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ARMF II REGULATING ROD READOUT AND
SHIM ROD DRIVE AND POSITION DISPLAY

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US ATOMIC ENERGY COMMISSION

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by

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Instrument Development Branch

PHILLIPS
PETROLEUM
COMPANY

Atomic Energy Division

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ABSTRACT

A description of the digital readout and drive portion of the Advanced Reactivity Measurement Facility II is presented along with the philosophy used in selecting the system block diagram and components, accuracy considerations and a preliminary evaluation of performance and usability. The presentation discourages duplicating of the equipment; advantage should be taken of the opportunity to improve upon it. To this end guideposts are provided as well as a documentation of those aspects of the design which are considered worthy of duplication.

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FRONTISPIECE Photograph of the ARMF Reactors

The bridge of ARMF (I) can be seen in the left foreground, ARMF II with bridge in place lies in the right center and its control instrumentation immediately behind it. The digital subsystem occupies the right hand frame of the instrumentation cabinet and the digital averager with its card punch may be seen at the extreme right center adjacent to the digital subsystem.

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1.0 INTRODUCTION

1.1 General

Through the years, nuclear physicists have tried a number of schemes for measuring nuclear reactivity. At the National Reactor Testing Station, Phillips Petroleum Company has designed and built three facilities all of which employ one of the most successful measuring schemes. It incorporates a low power critical reactor and measures reactivity by substitution. More explicitly, a servo driven, calibrated, neutron-absorbing regulating rod holds reactor power constant; when a sample is placed into a specified test location in the reactor, the regulating rod moves to a new position. Its change in position can be translated into the reactivity of the sample.

In 1955, a reactor built specifically for this purpose, the Reactivity Measurement Facility¹ (RMF), was placed into service. It was dismantled in 1962 some time after its first successor, the Advanced Reactivity Measurement Facility (ARMF) had been calibrated. The ARMF has now operated for several years, and a further improved version, the ARMF II, went critical in December, 1962.

In these later reactors, a neutron detector provides the power level signal to the regulating rod servo motor which drives the rod directly. Random neutron detection limits the operating power level at the low end while temperature effects and sample disturbance establish a practical high limit. The usual operating power in these open pool reactors ranges between ten and one hundred watts. The low reactivity worth of the regulating rod which is necessary for precise measurement also dictates the use of a shim rod for coarse control. The shim must be capable of extremely precise repositioning, but normally remains fixed during measurement. Both shim and regulating rods on both reactors employ rotary motion. The shims move approximately 42 degrees, while the regulating rods operate over 180 degrees.

1.2 Scope

The digital subsystems employed in the ARMF and the ARMF II provide regulating rod readout and shim rod drive and position display; hence, the problems associated with these sections, especially in ARMF II, will be considered in detail. The reader is discouraged from duplicating the equipment; advantage should be taken of the opportunity to improve upon it. To this end, and in the interests of economy, exact construction details and complete schematics have intentionally been omitted. Instead a brief history and design philosophy are considered, leading through block diagram formation, component selection and construction to a preliminary evaluation based upon six months of actual operation.

2.0 REVIEW OF ARMF

2.1 Background

The original RMF employed a geared down ac motor for shim drive; it was run against preset time for position determination. A potentiometer sensed regulating rod position, which was then recorded on a strip chart for later evaluation. This left much to be desired in the way of both accuracy and reliability. When the ARMF was designed, advancements in the state-of-the-art allowed the use of a digital stepping motor for shim rod drive and two identical, very precise photoelectric shaft angle encoders for position sensing of the rods. These devices and their associated circuitry, all basically digital, combined to form a digital subsystem² subservient to the main reactor control system of the ARMF.

2.2 Shaft Angle Encoders

The photoelectric shaft angle encoders, Wayne-George RD-17H, supply a seventeen bit cyclic, reflected or Gray scale^{3,4} binary output each time they are interrogated by external circuitry. Strobe lamp life varies inversely as interrogation rate, the maximum of which is 50 pps. The original encoders, quite sensitive to temperature and suffering from poor mechanical design in the strobe lamp assembly have since been updated by the factory and operate with good reliability. These encoders provide accuracy of ten seconds and reproduce to within three seconds of arc.

