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Review of the modulator MDK13 faults that occurred during Run 2.

G. Coudert, G. McMonagle, P. Pearce, G. Rentier

Introduction.

The performance of all modulators in Physics Run 1 was normal with a low failure rate that was distributed reasonable equally over most of the six modulators on the LIL. During week 32 of Run 2 the problems began, and almost exclusively centred on MDK13. The fault problems stayed from the 12th August until the 12th October 1994, or a period of 8 weeks during the peak summer holiday period.This note describes the types of faults and how some were hidden by more predominant and highly intermittent faults, and so making detection difficult. A conclusion is made as to what should be done to improve fault finding methods under these conditions.

Modulator faults.

The fault scenario shown in Figure 1 indicates that there were two main problem areas associated with the modulator. The first, called the Main Breaker 2.41 fault went from the 12/8/94 until 2/10/94. The second principal fault area was the EOLC or end-of-line circuit faults that appeared from the 3/10/94 until the 12/10/94.

Under the Main Breaker fault was an intermittent klystron vacuum fault that appeared on two different klystrons that were operational in this position. The first klystron that showed vacuum problems was replaced with a second (the hot spare) that also gave similar symptoms. But overlaying these "secondary" problems was the highly intermittent Main Breaker fault. This fault caused the main breaker to the modulator to be opened with apparently no actual fault being recorded, and also with no command from the control system to put MDK13 into the standby state being given.

All routes to the main breaker were monitored and where possible, were imobilised in order to locate the source of the problem. This included energising the principal high voltage command relay from a separate power source. Many of the items in the power command chain and d'quing system were changed and interlock trip levels were adjusted to ensure that only true faults would activate the tripping process. These measures had no effect on the problem which persisted.

Almost incidental to these events was the electronics fault in the actual protection interlock unit of the modulator. An opto coupler on the peripheral interface card became marginal and created an intermittent state, similar to the one created by the main breaker problem. Once this electronics fault was cured the original problem however again predominated the situation.

Finally a broken 15 volt supply cable, that is part of a multi-cored cable, was found to intermittently either, touch its grounded metal connector case, or simply become open circuit. This cable supplies the low voltage to a head amplifier used for buffering the high voltage measuring signal from the klystron tank. The amplifier is mounted on the tank and vibrates at the 100Hz pulse rate of the system. The same 15 volt supply is used by interface cards within the protection system and consequently affects all interlocks and caused the main breaker to trip without any interlock being invoked. Once the cable had been repaired the intermittent main breaker fault was cured.

The patience needed to get to this situation had been considerable, - and then the original klystron vacuum faults started to become predominant. Two Philips klystrons had been used in this same position, and both showed vacuum problems of an intermittent nature. The vacuum ion pump power supply had previously been changed but with no effect. It was decided to change the klystron for a second time, and to use the spare Thomson assembly that had only just been removed from the new CTF modulator.

Once the Thomson tube had been installed almost immediately the vacuum faults vanished, but unfortunately end-of-line current faults (EOLC) took their place. This led to believing that poor thyratron performance could be the cause, and then maybe the end-of-line assembly itself. Both of these suppositions were wrong, although the thyratron switching performance had been disturbed by the fault.

During the preceeding months to this situation we have been testing and evaluating EEV thyratrons in several modulators. These tubes do not require the regular ranging of reservoir voltage (gas pressure) that the ITT thyratrons need. In addition we have experimented with pulsed keep-alive current circuits as well as the usual dc current keep-alive on the EEV tubes.

The EOLC fault situation, which turned out to be a short circuit at the klystron tank level, showed up the different recovery performance characteristics of both EEV and ITT thyratrons, with the different keep-alive conditions. For the EOLC fault observed the ITT tube with dc keep-alive allows reverse current to flow for a longer time than does the EEV tube with pulsed keep-alive. In fact the EEV tube acts as a better diode under these conditions and switches off and so prevents excessive voltage spikes appearing on the klystron cathode. From the fault finding view point this made the fault appear as a short circuit with the ITT tube (which was correct) and a lack of gas pressure in the EEV tube, because it was switching off during the pulse at the moment of the fault occurring.

The Thomson tank had been working correctly for some months previously in MDK98, where it was used at a lower voltage. The short circuit fault developed at the higher voltage level that is being used in MDK13.

This fault condition had been observed with the same klystron and tank one year before. The high voltage tank components had been tested and changed and the assembly re-tested at 32 and 35kV reference values (about 230 and 260kV at the klystron). The majority of the test time had been at 32kV, and consequently the problem at 35kV did not show up. This has meant that a faulty klystron tank assembly was installed into the MDK13 position and was responsible for the EOLC faults.

Aftermath.

After the faults had all been cleared a few initial stops of MDK13, mainly thyratron current and primary input current, occurred. These were assumed to be due to the fault current doubling in the thyratron that had disturbed the tube momentarily. After about 12 hours these faults went away and the modulator has functioned correctly at the required operating power ever since.

The equipment that has been changed, including the two Philips-Valvo klystrons, have either been tested, repaired or are pending action. The results of the tests are given in Figure 2.

All the vacuum ion pump HV cabling for the Valvo S.No 10 klystron has been replaced and the tube tested and installed in MDK97 for CTF operations.

The Valvo klystron S.No 09 has been found to have a water leak at the collector O-ring. This has been repaired as well as replacing the water filled RF input cable, using spare parts given to us by Valvo, and the tube is to be re-tested soon.

The Thomson klystron tank assembly will be also re-tested in its present state on the test modulator to diagnose more fully the fault, and then will have to be dismantled for repair.

The two EEV thyratrons have also to be tested at maximum voltage to ensure they are still operational. A new triaxial high voltage pulse cable was made during the period of problems since the original spare was fitted to the new MDK98 modulator. This cable also needs testing at full operational voltage.

The electronic cards that were found to be faulty have been repaired and/or tested in one of the on-line modulators.

Fault simulation.

The two types of fault that affected the modulator through the thyratron performance have now been simulated using a computer model of the whole modulator. The results are shown in Figures 3, 4 and 5. These results can be compared with the photos taken of these types of fault, either previously in MDK29 or during the problem period in MDK13 of Figures 6 and 7.

