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CONTROLS FOR EBR-II PRIMARY-TANK HEATERS

by

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ABSTRACT

"Zero-crossover" SCR (silicon-controlled rectifier) controllers for the EBR-II primary-tank heaters were installed to reduce electrical-noise generation caused by the original "phase-fired" SCR controllers. The system consists of six controllers and heaters rated at 112 kW each with a three-phase, 480-V power supply; two heaters and controllers are on each phase. One of the controller-heater pairs (W5) is limited automatically to 70 kW because of the closeness of the heaters to the primary-tank wall. Higher power could cause undue stress in the tank wall. The heaters can be controlled separately or collectively from the EBR-II control room, or separately via local controls in connection with a permissive control function in the control room. Individual and total heater powers are indicated in the control room, and individual heater power is indicated locally at each heater controller.

I. INTRODUCTION

At the start of EBR-II plant life, the primary-tank heaters were controlled by manual reconnection of the four 28-kW heater elements, constituting each heater, in series or parallel as required to produce the desired heat. The heat was applied in steps that, at the desired operating temperature, were too large for control within established temperature limits.

*Mention of commercial products, their manufacturers, or their suppliers in this report does not imply or connote approval or disapproval of the product by the Argonne National Laboratory or the U. S. Atomic Energy Commission.

Later, the system was modified to include individual phase-fired* controllers for each heater, with the four 28-kW elements for each heater connected in parallel. This system provided the temperature control desired. However, because of the nature of phase-firing SCR control, electrical noise was generated; this noise included harmonically related frequences extending well into the radio-frequency spectrum. This noise has been a continuous problem in that electronic instrumentation was affected adversely; efforts to eliminate the problem at the instruments have not been effective enough. The noise generation can be traced to the very steep wave front that occurs at the instant the SCR turns on (energizes the heater) during some portion of the initiating 60-Hz voltage wave form. Because of the noise problem, the heater controllers for the primary tank were changed to zero-crossover control.** The advantage of the zero-crossover SCR controller is that it does not generate steep voltage wave forms, because the SCR fires only when the voltage wave form passes through zero. The zero-crossover controller causes the SCRs to fire in bursts of complete cycles for a given period. The SCRs are then shut off for the remainder of the interval. The cycle time for one complete interval is about 1 sec. Power to the load is controlled in the zero-crossover scheme by controlling the number of complete cycles in each burst.

Power in a zero-crossover SCR system cannot be monitored with conventional voltmeters or ammeters because of the pulsing of the system. To read current (or in this case power from an ammeter) with appropriate scales, an average-reading ammeter with a time constant much greater than 1 sec is required. Power or current, or both, is indicated by rectifying a voltage proportional to current and then using a filter in the rectified output with a long time constant. A voltmeter is used for this measurement. See Fig. 1. for a schematic drawing showing the power metering. The power-metering circuit uses current transformers, relay switching, and load resistors that were part of the original system. The

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*Phase firing is a turning-on, or firing, in which the firing is controlled by the relative phase of the SCR trigger signal and that of the circuit being controlled.

**Zero-crossover control or firing is, unlike phase firing, a method of firing the SCR in which the wave form of the controlled circuit voltage is crossing through zero as it swings from plus to minus or vice versa.