2.3 ARMF Regulating Rod Readout

As shown in Figure 1, external electronics interrogate the regulating rod encoder once each 64 milliseconds, convert the output binary and offset binary all in one register, then ultimately to an analog voltage for strip chart recording. The system maintains high accuracy by

recording some of the most significant binary bits, typically four but adjustable, as pips left or right by using an operational pen at the edge of the strip chart. Then the lesser order bits feed the binary to analog converter in order to achieve an expanded scale strip chart record, typically expanded sixteen times. Because the regulating rod hunts due to servo action and may be hunting across a transition between full scale on one range and zero on the adjacent range the operator may select an offset mode which subtracts half of a chart scale from the binary register and records this action as an appropriate pip along with the more significant bits. This correction is then added during later chart analysis.

Figure 1
ARMF Digital Subsection
Block Diagram

2.4 ARMF Shim Display

Display for the shim rod consists of 14 glow thyratrons driven through inverting amplifiers from the 14 least significant cyclic binary bits of the shim encoder, which is interrogated approximately 10 times per second. Not only are the thyratrons somewhat unreliable, the display, from an operator's point of view, is practically worthless.

2.5 Shim Drive

A solid state bidirectional two bit counter and associated circuitry drives a modified Slo-Syn stepping motor, which through a standard planetary gear train and a special worm and sector, moves the shim rod. Reactor safety dictated the incremental step size of approximately 3.6 seconds of arc on the basis of maximum rod withdrawal permissives and maximum possible motor speed. Actual motor speed may be varied 0-100 steps per second. An extended shaft on the rear of the motor turns a synchro transmitter, the receiver for which turns a mechanical counter at the console for coarse position indication. The shim always remains fixed during a measurement period. Occasionally it must be moved to a new fixed position to accommodate measurement of a sample whose reactivity approaches or exceeds that of the regulating rod.

The original design also incorporated a torque motor operating directly on the shim. This motor was to have held the rod directly on the transition between two adjacent bits of the encoder by servo techniques. Flash lamp intensity variations and other encoder noise resulted in failure to achieve satisfactory operation. Alternately, when the

torque motor was employed merely to reduce backlash, the stepper had the capabilities of accomplishing the same result. Hence the ARMF system employs this latter technique.

2.6 Accuracy Considerations

Figure 2 shows a plot of relative reactivity vs. angular motion of the shim and regulating rods. Over the practical operating regions an incremental sensitivity ratio of sixteen between shim and regulating rod indicates the use of a position transducer sixteen times more sensitive on the shim. Furthermore, since the regulating rod hunts in a servo loop, a measurement actually consists of an average of many samples. This further extends the required sensitivity ratio to perhaps 64. However, most samples can be measured without moving the shim; under these conditions structural rigidity, temperature stability, amount of regulating rod hunting and time for averaging determine the accuracy. Although at present the four lesser order bits from the regulating rod encoder do not contribute to the measurement, they leave room for further reactor improvement. Use of identical encoders on both rods reduces spare parts and maintenance techniques.

Figure 2
Angular Position-Reactivity Curves,
ARMF Reactors

3.0 ARMF II DESIGN OBJECTIVES

3.1 General

The subsystem of ARMF II was, in general, to have accomplished the same overall job as its counterpart in the ARMF (1.2). Initially, at least, the electronic circuitry was to have been a duplicate of ARMF, but as system work proceeded a number of additions and changes were required. Furthermore, in the ARMF the circuitry had demonstrated some deficiencies which could be improved upon.

3.2 Reliability Considerations

None of the system under discussion contributes to or detracts from the operational safety of the reactor. However, an inoperative facility of this type costs just as much as an operating facility. Furthermore, samples just irradiated in the Materials Testing Reactor must often be measured before short half life isotopes have decayed significantly. Thus, economics provide the greatest incentive for reliable operation.

3.3 Modifications and Additions in ARMF II

While a number of changes were required, others were requested, suggested or proposed, all through constructive criticism of ARMF. Consideration of all these changes ultimately forced a redesign of this subsystem in the interests of economy.

3.3.1 Average Rod Position

A good deal of thought over a number of years has been devoted to the idea of being able to calculate sample reactivity simply with a high degree of repeatability by digital techniques. The new reactor was to incorporate a feature which would provide digital average regulating rod position output.

3.3.2 Shim Display

Poor usability of the ARMF shim display forced some improvement in order to achieve ease of reposition to within three or four seconds of arc, primarily to check long term drift characteristics in the reactor, but also in measurement of samples whose worth exceeds that of the regulating rod. Decimal was regarded as ideal, but just pure binary would have been an improvement over the cyclic code display of the ARMF.

