SYSTEM INTERCONNECTION AND PROTECTION OF THE MODULATOR

This note replaces TN-62-59. The system interconnection problems as detailed in TN-62-59 were based on the "KCA Modulator" concept and a high-voltage dc distribution system with eight centralized transformer rectifiers. The new dc supply system adopted, and changes in the modulator concept, affected the interface problems described in TN-62-59. A re-evaluation is made here. This note represents the present concept. The functional requirements are rather numerous and involved. Detailed descriptions of the interactions during operation and of fault protection are given.

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I. THE PROTOTYPE MODULATOR

As a background to the problems to be analyzed, a brief description of the Prototype Modulator and its operation will be given here. Refer to Drawing No. 7 (BD-730-223-RC).

A. FUNCTIONAL DESCRIPTION

The main elements determining the interaction with the Control System are:

Transformer Rectifier: Each modulator is given a separate transformer rectifier accepting ac voltage in the range of 260-600 volts and supplying dc voltage to the Pulse Forming Network (PFN). The circuit breaker is used to disconnect individual modulators and to protect against severe overloads. The contactor senses temporary overloads in the switchtube and high-voltage circuit and disrupts service for several hundred milliseconds. A recycling and fault-counting circuit is attached to the contactor. The contactor, in connecting the modulator to the line, is also used to minimize inrush currents by temporarily inserting a resistance into the line. The regulator keeps the ac input voltage constant within ± 0.25%. A reaction time of about 50 msec is expected. The set point for this fast regulator will be under control from the Central Control Room (CCR).

PFN and Switch: These are the major parts of the high-voltage dc circuitry. The filter condenser return is monitored and acts upon the contactor as explained above.

Interlock and Protection: During start-up and operation, the modulator is protected against failures in the auxiliary services. The auxiliary service interlocks are shown in Drawing No. 7.

PFN Load: The PFN load normally includes the cable, the pulse transformer, the tank and the klystron proper. It is proposed to monitor the load current flowing into the cable and to compare it with the network voltage. The analogue to the latter can be derived from the reference voltage. If this is done properly, damaging values of pulse current can be monitored and used to stop discharging the PFN by removing the trigger outside the modulator.

The measurement can also be used to monitor long term changes in load impedance, such as caused by changes in klystron permeance.

B. THE DC SUPPLY

Sixteen modulators, or two sectors in Stage I, will be supplied from a voltage variable device. This device, either an IVR or tap-changing transformer will operate from 12 kv and will be adjustable to voltages in the 260-600 volt range. A control device will be provided to keep the secondary voltage to within ± 1%, with a reaction time of about 1-2 sec.
C. MODULATOR TURN ON PROCEDURE

1. Cold Start
   (a) Close the following 120-volt circuit breakers
       (1) control power (interlock chain)
       (2) klystron filament
       (3) low voltage power supplies (trigger, etc.)
       (4) fans
       (5) heat lamps
       (6) contactors (control power)
   (b) Close main power circuit breaker (260-600 volts)
   (c) Press control power push button. This applies klystron filament
       power and core bias power. The klystron filament timer starts
       (30 min). Klystron filament elapsed time meter starts after a
       30 minute delay; the fan power comes on if water flow is present.
   (d) Close key switch
   (e) Close doors
   (f) Check that core bias light is off (OK)
   (g) Check that the cabinet temperature lights are off. The recycling
       timer (100 msec - 3 min) is now activated, the power to the
       trigger circuits is applied and the green "ready" light comes on.
   (h) Press high-voltage button. This turns off the green "ready" light
       and the "Mod Ready" light comes on. The modulator is now ready for
       operation. Pressing the high-voltage button closes the auxiliary
       relay at main contactor. One of the two following series of events
       will occur
       (1) If the 260-600 volt ac input is present, a red light comes on
           and contactor 1 closes and inserts resistors in series with the
           power transformer (to minimize the inrush current). After a
           short delay, contactor 2 shorts out these resistors. The high-
           voltage elapsed time meter is also started.
       (2) If the ac input is not present, only the auxiliary relay is
           closed. When the high voltage appears later, contactors 1 and
           2 go through their cycle automatically. Conversely, if the high
           voltage is removed external to the modulator, contactor 2 will
           open first, the resistors will be inserted and a short time
           later, contactor 1 will open, thus opening the ac circuit to the
           modulator.

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(1) Apply the trigger. If the high voltage is present, the klystron is pulsed and draws average current. Then the "Mod On" relay comes on. In addition, a light at the modulator comes on, indicating "Klystron Current" flow.

