. W. McDonald of the Instrumentation and Controls Division, both of ORNL, for their advice on this work.

References

1. Mack, J. E., and W. H. Pechin, *Automatic Particle-Size Analysis of HTGR Recycle Fuel*, Oak Ridge National Laboratory Technical Report ORNL/TM-5907 (September 1977).

2. Bayne, C. K., and D. R. Johnson, *Relationship Between Length Variations of HTGR Fuel Rod Stack Lengths and Individual Rod Lengths*, Oak Ridge National Laboratory Technical Report ORNL/TM-5544 (October 1976).

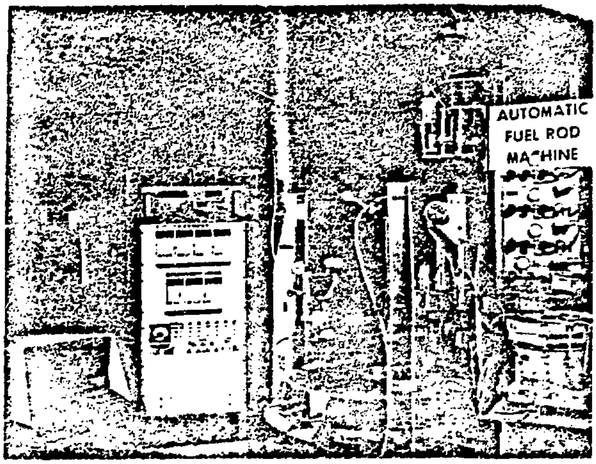

Fig. 1. Laboratory fuel rod molding machine system.

ORNL-DWG 71-9836R2

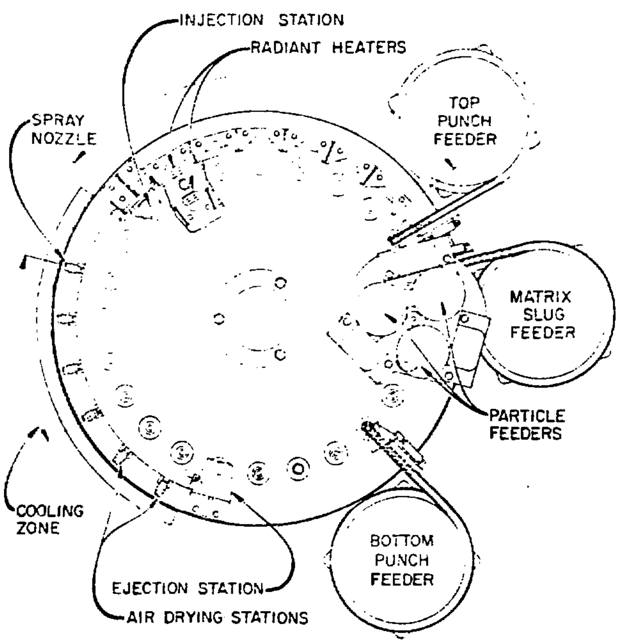

Fig. 2. Laboratory fuel rod molding machine schematic.

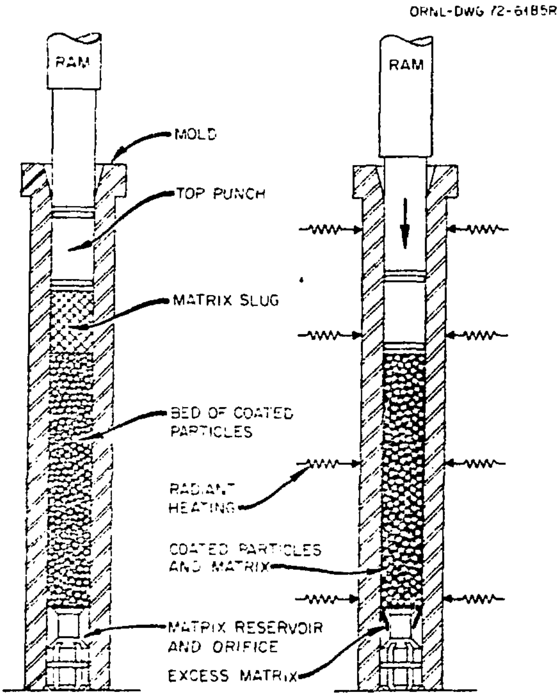

Fig. 3. Fuel rod molding components and technique for making bonded fuel rods.