These simulations show:

Figure 3. The normal waveforms that are observed in an operational modulator. The klystron voltage waveform can be compared to the top photo in Figure 6.

Figure 4. The thyratron switching off during the current pulse and the subsequent effect of a positive voltage bump (Kly. Voltage 3) at the klystron cathode. This effect was produced by the EEV pulsed keep-alive thyratron due probably to insufficient gas plasma density in the tube. This can be compared to the bottom photo (klystron pulse voltage) in Figure 6 and the top photo (thyratron current) of Figure 7. This effect is also produced when an ITT thyratron runs out of gas pressure and can no longer support the current during the whole pulse width. It then requires that the reservoir voltage be ranged to correct this.

Figure 5. This shows the effect of a short circuit on the high voltage side being applied for 1 µs at a point 3µs into the voltage pulse. The effect of current doubling due to the short circuit, and the appearance of a large negative EOLC signal are also seen in the bottom photo of Figure 7.

Fault situation overview.

Always when difficult situations arise the maximum of information is required to solve the problem. This fault situation was no different from any others, and particularly when equipment responsibilities are shared over different groups the need for a common picture of the system is required. ***The general modulator schematic of Figure 8 that was used was found not sufficient and lacked important fault finding information.*** A better schematic that will show the principal power, timing, control and interlock interconnections between equipment as well as signal viewing points is being made.

Evaluating different modes of thyratron operation in the on-line modulators is one way of getting sufficient high voltage hours to prove or disprove a method. ***However, if a fault situation arises the standard method of operation should always replace the method on trial so as to reduce the number of unknown variables and perhaps be able to find the fault more quickly.*** The other way is to use the test modulator. In the particular case of MDK13 it was thought that enough test modulator hours (about 400 hours) had been made in the pulsed keep-alive mode to not have any danger. This was the case, except that the different performance of the two methods (under fault conditions in the system) was not appreciated. Now that this is known a clearer evaluation of similar faults in the future can be made.

The test procedures for faulty tubes and equipment must be reviewed. This is to avoid the problem of having repaired and tested an assembly (klystron tank) and not having pulsed it for enough high voltage hours at the highest operational voltage that is being used. ***A test sheet that specifies the testing requirements, the test duration and the measurements to be taken needs to be designed for each of the critical assemblies.***

The new interlock equipment that has been installed in some modulators, and installed in the MDK13 during the week 43 technical stop, was particularly useful. The order of appearance of faults together with the date and time are stored and can be viewed via the controls system by the operators and maintenance staff over the control network. ***The installation of the remaining three units in MDK's 27, 31 and 35 must be completed as soon as possible.***

Up until the present time all changes and movements of thyratrons and klystrons in the system have been recorded in the logbooks of the individual modulators. This has made necessary additional recording of tubes that are spares or being repaired. ***In order to track more easily the movements of thyratrons and klystrons within the system, a set of change report forms were introduced in August.*** These are shown in Figures 9 and 10, and are to be used for tracking tubes either as operational units in a modulator, hot spares waiting to be used, cold spares that have been tested and are held in stock, or tubes that are being reconditioned at the manufacturers. This can also be extended to the complete assemblies like the klystron tanks and thyratron units. Information from these forms is to be taken and inserted into a database programme (to be written) that will replace the present EXCEL spreadsheet recording system currently used.

Information indicating the location and status of spare equipment is a requirement, although the test modulator is always considered the first source of known working equipment. ***The number of spare parts were found to be adequate but the information on location and status needs to be formalised.***

A new software aid was recently purchased for helping with the maintenance of the modulators. This software enables tasks to be written for creating check lists of testing, assembling and measurement procedures that will capture valuable information and make it easily available on the soon to be installed modulator PC in the gallery. This possibly could have sped up the fault finding time in the above situation.

Conclusion.

Better documentation with more measurements and analysis being made and less equipment movement at the start of the problems may have speeded up the finding of the first major fault, and therefore would have reduced the total overall downtime. The second major fault came about because one unit was replaced with another that carried a "hidden" fault. Better test records should have indicated that this unit had not been completely tested, even though it had served for some months in another modulator at lower operating voltages. Identifying this may well have avoided the second period of downtime.