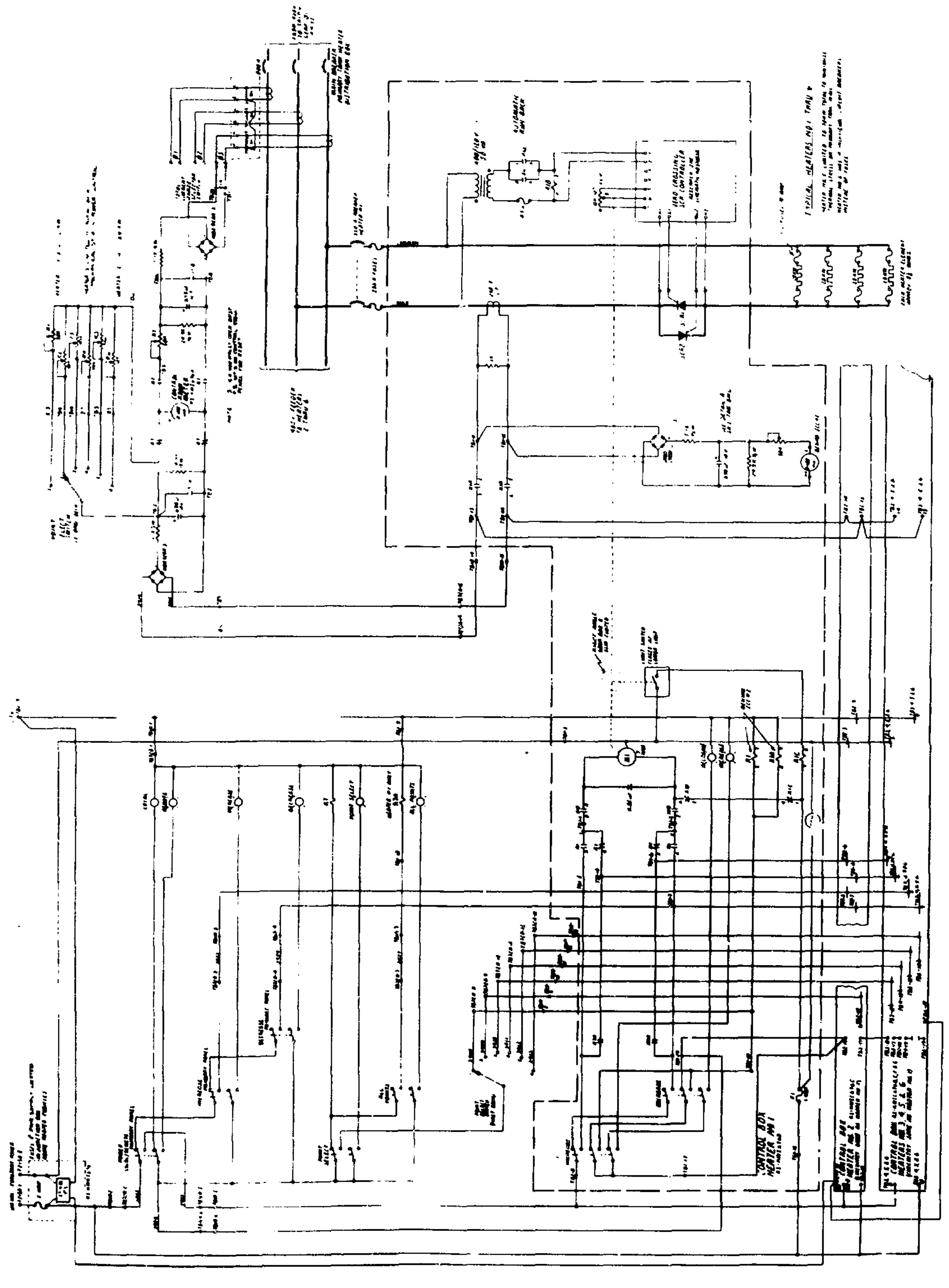

Fig. 1. Overall Schematic of Primary-tank Heater System

power meters, including the integrating circuit, were built in modular form to replace the original meters without requiring mechanical or electrical modification external to the meters. The local meters read in kilowatts, and the control-room meter reads in both kilowatts and amperes. Switching at the control-room meter selects any of the six heaters for individual indication of power or line current on each phase of the 480-V heater power supply.

The conversion from phase firing to zero-crossover also retained the original SCRs and enclosures. Rewiring and minor mechanical changes to the enclosures were required. The automatic rundown feature of the original system was retained, with modifications. The automatic rundown system automatically operates to return each controller (heater) to zero power in the event of power failure and thus prevents the system from being energized at high power when power is restored. Power for operation of the rundown system is obtained from the EBR-II constant-power system, which is independent of the normal heater power source. The original automatic rundown system sensed power loss on only one of the three phases of the power source. The new system senses loss of power at each heater controller and provides individual rundown. Additionally, a cooling fan larger than the original was installed on each controller enclosure, not because the new circuitry and firing scheme generated more heat, but to provide an extra safety margin for cooling and to provide an air filter to lessen maintenance required due to dust accumulation.

