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NUCLEAR INSTRUMENT MODULE MAINTENANCE MANUAL

PART 13

MAGNET CONTROL AMPLIFIER, ORNL MODEL Q-2613

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ABSTRACT

The circuit, application, maintenance procedures, and acceptance tests for a magnet control amplifier are described. The amplifier is normally used to control the current to a scram latch magnet in a reactor safety system. When the bistate input signal is normal, the amplifier output is a regulated current adjustable from 0.3 to 2.2 amp. When the input switches to the abnormal state, the output current is switched to zero in less than 5 msec for a typical compatible magnet design. The control amplifier was designed specifically for the HFIR 3-coil, 2-out-of-3 coincidence magnet system, but may be used for single coil magnets as well. The circuit is constructed in a "3-unit" module of the ORNL Modular Reactor Instrumentation series, Q-2600.

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1. DESCRIPTION

1.1 General

The Magnet Control Amplifier is a control unit designed to regulate and switch the current flowing in a coil of a safety release electromagnet in a nuclear reactor. The input is a bistable logic signal that is -10 v normally and switches to 0 v when a scram command occurs. The output is a regulated current that is adjustable from 0.3 to 2.2 amp normally and is switched to zero when a scram command occurs.

1.2 Construction

The Magnet Control Amplifier is constructed in a module 4.25 in. wide, 4.72 in. high, and 11.90 in. deep. It is a standard "3-unit" plug-in module of the ORNL Modular Reactor Instrumentation series depicted on drawings Q-2600-1 through Q-2600-5.

The low-power circuitry is on a printed circuit board near the front of the module. The large output transistor is on a heat sink towards the rear of the module. The output current is indicated on a front-panel meter.

1.3 Application

The Magnet Control Amplifier is intended to regulate and switch the current being supplied to the coil of a safety-rod scram magnet in a nuclear reactor. A compatible magnet design is necessary to achieve proper performance. The circuit was designed primarily for a 3-coil coincidence magnet, but it may be used with single-coil magnets as well. The normal steady-state, regulated current output is adjustable from approximately 0.3 to 2.2 amp provided that the voltage drop across the load (magnet) does not exceed 20 v. Thus, the magnet with which the amplifier is used must be designed with an appropriate wire size such that, at the desired operating current, the voltage drop is less than 20 v.

If the magnet is to be of the 3-coil coincidence type, then some additional considerations are necessary. In a coincidence magnet, excessive current in one coil caused by a failure or misadjustment of the Magnet Control Amplifier may provide sufficient holding force so that reducing the current to zero in the other two coils may not release the rod. This is particularly likely to occur when the output transistor fails short-circuit. To guard against this difficulty, an external resistor of suitable resistance and power rating should be placed in series with the magnet coil to limit the current to an acceptable value when the output transistor is short circuited from the collector to emitter. At normal operating current, the combined voltage drop across the added resistor and the magnet coil must not exceed 20 v. This added resistor will ensure that a single coil current cannot become high enough, when misadjustment or likely failure conditions occur, to hold up the rod with the other two coils de-energized. The resistance of the typically long lines between the Magnet Control Amplifier and the magnet should be considered as part of the magnet resistance for the above considerations.

The zener diodes used to protect the output transistor limit the surge voltage across the magnet coil to about 260 v. This voltage limit should be considered when designing the magnet to have adequate release time.

1.4 Specifications

1. Output:	Regulated current adjustable from 0.3 to 2.2 amp.
2. Input:	Logic signal is −10 ± 2 v normal and 0 ± 2 v tripped. Maximum drain on source is 1.2 ma.
3. Response:	100% to 10% response less than 100 μsec with resistive load.
4. Voltage limiting:	Surge voltage across inductive load is zener diode limited to 260 ± 40 v.
5. Power required:	−32 ± 4 v up to 2.5 amp, depending on adjustment.
6. Line regulation:	± 2% output current change for a change from −28 to −36 v input.
7. Load regulation:	± 2% output current change for load variation causing from 0 to 20 v drop across load at any current.
8. Overcurrent protection:	By added external resistance.
9. Ambient temperature range:	0° to 55°C.

