IOT TESTING AT THE ERLP

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Abstract

The testing of Inductive Output Tubes (IOT) at 1.3GHz is underway for use on the Energy Recovery Linac Prototype (ERLP) being constructed at Daresbury Laboratory. A 50KV high voltage power supply (HVPS) has been commissioned and characterised for use as a test RF supply. This will be used to power the ERLP RF system in both continuous and pulse modes of operation. First results are presented of the IOTs and the use of the HVPS system.

INTRODUCTION

The Daresbury Laboratory (DL) ERLP is presently being constructed on the DL site. The purpose of the ERLP is primarily to facilitate the successful production of the Fourth Generation Light Source (4GLS) at DL. This will be achieved in two ways.

- Increasing the skills and expertise of DL staff in areas relevant to the development of 4GLS.
- Investigating possible solutions to the technical problems envisaged.

In keeping with these aims it was decided to evaluate the effectiveness of Inductive Output Tubes (IOTs) as RF power sources in Energy Recovery Linacs. IOTs have not previously been implemented in energy recovery machines, or operated at the required 1.3 GHz frequency.

IOTs

An IOT can be considered as a klystron/tetrode hybrid. It has advantages over the klystron in terms of linearity and efficiency and over the tetrode in gain and output power [1]. IOTs have become an accepted technology in the commercial sector, notably as TV transmitter tubes. They are now beginning to see service in scientific applications. An example of this is the Diamond Light Source, which is due to become operational in 2008. Diamond will use four 80k W, 500 MHz IOTs for each superconducting RF cavity.

1.3 GHz is the frequency of choice for many new and planned accelerators and DL has been working closely with tube manufacturers to help develop and test IOTs at this frequency.

ERLP High Voltage Power Supply

The ERLP High Voltage Power Supply (HVPS) was originally the DL Synchrotron Radiation Source (SRS) HVPS, used to power a single 250 kW klystron operating at 500 MHz. It was in operation in this role for twenty years before being replaced by a Thales power supply, which uses Pulse Step Modulation (PSM) techniques. The old power supply was then redeployed to the ERLP site and recommissioned. Recommissioning included replacing the original ignitron based Crowbar Switch with a semiconductor based design and a number of other improvements. The HVPS is of conventional design and is shown schematically in figure 1.

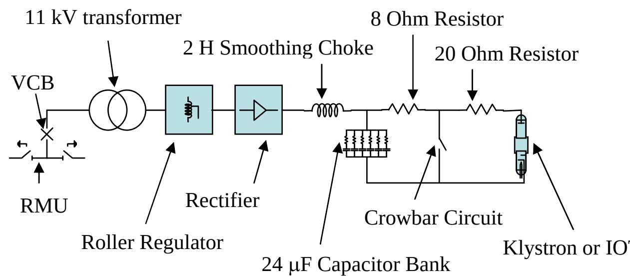

Figure 1: ERLP HVPS.

TESTING

Aims

- Assess the relative merits of the different tube manufacturer's products. We have been in close liaison with e2v, Thales and CPI and hope to test all of their products at our test facility.
- To prove pulsed operation of a 1.3 GHz IOT. The accelerating cavities within the ERLP require high RF power to accelerate the electron beam. In order to limit the average power experienced by the cavities/couplers they will be operated in pulse mode. Testing will be carried out at up to 3 ms pulse width, 20 Hz pulse repetition frequency (PRF).
- Assess phase variations of the IOT output as a function of HVPS fluctuations in HT. All four ERLP IOTS are likely to be powered by the same HVPS. Variation in load (beam current) in any IOT will produce a slight change in HT for all IOTs. This becomes more of an issue when some (or all) IOTs are operated in pulse mode. Ideally any phase shift due to HVPS HT fluctuation should be minimal.