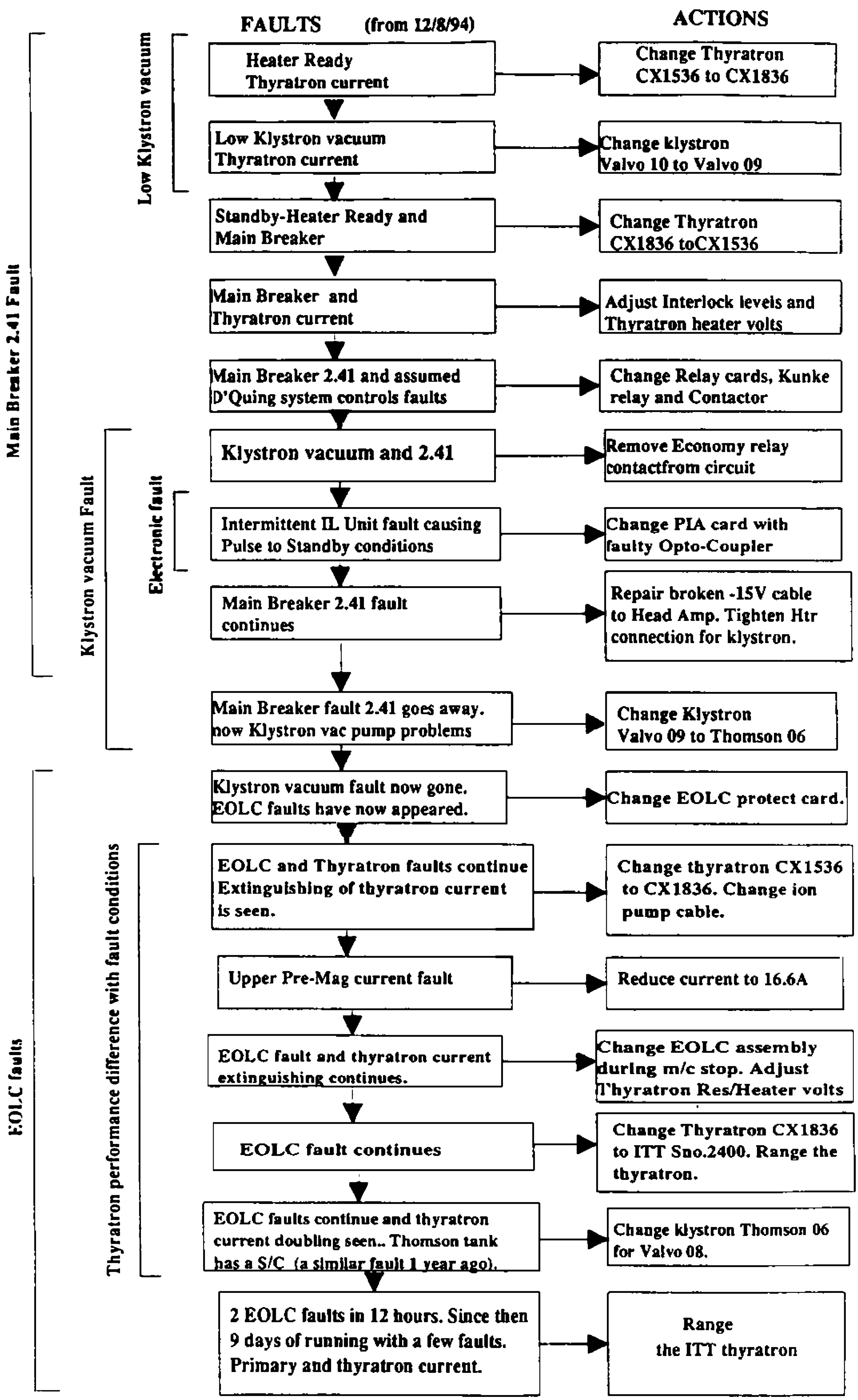

FAULTS (from 12/8/94)
ACTIONS
Main Breaker 2.41 Fault
Low Klystron vacuum
Heater Ready Thyratron current
Change Thyratron CX1536 to CX1836
Low Klystron vacuum Thyratron current
Change klystron Valvo 10 to Valvo 09
Standby-Heater Ready and Main Breaker
Change Thyratron CX1836 toCX1536
Main Breaker and Thyratron current
Adjust Interlock levels and Thyratron heater volts
Main Breaker 2.41 and assumed D'Quing system controls faults
Change Relay cards, Kunke relay and Contactor
Klystron vacuum Fault
Klystron vacuum and 2.41
Remove Economy relay contactfrom circuit
Electronic fault
Intermittent IL Unit fault causing Pulse to Standby conditions
Change PIA card with faulty Opto-Coupler
Main Breaker 2.41 fault continues
Repair broken -15V cable to Head Amp. Tighten Htr connection for klystron.
Main Breaker fault 2.41 goes away. now Klystron vac pump problems
Change Klystron Valvo 09 to Thomson 06
EOLC faults
Klystron vacuum fault now gone. EOLC faults have now appeared.
Change EOLC protect card.
Thyratron performance difference with fault conditions
EOLC and Thyratron faults continue Extinguishing of thyratron current is seen.
Change thyratron CX1536 to CX1836. Change ion pump cable.
Upper Pre-Mag current fault
Reduce current to 16.6A
EOLC fault and thyratron current extinguishing continues.
Change EOLC assembly during m/c stop. Adjust Thyratron Res/Heater volts
EOLC fault continues
Change Thyratron CX1836 to ITT Sno.2400. Range the thyratron.
EOLC faults continue and thyratron current doubling seen.. Thomson tank has a S/C (a similar fault 1 year ago).
Change klystron Thomson 06 for Valvo 08.
2 EOLC faults in 12 hours. Since then 9 days of running with a few faults. Primary and thyratron current.
Range the ITT thyratron

FIG 1

AFTERMATH of the problems.

1.	Valvo Klystron 010.	The HV ion pump cables have been replaced. The tube is now working in MDK97 and the vacuum problems that were seen in August have gone.
2.	Valvo Klystron 09.	A water leak at the collector has since been found. This caused water to go into space around the cavities as well as in the space between the focal/bucking coils. The tube has to be tested to see if other faults (vacuum ?) are present. Tube heater hours are about 4000 hr.
3.	Thomson Klystron 06.	This has to be fully tested and most likely have tank repairs made to it to cure the fault.
4.	Thyratrons.	The EEV tubes CX1536 and CX1836 will be re-tested in MDK29. A new EEV tube will be installed in MDK13 for the start-up in week 44.
5.	Triaxial cable.	A new spare cable has been made during the problems in case a change was needed. To be tested in MDK29.
6.	Electronics.	The changed and repaired cards and components will have to be tested in MDK29 to determine their status.
7.	Block diagram.	A block diagram showing all the major units in the modulator, their primary inter-connections and all signal test points is to be made.

FIG 2.