1.5 Applicable Drawings and Specifications

The following list gives the drawing numbers (ORNL Instrument Dept. drawing numbers) and subtitles for the Magnet Control Amplifier:

1. Q-2613-1	Circuit.
2. Q-2613-2	Details.

3. Q-2613-3 Metalphoto Panel.
4. Q-2613-4 Printed Circuit Board.
5. Q-2613-5 Assembly.
6. Q-2613-6 Parts List.

The following list gives the drawing numbers and subtitles and the number of the fabrication specification for the Plug-In Chassis System:

1. Q-2600-1 Assembly.
2. Q-2600-2 Details.
3. Q-2600-3 Details.
4. Q-2600-4 Details.
5. Q-2600-5 Details.
6. Q-2600-6 Module Extender Assembly and Details.
7. SF-245 Fabrication Specification.

2. THEORY OF OPERATION

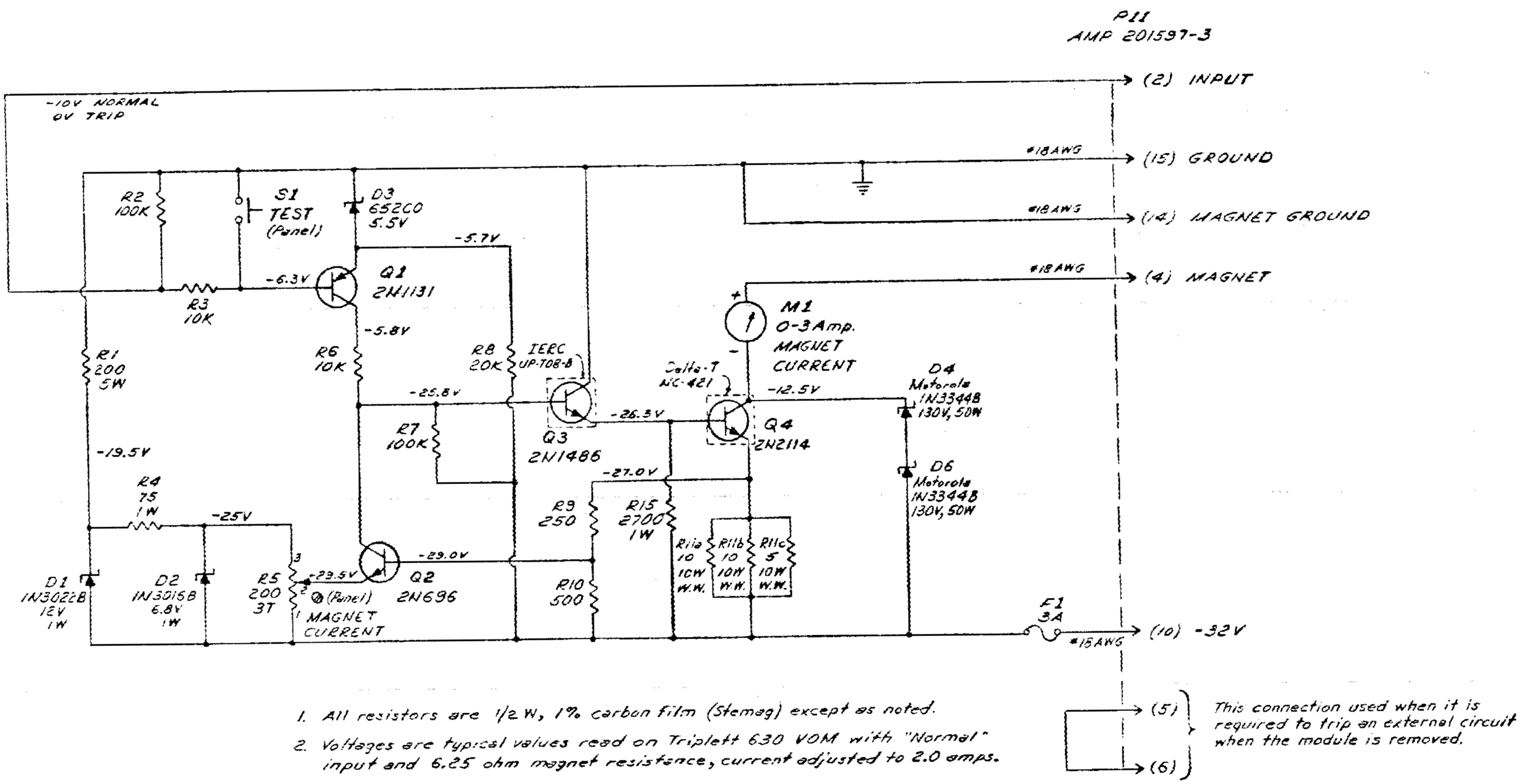
2.1 General

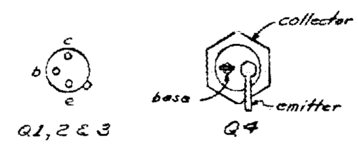
The Magnet Control Amplifier is basically a current regulator with provisions for rapidly switching the output current to zero. The output circuit has special protection to prevent damage to the regulation transistors when the highly inductive magnet load is switched without lengthening the release time significantly.

2.2 Circuit Description

A circuit diagram of the Magnet Control Amplifier is shown in Fig. 1. The magnet coil in which the current is to be controlled is in the collector circuit of output transistor Q4, which is a special high-voltage, high-power silicon transistor selected to withstand the high-voltage surge that occurs when the magnetic field collapses. With a 3-coil coincidence magnet, this surge can occur when the transistor is conducting high current, resulting in a very high peak power.

Zener diodes D4 and D6 limit the voltage surge to about 260 v to further protect Q4. Diode D6 is returned to the negative 32-v supply instead of to ground to eliminate the necessity for an additional blocking diode in the magnet circuit. The average power dissipated in the zener diodes is negligible, since they are conducting





SEMICONDUCTOR BASE CONNECTIONS
BOTTOM VIEWS

Fig. 1. Magnet Control Amplifier Circuit.

only during release transients; these occur very infrequently. However, because the peak-surge current is the same as the steady-state magnet current and the transient peak power is high, 50-w rated zener diodes are required.

