PS/LP Note 99-05 (Min)
11th October 1999

Notes of a visit to the EEV Ltd plant at Chelmsford, UK, for thyratron problems and on klystron acceptance testing.

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1. Introduction

The visit was arranged for discussing several urgent matters concerning thyratrons and klystrons supplied and/or repaired by EEV for the LIL and CTF accelerators at CERN. Three klystron-modulator subjects were addressed during the visit of the 8th to 9th October. These were:

a) Recent thyratron problems that had occurred on the LIL accelerator, causing some machine down time and associated damage to triggering equipment.
b) Calibration problems of operational signals from a pulsed klystron under test, using the old Valvo modulator. The acceptance testing of the repaired (Valvo) klystron by EEV.
c) A repair/reconditioning contract for the existing Valvo klystrons presently used in LIL and to be used in CTF3 over the next 5 to 6 years.

Present at most of these discussions and tests were:

CERN P. Pearce and G. McMonagle

EEV C. Pirie, C. Roberts, C. Weatherup, E. Livingstone, R. Sheldrake, J. Kerr, J. Brewster, C. Neale, J. Przybyla.

2. Thyratrons

The operational problems that occurred recently with four CX1836A thyratrons being used with the LIL machine were discussed. These previously new tubes (zero hours) had been installed in March 1999 and had been working normally since then up until quite recently when all four failed within days of one another. All had the same fault symptoms of breaking down internally and externally between grid 1 and cathode after about 4000 hours use. Previous experience with these tubes has given around 15-17000 hours of useful life before similar problems had occurred.

Circuit changes had been made to the modulator trigger drive amplifiers during the winter shut down of 1998/99, which involved applying a negative bias to each of the thyratrons to aid their recovery and help to ensure good double trigger conditions. Apart from this modification the trigger circuits were essentially the same as in the previous year. To overcome this sudden thyratron failure problem, new spare tubes from stock were inserted into the faulty modulators, and the negative bias voltages (-100 volts at a max current of 300mA) were removed. A small modification was made to a few trigger amplifiers (adding capacitance at the output) to try and reduce the effect of a high voltage reflected spike (~6kV) from the thyratron grid that was destroying small pulse transformers in each amplifier unit. Eventually this damaging problem of the reflected voltage spike was traced back to incorrect protection diodes that had been fitted to all modified thyratron chassis units during the previous shutdown. Once these diodes were changed the transformer problem, and the reliability problem of the trigger amplifier units was improved.

However, the original breakdown fault occurring in the thyratron tube (that created the high voltage spike in the first place) had not been removed. This high voltage spike generation at the thyratron grid can be explained in the following way.

When operating normally the thyratron emits from its hot (~1030 C°) tungsten matrix cathode quite a lot of barium in vapour form, which condenses on "cooler" parts of the internal structures of the tube. This causes a build-up of "virtual" cathodes to be formed in close proximity to the proper tube cathode. When these virtual cathodes are sufficiently prominent they can strike a plasma discharge as the tube is switched on and will support the initial pulse current during the rise time of the thyratron. However, towards the end of the pulse current rise time the plasma will transfer itself to the proper cathode via a mechanism probably due to the limited current carrying capacity of the virtual cathode. That is, the virtual cathode runs out of current. This fast switching action of the high current plasma between the virtual and proper cathode causes a high voltage spike, due to internal inductance, to be generated at the trigger grid of the tube.
This spike is seen directly by the output circuit of the trigger amplifier, and unless some clamping protection is provided at the thyratron, will eventually damage the amplifier and cause external high voltage breakdowns across the ceramic insulation between grid 1 and cathode. The breakdown becomes visible on the outside of the ceramic insulator once the spike has sufficient amplitude and tracks across the dusty surface. The short circuit created between grid 1 to cathode can also cause a higher bias current to flow from the 100 volt, 300mA bias power source. This may be a reason for some of the damage in the trigger amplifier units, and it may also be having a sustaining effect on the actual tube breakdown itself.
Two of the faulty thyratrons have had the burnt ceramic cleaned with aluminium powder and tested in the MDK35 modulator up to about 34kV on their anodes. The two other faulty thyratrons will be inspected and sent back to EEV for replacement. Possibly the first two tubes that have been cleaned and tested in CERN could follow them, if the anode voltage cannot be increased to the specification level.

a) Thyratron trigger units.

The actions taken above render the trigger circuits the same as last year by eliminating this bias circuit and an external coupling capacitor between grids 1 and 2. However, in order to be sure we have the best triggering conditions for the CX1836A tube, the special EEV amplifier units will be installed in the future. These units apply two separate trigger pulses to the thyratron. The grid 2 is provided with a pre-pulse of up to 100A to establish pre-triggering conditions in the thyratron, before the arrival of the (delayed by 0.5μs) 1kV trigger pulse (with negative bias) applied to grid 1.
The onset of the voltage spike generation within the thyratron is significantly retarded when using the EEV delayed-double trigger amplifier method. This is because of the large amount of plasma generated by the pre-pulse from the matrix cathode (according to EEV), which stops any tendency to strike from a virtual cathode, and is said will enable thyratrons already suffering from this problem to be recovered and used again.
One trigger unit has been on test in the CTF for some weeks and a second unit has been ordered for the LIL machine. Further orders for trigger amplifier units will be made when tests confirm their reliable operation in our systems. Installation of new units is forseen for the January 2000 shut down period.

b) Thyratron spare tubes.