II. DESCRIPTION OF ZERO-CROSSOVER CONTROL

The zero-crossover feature for the control system, in each of the six EBR-II primary-tank heaters, consists of a single printed-circuit card manufactured by Research, Incorporated. See Fig. 2. The card is mounted in the control cubicle by four screws. It has four soldered and five screw terminal connections for external connections. Three of the screw terminal connections are used to connect an external control potentiometer; the other two are for the 120-Vac power. The four soldered connections are for gate and cathode connections to the two power SCRs for control of heater power.

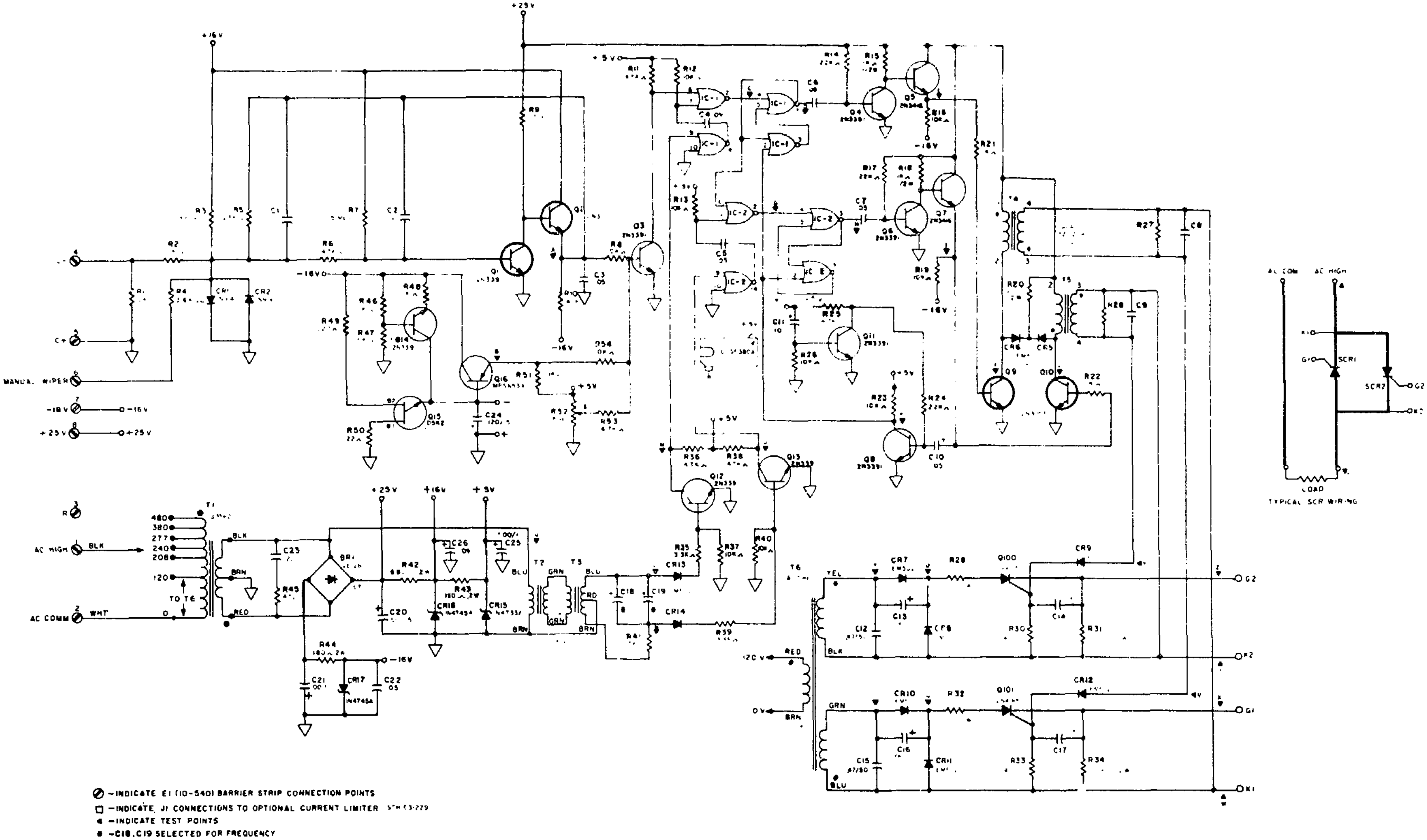

Fig. 2. Zero-crossover Firing Circuit (Drawing courtesy of Research, Incorporated)

