THE 150 KJ CAPACITOR BANK FOR THE MAGNETIC HORN

by

M. Giesch and S. van der Meer
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SUMMARY

The construction and operation of the pulsed power supply of the magnetic horn, a 150 kJ capacitor bank is described below. It has worked satisfactorily for more than 3 million CPS cycles during the CERN Neutrino Experiment.

2. BASIC CIRCUIT AND PARAMETERS

A peak current of 300 kA is required for the operation of the magnetic horn (1). The current has to be fairly constant for at least 2 μs which is the duration of the fast ejected proton beam of the CPS. In view of the construction of the horn only a pulsed current could be used. Therefore a damped oscillatory type capacitor discharge circuit was chosen. The more efficient crowbar circuit could not be used, because the horn could be damaged, by overheating in case of a failure of the crowbar ignitron.

The parameters of the capacitor bank are as follows:

- Capacitance 2227 μF
- Charging voltage 11.6 kV
- Total resistance 25 mΩ

With the total inductance of the circuit of about 1 μH one has:

- Peak current 300 kA
- Resonance frequency 3 kc
- Voltage reversal on capacitors 20 o/o

The discharge circuit is split into 8 parallel sections (Fig. 1). Each of these sections has a stored energy of about 20 kJ and gives a discharge current of about 37 kA amplitude. This arrangement has several advantages:

a) in case of a short circuit in either capacitors or their connection leads only the energy of this section is released, thus avoiding a serious damage of one or several other components;
b) the peak current of each section is low enough to be switched by a commercially available ignitron which increases the reliability of the circuit;

c) the mechanical construction is simplified.

Fig. 2 shows the capacitor bank installation; Fig. 3 is a cross-sectional view of one section of the capacitor bank, showing the arrangement of the main components.

2. CAPACITOR BANK COMPONENTS

2.1 Capacitors

The capacitors, designed for pulsed application are of the metallized paper type. They consist of units of 17.4 μF; 16 capacitors are grouped in each section. The failure rate during the first 1 million discharges was around 5 a/o possibly because of a too high ambient temperature. Once sufficient ventilation was provided the failure rate was negligible.

2.2 Ignitrons

The ignitrons are of the BK 178 type, delivered by A.E.I. They are constructed for a voltage of 20 kV and can switch a current of up to 40 kA amplitude. With the trigger supply used the jitter was found to be less than 200 ns, the firing delay is some μs. No effort was made to reduce these times, although this might well be possible. The inductance of the tube mounted in a coaxial housing was measured to be 250 - 300 nH. A stable operation (reduced prefiring) is obtained when the cooling water temperature is kept around ambient temperature. Before starting operation the anodes should be heated in order to remove condensed mercury from the anode. The lifetime of the ignitrons obtained in this particular circuit is of the order of 500'000 pulses at a repetition rate of one pulse per two or three seconds. This, however, is an average value, the variation between different tubes are large. Some might fail already after 100'000 pulses while others last for 1 to 2 million pulses. The failure is due to an increasing rate of prefiring. They are usually replaced when the prefiring rate exceeds one or two per minute.
2.3 Damping Resistor

The special feature about the damping resistor is its low inductance design. The resistance elements are made from stainless steel bands 0.4 and 0.5 mm thick and 150 mm large. They are folded into several layers and clamped between copper plates (Fig. 4). Sheets of mylar between the layers of stainless steel and the copper plates provide electrical insulation. There is one damping resistor of 90 m\( \Omega \) in each section. The power dissipation per pulse is about 12 kJ. It is water cooled through tubes soldered around the copper plates.

2.4 Cables

The connection between capacitor bank and horn is made by means of two low inductance cables per section. Their inductance and resistance are 0.04 \( \mu \)H/m and 1.5 m\( \Omega \)/m respectively. A schematic drawing of the connectors is given in Fig. 5, which shows also the principle of the insulation of horn flange and capacitor bank bus bars.

