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The High-voltage Interface for the LEP II RF Power Generation System

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For the $W^{\pm}$ pair production at centre-of-mass energies around 180 GeV the maximum circumferential accelerating RF voltage in LEP has to be increased from 350 MV at present to about 2000 MV. This will be achieved by the installation of 12 additional RF units, each consisting of two klystrons with a maximum output power of either 1000 kWcw or 1300 kWcw, two high-power circulators, a 100 kV, 40 A power converter with a HV interface, a waveguide RF power distribution system, 16 superconducting (sc) cavities which are housed in four cryostats, and all associated electronics and interlock systems. The HV interface of an RF unit, which is the subject of this report, comprises a commutator switch, a smoothing capacitor, a thyratron crowbar, two hard tube modulators with HV protection resistors and insulating transformers. In order to increase the output power of the klystrons from 1000 kW cw (LEP 1) to 1300 kW cw their d.c. operating voltage and current had to be increased from 88 to 100 kV and from 18 to 20 A respectively. Therefore, the above-mentioned HV equipment had to be adapted to the higher klystron operating voltage and current. A description of the redesigned HV interface system is given and, in particular, the improved performance of the eight-gap thyratron crowbar and hard tube modulator is discussed.

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The High-voltage Interface for the LEP II RF Power Generation System

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Abstract

For the $W^{\pm}$ pair production at centre-of-mass energies around 180 GeV the maximum circumferential accelerating RF voltage in LEP has to be increased from 350 MV at present to about 2000 MV. This will be achieved by the installation of 12 additional RF units, each consisting of two klystrons with a maximum output power of either 1000 kWcw or 1300 kWcw, two high-power circulators, a 100 kV, 40 A power converter with a HV interface, a waveguide RF power distribution system, 16 superconducting (sc) cavities which are housed in four cryostats, and all associated electronics and interlock systems. The HV interface of an RF unit, which is the subject of this report, comprises a commutator switch, a smoothing capacitor, a thyratron crowbar, two hard tube modulators with HV protection resistors and insulating transformers. With the exception of the smoothing capacitor, all these high-voltage components are immersed in oil and housed in fire-proof bunkers which are located in the klystron galleries. In order to increase the output power of the klystrons from 1000 kW cw (LEP I) to 1300 kW cw their d.c. operating voltage and current had to be increased from 88 to 100 kV and from 18 to 20 A respectively. Therefore, the above-mentioned HV equipment had to be adapted to the higher klystron operating voltage and current. A description of the redesigned HV interface system is given and, in particular, the improved performance of the eight-gap thyratron crowbar and hard tube modulator is discussed.

1. INTRODUCTION

At present the LEP RF system is being upgraded and will eventually comprise 20 RF units of which eight are equipped with RF cavity assemblies made of copper (LEP I) and 12 with sc RF cavities (LEP II). In an earlier publication [1] it was stated that in the latter one klystron would supply the RF power for all 16 sc (sc) cavities of an RF unit. However it has been decided recently that eight sc cavities must be powered by one klystron, but the HV for the two klystrons of an RF unit is supplied by one HV power converter and only one thyratron protection crowbar is used. Higher operation reliability is thus ensured and the LEP RF system is able to cope with beam intensities > 5 mA/beam at $W^{\pm}$ energies.

Each of the 12 additional RF units thus comprises two high-power klystrons and circulators, one 100 kV, 40 A a.c./d.c. power converter with a high voltage interface, a waveguide system for the RF power distribution, 16 sc cavities housed in four cryostats and all associated electronics and interlock systems. All the equipment mentioned is located in the LEP tunnel with the exception of the HV power converter which is installed at the surface. The HV interface which is the subject of this report is housed in a fireproof bunker in the LEP tunnel adjacent to the two klystrons to be powered. It comprises a HV commutator switch, a smoothing capacitor, a horizontally mounted thyratron crowbar system and two hard tube modulators which include HV resistors and insulation transformers. For reasons of HV insulation and/or cooling all HV interface components with the exception of the smoothing capacitor are immersed in oil.