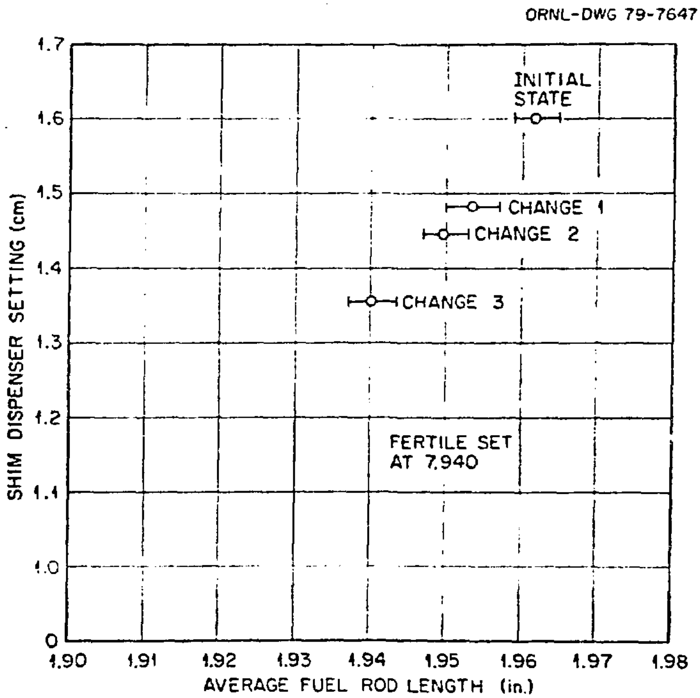

Fig. 4. Manually controlled shim dispenser setting vs fuel rod length.

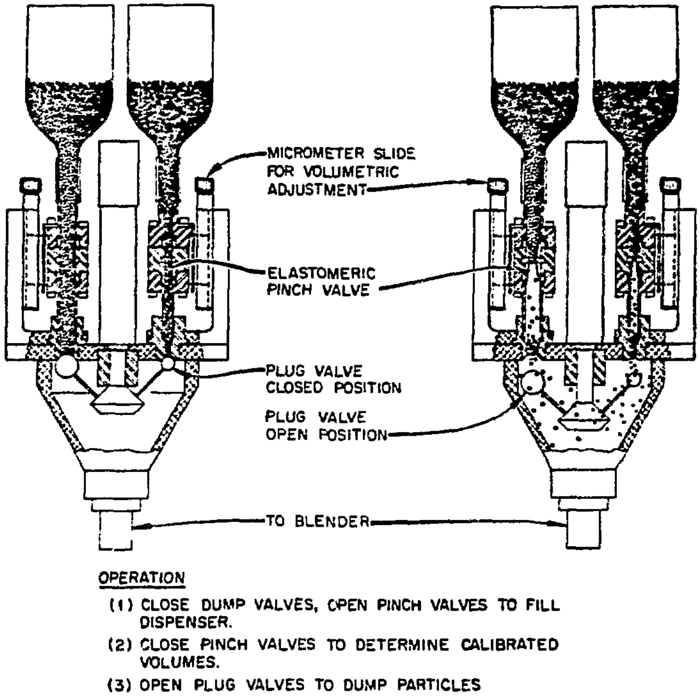

Fig. 5. Fuel rod molding volumetric fuel particle dispensers.

ORNL-DWG 79-7648

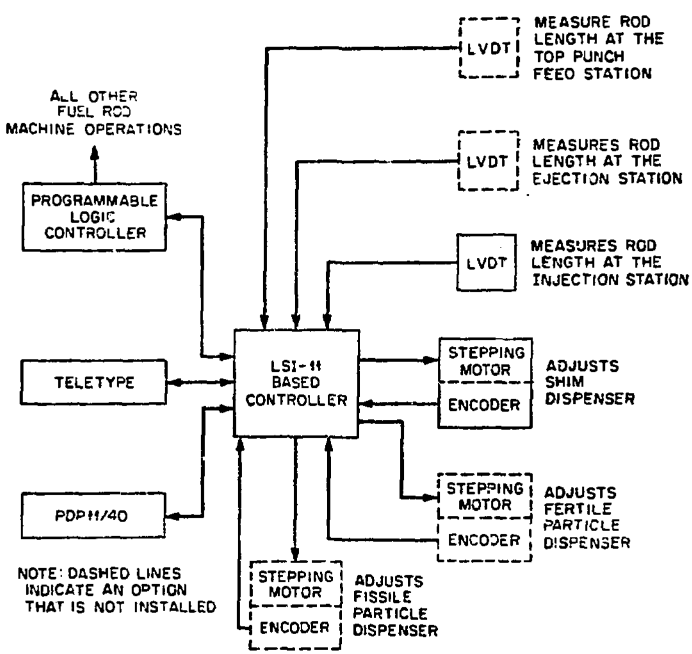

Fig. 6. Laboratory fuel rod molding machine control system block diagram.