2.5 Polarity Changer

Originally the polarity of the horn current was changed directly on the horn flange by reconnecting the cables. The operation took rather a long time and moreover was not very convenient because of the high radiation level around the horn. Therefore a separate polarity changer was built which could be placed well away from the radioactive zone around the horn. It consists essentially of 5 plates (Fig. 6). Ingoing cables are connected to plate 2 and 4, outgoing cables to plate 3 and 5. By connecting either plate 2 with 3 and 4 with 5 or plate 1 with 2 and 3 with 4 the polarity can be reversed. The connections are made by means of copper blocks which are rigidly bolted between the slots of the corresponding plates. For changing the polarity, copper blocks and p.v.c. insulating blocks are interchanged.

2.6 Charging Supply

The 240 kVA charging supply has 8 separate sets of silicon rectifiers, so that each section of the capacitor bank is independent from the others. The charging current is constant during the time of charging. It is regulated PS/5422
by transducers on the low voltage side. The voltage can be regulated in steps of 500 V up to a maximum of 12 kV. It is constant within ± 0.4 o/o. The minimum charging time for the whole capacitor bank is 2 seconds.

2.7. Controls

The discharge current is measured by means of a mutual inductance on the earth side of each section of the capacitor bank, (see Fig. 3 and 7). The current passing through the bolt induces a signal in the coil, which is after being integrated with an R-C circuit, proportional to the current pulse. The coil is a silver-plated plexiglass tube with ten turns cut into the silver layer. The accuracy of measuring is around 2 o/o.

A Logic circuit designed by G. Pluym (4) checks the operation of the ignitrons. It gives an indication when an igniton prefires (i.e. ignites without a trigger pulse) and when an igniton does not fire. The principle of the circuit diagram for one igniton is shown in Fig. 8. The pulse from a pick-up coil, placed near the anode lead of each igniton (Fig. 3) and the trigger pulse are used to set a flip flop by an Or gate and reset it by an And gate. During normal operations both pulses are present, the flip flop stays in its rest position. When the igniton does not fire (absence of igniton pulse) the first flip flop is set and operates a lamp, connected to the flip flop via an emitter follower. When the igniton prefires (absence of a trigger pulse) first and second flip flop are set. The first operates again the lamp, the second operates a counter and a relay P, which interrupts the charging. In case an igniton does not extinguish after the discharge 8 times the normal charging current is flowing through this igniton. When this happens a relay, placed in the charging lead sets the second flip flop, thereby interrupting the charging cycle. Charging is automatically resumed after the next trigger pulse.

To detect a breakdown in the discharge circuit, a circuit, as shown in Fig. 9, is used for each section.
The pulse shaper (PS 1) is used as a Schmitt-trigger. When the discharge current exceeds its nominal value at nominal charging voltage by 5 - 10 o/o the charging supply is switched off. When a prefire occurs in one section the discharge current of this section is about 15 o/o higher than during normal operation. To prevent a short circuit indication a contact of relay F from Fig. 7 is used to reset the flip flop before the charging supply is switched off.

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Fig. 2  Front View of the Capacitor Bank
Fig. 3 Cross-section of Capacitor Bank
Fig. 4 Damping Resistor

- Copper plate 990 x 160 x 6
- Mylar sheet 0.3mm
- Stainless steel band 0.4mm

Point C

Point D
Fig. 7 Mutual Inductance
**Fig. 8 Ignitron Fault Indication**

**FF1** Flip-Flop Philips B8 92000

**2.EF1** Twin Emitter Follower " B8 94001

**2.EF2** " " " " B8 94003

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**Trigger Pulse**

**Pick-up Pulse from Ignitron**

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Relay F

Counter

Input from Cap. Bank

To Charg. Supply
PS1  Pulse Shaper  Philips  B8 95000
FF1  Flip-Flop  "  B8 92000
EF1  Emitter Follower  "  B8 94000

Fig. 9  Short Circuit Interlock