The output transistor Q4 has a low current gain (10 to 100). A medium power transistor Q3 is added in cascade to provide additional current gain. Current regulation is achieved by maintaining constant voltage across a fixed resistance R11 in the emitter of Q4. This voltage is sensed at the junction of R9 and R10 and applied to the base of Q2. Transistor Q2 is, in effect, a difference-amplifier, amplifying the difference between an adjustable reference voltage applied to its emitter and the signal voltage applied to its base. The amplified difference on the collector of Q2 is applied to the base of Q3, closing the loop. The loop-voltage gain is approximately 50. The reference voltage on the emitter of Q2 is derived from two cascaded zener regulators D1 and D2. The double regulation is used to reduce the effect of power supply variations on the reference voltage. R5, a screw-driver adjusted potentiometer on the front panel, is used to set the desired output current.

Switching action is accomplished by transistor Q1. The "normal" input signal is -10 v, and is applied to the base of Q1 through current-limiting resistor R3. The resulting base current is sufficient to completely saturate Q1, effectively connecting its collector and emitter together. Transistor Q1 then provides a current path from R6, the collector load resistor of Q2, to ground through zener diode D3. As long as Q1 is saturated, the regulator Q2, Q3, and Q4 will perform as described. If the input is changed to the "trip" state, i.e., zero volts, the base of Q1 is also at zero volts. The emitter of Q1, however, is held at -5.5 v by the drop across D3. This reverse base-emitter voltage is sufficient to completely cut off transistor Q1. With Q1 cut off, current can no longer flow through R6, and the base of Q3 is pulled to -32 v by resistor R7. This cuts off transistors Q3 and Q4, reducing the output current to zero.

Disconnecting the input is equivalent to an input signal that is in the "trip" state, in that the output current is reduced to zero. Zener diode D3 allows the circuit to operate satisfactorily for a reasonable variation in the input signal. Q1 is cut off when the input voltage is just slightly less negative than -5.5 v, and Q1 is saturated when the input signal is just slightly more negative than -5.5 v. D3 is maintained in the break-down state by a small current drain through R8.