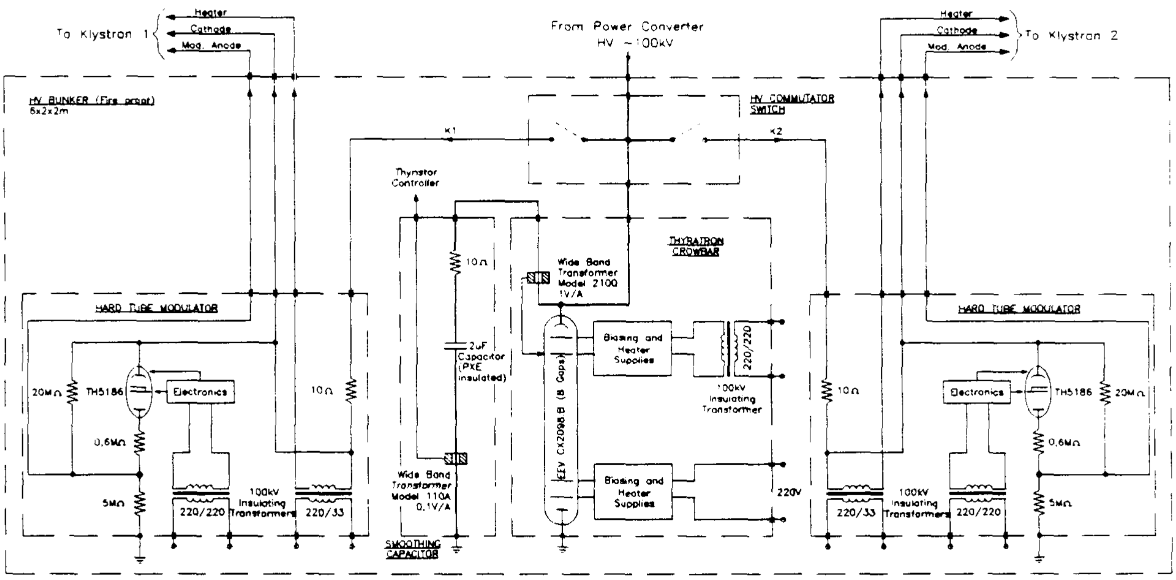

FIG 1 : HV INTERFACE FOR A LEPII/RF UNIT (simplified)

2. COMMUTATOR

Under normal operation conditions the HV is supplied to both klystrons of a unit by means of the HV commutator. In the case of a major klystron failure, however, the damaged klystron can be isolated from the HV power converter and operation can be continued with the other one. As can be seen in Fig. 1 the crowbar thyratron and the smoothing capacitor always remain connected to the HV power supply, independent of the commutator's operation mode.

3. SMOOTHING CAPACITOR

The purpose of the 2 μF/100 kV capacitor is to limit the ripple on the HV under all klystron operation conditions to ≤ 1% and thus to keep the amplitude and phase ripple of the klystron RF output signal within acceptable values. The insulating material of the capacitor is paper, impregnated with synthetic PXE oil.

In series with the high voltage lead of the capacitor a 10 Ω resistor, made of carbon-ceramic disks is mounted in order to limit the maximum capacitor discharge current to 10,000 A. In the low-voltage lead a wide-band current transformer is inserted, the output of which is connected to the thyristor controller at the input of the HV power converter. In the case of a discharge current ≥ 500 A the output voltage of the power converter is set to zero within 10 ms by means of the fast signal from this transformer.

4. THYRATRON CROWBAR

At an early stage of the construction of the LEP RF system it was decided that the high power klystrons would be protected against internal HV breakdowns by means of a thyratron crowbar rather than ignitron or spark-gap ones [2]. In the case of an arc occurring inside a klystron, due to the high d.c. operating voltage, the high voltage must be removed from the klystron within a few microseconds in order to avoid damage which could result in such a reduction of its HV holding capability and/or increase of its modulation anode current that the tube has to be replaced. The diversion of the HV energy is achieved by triggering the deuterium-filled thyratron which then becomes conducting and acts as a short-circuit to the HV power supply. Due to the relatively long cable between HV power converter and crowbar circuit ringing is likely to be caused by the sudden short-circuiting of the high voltage. Therefore, a double-ended thyratron, which is able to conduct current in either direction was chosen. It remains conducting until virtually all stored energy and that from the follow-on short circuit current is dissipated. No multipulse triggering is required since the period of the ringing frequency is short compared to the deionisation time of the deuterium gas in the thyratron.