CERN has ordered 3 replacement thyratrons of this type (CX1836A) for use in LIL and CTF. One of these tubes will be a fully-paid for thyratron, whilst the other two are called "advance replacements" and will be paid for at a rate depending on what is found with two faulty thyratrons to be returned to EEV for inspection and testing. So far the first two thyratrons of this order have arrived in CERN, and the third will be sent within two weeks. Testing of the faulty thyratrons will continue for a while to assess the effect of cleaning the ceramic insulators. The quantities of this thyratron type, supplied each year on a CERN wide contract, should probably be reviewed upwards to avoid any maintenance replacement problems of this type re-occurring.

3. Klystron testing.

This relates to the repair and reconditioning of an old Philips (Valvo) 35MW S-band pulsed klystron with Serial No. 010, by EEV Ltd at their Chelmsford UK plant. A contract (CA 1125665) for this work was placed with EEV on the 23/9/97 and the klystron repair was completed about May 1999. Testing of the old pulse modulator (purchased from Philips, Hamburg), which had been previously assembled at EEV, began using an old, low perveance Valvo klystron, loaned by CERN as a diode load. Difficulties were experienced by EEV to understand and correctly commission this test facility, and in particular the measurement systems associated with the klystron parameters. CERN personnel gave some technical support where possible in order to speed up this modulator commissioning process. Finally the repaired klystron was inserted into the test socket and diode tests made to establish the electrical parameters of the tube. When this was completed by EEV, although with not too much confidence in the values obtained for the perveance etc, the RF testing was started by them. The present visit concerns mainly the klystron RF power acceptance testing made at EEV with CERN people present on the 7th and 8th October to validate the overall performance of the repaired device at peak powers up to 35MW.

a) Diode tests of repaired Valvo klystron Serial No. 010

Six different tests were made with the focal current settings below and are shown in the Table 1:

A: 166 Amps, B: 112 Amps, C: 86 Amps

Test number:	1	2	3	4	5	6
V klystron (meter) kV	260	240	220	200	180	160
I klystron (meter) A	319	285	240	220	189	158
V PFN (meter) kV	46	42	37.4	33.6	29.5	25.8
V klystron (tank divider) kV	281	259	238	219	197	176
I klystron (tank CT) A	315	283	249.6	223	192.8	163.2
Microperveance	2.11	2.14	2.15	2.17	2.2	2.21
Mismatch (load to PFN) %	3.2	4.2	5	5.5	6	7.9

Table 1. Diode tests of repaired klystron

b) RF power testing

i. 25 MW peak power test

Initial Test   Focal A 180 Amps
Focal B 80 Amps
Focal C 110 Amps

V klyston 240 kV (analogue meter on test gear)   V klystron 259 kV (measured on voltage divider HT tank)   Waterflow in RF load 15 l/min   RF frequency 2997.5 Ghz

I klystron 285 Amps (analogue meter on test gear)   I klystron 283 Amps (measured at current transformer in HT tank)

The peak power measurements for input and output are only estimates as EEV could not provide a calibration of the cable coming from the calibrated attenuators

The attenuation was estimated at 0.3 dB per metre for the cable, although we did not know the precise cable length

Peak Power Input (watts)	Peak Power Output Water load MW	Peak Powe meter MW
10	11.1	13.5
20	13.5	15.3
40	16.7	18.3
60	19.5	21
80	21.5	23.5
100	23.7	25
120	24.3	25.7
140	24.4	24.9
160	24.6	25.2
180	24.9	25.2
200	25.3	24.3
220	24.6	23.6
240	24.9	24.3
280	24.9	24.3

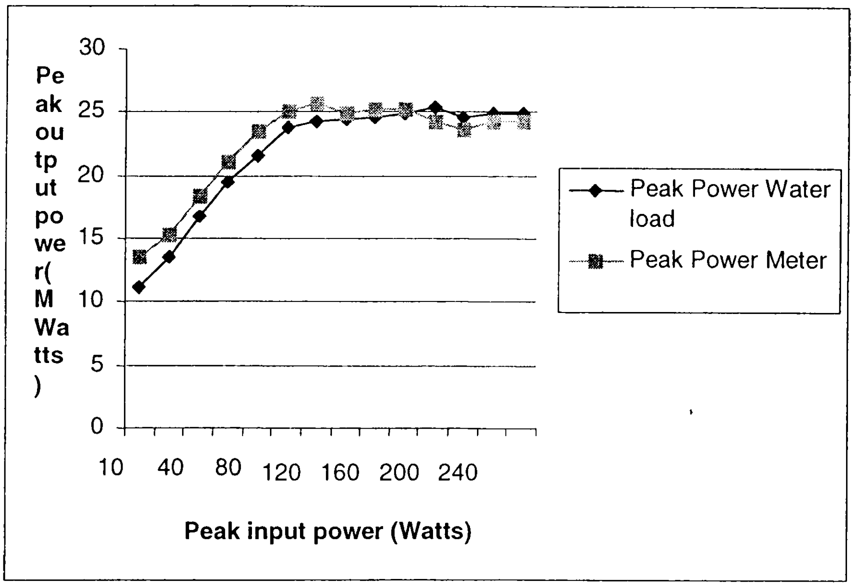

Figure 1. 25 MW peak power test curve

ii. 30 MW peak power test

Focal A 180 Amps
Focal B 80 Amps
Focal C 110 Amps

V klyston 260 kV (analogue meter on test gear)