Remote and local heater control is by control, through relays, of a small gearhead motor, which in turn rotates a ten-turn potentiometer external to the zero crossover printed-circuit board. See Fig. 1 and Fig. 3. Total transit time of the potentiometer corresponding to zero to full power or vice versa is preset at about 75 sec. If there is a loss of 480-Vac heater power, the motor-control relay circuitry senses this loss and the drive motor is automatically operated in the "lower-power" direction until the lower-limit switch causes the motor to stop (automatic rundown). Motor and control circuit are independent of the heater power to make this feature possible. A friction clutch is interposed between the gearhead motor and the control potentiometer to preclude mechanical damage at the high-power mechanical limit and at the low-power limit should the limit switch fail or not be adjusted properly. The high-power limit is controlled by an adjustable mechanical limit. For all heaters except No. 5, the limit is 100%; heater 5 must be limited to 70 kW to prevent mechanical stresses in the wall of the primary-tank vessel.

The output of the printed-circuit board provides appropriate gating signals to the two SCRs used at each controller. The same SCRs are used with the zero crossover system as were used in the original phase-fired system. The printed-circuit board used in the heater system for the EBR-II primary tank is designed to control, without modification, a wide range of power SCRs manufactured by International Rectifier Corporation. Provisions are made on the circuit card for operation from 480, 380, 277, 240, 208, or 120 Vac by movement of a transformer tap. The control boards are operated on 120-Vac power taken from EBR-II "continuous" power system, which uses a motor-generator set with backup batteries. A 480/120 step-down transformer furnishes power for the control-motor relays. If 480-Vac power is lost, the motor is automatically operated to the lower limit.

III. TESTING

A. Initial Testing

Initial testing consisted of a 30-day operating cycle with three controllers and three resistive loads, all operated from a three-phase, 480-Vac