Test Set-Up

Figure 2, shows the interconnections between the IOT and the ancillaries required for operation. Note that the tube operates with a negative voltage at the cathode. This means that the Grid and Heater power supplies need to be fed via an isolating transformer and are "floating" at HT. Not shown in the figure are the IOT cooling, the RF circulator and the high power load at the RF output.

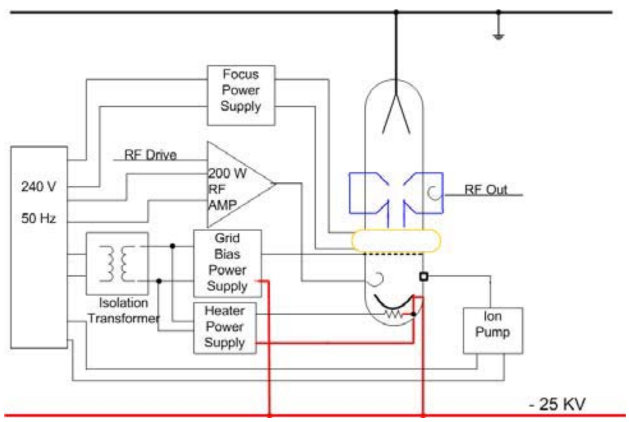

Figure 2: IOT Ancillaries.

Limitations

Generally the ERLP IOT test stand has worked well. However communications with the floating grid/heater power supplies and control system were problematic. The original RF communications system failed to perform as it should have and it was decided to replace this system as soon as possible. Most tests were carried out by manually varying the grid and heater supply outputs before switching on HT. Any variation in these parameters necessitated switching down, making the HVPS safe and carrying out the necessary changes. This made testing the IOT time consuming and frustrating. After a limited run it was decided to cease testing so that a more effective PLC controlled fibre optic system could be installed in the HVPS.

RESULTS

As yet, we have only tested a pre-production IOT manufactured by e2v (IOT116LS serial number 10).Table 1 and Figure 3 show the results in for this tube in CW mode, Table 2 and Figure 4 show pulsed mode operation.

Table 1: IOT116LS S/N 10 CW Test Results

Beam V (kV)	Beam I (mA)	Grid V (V)	IOT Drive (W)	Output Power (kW)	Efficiency (%)	Gain (dB)
25.194	440	105	45	2.8	25.258	17.9
25.136	550	105	84	5.2	37.613	17.9
25.08	642	105	120	7.4	45.958	17.9
25.08	741	105	152	9	48.428	17.7
25.08	822	105	182	10.6	51.4169	17.6
25.08	891	105	216	12	53.7	17.4
25.02	966	105	250	14	57.924	17.4
25.02	1042	105	275	15	57.535	17.3

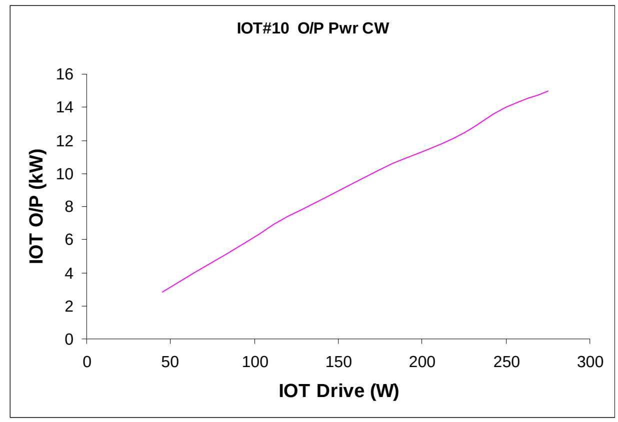

Figure 3: IOT116LS S/N 10 CW Output Power Graph.

Results for output power and gain were not as good as was anticipated. This can be attributed to two causes;

- Difficulty optimising the heater and grid power supply outputs due to lack of remote control.
- The IOT was a pre production prototype and the original electron gun design proved to be of low gain. This design has since been optimised for production IOTs, Table 3 shows IOT116LS S/N 17 results for comparison.