2. Recycling and Resetting After Fault in DC or AC Part of Modulator

(a) AC part:
(1) Fault opens main circuit breaker; no recycling; removes the 260-600 volts.
(2) Resetting: close circuit breaker only, no further action necessary if fault is cleared.

(b) DC part:
(1) There are four fault-sensing elements: ignitron overload, grid overload, bias overload, and high-voltage overload (overcurrent). Each of these opens the power to the auxiliary relay of the contactor and thus removes high voltage and power from the trigger circuit.
(2) When high-voltage removal makes a fault disappear, the fault relay closes and starts the recycling timer, which in turn closes the main contactor after the preset timer (100 msec - 3 min) runs out, and restores power to the trigger circuit.
(3) The opening and closing of a fault relay causes a stepping relay to count one fault.
(4) Concept of the fault selector switch: it can be set for 1-10 faults. If preset number of faults is reached in less than 25 minutes, the recycle lockout relay opens, an amber light comes on and the high voltage and power to trigger is removed. Resetting is done manually by pressing reset push button. This resets the stepping relay to zero and reapplies high voltage and trigger power. If the preset number of faults is not reached within 25 minutes, the stepping switch is automatically reset to zero.

*This is for ignitrons. For thyatrons, two fault sensing elements will be used: grid overload and high voltage overload.

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II. SYSTEM INTERCONNECTION PROBLEMS OF THE MODULATOR AND KLYSTRON

A. INTERACTION PROBLEMS GENERATED

During operation, the modulator and klystron interact with the:
1) AC system for the high-voltage supply
2) RF drive system
3) Trigger system
4) Accelerator waveguide system
5) Central control

The interaction problems create requirements for specific equipment. This equipment will be placed in a rack near each modulator. The term "FIAT rack" has been coined, an acronym derived from the components: Phase shifter - Isolator - Attenuator - Trigger. The three units, the modulator, the klystron and the FIAT rack, form an operational unit and will be treated here so. The term, "Modulator," as used in the text is meant to stand for this three-part operational unit.

1. AC System for the High-Voltage Supply

No specific interaction problems are generated here, except for the supplying of a suitable reference signal to the fast regulator and for some operational provision when maintenance of a modulator is performed during accelerator operation.

2. RF Drive System

The drive input line to each modulator is equipped with a phase shifter, an isolator, a manual attenuator, and a motor-driven attenuator. The component parts are mounted in the FIAT rack. All items are used locally for operational adjustments. The motor-driven attenuator is to bring up the drive level gradually after the klystron beam voltage has been applied. Functionally, the control depends on the presence of drive power ahead of the attenuator and on the knowledge that the klystron is operating.

Interaction with the other subsystems and operational constraints are shown on Drawings No. 1 and No. 2.

3. Trigger System

The trigger integration is resolved as follows:
(a) Ignitron and grid trigger pulse to be supplied to the modulator separately on 100 ohm cables, at a level of 100 volts.
(b) External ignitron pulse delay of 0-10 μsec to be provided.
(c) External grid pulse delay of 0-1 μsec to be provided.
(d) Provision to be made to remove the trigger pulses when a PPM load fault is sensed.

The component parts will be located in the PIAT rack. Operational interaction and constraint are shown on Drawings No. 1, No. 2, and No. 4.

4. Accelerator Waveguide System

The interaction with the waveguide system provides vacuum and power monitoring. The electronic part of the system will be located in the PIAT rack. The basic arrangement is shown in Drawing No. 1. Monitoring of vacuum and reflected power is done to prevent damage to the waveguide system. In case of arcing, the trigger to the modulator will be removed. Forward power monitoring is done for the CCR to indicate that an acceptable level of rf power exists.

Details of the interaction are shown on Drawing No. 3. Provision will also be made for exact power measurements at the klystron by means of a portable meter.

5. Central Control

Under the present concept, the following information from each modulator-klystron is needed at Central Control:

(a) A two-state signal indicating that the local turn-on is completed and the modulator is operationally ready for high-voltage and trigger to be applied. This signal is called "Mod Ready" and will be made available at the modulator. Relays with form "C" contact will be used.

(b) A two-state signal indicating the klystron is operating after the trigger has been applied. The presence of average klystron current is used for this indication over the 60-360 pps range. This signal is called "Mod Op" and is available via a relay with form "C" contacts.

(c) A two-state signal indicating that at least 80% of the rf power available for the operating conditions is established. This is called "RF CK" and is available via a relay with form "C" contacts.