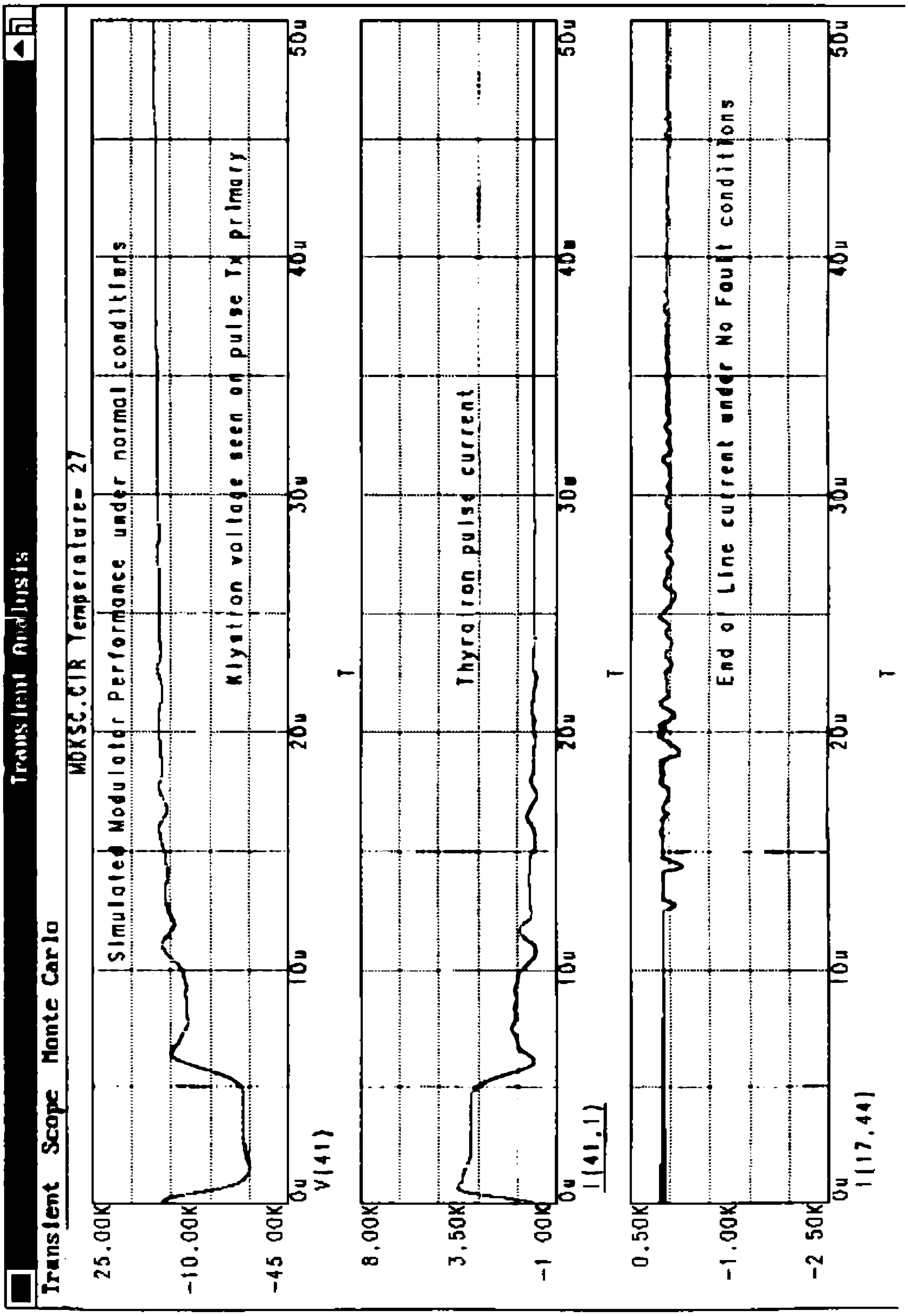
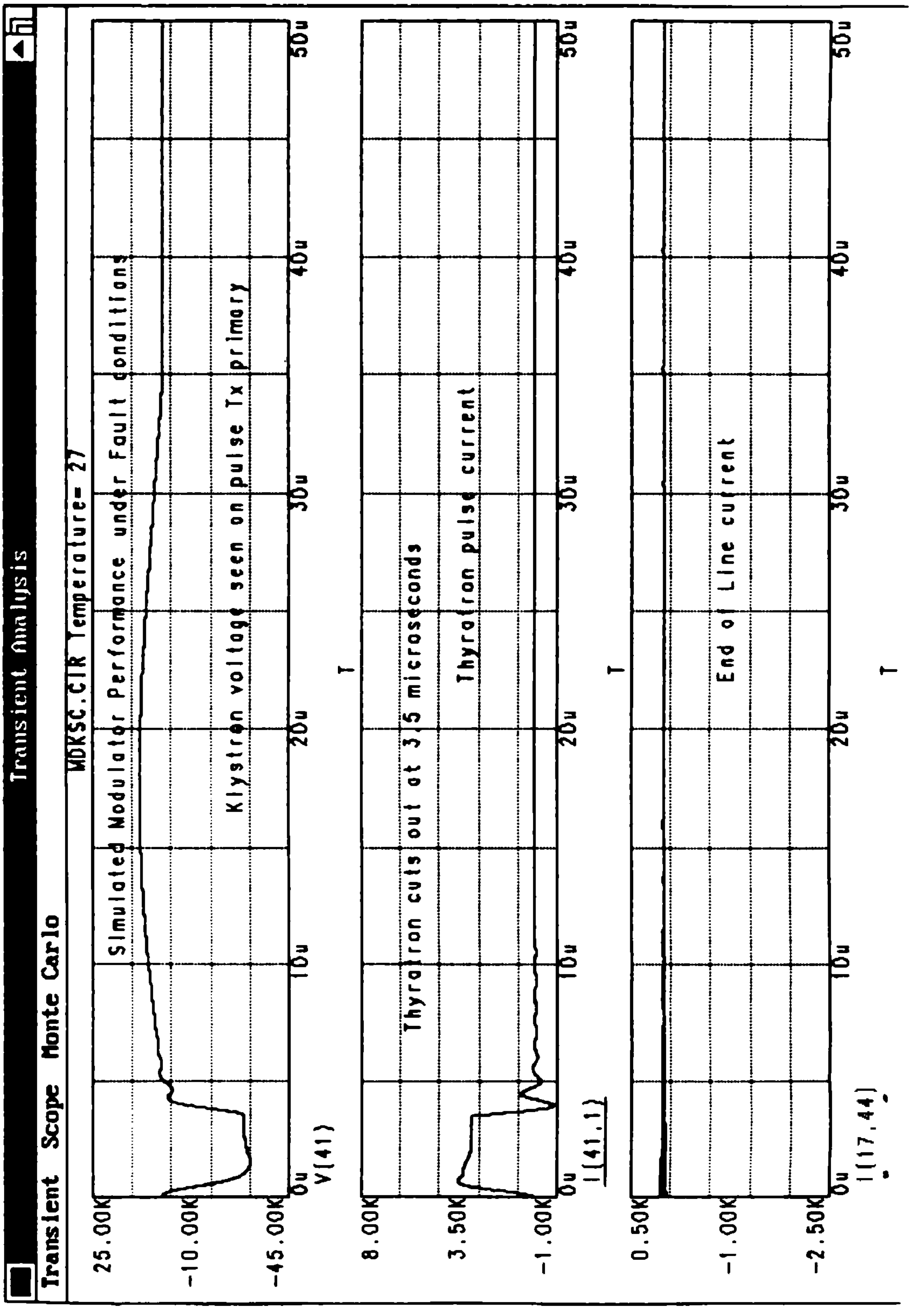