3.3.3 Self Check

The ARMF equipment had proven much less reliable than presupposed. This necessitated a review of system logic to add end-to-end self checks wherever possible.

3.3.4 Isolators

One of the encoders in the ARMF still persists in internal noise sensitivity. Apparently when a sufficient number of output pulses terminate simultaneously, they trigger inactive outputs into operation. This was deduced by the time relationship of the spurious pulses. Because of the repair cost involved in operating time and recalibration, ARMF II was to incorporate isolators which look for outputs only when valid pulses occurred. Thus, if the ARMF II encoders exhibited this deficiency, the system was to operate normally.

3.3.5 Logic and Circuitry

In order to provide digital averaging access and an improved shim display, the system approach changed significantly and allowed the use of completely different circuitry.

3.3.6 Shim Motor

Superior Electric had introduced a newer version of their Slo-Syn motor with separate center tapped windings. This motor not only simplified drive circuitry, its lower winding inductance improves its acceleration characteristics. And while synchro driving necessitated a motor modification on the ARMF, the ARMF II motor, a type SS-150-1048, specification BM101010, contains a shaft extending from the rear of the motor which could be used for synchro drive. A heavy duty clock spring was to replace the anti-backlash torque motor atop the shim.

4.0 ARMF II SYNTHESIS

4.1 General

Figure 3 shows the block diagram of the digital equipment in ARMF II, and Figures 4, 5, and 6 picture the finished product. Note the considerable differences between ARMF II and ARMF (Figure 1). Since

Figure 3
ARMF II Digital Subsystem Block Diagram

Figure 4
ARMF II Digital Subsystem Equipment Cabinet

Figure 5
ARMF II Control Console

Figure 6
Logic Chassis, Showing Backwiring

expanded objectives forced a redesign, the newer equipment design was to give consideration to the following criteria:

1. Increased flexibility.
2. Implementation through use of as few logic types as practical with as low a bandwidth as practical.
3. Incorporation of self check and test provisions.
4. Consideration for checkout and service simplicity, even though this might not result in a minimum configuration.

During the system design phase a number of logic circuit types received consideration. Although the system employs RTL nor logic (5.4.1) extensively, most of the design objectives can be attained by the use of other static logic types.

4.2 Regulating Rod and Shim Register

Although one register can perform all functions, as in ARMF, the circuitry must be fast in order to minimize analog discontinuities on the strip chart record. Otherwise, actual speed requirements do not actually preclude the use of relays, except for reliability. The block diagram started by specifying a parallel entry, jam set register of sixteen bits for holding the latest regulating rod binary number. For simplicity, the shim rod register could be a duplicate, and both could be supplied binary data on a time sharing basis from a single cyclic to binary conversion circuit.

4.3 Input and Cyclic to Binary Conversion

The following procedure converts cyclic numbers to their binary equivalents: Examine the most significant bit. This will be identical in both codes. If it is a one, complement the next most significant bit, otherwise do not. If the second bit becomes a one in this process (either through complementation or because it was already a one and was not complemented) complement the third bit. Continue sequentially until all bits have been operated upon.

This conversion process immediately suggests the use of serial logic for implementation and indeed one may employ ring shift register techniques. Shaft angle encoder outputs, being of only 20 μ sec duration, indicate the use of some sort of register at the input. However, whether employing a duo-parallel entry shift register, two single parallel entry shift registers or a duo-parallel entry static register and parallel converting gates, costs for practical hardware remain substantially the same. The latter case offers other advantages, since it can be implemented with a single logic type (nor or nand, either of which is more reliable than shift register circuitry) and generally

speaking, is easier to check out and service. On these grounds, the shim and regulating rod registers are preceded by a static input register and parallel cyclic to binary logic (Figure 7).

Figure 7
Cyclic to Binary Logic

4.4 Isolators

The encoder isolators (Figure 7), located on the reactor bridge near the encoders, serve to eliminate spurious pulses occasionally initiated by the encoders (3.3.4). The encoder interrogating pulse, adjusted to terminate simultaneously with valid encoder output pulses, gates out the spurious pulses.

4.5 Offset

The system accomplishes offset subtract and borrow (2.3) by a series of exclusive-or gates arranged as binary half subtractors (Figure 8). These again take advantage of the properties of the common logic type in terms of reliability and ease of checkout and servicing. An alternate technique, that of backward counting, offers one other disadvantage in that the variable expansion factor requirement complicates its implementation.

