KICKERS AND SEPTA AT THE PS COMPLEX, CERN

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Paper presented at the Magnet Workshop, TRIUMF, Vancouver, B.C., Canada
3rd - 5th October, 1988

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ABSTRACT

The story of kickers and septa of the PS complex started in May 1963 when the first fast extracted beam was obtained from the 20 GeV synchrotron. Since those early days of the plunging small aperture kicker and its associated bending magnet there has been a constant evolution and increase in complexity as ring after ring has been added and the particle species widened. Today the complex has 20 kicker systems containing nearly 100 magnet modules and requiring no fewer than 200 thytratrons for PPN switching. The septum magnet population, whether d.c. or pulsed, approaches 40.

The design of the kicker systems has been influenced by the shortage of straight section length and the relatively short inter-bunch interval of all the PS machines. Typically needed field rise and fall times are 30 - 100 ns and the impedance levels are 8 - 30 ohms. The paper reviews the current family of kickers, including their pulse generators, tries to justify the design options which were taken and relates the positive and negative aspects of operational experience extending over 15 years in certain cases. A similar but brief account of the septa is also given, but limited to magnet considerations.

INTRODUCTION

Kicker and septum magnet systems have become a way of life in the PS complex, accepted as mundane pieces of electrotechnical equipment and expected to have the same reliability as any other accelerator component. To a large extent this latter wish has been met, which is not to say that kickers and septa do not fail but rather that they do not fail too often. When misfortune strikes the damage can often be spectacular, which serves to remind that much of the design is often at the limits of the technically possible.

Over the past 25 years lessons have been learnt from the prolonged and arduous operation to which some of the systems have been subjected. These, together with the now available powerful and user friendly calculation programs, have allowed a continuous evolution in design such that it has become much easier today to build reliable systems of predictable performance. This is not to say that at the outset the designer is still often faced with a range of daunting questions typical of which are what voltage/impedance level to choose, what magnetic circuit (if any) to use, whether to place the kicker in machine vacuum or not and in the case of septa, whether to use d.c. or pulsed. To all these questions there is no simple or single answer because they take on a significance which depends very much on the machine environment. Suffice to say that at the PS we have striven to keep the $Z$ of our fastest kickers as high as possible (typically 25 - 30 Ω) and never constructed a travelling wave kicker below 12.5 Ω. We have also consistently opted for placing our kickers in machine vacuum, even when this has meant putting hundreds of kilograms of
ferrite in the ultra high vacuum systems of the AA and LEAR. We have tended to choose two operating voltage levels, 80 kV and 40 kV, for charging our pulse generators, the higher voltage being reserved for situations where we are desperately short of straight section length and where kick is more important than cost. All our generators have used pulsed resonant charging because we quickly discovered the enormous benefit that this type of rapid PFN charging had on the rise time of our thyatron switches. The magnetic circuits of our kickers have always been built with nickel zinc ferrites but we have used both C-core and window frame construction, the former for travelling wave magnets and the latter for lumped inductance magnets. On the septum front the uniformity of approach is even less obvious, the only two rules being that septa should not be placed in the UHV machines (where external to vacuum multturn d.c. septa are employed) and that the high repetition rate septa for the lepton programme should be d.c.. Otherwise we have a mixture of pulsed and d.c. septa installed in machine vacuum.

Hindsight always permits the redesign and improvement of everything that has ever been made and the kicker and septum systems of the PS are no exception. However, it is a fact that only one of the modern (post 1970) systems has had to be replaced because of performance weakness; all others are substantially still in the form in which they were created. The fault statistics for 1987, the last available, show that injection and ejection systems, principally but not exclusively kickers and septa, were responsible for only 6% of the total fault time (itself only 6% of the scheduled running time). This is not a bad record when considering how close to the limit some of the equipment is operated.

KICKER SYSTEM DESIGN CONSIDERATIONS

Magnets

Kicker magnets, by the very nature of their task, are fast magnets having only single turn excitation. Multi-turn magnets are not a design option where rise-times below a few hundreds of nanoseconds are concerned.