V klystron 281 kV (measured on voltage divider HT tank)

Waterflow in RF load 15 l/min
RF frequency 2997.5 Ghz

I klystron 319 Amps (analogue meter on test gear)

I klystron 315 Amps (measured at current transformer in HT tank)

The peak power measurements for input and output are only estimates as EEV could not provide a calibration of the cable coming from the calibrated attenuators

The attenuation was estimated at 0.3 dB per metre for the cable, although we did not know the precise cable length

Peak Power Input (watts)	Peak Power Output Water load MW	Peak Powe meter MW
5	18	21
10	21.5	23.5
20	26.5	28.9
40	29	29.7
60	29.9	29.7
80	30.2	31.2
100	30.2	30.7
120	29.9	30.5
140	30.2	30.7
160	29.9	29.7
180	30.2	30.8
200	30.2	30.8

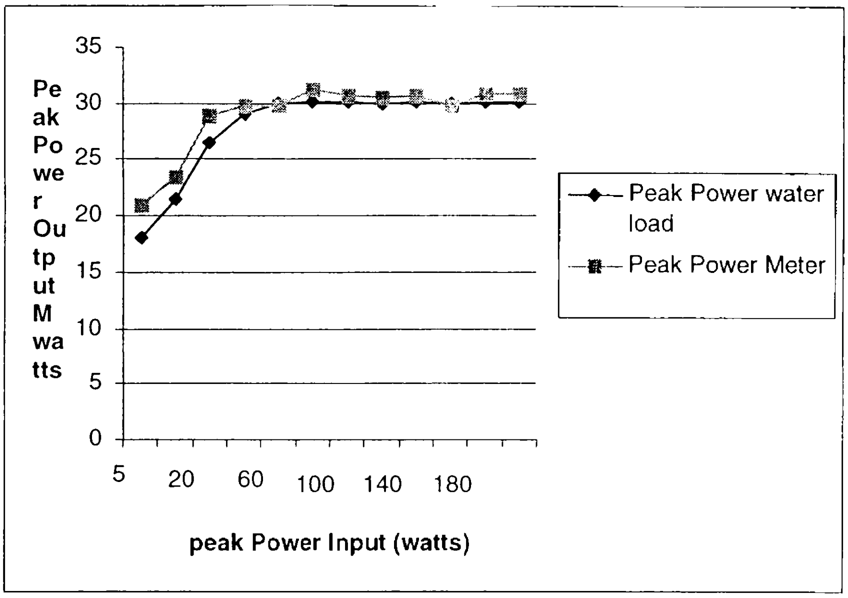

Figure 2. 30 MW peak power test curves

at Saturation Frequency (GHZ)	Peak Output Power (MW)
3.0035	29
2.9985	29.7
2.9935	30

Focal A	180 Amps
Focal B	80 Amps
Focal C	110 Amps

V klyston (analogue meter on test gear)	270 kV	V klystron (measured on voltage divider HT tank)	Waterflow in RF load	15 l/min
			RF frequency	2998.5 Ghz

I klystron
(analogue meter on test gear)

I klystron
(measured at current transformer in HT tank)

The peak power measurements for input and output are only estimates as EEV could not provide a calibration of the cable coming from the calibrated attenuators

The attenuation was estimated at 0.3 dB per metre for the cable, although we did not know the precise cable length

Peak Power Input (watts)	Peak Power Output Water load MW	Peak Power meter MW
80	32.5	33

Due to limitations in the test gear there was not enough time to complete a power curve as either the test gear would break down or the RF source would not recover when the test gear broke down

The unreliability of the small RF drive amplifier and the repeated voltage breakdowns in the PFN of the test modulator at this higher operating voltage of 270 kV caused the tests to be terminated. The klystron however was provisionally accepted and will be shipped to CERN in the coming week together with the test water load and instrumentation loaned to EEV. The final acceptance tests will be made using the MDK35 test modulator and the above measuring instrumentation. The full 35 MW peak power performance should then be demonstrated. People from EEV will be present at these tests in CERN.

4. Klystron repair contract.

At the present time it is a little premature to decide on a 3 year contract for repair of existing Valvo klystrons. However, EEV will be sent some details of the previous (and outdated repair contract) made with Philips Hamburg. A call for tender with EEV should be considered towards the end of this year, for a contract starting date in the year 2000.