The high operating voltage of the LEP klystrons (up to 100 kV) necessitates the use of multigap thyratrons and, for reasons of reliability, the only available eight-gap thyratron had been selected: the model CX 2098B made by EEV. The maximum voltage across each gap is thus 12.5 kV which is half the specified value and, therefore, voltage breakdowns should not occur or if so very rarely.

As shown in Fig. 2, the heaters for both cathodes and reservoirs are all powered via a mains stabilizer and two transformers. The transformer which supplies 220 V to the high voltage end of the thyratron is 100 kV-insulated and for this purpose located inside the crowbar oiltank. Also derived from the secondary of each transformer are the grid 1 and 2 d.c. biasing voltages of +100 and -150 V respectively via cascaded diode/capacitor circuits. The total power requirement of the thyratron is about 600 W only, mainly dissipated in its heaters, and by forced air cooling of the tank the oil temperature is kept below 40°C.

By means of the positive voltage of +100 V applied to grid 1 at both ends the cathode/grid spaces are kept ionized and currents, adjusted by series resistors to about 30 mA each, are drawn when the cathodes and reservoirs are heated correctly. These currents are therefore used as an indication for the state of readiness of the thyratron to act as a rapid HV protection device. Their values are measured and incorporated in the interlock system, the current value from the grid at the high voltage end via an optical link (see Fig. 2).

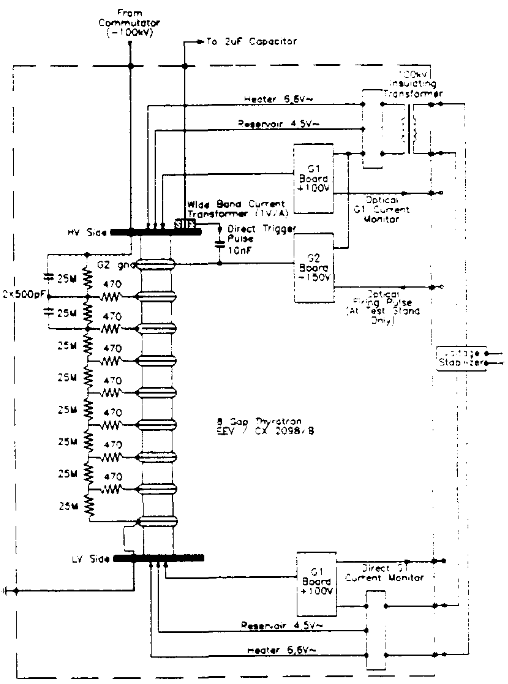

FIG 2 · CROWBAR THYRATRON

In order not to affect the maximum hold-off d.c. voltage of the thyratron when grid 1 is positively primed with respect to the cathode, a negative biasing voltage must be applied to grid 2 at the high voltage end. The thyratron switching action is exclusively controlled by means of grid 2 to which a positive voltage pulse is applied. This trigger signal is derived from a wide-band current transformer which is inserted in the HV line between the 2 μF capacitor and thyratron. It is housed in the crowbar oil tank close to the thyratron and its secondary, which generates 1 V per 1 A discharge current, is connected to grid 2 via a short cable and a ceramic capacitor.

Thyratron firing is insured at discharge currents ≥ 400 A and at operating voltages between 25 and 100 kV.

The upper trace in Fig. 3 shows the discharge current signal through the thyratron and the lower one the signal of the wide-band transformer inserted in the capacitor's low voltage lead. It can be seen that the current through the thyratron reaches its maximum in less than 2 µs after the onset of the capacitor discharge.