(d) A two-state signal indicating the modulator is operating in the "Accelerator" or "Operational Standby" condition. This signal will be derived from the trigger input circuitry via relay contacts.

(e) A control signal will be provided at the CCR to set each modulator into one of the two conditions described in (d) above.

The above signals are also used at the modulator for operational constraints during start-up and fault conditions, as indicated on Drawings No. 1 and No. 2.

B. DESCRIPTION OF FUNCTIONAL ARRANGEMENTS

1. System Interconnection Problems at the Modulator (Drawing No. 1)

This is a presentation of the problems involved. The interconnecting lines
indicate mutual interactions; they are identified on Sheet 2 of Drawing No. 1. Subsequent drawings give further details on trigger input, drive input and rf output monitoring equipment.

The principle of PFM load fault sensing is illustrated on Drawing No. 6.

Box 21 of Drawing No. 1 is not detailed yet. It indicates anticipated but unspecified requirements for local maintenance during operation. Details depend on the Variac and fast regulator design.

Details to connections 11, 12, and 23 are still open; also the contents of box "Reference Voltage" are not yet specified.

2. Requirements and Constraints on the Interactions (Drawing No. 2)

The nature of the interactions indicated on Drawing No. 1 are detailed on Drawing No. 2. The various conditions for start-up, operation, fault protection and recycling are as follows: (The relay circuitry is for illustration only and does not prejudice the hardware solution.)

(a) Initial or ready-for-operation condition

(1) Requirements. The trigger path to the modulator must be closed. The ignitron and grid pulse must be in the delayed position.

(2) Arrangements. The trigger path is constrained in the following manner: If the motor attenuator is in the full-attenuation position, relay A is closed. If the vacuum is good, relay B is closed. If no fault exists, relay C is energized; then relay D closes and permits the trigger to reach the modulator.

Relay F in its relaxed position connects the delayed or standby pulses to the modulator. Activation of relay F is possible when the modulator is fully operating. This is in agreement with the proposed concept, that the modulator should start up in the "Standby" condition and should return to that state after recycling.

(b) Transient condition during removal of attenuation

(1) Requirements. Start the motor to remove attenuation (if rf drive power is present and klystron is pulsed). Keep trigger in operation.

(2) Arrangements. When the modulator is pulsed, the "Mod On" signal appears, which is derived from the presence of average klystron current, and relay K is closed. When rf drive power is present, relay I is closed and relay K is activated. One set of contacts on relay K starts the motor, the other set keeps relay D energized (thus keeping the trigger path closed) when relay A
moves away from the full attenuation position.

(a) End condition after attenuation is removed

(1) Requirements. Indicate the fully operational condition if the motor has removed all attenuation and rf output power is at least 80% of the power corresponding to the established operating condition.

(2) Arrangements. The motor full-drive position closes relay L. The rf "OK" signal closes relay M. Relay F remains de-energized.

As indicated, the modulator started up in the trigger delayed position and the "Accelerate" command can now be given if so desired.

If this command is not given, rf "OK" will be indicated, but "Accelerate" position will not be indicated. This combination represents to CDR the operational standby.

If the "Accelerate" command is given, relay G is temporarily activated; this energizes relay F and contact set "a" locks the relay in, contact set "b" indicates "Accelerate" position and contact sets "c" and "d" transfer the trigger pulses into the normal position.

When subsequently it should become necessary to revert to the operational standby state, relay K is activated temporarily, thus interrupting power to relay F which then drops out.

(d) Fault protection and recycling

The following situations are covered:

- A reflected power signal due to a mismatch in the waveguide system.
- A reflected power signal due to a mismatch in the waveguide system, but with subsequent poor vacuum.
- Poor vacuum.
- PPM load fault signal.
- Contactor recycling and shut-off.

(1) Reflected power fault.

Requirements. Open trigger gates immediately, i.e., before next pulse comes; start the motor attenuation cycle and return modulator to the operational standby condition if it was in the "Accelerate" state before. Furthermore, the trigger path should be kept open while inserting attenuation.

Arrangements.

(1) Removal of trigger and start of attenuation: The reflected power fault signal opens the trigger gates and holds them open between 1-2 seconds. During
that period, the klystron is not pulsed and the "Mod On" signal, which has a holding time of about 1 sec, disappears. This opens relay K, thus starting the insertion of the attenuation and de-energizing relay D and opening the trigger path, keeping the trigger off when the trigger gates close again.