Transient Analysis
Transient Scope Monte Carlo
MDXSC.CIR Temperature= 27
Simulated Modulator Performance under normal conditions
Klystron voltage seen on pulse Tx primary
25.00K
-10.00K
-45.00K
0u
10u
20u
30u
40u
50u
V(41)
T
Thyratron pulse current
8.00K
3.50K
-1.00K
I(41,1)
End of Line current under No Fault conditions
0.50K
-1.00K
-2.50K
I(17,44)

FIG 3



Transient Analysis
Transient Scope Monte Carlo
WDKSC.CIR Temperature= 27
Simulated Modulator Performance under Fault conditions
Klystron voltage seen on pulse Tx primary
25.00K
-10.00K
-45.00K
V(41)
Thyratron cuts out at 3.5 microseconds
Thyratron pulse current
8.00K
3.50K
-1.00K
I(41,1)
End of Line current
0.50K
-1.00K
-2.50K
I(17,44)
0u
10u
20u
30u
40u
50u
T

FIG 4.

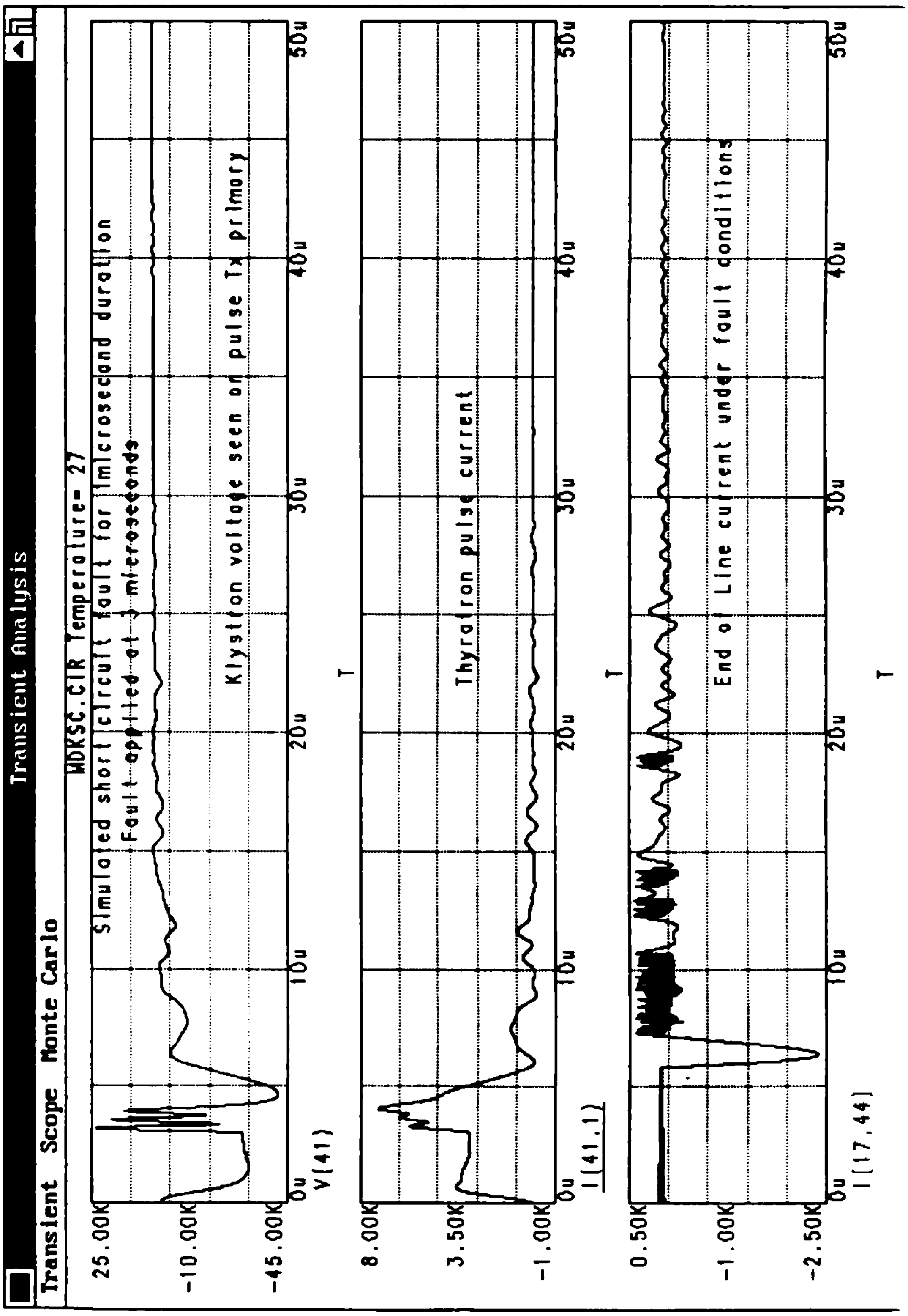
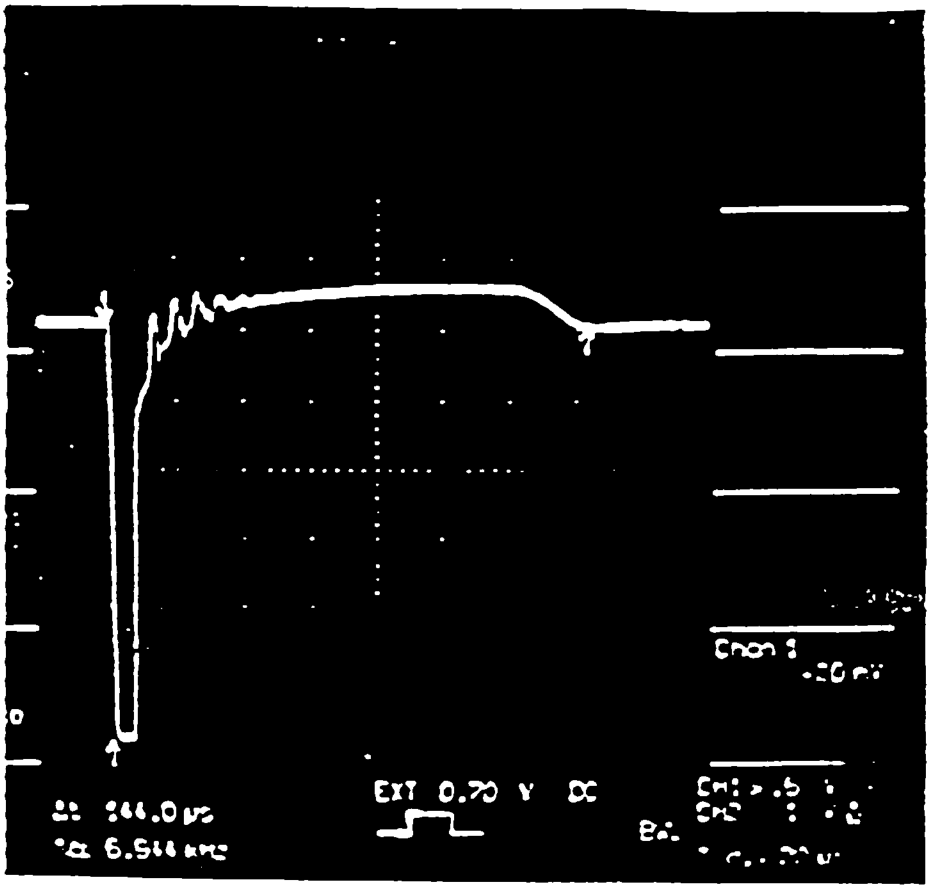
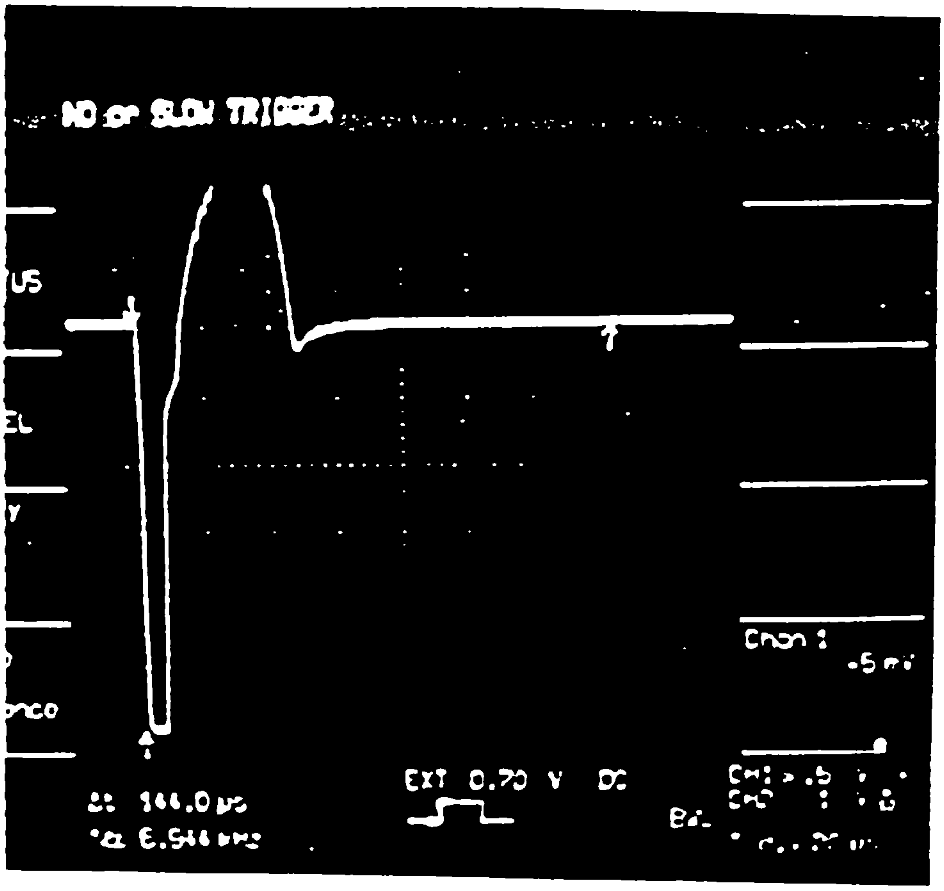

Transient Analysis
Transient Scope Monte Carlo
WDKSC.CIR Temperature= 27
Simulated short circuit fault for 1microsecond duration
Fault applied at 3 microseconds
Klystron voltage seen on pulse Tx primary
Thyratron pulse current
End of Line current under fault conditions
25.00K
-10.00K
-45.00K
8.00K
3.50K
-1.00K
0.50K
-1.00K
-2.50K
0u
10u
20u
30u
40u
50u
V(41)
I(41,1)
I(17,44)
T

Fig 5.