Figure 8
Offset Logic

4.6 Shim Display

The operator seldom refers to the shim position display except while operating the shim motor drive, at which time the numbers change sequentially. An octal display, even for people not previously familiar with octal counting, provides a good compromise between the poor readability of cyclic or binary lamps and the high cost of binary to decimal conversion.

4.7 Timing

A potted 1 kc fork oscillator provides clock signals for all electronics except the variable speed shim motor circuit. Logic divides the 1 kc signal down to eight staggered pulses, each with a 64 millisecond rate. These pulses perform the following tasks:

1. Reset the input register.
2. Interrogate the regulating rod encoder, which results in setting up the input register and the cyclic to binary logic.
3. Transfer the new regulating rod binary number into its respective register.

4. Transfer to the averager.
5. Reset the input register.
6. Interrogate the shim rod encoder.
7. Transfer to the shim rod register.
8. Spare.

In addition, the averager also used the 1 kc clock for its serial adder.

4.8 Shim Drive

The shim drive logic (Figure 9) consists of a two bit up-down counter which derives its signals either from a switch actuated monostable multivibrator (for jogging) or a variable speed oscillator (for running). Console switches select signal source and direction.

4.9 Test Lamps

In order to allow maintenance personnel to spot trouble rapidly the system includes 16 test lamps and drivers, switch selected to all important registers.

4.10 Alarm

The ARMF certainly demonstrated that self check routines are of value. The encoder flash lamp darkens with usage and sometimes fails to trigger. An operator familiar with the problem can detect these deficiencies by examining the strip chart, but this may be too late, since a good deal of poor data may have already been acquired. Since both shim and regulating rods move less than 180° , the encoders are oriented so that the most significant bit always remains a one. The equipment then monitors this bit and in its absence sounds an audible tone which indicates the need for maintenance.

4.11 Other Self Checks

The operators calibrate the strip chart recorder daily. The logic, in setting up of the zero and full scale voltages, replaces the encoder outputs with simulated signals in order to acquire an end to end self check.

4.12 Averager

4.12.1 Design Considerations

Initially, two approaches seemed attractive as a means of acquiring digitally the average regulating rod position. One consisted of punching out each individual regulating rod position sample on perforated tape and allowing a computer to calculate average. This had, in fact, been done experimentally on the ARMF. Although it results in a considerable volume of data, it allows determination of peak as well as mean deviation and provides data of considerable value for reactor noise studies. The other approach would acquire a single average, and without added computational power, would not provide any deviation figure. Use of a stored program computer for on-line calculation was rejected on the basis of cost; this equipment was to acquire the data in a form acceptable to off-line computer facilities. A sequential set of rod positions allows a computer to check reactor stability, but with a reactor time constant in the order of two minutes (due to delayed emitters) it hardly seemed necessary to record a rod position every 64 milliseconds, the nominal interrogation rate required because of rod hunting. The final system incorporated acquisition of eight sequential averages over a total time selectable between 1/2 and 32 minutes in multiples of two. The averager punches these figures along with other pertinent information on a standard IBM card.

4.12.2 Operation

The readout equipment allows access to all important numbers for use in the digital averager or similar accessories. The averager uses system clocks and the information in both the shim and regulating rod registers. Figure 10 shows a block diagram of the averager; it is pictured in Figures 11, 12 and 13. When manually started, the averager punches on a card 24 digits of pertinent measurement information: sample number, sample location; temperature, number of samples per average, sampling rate, time of day and shim position. The latter is octally coded for easy comparison with the octal shim position display on the control panel. Time recording is automatic; manual entry switches provide the rest of this data. The machine then accumulates the prescribed number of samples, this number being a binary multiple to simplify the average calculation. It punches the average onto the card (six

Figure 10
Digital Averager Block Diagram

Figure 11
Averager Control Panel

Figure 12
Averager and Punch

Figure 13
Averager Chassis Showing Backwiring

octal digits), and proceeds directly into another average, completing eight averages before releasing the card and stopping. It carries all significant bits through the accumulation, truncating to 18 bits (the six octal digits) in the punchout.

4.12.3 Accumulator

The basis of the design for this equipment rests heavily on the use of a single logic type (specifically the RTL nor), except for miscellaneous scalars and frequency dividers. A nor accumulator, however, would cost approximately three times that of a serial adder using shift registers, so the latter technique was chosen, notwithstanding its greater susceptibility to noise.