Design options do present themselves when it comes to choosing

a) environment - installed in machine vacuum
   - external to machine vacuum
b) type - transmission line of specific $Z_0$
   - lumped inductance
c) aperture - window frame
   - closed C-core
   - open C-core
d) termination - matched
   - short-circuited.

The advantage of installing kickers in machine vacuum is that aperture dimensions are minimised, reducing both voltage and current for a given kick and rise time. Metallised ceramic vacuum chambers for containment of machine vacuum and provision of image current path are
avoided. However the in vacuum magnet is costly, both in terms of its
collection and its vacuum tank and pumping. More worrying, particu-
larly in machines having short high density bunches, is the coupling
impedance which the kicker presents to the beam. Machine vacuum is a
reliable dielectric and PS experience has shown that even with the
very large capacitor plate surfaces involved (several tens of $m^2$)
stresses of 70 kV/cm can be safely adopted without running into
voltage conditioning problems. Externally mounted magnets leave open
the choice of dielectric; compact dimensions can be obtained for
transmission line magnets built with high ε solid or liquid dielec-
tric. Breakdown of these dielectrics, if it occurs, presents greater
risk than a vacuum flashover — the solid dielectric is likely to
suffer fatal failure on the first breakdown and the liquid dielectric,
even if self healing, can propagate shock waves which can shatter the
ceramic vacuum chamber. Perhaps through lack of courage the PS has
opted for the "in vacuum" solution.

The decision between a transmission line magnet of specific $Z_0$
and a lumped inductance magnet is mainly a question of rise time. The
latter has reached only 0.1% of its kick strength when the former is
fully excited; this disadvantage can be partially overcome by adding a
shunt capacitor to the lumped magnet which steepens the final stage of
the rise, provoking some overshoot if the capacitor is above the
critical value. How valid is this approach depends on the degree of
overshoot which is acceptable and on the kick limits defining the rise
time. Lump inductance magnets, unlike transmission line ones, are
traditionally installed after their terminator, in which position they
are only subject to voltage during the rise and fall of the current
pulse. This helps their voltage hold-off, particularly for long pulses
but exposes them to bi-polar voltage. Another consequence of lumped
inductance magnets is that they present a transient mismatch to the
pulse generator, which results in post-pulse reflections at the magnet
if specific measures are not taken to absorb them at the remote end of
the PFN. The PS policy has been to use lumped inductance magnets only
where the permissible rise time has exceeded 150 ns.

The choice of $Z_0$ for a transmission line magnet is a question of
the available straight section length. In general the highest im-
dedence (say up to 50 Ω) should be used consistent with the length
available and the chosen level of PFN charging voltage, which in turn
determines the number of parallel modules needed. The higher the $Z_0$
the lower the switched current and the higher the magnet cut-off
frequency. Both are particularly important elements in obtaining
clean, fast, low flat-top and post-pulse ripple kick pulses. The cut
off frequency $f_c$ (Fig. 1) depends on the cell inductance $L$ and capa-
citance $C$ and also on the equivalent series inductance $L_s$ of the capa-
citor, due in part to the physical inductance in the capacitor branch
and in part representing the mutual coupling between cells. Whilst in
theory the fall of $f_c$ with reducing $Z_0$ can be arrested by reducing the
cell dimensions, in practice this leads to wafer thin capacitor plates
and an impossible mechanical construction as two vacuum gaps must
still be maintained per cell. Typical $f_c$ values as a function of $Z_0$
for the type of construction used in the PS are listed in Fig. 1.

