THE 3.6 MW HIGH VOLTAGE INTERFACE FOR THE LEP MAIN RING KLYSTRONS

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Summary

Each LEP main ring accelerating station has a high voltage interface wherein power is distributed and regulated for two 1 MW klystrons. Operating at 92 kV d.c. the interface comprises a switch, protection resistors and a filter capacitor, two tetrode regulated modulators, as well as a single stage rapid protection device or crowbar. Filamant power for each klystron is also provided at the high voltage level. A general description is presented. All of the elements of each high voltage interface are housed in a small chamber 2 m high × 2 m wide × 5 m long in the klystron galleries of LEP.

Full scale and full power trials have recently been completed using a complete set-up simulating one LEP acceleration station. All elements have performed according to design expectations and no major changes are required for the definite installation in LEP.

Description

Each of the 8 LEP main ring accelerating stations is fed with electrical power, 3.6 MW, rectified on the surface and fed into subterranean galleries. Distances from surface to arrival at the acceleration points varies between 330 and 550 meters[1].

At each of the acceleration stations and in the respective klystron gallery, the power supply lines are terminated at the so-called high voltage interface. There, the final filtering of the supply voltage is done, the protection elements are connected and the power is distributed via the protective devices to each klystron and its auxiliaries.

Wherever possible, the high voltage interface has been constructed from elements readily available from industry. This has been the case for the cables and cable links, the filter capacitor, the isolation transformers and the crowbar thyratron. Some elements, the filament power supply for example immersed in oil were not so readily available. The switch had to be made in-house. Because of the high voltage up to 95 kV and the high short circuit capability of 36 MVA at each station, the electrical insulation of all the elements has been of particular concern.

Except for the filter capacitor, the most common solution for both electrical insulation and thermal cooling problems is the use of transformer grade mineral oil in all of the high voltage interface elements. This is acceptable since all of the elements can be grouped and housed in a fire-resistant bunker.

No element contains more than 200 ℓ of oil and the bunker will be equipped with a means of fire suppression. On a stand-alone basis, the bunker will resist any internal combustion for at least one hour.

Fig. 1 shows the basic circuit of the high voltage connections and its elements.

For the high voltage cables arriving from the surface and for the interconnections between the switch and the filter capacitor and the crowbar, these are prepared for immersion directly into the oil tanks where they are solidly clamped. All other high voltage links are made from very flexible, EPR, high voltage cable terminated with industrial, x-ray machine connectors.

The switch has been included to permit test work as well as single klystron operation. It is designed for off-load operation only.

Power resistors

The power resistors shown in the circuit are designed to limit the amount of energy that can be dissipated in any fault that might occur downstream in the sensitive elements such as modulator or, more importantly, klystron.

Each of these resistors has a nominal value of 10 Ω and is made up of 10 carbon-ceramic discs. Anti-tracking coated discs are used to ensure that each stack can support the maximum supply voltage.

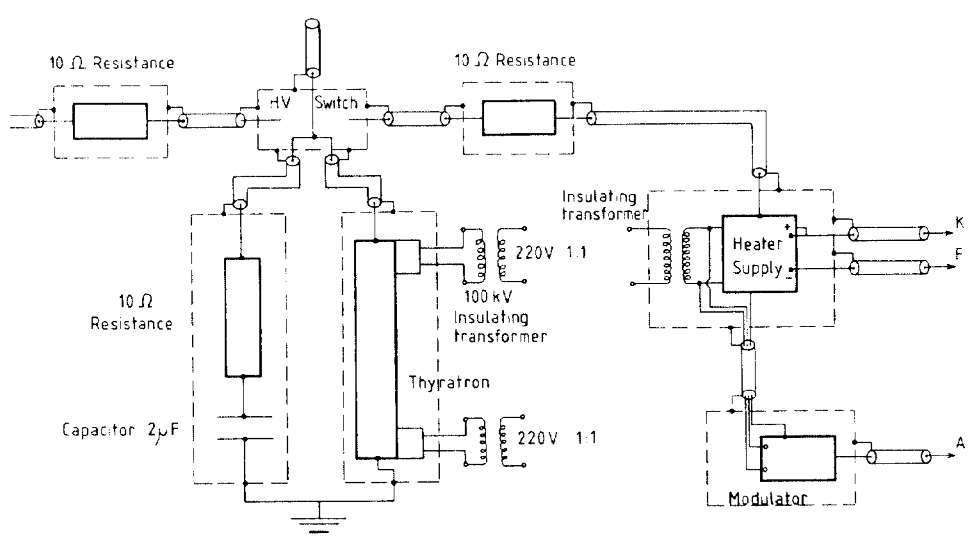

Fig. 1. Basic circuit connections for one klystron

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Resistors in series with klystrons are rated for 4 kW. Forced cooling of the oil is made by circulation through internal water cooled channels such that the oil temperature does not exceed 50°C. The resistor in series with the capacitor serves to dampen the supply circuit and to limit the capacitor discharge current in the event of fault and crowbar operation. Cooling is by natural means since the continuous dissipation due to ripple is ~ 150 W and faults (crowbar firings) are rare. This resistor is mounted directly on the high voltage terminal of the filter capacitor.