3. OPERATING INSTRUCTIONS

3.1 Installation

The Magnet Control Amplifier, ORNL model Q-2613, is a module in the ORNL Modular Reactor Instrumentation series. Like the other modules of the series, this module has standard connectors and dimensions and a pin- and hole-code on the rear plate so that the module will not be inserted in a wrong location in a drawer. The module is installed by placing it in its proper location, inserting the module firmly, and tightening the thumb screw.

3.2 Operating Controls

3.2.1 Panel Meter

The panel meter is calibrated to read from 0 to 3 amp. The meter is in series with the magnet coil and reads coil current directly.

3.2.2 Test Pushbutton

On the front panel is a recessed, screw-driver actuated pushbutton, which when depressed switches the output current to zero regardless of the state of the input logic signal. The test is independent of and does not interact with any other magnet control amplifiers in a system. If the button is rotated 1/8 turn while depressed, it will remain in the "Test" or "Trip" state.

3.2.3 Current Adjustment

Located on the front panel is a recessed screw-driver adjustment, labeled "Magnet Current." This is a 3-turn potentiometer that adjusts the output current from approximately 0.3 amp to greater than 2 amp.

3.3 Connections

All connections are made through the rear connector P11 when the module is inserted. A jumper between pins 5 and 6 of P11 is provided so that the presence of the module in its proper drawer location can be monitored if desired.

3.4 Operating Procedures

The proper operating magnet-coil current and the procedure for testing by use of the front-panel pushbutton S1 are dictated by the magnet requirements and the system details.

3.5 Precautions

There is a very small, but finite, possibility that a very large magnet might store enough energy in this circuit to be lethal when discharged. Care should be taken not to handle output transistor Q4 or its heat sink, which is in electrical contact with the collector.

4. MAINTENANCE INSTRUCTIONS

4.1 General

This module is designed to operate continuously with a minimum of maintenance and adjustment. Drift is so low that magnet current readjustment should not be required except as required by the magnet and its load. Functional testing is likely to be accomplished as part of a routine system test, and operation of test button S1 should be required infrequently. Should a failure occur, any part listed in the Replaceable Parts List (Sect. 5) can be replaced.

4.2 Periodic Maintenance

No periodic maintenance is required.

4.3 Calibration Procedure

There are no calibration procedures.

4.4 Trouble Shooting

Because of the inductive surge of the magnet, plugging or unplugging the module with power on may blow fuse F1. This should be suspected first if the trouble is no magnet current. Frequent or repeated blowing of F1 may be due to intermittent connections elsewhere in the magnet circuit.

Other troubles may be located by measuring voltages and comparing them with the voltages given in Table 1.

Table 1. Transistor and Diode Voltage Chart[1]

Transistor	Emitter	Base	Collector
Q1	-5.7	-6.3	-5.8
Q2	-29.5	-29.0	-25.8
Q3	-26.3	-25.8	0
Q4	-27.0	-26.3	-12.5
Diode	**Anode**	**Cathode**	
D1	-32.0	-19.5	
D2	-32.0	-25.0	
D3	-5.7	0	
D4	-	-12.5	
D6	-32.0	-	

[1] All voltages were measured with respect to ground with a 20,000 ohm/v voltmeter. Actual readings may vary ±15% from those given. The magnet resistance was 6.25 ohms, the "Normal" input was -10 v, and the current was 2.0 amp.

5. REPLACEABLE PARTS LIST

A description and an ORNL Stores number for all replaceable parts are given in Table 2.

Table 2. Replaceable Parts List

Part No.	ORNL Stores No.	Description
Q1	06-996-1710	Transistor, PNP, silicon, type 2N1131, T.I.
Q2	06-996-1610	Transistor, NPN, silicon, type 2N696, T.I.
Q3		Transistor, NPN, silicon, type 2N1486, RCA.
Q4		Transistor, NPN, silicon, type 2N2114, West.