Aperture considerations are very much influenced by whether or not
a high μ magnetic circuit is used. PS practice is always to use a
magnetic circuit because failure to do so considerably increases the effective vertical aperture, lowering in consequence the $Z_0$ and making control of the field quality in the useful aperture more difficult. Having decided on a magnetic circuit it remains to choose its form and the specific material. Both window frame and C-core sections are used in the PS, the former restricted to lumped inductance magnets and the latter always adopted for travelling wave designs and occasionally for the others. C-core configurations usually have the aperture closed by the return conductor but this is not possible where the beam has to be swept into or out of the aperture by RF gymnastics. In this case the return conductor is located above and below the aperture or even placed around the backleg but with a 10% or so penalty in inductance. The magnetic material is invariably nickel zinc ferrite, but this comes in a very wide variety of grades with different magnetic and outgassing properties. Slowly acquired experience in the PS has shown that for the current pulse rise times which we employ (in turn limited by what we can get out of the thyratron switches) and typically no faster than 17 ns (10-90%), ferrite with a $\mu$ of around 1000 can track the excitation pulse with a negligible delay of a nanosecond or so. Grades which have found favour are Indiana H2, Philips BC11 and Ceramic Magnetics CMD 5005. The one most extensively used is that of Philips, and exclusively so for the UHV machines. As a matter of routine all ferrite (fully machined) is now vacuum fired at 1000°C prior to assembly into magnets. The as installed outgassing rate is $10^{-12}$ Torr litre/sec/cm$^2$. Low $H_0$ is required to minimize the remanent field, typically 0.2 Oersteds for $B_{max}$ of 3k Gauss. This holds the $J_B$ $dl$ of most of our kicker systems below 0.5 Gauss-meter.

The final option, not so much of magnet design but rather of system configuration, is whether or not the magnet should be terminated or short circuit. Short-circuiting is the ultimate measure for dealing with a space shortage. It allows the same kick with the same rise time to be obtained from half the space or alternatively the $Z_0$ to be doubled in the same space. The price to pay is in pulse generator complexity because double endedPFN switching is required, one switch having to be bi-directional. The inability of the switches to rapidly transmit the magnet generated current wave usually results in some small post-pulse reflections, rendering this approach more, attractive for ejection than injection schemes. Nevertheless it has been successfully applied to both in the antiproton collector of the PS, space shortage obliging.
Pulse Generators

Design considerations for pulse generators fall broadly into two classes: configuration and components. The configuration possibilities often depend on the magnet options and the kick gymnastics required.

The simplest configuration is that of a cable PFN, charged to double the needed pulse voltage, switched into a terminated transmission line magnet. The switch is fully floating; if an ordinary thyratron it can be damaged by inverse current from a load short. A variant, frequently used at the PS, is to add a remote end terminator and switch which has the advantages of permitting pulse length control (partial extraction), improving the fall-time (by pre-distortion if necessary) and limiting switch damage from a load short. A lesser alternative is to double the PFN length and connect a magnet load to each end. Cable PFN's furnish ripple free pulses but low attenuation is essential if droop and "cable tail" are to be within acceptable limits for long pulses. Attenuation is adversely affected if semiconductors are added at the dielectric boundaries to improve voltage withstand. The PS solution has been to use SF6 pressurised PE tape cables without semi-conductors for the 80 kV systems. Typically droop is limited to 1% on a 2.7 μs 26 Ω pulse, with no HV failure in 10 years service.

The cable PFN ceases to be attractive for pulses exceeding about 3 μs on account of cost, bulk and the droop/tail problems. The alternative is the lumped element PFN with R-L-C head cell to improve the initial rise. So equipped the lumped element line can equal the cable for rise but the fall can never be made fast enough for injection applications without recourse to a shorting clipper switch on the kicker transmission. Such a clipper creates multiple reflections within the lumped element line which in turn may require a third switch and terminator at the remote end for their absorption. Thus whilst for ejection applications a lumped element line with single switch is perfectly satisfactory, at least two if not three switches are needed when the task is injection. Clipper switch rise time needs special care because it has to handle twice the magnet current. A few examples of both one and three switch lumped element PFN's exist in the PS, reserved for low Z₀ (down to 8 Ω) and long pulse (up to 24 μs) applications.