(ii) Transfer to standby: Trigger interruption removes the rf "OK" signal and relay M is opened. Thus relay F is de-energized (if relay F had been energized by the remote accelerate command) and if the modulator happened to be in standby, no further action is taken.

(iii) Start up in standby: When the full attenuation position is attained, relay A is closed which closes relay D and the trigger is applied, "Mod On" appears, relay M is closed and the cycle continues as outlined under 2(a) above, Initial or ready-for-operation condition. The unit comes back to "operational standby" and can be transferred to "accelerate" when necessary.

(iv) Recycling and shutoff: When the unit comes back to operational standby, another reflected power fault may be produced. This may even happen before the motor reaches its full drive position. In any case, the steps (i) through (iii) above are repeated.

When a preset number of faults per specified time is exceeded, a fault counter will open relay C to keep the trigger locked out, when the motor reaches the full attenuation position.

This situation requires local attendance and is so indicated at CCR by the removal of the "Mod Ready" signal.

(2) Reflected power fault with subsequent poor vacuum.

Requirements. Keep rf power out of waveguide system as long as vacuum in the system is not satisfactory.

Arrangements. Poor vacuum resulting from the reflected power fault situation will de-energize relay B and interrupt the trigger path. The basic protection cycle as described under (1) above will proceed; however, when the full attenuation position is reached,
the trigger is locked out by relay B being open. When the vacuum is improved to the acceptable level, relay B closes, the modulator is triggered, and the cycle proceeds in the manner explained previously.

(3) Poor vacuum before start-up.

The requirements and arrangements are as outlined under (2) above. Trigger application is withheld until the vacuum improves to close relay B.

(4) PFN load fault signal.

Requirements. A fault in the PFN load will open the trigger path before the next trigger pulse comes around. The trigger pulse will be withheld for about 0.5 seconds. After this time period, the modulator may come back on with full rf power.

Arrangements. The PFN fault recognizer produces an inhibit pulse of about 0.5 seconds. This pulse opens the trigger gates and keeps them open over the duration of the pulse. During this period the klystron is off; however, the "Mod On" signal has a 1-second time delay before actuating relay H. Hence, the attenuation cycle is not started and when the trigger gates are closed, the modulator is fully operative.

Multiple faults. Closing the trigger gates after the above cycle may produce another fault signal. However, when the klystron is shut off for more than 1 second, the "Mod On" signal actuates relay H, thus starting the attenuator cycle and introducing a delay of about 20 seconds.

The fault counter is used again to lock out the trigger completely if a preselected number of faults is exceeded in a specified time interval.

(5) Contactor recycling and shut off.

The contactor is used, as explained previously, to remove the high voltage when a temporary overload exists in the high voltage circuitry of the modulator. It is designed to interrupt the voltage for several hundred milliseconds and to repeat this a specified number of times, before shutting off completely.

The effect on the circuitry under discussion is felt when the recycling process of the contactor has not been successful.
within 1 second. The "Mod On" signal will then start the attenuation cycle.

The following situations may exist:

(i) Fault is cleared immediately: No interruption in operation.
(ii) Fault is persistent, contactor recycles and will shut off after a specified number of faults.
(iii) Fault is cleared after a few cycles, but attenuation cycle is started and fault may appear again, when trigger comes back on.

When the fault is persisting, both contactor and trigger removal counter start counting. Shut-off may be effected by either, depending on the relative setting.

3. Output Monitor Equipment (Drawing No. 3)

The presently contemplated arrangement is shown in Drawing No. 3. Some changes may be necessary when the second window will be replaced by a valve.

The forward and reflected power measurement concept is based on the relation shown on Sheet 2 of Drawing No. 3.

Circled numbers can be identified from Sheet 2 of Drawing No. 1.

4. Trigger Input Equipment (Drawing No. 4)

The interconnection of the trigger system with the prototype modulator is done by providing the ignitron and grid pulse as positive pulses on two separate cables. The cables will have an impedance of 100 ohms and will supply 100 volts to the modulator.

Adjustable ignitron pulse delay of 10 µsec and grid pulse delay of 1 µsec will be provided at the FIAT rack.

Some details of the basic functional requirements of the trigger input equipment are shown on Drawing No. 4. Interconnection with the other parts of the FIAT rack are shown and marked by circled numbers. The latter can be identified by means of Sheet 2 of Drawing No. 1.

5. Drive Input Equipment (Drawing No. 5)

The major components involved and the basic functional arrangements are identified in Drawing No. 5.