Table 2. Replaceable Parts List (Continued)

Part No.	ORNL Stores No.	Description
D1	06-995-7096	Diode, zener, 12 v ± 10%, 1 w, type 1N3022B, Motorola.
D2	06-995-7092	Diode, zener, 6.8 v ± 10%, 1 w, type 1N3016B, Motorola.
D3	06-995-7460	Diode, zener, 5.0 v ± 5%, type 652CO, T.I.
D4, D6		Diode, zener, 130 v ± 10%, 50 w, type 1N3344B, Motorola.
R1		Resistor, 200 ohms ± 5%, ww, vitreous enamel insulation, Ohmite code 7/8-C-54-F.
R2, 7	06-932-0189	Resistor, 100 kilohms ± 1%, 1/2 w, Stemag, type SLAK.
R3, 6	06-932-0147	Resistor, 10 kilohms ± 1%, 1/2 w, Stemag, type SLAK.
R4	06-932-1998	Resistor, 75 ohms ± 5%, 1 w, composition, A-B.
R5		Potentiometer, 3-turn, 7/8-in. diam, 200 ohms ± 3%, linearity 0.3%, 1/4-in. shaft, Bourns No. 3510S-71-201.
R8	06-932-0155	Resistor, 20 kilohms ± 1%, 1/2 w, Stemag, type SLAK.
R9	06-932-0063	Resistor, 250 ohms ± 1%, 1/2 w, Stemag, type SLAK.
R10	06-932-0079	Resistor, 500 ohms ± 1%, 1/2 w, Stemag, type SLAK.
R15	06-932-2183	Resistor, 2700 ohms ± 5%, 1 w, composition, A-B.
R11a, R11b	06-934-0519	Resistor, 10 ohms ± 5%, 10 w, ww, vitreous enamel insulation, Ohmite "Brown Devil."
R11c	06-934-0514	Resistor, 5 ohms ± 5%, 10 w, ww, vitreous enamel insulation, Ohmite "Brown Devil."
F1	06-874-3080	Fuse, micro, 3 amp, Little Fuse No. 273003.

6. ACCEPTANCE TEST PROCEDURES

6.1 Test Equipment

The following test equipment is required:

1. One power supply, 28 to 36 v dc, 3 amp
2. One power supply, 0 to -12 v dc, 2 ma (or volt-box)
3. One calibrated Oscilloscope (Tektronix 531, 536, 541, etc.)
4. One dummy-load resistor, 6 ohms, 25 w
5. One magnet, if available.

6.2 Adjustment Procedure

Mechanically zero the front-panel meter.

6.3 Acceptance Test

6.3.1 Check of General Operation

1. Connect a 6-ohm resistor to magnet connections pin 4 and pin 14, and connect a volt-box to the input.

2. Energize the 32-v supply and adjust to approximately -32 v.

3. Slowly increase the negative voltage applied to the input, and observe the magnet current on the front-panel meter. The current reading should start at zero, and then should suddenly increase when the input voltage is between -5 and -7 v. Record the value of the input voltage at which the magnet current first started to rise from zero, and then increase the input voltage to about -10 v and leave it at this setting.

4. The magnet current should now be on scale. By use of the front-panel screw-driver control, adjust the magnet current over the entire range of the potentiometer and record the maximum and minimum current values. The current should be adjustable from less than 0.3 amp to more than 2.0 amp.

6.3.2 Line Regulation

Adjust the current to exactly 2.0 amp, vary the 32-v supply from 28 to 36 v, and record the variation in magnet current. The variation should be less than ±2%, or from 1.96 to 2.04 amp.

6.3.3 Load Regulation

Readjust the supply voltage to 32 v, and short circuit the dummy-load resistor (6 ohms, 25 w). The magnet current should change less than ±2%.

6.3.4 Response

Connect a dc-coupled oscilloscope across the dummy-load resistor so as to observe the effective changes in output current. Step the signal input from -10 v to 0 v with a nonbouncing switch, and observe the time for the magnet current to reduce to less than 10% of its initial value. This time should be less than 100 μsec. Record the actual time.

6.3.5 Voltage Limiting

Replace the resistive dummy load with a suitable magnet. Observe the voltage across the magnet with an oscilloscope. Adjust the magnet current to a suitable value for the magnet used, and step off the input signal as in the response measurement (Sect. 6.3.4). The magnet voltage should surge to +250 ± 25 v. The voltage wave form should have a flat top at the limiting voltage. Record the actual voltage measured. Note that the dc-voltage level across the magnet is negative with respect to ground when the circuit is conducting normally, but that the surge becomes positive with respect to ground when the circuit is switched off.

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