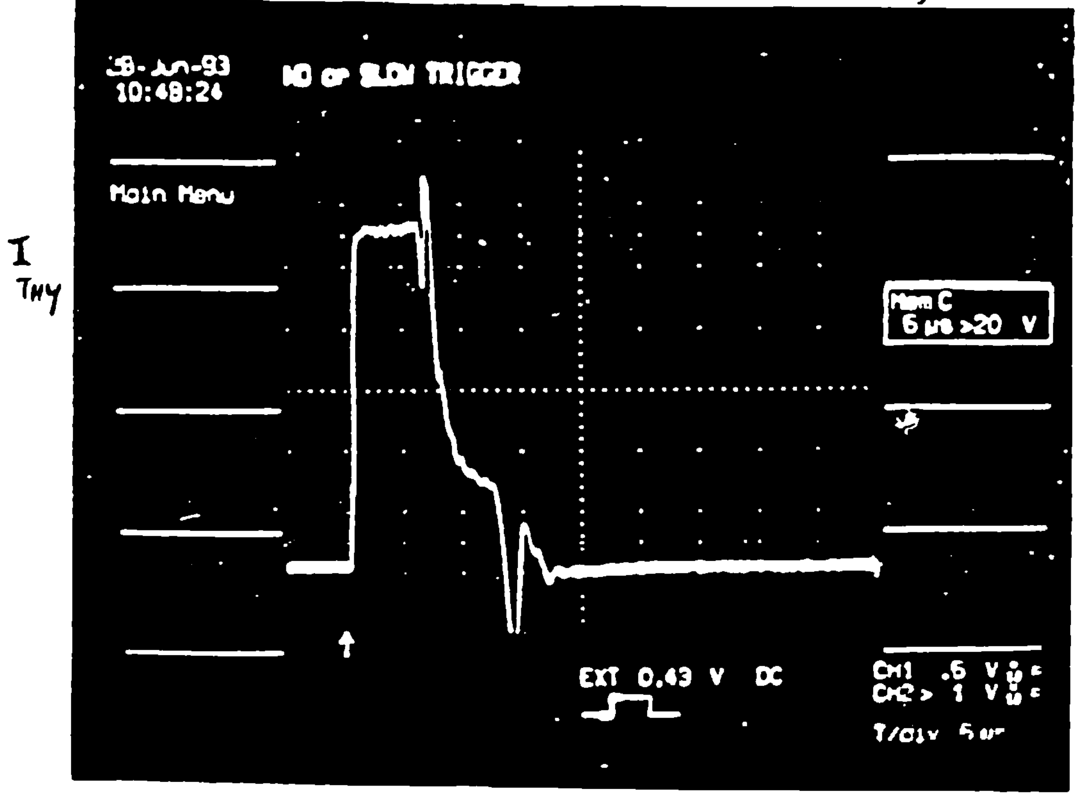
KLYSTRON VOLTAGE (NORMAL)



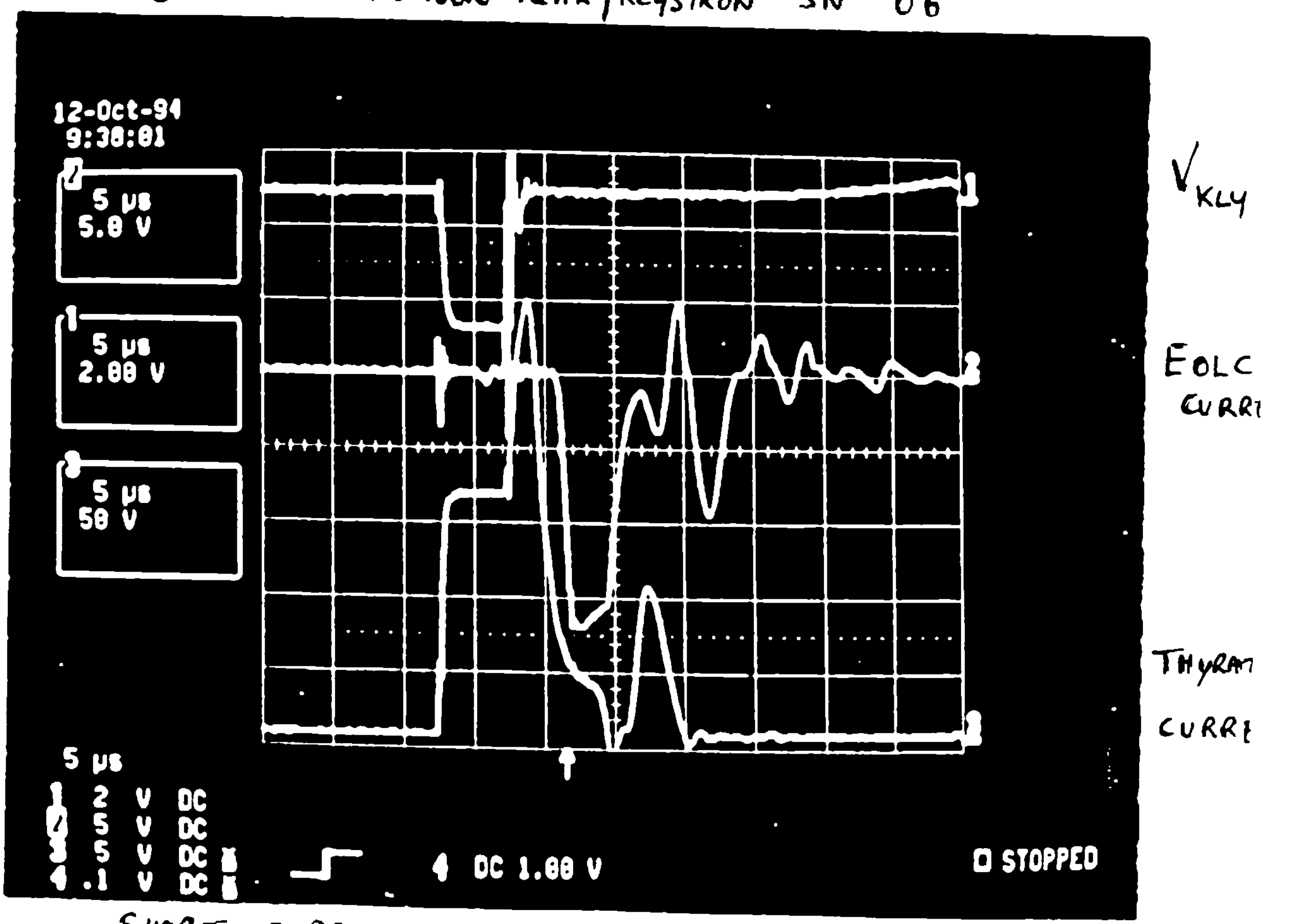
KLYSTRON VOLTAGE (THYRATRON OPEN CCT)

Fig 6.