Crowbar

This device serves to protect the klystrons from rapidly developing faults such as high voltage breakdowns or sudden changes in beam behaviour due to extraneous faults. Such faults can be sustained or amplified due to the stored energy of the filter capacitor and the power supply. At full power the stored energy exceeds 8.5 kJ whereas experience has shown that only several tens of Joules are sufficient to initiate klystron failure. The crowbar has to be very fast in overall response time as well as being very reliable.

An EEVC 1194B deuterium thyratron is being used in this application and the assembly is shown in Fig. 2. A five gap tube gives reliable voltage hold-off during stable operation with internal gas pressures commensurate with high coulomb rating when in crowbar-conduction-mode. Consistent with the high coulomb rating, the tube has a gaseous anode as well as cathode and can therefore accommodate current flow reversals under any fault condition[2].

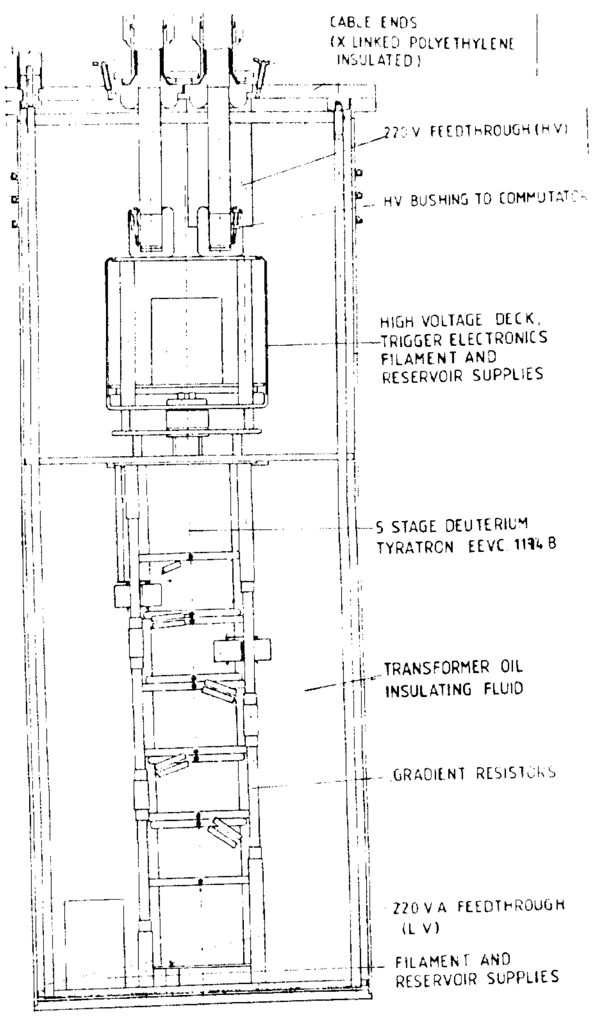

Fig. 2. Thyratron Crowbar

Before delivery to CERN, each thyratron has to be dc conditioned to 120 kV and current pulsed (RC=20 uS) with a peak of 12 kA. In the LEP application, the thyratron will have to remain in a conductive state significantly longer than a few RC-times. This is to ensure that there can be no follow-on or other supportive fault.

Normally, fault current signals will put the thyratron into conduction state in less than 1 µs and the same signal will block the power supply within the next 10 ms followed by opening of the main circuit breaker that isolates the dc power supply from the mains after a further 100 ms. To ensure that this sequence is followed and that the klystrons are fully protected in the event of a fault, the thyratron will be maintained in a conductive state by a multi-trigger facility of 1 kHz for one second. This is more than sufficient to enable the power supply overload protections to come into play. At the moment, fault detection is based on a ferrite cored transformer at the high voltage bushing of the filter capacitor. This detects current surges and via electronics circuits and a light link between the detector and the high voltage end of the thyratron, provides the trigger signal. Multi-triggering follows automatically on the initial trigger. A method to use a transformer local with, and directly connected to, the thyratron for the initial fault trigger is being developed.

Fig. 3 shows the overall delay-times achieved from fault detection to start of conduction in the thyratron.

During tests, two methods to confirm the correct functioning of the crowbar are employed: firstly at low voltage, a manual trigger demonstrates that connections and multi-trigger are correct and functioning; at intermediate voltages fault conditions are simulated by using a spark-breakdown apparatus plugged into the klystron circuit and wherein an electric arc is caused to traverse a thin (0.2 mm) aluminium foil. At test voltages of 50 kV the foil is completely perforated when the crowbar is disabled. With the crowbar active, the criterion for safe operation is that there is no material damage to the foil.