An alternative form of energy store is the Bläulein arrangement which has the virtue of generating pulses of voltage equal to the PFN charge voltage. However it requires cables of half the Z₀ of the load and the closing switch has to handle twice the magnet current. It is a current against voltage trade-off with respect to the simple cable PFN. It is not used at the PS because of the increased thyratron switching time which would result.

Some of the advantages of the Bläulein system but without its disadvantages can be obtained by incorporating the transmission line magnet as part of a cable PFN with a shorting switch at one end and a terminator and second switch at the other. The rise time is that due to a single magnet propagation and the pulse voltage is the PFN charge voltage. The fall time cannot be shorter than two magnet propagations. An additional penalty is that the magnet must withstand the PFN charge
voltage prior to the pulse and suffer partial voltage inversion during it. This arrangement is particularly attractive where space is limited and where only rise time is important. It is used in the PS for the Booster extraction and recombination kickers.

Certain ejection schemes at the PS have required the generation of staircase waveforms and short interval pulse trains. These are not of interest for the KAON factory and will not be further discussed except to say that entirely satisfactory results in both cases can be obtained by the discharge of serially combined PFN’s and thyratron switches.

On the component side, principal attention has to be paid to the choice of high voltage switches, recharging power supplies and terminating resistors. Present-day practice, fully justified by results, is to use thyratron switching throughout. Care must be taken in tube selection, particularly in circuits prone to inverse current in often repeated fault conditions. Today there exists an extensive range of bi-directional thyratrons, either of the double cathode or hollow anode type, capable of safely handling inverse current. The small cost increase which they represent is often an excellent investment. Tube ratings need to be regarded with a certain conservatism, particularly the voltage rating of multistage tubes which have to be pushed to maximum dI/dt. PS experience is that in good housings with correctly designed circuitry and triggering an average dI/dt of 100 A/ns can be readily obtained and held between the 10 and 90% points, even for the 80 kV applications. As much as 150 A/ns is possible in 6.25 Ω circuits operating at 40 kV. Repetition rates of 100 Hz have shown no additional problems. Tube lifetime in our modestly (low Hz) rep. rated systems averages more than 20000 filament hours. Jitter is greatest on multi-stage tubes but still under 5 ns, including the triggering system. Slow drift is easily stabilised by suitable electronics. The most used tubes in the PS systems are the CX 1171 and its variants for the 80 kV systems and the CX 1154 and its variants for the 40 kV systems. Glass CX 1159 tubes are used up to 30 kV. Almost without exception the tubes are oil immersed, often forced cooled.

Power supplies are, without exception, of the pulsed resonant type permitting PFN recharge in a few ms. Fast recharging has a very favourable influence on the self firing frequency of thyratrons at any given reservoir setting and is a necessity if the previously quoted dI/dt values are to be obtained. The PS supplies use a step up transformer as the resonating inductor. Core bias, which influences recovery, is applied through a tertiary winding. HV diodes when fitted between transformer output and PFN, improve operational flexibility in decoupling the power supply and thyratron trigger timing. This is always done at the PS. The primary energy store is often a large electrolytic capacitor running at about 200 V.

Terminating resistors can be of the electrolytic or carbon mass type, the latter of disc or tubular form. At the PS we have standardised on the disc carbon mass type, oil immersed with forced oil cooling. Stability, particularly in a radiation environment, is not excellent and rebuilding of resistor stacks represents a major proportion of our maintenance effort. Probably the tubular type is more stable but contact problems are more severe. The ideal terminator is yet to be found.
PS KICKERS

Historical background

The first small aperture, hydraulically actuated kicker became operational in the PS ring in May 1963. It had an aperture of 5 x 3 cms and rise time fast enough to eject cleanly one bunch. Excitation was from either short or long spark gap switched lumped element lines, located inside the machine tunnel. It remained operational until 1968 when it was replaced by another plunging magnet of useful aperture 2.0 x 2.2 cms excited from remotely positioned lumped element lines with main, dump and clipper spark gaps for full control of pulse length. In 1974 this equipment was replaced by the present full aperture kicker system. During 1964-9 a single module push-pull excited (± 120 kV) full aperture device was developed. Its ferrite circuit, suitably impregnated with epoxy resin, formed part of the containment for machine vacuum and also furnished capacitance for the delay line magnet. Whilst it was successfully tested with beam it was abandoned in 1969 because it could not satisfy the tightening PS vacuum specification and was considered an oil hazard in the event of high voltage breakdown. At this point development started on the present PS full aperture kicker, from which most of the other kickers have since evolved.