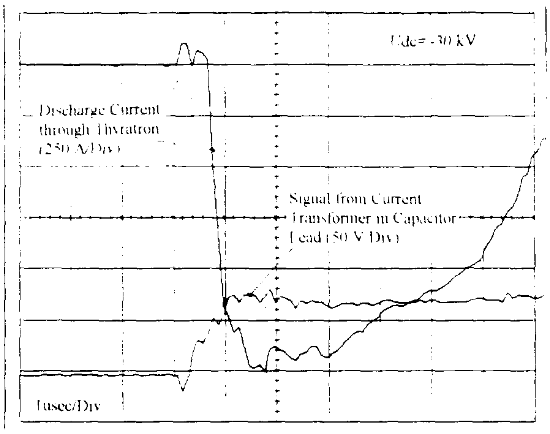

Fig. 3 Discharge Current through Thyratron

The signal derived from the capacitor discharge current and detected by the wide-band transformer is the only one which is used as crowbar trigger. Since the trigger circuit only consists of this transformer which is located inside the crowbar tank and thus well shielded against all electrical transient signals a high reliability of the crowbar system is achieved.

At the crowbar test stand, however, where after its assembly each crowbar is tested, an electronic trigger circuit is used which makes it possible to trigger the thyratron manually from outside the HV cage via an optical link. The same trigger circuit is used at the crowbar of the klystron test stand. Here, the klystrons undergo their acceptance test including a 100-hour run at rated output power. Usually when they arrive at CERN they have not accumulated many operating hours at rated output power and frequent HV discharges are observed. Besides the wide-band transformer signal three more trigger signals are therefore fed to the thyratron. A trigger signal is supplied to the thyratron grid when

a) the klystron current exceeds 22 A (the nominal current at rated output power is 20 A),
b) a fast increase of the klystron current of at least 6 A occurs and
c) the vacuum pump leak current exceeds 100 µA.

At the 16 klystron stands of the LEP I RF system, at which so far a total of about 320 000 HV operating hous have been accumulated, no klystron has been damaged due to a high voltage failure.

5. MODULATOR

Each LEP klystron is equipped with a modulation anode. Its voltage with respect to the cathode determines the intensity of the electron beam departing from the cathode. At nominal cathode operating voltage the beam current can be varied by means of the modulation anode voltage between 2.5 and 20 A, resulting in an RF output power variation from 1 to 1300 kW. The interception of beam current by the modulation anode is normally ≤ 1 mA within this range of operation. For reasons of reliability the output power of the two klystrons of an RF unit must be individually controllable. Therefore each klystron is equipped with a modulator.

The modulator comprises mainly HV power resistors and the HV tetrode TH 5186. Its two grids have been short-circuited and the tube acts thus as a triode, requiring only one grid biasing supply. The function of the tube is that of a variable high voltage resistor. The divider resistors R_1, R_2 and R_3 determine the maximum and minimum voltages the modulator can supply to the modulation anode. The tetrode must then present either a virtually infinitive or a very small resistor value.

By means of a variable grid supply which is controlled via an optical link the internal impedance of the tube can be varied between these two extremes within half a second. The new divider resistors permit the modulation anode voltage to be ramped to about 80% of the klystron operating voltage. All klystrons with a gun perveance ≥ 1.5 µp are thus able to supply a maximum RF output power of 1000 kW when operated at 77 kV. This is to be compared with an operating voltage of 88 kV required in the LEPI RF system for the same klystron output power.

Beside the tetrode and the HV divider resistors two 100 kV insulating transformers and a 10 Ω carbon-ceramic resistor are housed in the modulator oil tank. One of the insulating transformers provides the operating voltage for the cathode heater of the klystron and the other supplies the voltage for the heater and grid electronics of the tetrode. The 10 Ω ceramic resistor is inserted in the high voltage line in series to the klystron and serves as an energy limiter in the case of an arc in the latter.

During operation a total maximum power of 5 kW is dissipated in the 10 Ω resistor, in the tetrode's heater and in its anode resistor (5 MΩ). In order to keep the oil temperature below 50°C the oil of the modulator tank is pumped through a heat exchanger and cooled there by demineralized water, available in the HV bunkers.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

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