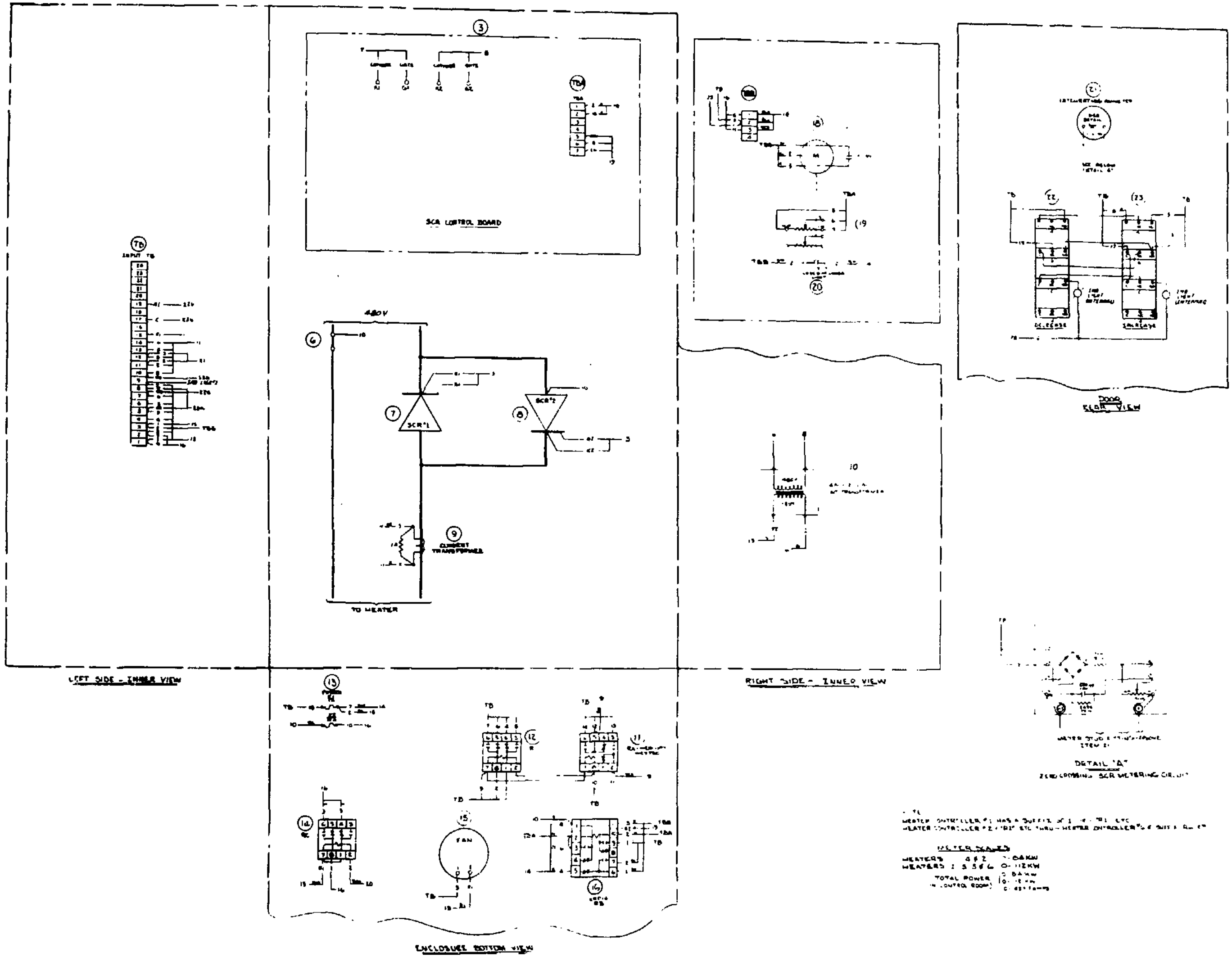

Fig. 3. Wiring for Zero-crossover Controller Cubicle

power source. Because of power-source limitations, testing at full power was not possible. Maximum power possible was limited to 10 A per line. This limitation did not degrade the test results, because the load-handling components of the system, primarily the SCRs are the same components as those in the original system and did not require retesting. The test was to determine: (a) reliability of the new zero-crossover firing circuit; and (b) whether there would be interaction among three units interconnected, one on each of three phases of the same power supply. None of the control components failed during the 30-day test. The interaction was not detectable with simulated operating conditions. During this test, the metering-circuitry design was finalized and meter scale forms were determined experimentally. By varying the connected resistive load, the number of turns of the primary-current transformer and the relative power setting of the controller, an infinite range of load current and power level could be simulated for the metering circuit. Actual power in percent was obtained by counting, with a digital counter, the average number of complete 60-Hz wave forms delivered to the load per unit time. Counting time was 10 sec, and 30 counting intervals were required at each power level to obtain a good statistical average. At this time, metering time constant was experimentally optimized to provide reasonable response with minimum meter pulsation. Actually, there are two full-scale ranges -- 112 and 84 kW -- because two of the six heaters have one of their four 28-kW heater elements failed and disconnected.

B. Operational Testing

For operational testing, one of the zero-crossover controllers was installed on heater No. 6 (see Appendix B). Several failures of the installed control circuit occurred. The problems were eventually traced to handling damage to the printed-circuit card, which occurred during prefabrication. There have been no failures of the controllers in the two years of operation in the plant since the operational test.