THOMSON tank/Klystron SN° 06 (EEV CX1836 Thyratron)

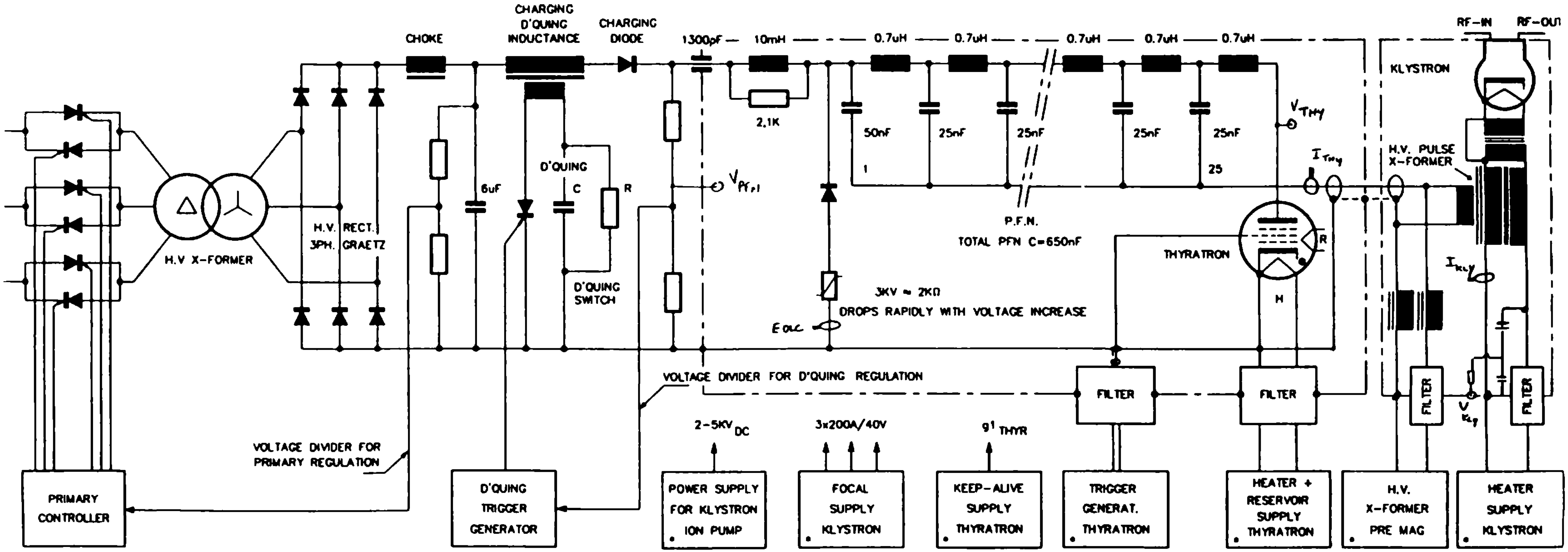


MDK13 with THOMSON tank/KLYSTRON SN° 06



SHORT CIRCUIT CONDITION IN TANK (ITT THYRATRON)

FIG 7



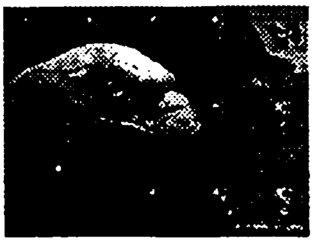
• ALL AUXILLARY POWER SUPPLIES REFERENCE VOLTAGES ARE MANUALLY CONTROLLED

ON + OFF, VOLTAGE AND CURRENT MEASUREMENTS ARE CAMAC CONTROLLED

MODULATOR SCHEMATIC-	SCALE 1/1	DESSINE G.A.	13/08/7
		N° PS/PO	J1014

FIG 8.

CERN
LEP PRE-INJECTOR ACCELERATOR



REPORT NO.
K__________

KLYSTRON CHANGE REPORT

KLYSTRON REMOVED.

DATE. ________ TIME. ________

MDK. ________ DONE BY. ________

KLYSTRON TYPE. ________ SERIAL NO. ________

HEATER HOURS. ________ HV HOURS. ________

KLY.HV ________ KLYSTRON CURRENT. ________ PERV. ________

REASONS FOR TUBE REMOVAL. ________________________________

____

KLYSTRON INSTALLED.

DATE. ________ TIME. ________

MDK. ________ DONE BY. ________

KLYSTRON TYPE. ________ SERIAL NO. ________

HEATER VOLTAGE. ______ HEATER CURRENT. ______ FOCAL CURRENTS A ______ B ______ C ______

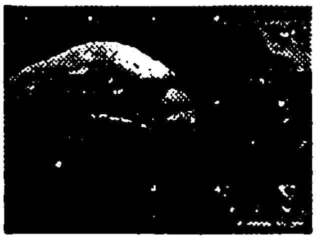
KLY.HV ________ KLYSTRON CURRENT. ________ PERV. ________

MISMATCH %. ________ RF POWER MW ________

KLY. HEATER HOURS. ________ KLYSTRON HV HOURS ________

Fig 9.

CERN
LEP PRE-INJECTOR ACCELERATOR



REPORT NO.
T________

THYRATRON CHANGE REPORT

TUBE REMOVED

DATE. ________ TIME. ________

MDK. ________ DONE BY. ________

THYRATRON TYPE. ________ SERIAL NO. ________

HEATER HOURS. ________ PFN REF kV. ________

RESERVOIR VOLTAGE. ________

REASONS FOR TUBE REMOVAL. ________

____

TUBE INSTALLED.

DATE. ________ TIME. ________

MDK. ________ DONE BY. ________

THYRATRON TYPE. ________ SERIAL NO. ________

SET RESERVOIR VOLTAGE. ________ HEATER VOLTAGE. ________

KEEP-ALIVE VOLTAGE. ________ KEEP-ALIVE CURRENT mA. ________

PFN REF kV. ________ MDK HEATER HOURS. ________

MISMATCH %. ________ THYRATRON CHASSIS HOURS. ________

Fig 10.