Reliability of the operational status of the thyratron is ensured by monitoring the power consumption of the filament and reservoir supplies for both anode and cathode as well as the respective grid bias.

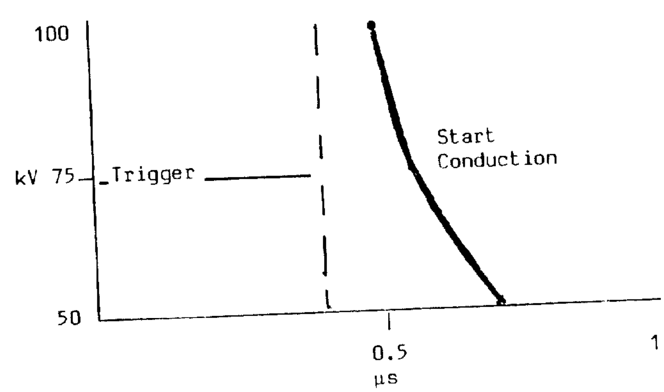

Fig. 3. Thyratron Delay Times

Modulator

This is the element that is used to control the klystron beam intensity by setting the potential of the klystron gun anode with respect to cathode. It is used in the closed-loop control of the klystron power output and has response faster than the power converter can follow.

Essentially, and as shown schematically in Fig. 4, it is a variable potential divider using a high voltage tetrode TH5186 as the variable element. Fixed resistors, R1 and R2, give a fail-safe setting for the klystron in the event of tetrode failure.

In LEP, the klystrons will normally be operated at one high voltage level and the klystron output power will be varied uniquely by the use of the modulator. This will, initially, result in long periods of the klystron being at reduced power and consequently the modulator will be at maximum dissipation of 1.5 kW. Convective cooling of the oil is therefore essential to maintain the ambient temperature for electronics and connectors at < 55°C. This is provided for by water cooled tubes on the modulator tank's cover.

Because of the fact that all controls and interlocks are at the high voltage level, extensive use of fibre-optic links is required, as in the crowbar. Commercially available links needed assessment and changes in the terminations before they could be employed in an oil environment.

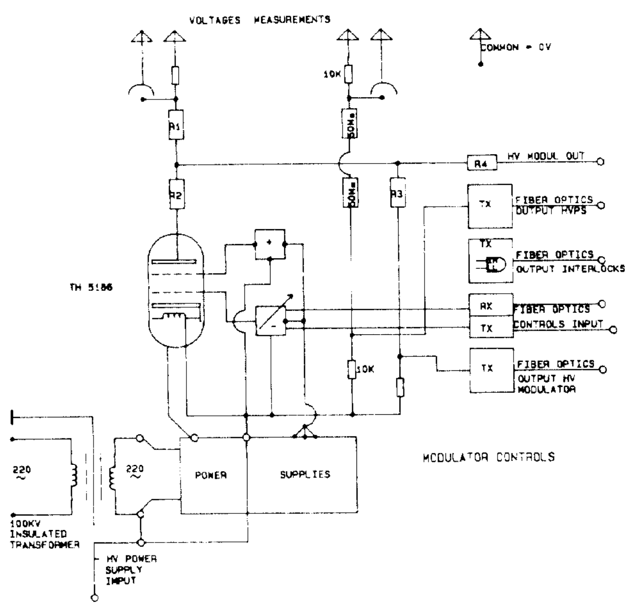

Fig. 4. Modulator Circuit

Filament supplies

At the present time a commercially available, 24 V-24 A, switched-mode power supply is used. This has required only small modifications at CERN to be compatible with the oil environment.

Initial trials of the high voltage interface revealed that it was the filament supply most prone to damage in the event of a crowbar discharge. This has been rectified by housing the power supply in an electro-magnetically screened container with capacitive feedthroughs for the electrical connections. The filament supplies are housed immediately above the isolation transformer and in the same container.

Earthing

In LEP the klystron galleries will have all the metallic structures (monorail, supports, waveguides, water pipes, ventilation tubes, etc.) electrically connected to a steel wire grid structure buried in and covering the gallery floor and walls. This mesh will provide the 'earth' for the high voltage interface.

Filter Capacitor

The 2 μF filter capacitor is rated for 100 kV continuous and tested at 150 kV dc. Under operating conditions, the ripple voltage is ~ 1 kV at 600 Hz. When the crowbar is fired, the instantaneous peak current is 8.6 kA rising in less than 1 μs. Discharge tests are made at - 130 kV.

The capacitor comprises 22 compressed coils of the extended foil type. A mixed film-paper dielectric is used and impregnated with phenyl-xylyl-etano (PXE)[3]. An hermetically sealed container is used and CERN provides the feedthroughs and mounts the load resistor of 10 Ω.

Acknowledgements

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2. Hannant, Rowe and Menown, Twelfth Modulator Symposium, February 1976.

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