IV. OPERATING EXPERIENCE

Primary-tank heater No. 6 was converted to zero-crossover control in June 1971 to obtain operational experience. (See Appendix B.) This test was completed in December 1971. The two failures that occurred shortly after the test began probably resulted from the proximity of the two capacitors to the two integrated circuits, so that the capacitors were physically disturbed when the integrated circuits were being changed. After two years, no additional failures have occurred. Causes of the original failure have been studied. The two capacitors that failed are axial-lead electrolytic capacitors about 3/4 in. in diameter and 3 in. long. They are mounted perpendicular to the circuit board, with the lead next to the board having no strain relief. The lead on the end of the capacitor away from the board, 3 in. long, has adequate strain relief. A small mechanical force perpendicular to the capacitors at their upper ends will result in a large stress in the lower lead of the capacitors and could easily pull this lead out of the circuit board because of the leverage available. Because the capacitor mounting protrudes, handling, especially during installation of one of the circuit boards, is difficult without disturbing the capacitors and possibly causing the failures mentioned. Therefore, the original failures are judged to have been caused by handling damage and not by any circuit or design failure. Handling precautions and visual inspection of the suspect lead connections have been put into effect; they are considered to have resulted in the record of zero failure achieved in the past two years of system operation.

After the system had been in use for a short time, adding a pushbutton switch to the control-room metering circuitry to discharge the power-meter filter circuit was necessary to allow quicker reading stabilization of the meter. During conditions when lowering power is necessary, the metering-circuit time constant becomes extremely long at the lower end of the scale, and discharging the filter system greatly reduces the time required for the meter to stabilize after a power reduction.

Electrical-noise levels have been reduced pronouncedly in experimental and operational nuclear instrumentation that must be close to the primary-tank heaters and their wiring.

APPENDIX A

Calibration and Maintenance Procedures

A. Calibration

Because of the "burst" nature of power control of the zero-crossover SCRs, conventional power-measurement instruments are of limited usefulness for calibration or monitoring. The instrumentation used in the primary-tank heater system is of the "integrating" or average-reading type. Comparisons between the two types for the purposes of calibration are valid only at zero and full power. Further, because of the high power level during operation and the number of elements in the metering system, the system can be calibrated only in place.

Procedure (See Fig. 3)

1. Have local control of the primary-tank heaters established.

2. Remove screws retaining control-enclosure door of heater W1.

   CAUTION: Circuitry inside of the enclosure is energized 480 Vac.

3. If heater W1 is not already operating at above 10 kW, raise the power level to 10 kW by depressing the "Increase" push button on the enclosure door and hold until the door-mounted meter indicates about 10 kW. Observe that the control motor operates and that the potentiometer connected to the motor rotates clockwise when viewed from the shaft end of the potentiometer.

4. While observing the motor and potentiometer assembly in heater-W1 enclosure, open the breaker for this heater and observe that the motor operates and the potentiometer rotates to its full counterclockwise position, at which point relay R1C should energize.

<u>CAUTION</u>: Opening breaker W1 removes 480-Vac power from the enclosure W1; however, 115-Vac power is still on.

5. Depress the "Increase" push button and observe that the meter and potentiometer move less than half of a turn and then reverse. Rotation of more than half of turn or no movement at all will require that the limit switch driven by the motor be adjusted. To adjust the lower limit, loosen the three mounting screws on the limit-switch assembly, and rotate the assembly clockwise slightly, as viewed from the switch end, to increase the rotation or rotate slightly counterclockwise to decrease rotation. If readjustment is required, the shaft-coupling components should be checked for tightness (tighten set screws, etc.). Recheck rotation as above.

<u>CAUTION</u>: The light switch, fan, relays, and push-button switches are all energized 115 Vac.

6. Disconnect 480-Vac input lead to upper SCR heat sink and insert a Weston Type 461 instrument current transformer (thread 480-Vac lead through large hole in current transformer). Reconnect lead and connect output of current transformer to Weston Type 433 ac ammeter. Use the "low" or 2.5-A range. The meter is read by multiplying the 2.5-A scale by 200, i.e., a reading of 1 A would be read as 200 A.

7. Connect a Weston Type 433, 600-Vac voltmeter across the 480-Vac output leads from the control enclosure. Connect one lead of voltmeter to lead which passes through controller enclosure and the other voltmeter lead to the lower SCR heat sink. Use the 600-Vac range.

8. Close the circuit breaker opened in step 4.

<u>CAUTION</u>: The enclosure for heater W1 contains 480 Vac. Also, the instrumentation connected in steps 6 and 7 are energized 480 Vac.