4.12.4 Averager Maintenance

The averager incorporates one feature on an experimental basis worthy of mention. A multiple position rotary switch selects one of a number of key logic signals to be monitored by a small speaker. This can provide the maintenance technician with a rapid audio check on system performance, especially on serial logic systems where the clock rate falls in or near the audio spectrum.

5.0 COMPONENT SELECTION

5.1 General

This equipment was to employ components which would minimize mechanical design changes from the ARMF.

5.2 Shaft Angle Encoders

The ARMF II, like the ARMF, employs Wayne-George Model RD17-H encoders primarily to minimize mechanical change but also because an existing spare encoder had not proved to be as useful in maintenance as its spare component parts. These encoders provide excellent accuracy and good reliability.

5.3 Interconnections

System reliability requirements indicated the use of the best available techniques for both module backwiring and cable interconnections.

5.3.1 Module Backwiring

Previous experience had shown solder to be inferior because of difficulty in maintaining good quality control during check-out. Insulation burn, excessive wicking, flux, cold and crystallized joints cause considerable trouble in subsequent years and quite

surprisingly, labor costs, for acceptable work, run high. Wire-wrap, while electrically superior, causes difficulty during checkout or when making other changes or modifications. It also requires special annealed solid wire not particularly suited to flexible cabling. The taper pin has proved reliable, inexpensive and readily adaptable to modification. Wire stranding or alloys are not critical. Since environmental conditions are not hostile, the modules employ silver plated lands mating Kennedy Industries KI-1500-22 connectors which accommodate two silver plated taper pins for each of 22 circuits. This allows easy propagation of signal and power busses. Figures 6 and 12 show the chassis on which the technique was used. Note the improved wire routing on the averager (built after the readout) and the use of taper pins for thumbwheel switch connections as well as module wiring.

5.3.2 Cable Interconnections

The distaste for solder follows for cable wiring as well as backwiring, except that direct crimp removable pins and receptacles were favored over taper pins. A number of manufacturers make adequate units.

5.4 Circuitry

The circuit requirements call for logic capable of 10 kc operation, digital-to-analog converters, lamp drivers, solenoid drivers with transient protection and perhaps a few special circuits.

5.4.1 Logic

Experience acquired since the design of the ARMF led to the selection of a logic circuit series based primarily upon the resistor-transistor-logic (RTL) nor element. Several factors influenced this decision:

1. Adequate speed (nominally 50 kc) yet not so fast as to be noise sensitive.
2. Adequate fan-in (6) and fan out (6).
3. Insensitivity to power voltage variations. Reliable operation on bias and power voltage ratios anywhere between 1:3 and 3:1 with the power voltage set anywhere from 0.5 to 20 volts at room temperature.
4. Insensitivity to temperature. Reliable operation, at nominal supply voltages, from 0 to 135°F.
5. Excellent reliability with transistors of the 2N414-2N404 class, minimum large signal gains of 40 at 3 ma. With the exception of the possibility of inadvertent shorts to the negative power bus, component quality is the sole factor in reliability

determination, and circuit simplicity minimizes this factor.

The standard nor element (Figure 14) performs all logic decisions and two nors back-to-back as flip-flops for storage (Figure 15); addition of pedestal gates turns storage flip-flops into counters or shift registers (Figure 16). An oscillator (Figure 17) monostable multivibrator (Figure 18) and lamp drivers (Figure 19) complete the line. All may be packaged in a number of configurations in order to minimize space requirements and interconnections. The basic module size, 4-1/2 x 6 inches provides adequate space for component mounting, commensurate with use of 22 pin connectors.

Figure 14
Nor Circuit

Figure 15
Nor Flip-Flop

Figure 16
Counter-Shift Register

Figure 17
Oscillator Multivibrator

Figure 18
Monostable Multivibrator

Figure 19
Lamp Driver

5.4.2 Digital to Analog Conversion

Current summing digital-to-analog converters (Figure 20) provide the coarse rod position meter and the strip chart signals. The extra minimum bit allows calibration of full scale.

5.4.3 Solenoid Drivers

The solenoid driving circuit (Figure 21) supplies shim motor drive power and card punch drive. Separate modules house the suppression circuitry.