Interconnection with the other parts of the system can be identified as mentioned above.

6. FTM Load Fault Sensing (Drawing No. 6)

The components covered by the fault sensor and the position of the latter are shown in Drawing No. 6. The sensor will be inside the modulator. Circuit details
of the sensor are under study.

7. **Block Diagram of Prototype Modulator (Drawing No. 7)**

The prototype modulator as shown in block diagram form in Drawing No. 7 (EZ-730-223-R0).
## BASIC CONCEPT OF MODULATOR-KLYSTRON CONTROL

### AT MODULATOR

**OPERATIONS PERFORMED:**

1. Cold start
2. Resetting after shut-off due to PTN load faults or overloads in modulator
3. Maintenance: Scheduled checks
   - Repair
   - Basic adjustments

### AT CENTRAL CONTROL

**SIGNALS:**

1. "Mod Ready" *(operational availability)*
2. "Mod On" *(klystron operates)*
3. RF output "Ok" *(sufficient RF power is produced)*

**CONTROLS:**

Select accelerate or standby mode
DRAWING No. 1--System interconnection problems
at the modulator (Sheet 1 of 2).
IDENTIFICATION OF MUTUAL INTERACTION

(1) RF "OK" SIGNAL TO CCR
(2) REFERENCE FOR IDENTIFYING RF "OK"
(3) REFERENCE FOR FAST AC INPUT REGULATOR
(4) WAVEGUIDE AND ACCELERATOR SECTION FAULT SIGNAL
(5) VACUUM "OK" SIGNAL
(6) CURRENT AND/OR VOLTAGE SENSED AT INPUT OF CABLE (See Drawing No. 5)
(7) FULL DRIVE POSITION OF ATTENUATOR
(8) FULL ATTENUATION POSITION OF ATTENUATOR
(9) "MOD ON" SIGNAL
(10) RF DRIVE PRESENT
(11) OPERATIONAL PULSE
(12) STANDBY PULSE
(13a) TRIGGER INTO MODULATOR. (This may be two cables, one for ignitor trigger, the other for grid trigger. Both pulses to be positive.)
(13b)
(14) SIGNAL TO TURN "MOD READY" INTO "MOD NOT READY," IF FWM LOAD FAULT RESISTING IS NOT SUCCESSFUL
(15) MOTOR CONTROL SIGNAL
(16) KLYSTRON BEAM VOLTAGE PULSE
(17) OPERATION/STANDBY SELECTION FROM CCR
(18) OPERATION/STANDBY INFORMATION TO CCR
(19) REFERENCE ANALOGUE TO KLYSTRON BEAM VOLTAGE FOR COMPARISON WITH SIGNAL 6
(20) PORTABLE PULSE GENERATOR
(21) INTERCONNECTION ARRANGEMENTS WHEN LOCAL POWER SUPPLY IS USED FOR MAINTENANCE OR TESTING
(22) "MOD READY" SIGNAL
(23) INTERCONNECTION FOR AUTOMATIC PHASING
DRAWING NO. 2 - LOGIC DIAGRAM FOR EACH MODULATOR
KLYSTRON OUTPUT MONITORING CONCEPT

WANT TO KNOW:  \( \frac{P_{\text{Reflected}}}{P_{\text{Forward}}} \geq 0.1 \)

AND:  \( P_{\text{Forward}} > 0.8 P_0 \)

BUT:  \( P_0 = K \sqrt{v} \)

HENCE THREE INPUTS DESIRED:

- \( P_{\text{Reflected}} \): From directional coupler
- \( P_{\text{Forward}} \): From directional coupler
- \( V_0 \): Reference voltage could serve as an analog

OUTPUTS:

1) For \( \frac{P_R}{P_F} \geq 0.1 \) Generate fault signal to remove trigger

2) For \( P_F > 0.8 P_0 \) Indicate to Central Control: If output is OK

DRAWING NO. 3 (Sheet 2 of 2)
DRAWING NO. 4—Trigger input equipment.
Motor Logic:

1) Motor must be in +20 db position before trigger can be applied.

2) Motor starts to remove att. when rf drive and "Mod-On" are present.

3) Trigger stays on while att. is removed, and rf output is generated.

4) When trigger is removed, "Mod-On" signal disappears and motor starts inserting of attenuation. Trigger must stay locked out until full attenuation is reached.

Drawing No. 5--Drive input equipment.
An overload may exist in the
Cable
Pulse transformer
Tank
Klystron (gas burst)

DRAWING NO. 6--PFN load fault sensing.