9. Perform the following step (10) as rapidly as possible:

10. Depress the "Increase" push button and hold until the voltmeter and ammeter stop oscillating. Inability to reach the nonoscillating condition will require adjustment of the upper limit stop by loosening the locknut on the end of the limit-switch assembly and adjusting the Allen-socketed screw. Record voltage and current and calculate power by multiplying the two readings. Adjust the trim potentiometer on the rear of the enclosure meter to obtain a reading equal to the power level calculated. Simultaneously, have another person adjust R1 on the control-room metering to obtain identical indication on the control-room readout with meter switch in position No. 1. Press the "Decrease" push button and hold until the motor clutch begins to slip. Note that the front panel meter has a long time constant and may indicate for some time after the "off" condition has been reached.

11. The voltmeter and ammeter should read zero--no short-term pulses. See Fig. 2. If pulsing exists, use a nonconductive screw driver (plastic or phenolic-resin blade) and carefully adjust the small potentiometer (zero) on the SCR firing control board (see Fig. 2) counterclockwise until the pulsing just stops. Observe the metering for at least 30 sec for evidence of pulsing. This adjustment does not affect calibration and can be made whenever the controller will not turn completely off.

<u>CAUTION</u>: The control board is energized 480 Vac.

12. Open breaker W1 and remove instrumentation connected in steps 6 and 7. Reclose breaker after removal.

13. Repeat steps 2-11 for heater controls W2, W3, W4, and W6. Record data as in step 10 for each heater. Note that heater controller W5 requires slightly different procedures, which are detailed below:

14. Heater W5 must be limited to 70 kW to minimize stress on the primary-tank wall. To achieve this limit, the limit switch and stop are adjusted to limit rotation of the control potentiometer in the increase direction. To calibrate the metering, the stop must be moved so that the heater can be operated full on for the very brief calibration period.

15. Open heater-W5 480-Vac breaker and remove both fuses at bottom of the control enclosure.

16. Loosen lock nut on limit-switch-stop assembly and rotate Allen-socketed screw counterclockwise about five turns. Note the exact number of turns as an aid to resetting the stop after calibration is complete.

17. Reinstall fuses removed in step 15.

18. Close 480-Vac breaker W5.

19. Perform steps 3-12 for heater W5 except that breaker W5 is not reclosed. If, in step 10, the limit-switch-stop assembly requires readjustment to reach the full-on condition, be sure to note the number of extra turns required to aid in resetting the adjustment.

20. Remove both fuses on the bottom of the control enclosure W5. Check that 480-Vac breaker W5 is open.

21. On the limit-switch-stop assembly, rotate the Allen-socketed screw clockwise equal to the number of turns noted in step 16, plus those noted in 19. Secure lock nut.

22. Replace fuses removed in step 20, and close breaker W5.

23. Raise power level of heater W5 as far as possible until clutch on motor shaft begins to slip. The maximum power should be 70 kW. If power cannot be raised to 70 kW or if more than 70 kW results, reduce power to zero, open breaker W5, and remove two fuses on bottom of control enclosure. Make a small adjustment of the limit-switch stop. To raise the maximum power level, rotate the adjustment counterclockwise; to lower, rotate adjustment clockwise. Tighten lock nut. Replace two fuses, close breaker W5, and recheck maximum power. Record maximum power as indicated.

24. To calibrate the "total-power" meter scale in the control room, select the pair of heaters on one phase of the 480-Vac power that have the highest total power as determined from readings taken in step 10 for each heater.

25. Position the total-power selector switch in the control room to monitor the phase selected in step 24.

26. Raise the two heaters selected in step 24 to maximum power and, as quickly as possible, adjust R7 on the control-room metering circuit so that the control-room meter indicates the sum of the readings from the two heaters. Return the heaters to zero power.

27. This completes calibration of the primary-tank-heater metering system.

B. Preventive Maintenance

Perform the following ten steps on one heater-controller enclosure at a time:

1. Open 480-Vac breaker W1, W2, W3, W4, W5, or W6 as appropriate for the heater controller being serviced.

2. Remove both fuses at bottom of the controller enclosure.

3. Replace fan filter.

4. Check condition of fan bearings by grasping rotor and checking for wobble. Axial play is acceptable.

5. Lubricate fan by injecting lubricant, recommended by manufacturer, through rubber plug in center of fixed portion of fan motor (plug is covered by label).