Note: All Diodes Are IN457's

PP Co-A-4829

Figure 20
Digital-to-Analog Converter

Figure 21
Solenoid Driver

6.0 PRELIMINARY EVALUATION

6.1 Checkout and Installation

Construction techniques can best be analyzed by the photographs of some of the major assemblies (Figures 4, 5, 6, 11, 12 and 13). Checkout, with a nominal number of corrections, proceeded smoothly. All deficient connections, open or short, appeared in switch wiring where solder was employed. An analysis definitely shows that solderless techniques, a coherent logic series and a step-by-step block diagram approach more than justified the added parts cost by significantly reducing assembly and checkout costs.

Checkout of the equipment included temperature cycling of all components to at least 20°F above the highest expected ambient, and voltage tests with all power supplies at +50%. No failures occurred during these tests.

The averager output drive parted ways with four power transistors during card punch checkout. Proper suppression and filtering prevented recurrence.

6.2 Accuracy

Although current reactor performance probably exceeds that of the ARMF, the digital equipment accuracy still allows another order of magnitude improvement before it becomes an error producing factor.

6.3 Usability

Any evaluation on usability introduces a subjective viewpoint, at least to a degree. However, most of the reactor operators and maintenance personnel have been interviewed as objectively as possible in an effort to determine the usefulness of the improvements.

6.3.1 Test Lamps

This feature added considerable checkout time and cost; to date it has gone unused. Future systems of this type would probably omit the test lamps, or perhaps employ a required display (such as shim position) for this purpose.

6.3.2 Alarm

Although the alarm has yet to indicate a strobe lamp or encoder failure, the lamps do require replacement and the alarm will indicate replacement time. The system should incorporate a pushbutton test to establish operator confidence in the alarm circuitry.

6.3.3 Sound Monitor

Justification of this item became apparent during checkout. The ability of the human ear to detect slight differences in sound derived from a cheap, simple gadget proved quite valuable during the checkout phase, and probably will during maintenance as well.

6.3.4 Octal Shim Display

From the beginning the operators have preferred the more precise octal projection display to the coarser decimal mechanical counters, notwithstanding the fact that they had operated the ARMF for several years using the mechanical type. All have readily adapted to sequential counting in octal; some even have gained a fair quantitative insight. None of the operators had any previous digital data indoctrination.

6.3.5 Averager

This item gained rapid acceptance. However, its controls should be integrated into the console in order to be most useful. The operators would prefer an average rod readout which exactly corresponds to the strip chart because this would allow immediate correlation of results. Perhaps an octally graduated strip chart would circumvent this deficiency most economically, especially in view of the ease with which the operators can adapt to octal coding. BCD encoders provide another possibility, although at some sacrifice in resolution.

6.4 Reliability

The excellent reliability which this equipment has demonstrated since placed in service leaves nothing to be desired. The deficiencies of some of the components leave some room for improvement even though the system design circumvents these deficiencies.

6.4.1 The Shaft Angle Encoders

Although the principle of the photoelectric encoder provides tremendous reliability potentials, these have yet to be realized. However, the situation has improved by several orders of magnitude since ARMF and further improvements can be expected. Spare encoders do not prove to be practical because of the high cost for recalibration which is much more costly than the already expensive encoders. Spare plug-in electronics modules, power supplies and flash lamps, good mechanical accessibility and good free or filtered forced air ventilation can reduce maintenance costs and reactor down-time to a minimum.

6.4.2 Interconnections

The reliability of the solderless technique has to date proved absolute. On multipole switches, to which wires were soldered, several intermittent flux joints and shorts caused considerable delay in checkout.

6.4.3 Circuitry

With the exception of the solenoid drivers, all the circuitry in both the readout/drive and the averager have to date demonstrated absolute reliability. Even with zener diode suppression, when connected to an inductive load the solenoid drivers (Figure 20) exhibit a deficiency. With the output transistor cut off, both load and source present a high impedance to the line. This places it in a condition highly susceptible to high frequency noise pickup. The particular module layout introduces considerable input-output capacitance so that negative noise spikes (as from relay closures) picked up by the output line may couple to the input and drive the circuit into partial or temporary conduction. Although capacitive bypassing of the load removes this effect, redesign of the card would provide a better solution.

7.0 CONCLUSIONS

The ARMF II regulating rod readout and shim rod drive and readout equipment shows a substantial improvement over its counterpart in ARMF, especially in terms of reliability and usability. It contains

a superfluous test lamp feature and means should be devised to more readily obtain correlation between strip chart and card punch output. The averager controls should be integrated into the console. An octal display provides an excellent compromise between the poorer readability of binary and the higher cost of binary to decimal conversion, especially in sequential counting applications...

8.0 ACKNOWLEDGMENTS

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