Table 2: IOT116LS S/N 10 Pulsed Test Results

Beam V (kV)	Beam I (mA)	Grid V (V)	IOT Drive (W)	Output Power (kW)	Gain (dB)
25.43	270	105	45	3	18.239
25.194	320	105	81	7	19.366
25.194	320	105	120	9.5	18.985
25.136	320	105	150	12	19.03
25.136	320	105	185	14.5	18.941
25.19	320	105	216	16.5	18.83
25.37	320	105	250	18.1	18.597
25.37	320	105	284	20	18.477
25.37	320	105	320	22.9	18.546

Table 2 does not give values for efficiency, as we had no facility for measuring the instantaneous value of beam current during the pulse duration.

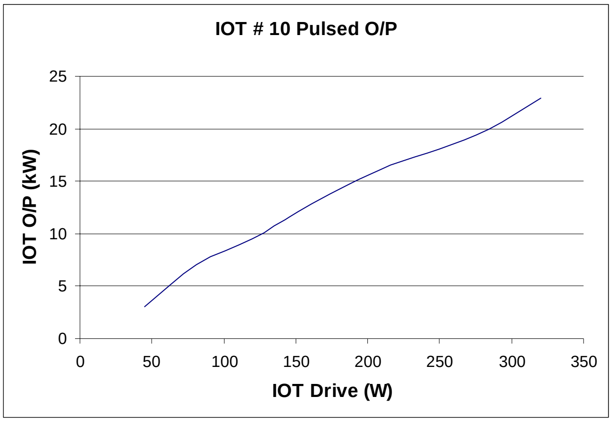

Figure 4: IOT S/N 10 Pulsed Output Power.

Table 3: IOT S/N 17 Parameters (courtesy of e2v)

HT Volts	24.6 kV	**Electronic Efficiency**	60.9%
Beam Current	1.2 A	**Grid Voltage**	78 V
Beam Power	30 kW	**Grid Current**	0 mA
Idle Current	200 mA	**Body Current**	22 mA
Drive Power	175 W	**Gain**	20.1 dB
Output Power	18 kW	**VSWR**	1.08:1
Reflected Power	0 kW		

As mentioned earlier, Phase/HT linearity will be an important issue, especially with regard to pulsed operation. It is important that changes in phase due to HT variations are kept small. It is also advantageous if these variations are linear as this facilitates feedback/feed forward phase control. Figure 8 shows good results for IOT S/N 17.

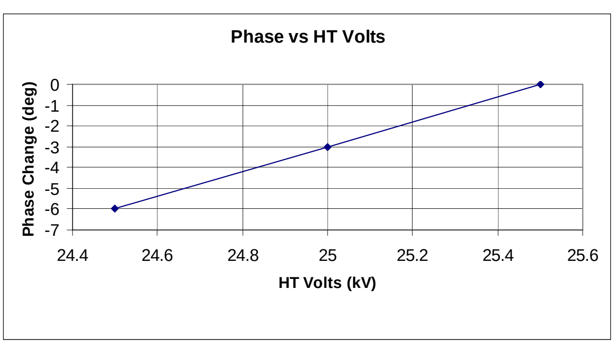

Figure 5: Phase/HT IOT S/N 17 (courtesy of e2v).

CONCLUSION

The IOT testing carried out at DL was extremely successful and achieved the following;

- Operation of a 1.3 GHz IOT using the ERLP HVPS.
- Operation of a 1.3 GHz IOT in pulsed mode for the first time.
- Demonstrated that 1.3 GHz IOTs are suitable for their role in ERLP/4GLS.

Future Developments

The ERLP HVPS, with full remote control for the heater/grid power supplies, is due to become operational in the coming weeks. This will allow us to continue testing, of a variety of production IOTs.

REFERENCES

[1] Jerry. C. Whitaker, Power Vacuum Tubes Handbook.