6. Clean fan blades and enclosure interior, including SCR heat sinks, circuit board, and mechanical drive system.

7. Check for loose electrical connections. Clean and retighten any loose connections found on SCR heat sinks.

8. Replace fuses removed in step 2 and check for noninterference between fan and fan filter.

9. Secure enclosure door and close breaker opened in step 1.

10. Check operation of heater controller by requesting remote-control operation and then raise the heater to full power and reduce to zero as quickly as possible.

11. Repeat steps 1-10 for each heater-controller enclosure.

APPENDIX B

In-service Testing

A. Initial In-service Test

The cubicle for the No. 6 primary-tank heater was modified to receive the zero-crossover SCR control board and the improved rundown system. After modifications were complete, the unit was bench-tested with a 4-kW load. The bench test was successful in all aspects. See Fig. 3.

The modified No. 6 cubicle was reinstalled in the reactor building and connected to the rest of the control system for primary-tank heaters. See Fig. 1. When the 480-V distribution breaker was energized, power for heater No. 6 went immediately to "Full On." This reading was checked with a clamp-on ammeter (≃ 170 A). No control could be obtained; the heater power would neither raise nor lower. The cubicle was de-energized, and the resistances of the individual main SCRs were then checked. This check did not reveal any defective SCRs. An isolated, portable oscilloscope was then used to look at the output wave form as well as the gate-signal input to the main SCR. All these signals were a steady, full sine wave, which could not be altered by raising or lowering the motor-driven potentiometer.

The above test results indicated that the zero-crossover board was defective. Replacing the board with a new unit solved the problem. Control of the heater power level was re-established, and no more board failures have occurred.

The in-service test of the No. 6 heater controller was successfully completed. No further incidents occurred during the remainder of the test. Furthermore, the zero-crossover controller has been in service three weeks with no apparent failure. Also, No. 6 heater has not shown any tendency to misfire owing to electromagnetic interference generated by the pulse firing of adjacent SCR units.

B. Experience with Failures

1. First Failure

a. Symptoms

In the first failure, heater operation was very erratic. With the motor-driven potentiometer to full on, the clamp-on ammeter indicated variations from 155 to 70 A (normal is about 155 A). The portable, isolated oscilloscope was used to check the SCR gate signal. The oscilloscope revealed that the gate for SCR No. 1 (lower one) fired correctly; however, the gate for SCR No. 2 fired erratically. See Fig. 3. This erratic firing caused the fluctuating amperage to the load. The board was removed from the cubicle for investigation.

B. Cause of Trouble

The intermittent gate firing was due to a cold-solder connection where capacitor C20 (500 μF, 50 V) joins the printed circuit board. This capacitor is shown in Fig. 3. After a good electrical connection was made, the controller functioned correctly in a smooth, steady manner.

2. Second Failure

a. Symptoms

Failure of the second board was observed when it was put into service to replace the failed board from the first failure. The main SCRs would be turned completely off or completely on, depending where the motor-driven potentiometer was placed. Full-on load was 70 A, as indicated with a clamp-on ammeter. Both gates into the SCRs appeared to be firing correctly when checked with the portable, isolated oscilloscope. The board was removed for repair.

b. Cause of Trouble

The above failure was a bad electrical connection where capacitor C21 (100 μF, 50 V) joins the circuit board. The capacitor connection to the board was repaired; the board then functioned correctly.

3. Precautions Against Future Failures

Both causes of failure described above are similar. The poor electrical connections discovered are believed to be due, in part, to the component location on the printed-circuit board. Both capacitors

(C20 and C21) are immediately adjacent to integrated-circuit logic modules used in the SCR gating circuitry. Because of their extreme closeness, the capacitors receive considerable jostling when a logic module is removed from or replaced on the board. This jostling, along with poor soldering technique, is believed to be the main reason for the failures observed.

To prevent similar failures, all capacitor connections to the circuit board will be carefully inspected and tested for soundness of the solder connection.