KICKING PROTONS, FAST AND CHEAP

A. Brückner
CERN, Geneva, Switzerland

Introduction

The CERN 800 MeV PS Booster with four parallel rings needs an extensive kicker magnet system for injection (IK) into, and ejection (EK) from each ring, for the recombination (RK) of the four beams into one single beam and for injection into the CPS (PS IK).

The requirements on these kicker systems are high reliability, low jitter, fast rise or fall time, flat top uniformity within ±2%/o, easy operation, control and service.

Main Parameters of Kicker Magnets

<table>
<thead>
<tr>
<th>System</th>
<th>IK</th>
<th>RK</th>
<th>PK</th>
<th>PS IK</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of identical systems</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Aperture (mm)</td>
<td>70 - 120</td>
<td>70 - 115</td>
<td>55 - 110</td>
<td>54 - 190</td>
</tr>
<tr>
<td>Magnet length (m)</td>
<td>0.95</td>
<td>1.95</td>
<td>1.60</td>
<td>0.80</td>
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<tr>
<td>Integrated field (Tm)</td>
<td>0.067</td>
<td>0.047</td>
<td>0.037</td>
<td>0.018</td>
</tr>
<tr>
<td>Deflection angle (mrad) at energy (MeV)</td>
<td>10</td>
<td>6</td>
<td>3.7</td>
<td>3.7</td>
</tr>
<tr>
<td>Rise time (ns)</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Fall time (ns)</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Magnet voltage (kV)</td>
<td>75</td>
<td>50</td>
<td>50</td>
<td>30</td>
</tr>
<tr>
<td>BPM voltage (kV)</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>60</td>
</tr>
<tr>
<td>System current (kA)</td>
<td>0.6</td>
<td>4.8</td>
<td>4.8</td>
<td>3</td>
</tr>
</tbody>
</table>

Special Aspects of Pulse Generators

For all main switch applications, hydrogen thyatrons (CX1154) were used to avoid pressurized spark gaps; their application posed several problems such as:

a) Current rise limited to approx. 100 A/μs per tube affecting either the economical use of the tube or the fast rise time.

b) Self-triggering at fast rising anode voltages, due to the anode-grid capacitance, a difficulty encountered in all tail-clipping applications.

c) Voltage creeping in for a time of 0.5 μs during switching, as the anode-cathode voltage decreases from initially 1.5 kV to about 100 V after 0.5 μs. This effect deteriorates the pulse flat top quality.

d) An anode delay time drift due to reservoir voltage variations of more than 50 ns over the lifetime of the tube affecting the triggering precision.

Satisfactory performance has nevertheless been obtained due to the following technical solutions:

a) By using a saturating ferrite loaded pulse steepening line, a 30 kV - 5 kA step pulse with 100 ns rise-time could be shortened to 5 ns.

b) An anode grid coupling opposing to the capacitive grid current:

\[ I_{ga} = C_{ga} \cdot \frac{dU_a}{dt} \]

the current:

\[ I_2 = -r \cdot C \cdot \frac{dU}{dt} \]

For a 40 kV-CX1154 tube, this correction is satisfactory up to a 35 kV-pulse rising within 50 ns.

The capacitance \( C \), of the same order of magnitude as \( C_{ga} \), represents a small additional charge only for the grid driving circuit.

c) An additional polarization of the anode, produced by an auxiliary supply and applied through a capacitor in parallel with a set of semiconductor diodes, compensates for the initial anode-cathode voltage drop immediately after firing the thyatron.
The thyatron "voltage drop" is now furnished by the charged capacitor C, matched to the thyatron characteristics. After full ionization time of 0.5 μs the current changes over from the capacitor C to the parallel diodes; stationary conditions are then reached.

0.5 μs/div.

before after correction

d) Drift stabilizing feedback circuit

1. RF signal counter
2. T10 preset delay
3. Voltage controlled delay
4. HV pulse generator
5. Kicker magnet
6. Triggering
7. Analog coincidence detector
8. Correction signal
9. Manual delay

The RF signal train is sent to a double preset counter which produces pulse 1 for triggering the pulse generator and pulse 2 to be compared with the effective kick-time. Pulse 1 passes through a voltage controlled delay and triggers the pulse generator. The effective leading edge of the kick is picked up and fed back into an analog coincidence detector where it should enter simultaneously with pulse 2. Any difference in time is detected with a maximum correction of ± 5 ns per cycle, sent in a digital form to the memory and added to its actual value.

The level of the memory controls linearly the delay of pulse 1, applied to the next cycle. The manual delay of pulse 2 allows the operator to correct the kick.

Self-triggering, tail biting series spark gaps

This device prevents inverse and destructive voltages to reach switching HV thyatrons in circuits with identicalPFN and magnet voltages.

Eight series 2 mm gaps are graduated with RC-elements in such a way that for slow phenomena (> 5 ms) the voltage is distributed uniformly over the 8 gaps; at fast discharges (< 1 μs) the graduation follows a geometrical series so that one gap is stressed with 80 % of the fast rising voltage and the gaps fire one after the other. The gaps are air-ventilated only. Without readjusting the gaps, a wide operating voltage range from 15 kV to 40 kV is covered. The electrodes are aluminium made so that sparking products are insulators which do not disturb normal operation. Cleaning is not necessary.