Present situation

Table 1 lists the ratings of the present kicker population of the PS complex. Comment will be restricted to the oldest high voltage system which is the 12 module full aperture kicker of the PS ring. Commissioned in 1973, this kicker was used initially for multiple partial extractions for bubble chamber physics; in later times it has served as the ejection kicker for protons for p production and SPS fixed target physics, and most recently for leptons. It also reinjects p into the PS ring from the Accumulator. The kicker has a six shot per cycle capability with minimum interval of 30 ms. Both kick amplitude and duration can be freely varied from shot to shot. The pulse generator is a gas pressurised PFP cable with CX1171 switching at either end. Transmission distance between generators and magnets is 170 m, mainly in gas pressurised cable but with final connections in solid PE cable to facilitate maintenance. To date each module has pulsed well in excess of 10^8 times, the standard charge voltage being 80 kV. There have been no serious high voltage failures in the pulse generators and the magnet vacuum tanks have never been opened. Principal weaknesses have been the flexible coaxial cables for final connection of the transmission lines and terminator stability. Recharging power supplies using 315/1 step up transformers and 210 V electrolytic primary storage have been totally trouble-free.

PS SEPTA

Table 2 lists the ratings of the septa currently in use in the PS complex. The mixture is mainly of multiturn d.c. and single turn
pulsed magnets, with a predominance for "machine vacuum" installation despite the considerable gas load which results. Magnetic circuits are ferrite or laminated steel for the pulsed magnets; certain d.c.

Table 1. Ratings of present PS complex kickers.

<table>
<thead>
<tr>
<th>Machine</th>
<th>Application</th>
<th>Type and L (G)</th>
<th>Aperture w x h (in)</th>
<th>No. of Modules</th>
<th>Total (in) (Beam-m)</th>
<th>PTF Voltage (10^-2 V)</th>
<th>Kick (5-95%) Base (in) (m)</th>
<th>Flat top (in) (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Booster</td>
<td>Ejection</td>
<td>Delay line 25 G</td>
<td>115 x 77</td>
<td>4</td>
<td>400</td>
<td>40</td>
<td>55</td>
<td>35</td>
</tr>
<tr>
<td></td>
<td>Transfer</td>
<td>Delay line 32.5 G</td>
<td>70 x 115</td>
<td>2</td>
<td>557</td>
<td>40</td>
<td>52</td>
<td>54</td>
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<tr>
<td>PS Ring</td>
<td>Injection (a)</td>
<td>Delay line 33.0 G</td>
<td>150 x 52</td>
<td>2</td>
<td>304</td>
<td>80</td>
<td>70</td>
<td>30</td>
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<tr>
<td></td>
<td>Injection (b)</td>
<td>Delay line 15.7 G</td>
<td>124 x 74</td>
<td>1</td>
<td>283</td>
<td>80</td>
<td>70</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>Fast injection</td>
<td>Delay line 15 G</td>
<td>147 x 52</td>
<td>12</td>
<td>1800</td>
<td>80</td>
<td>70</td>
<td>55</td>
</tr>
<tr>
<td></td>
<td>Fast injection</td>
<td>Delay line 25 G</td>
<td>159 x 52</td>
<td>1</td>
<td>210</td>
<td>33</td>
<td>55</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Continuous Transfer</td>
<td>Delay line 25 G and 0.7 G</td>
<td>150 x 52</td>
<td>1 + 1</td>
<td>543</td>
<td>Up to</td>
<td>40</td>
<td>400</td>
</tr>
<tr>
<td>DITTE</td>
<td>Delay line 15 G</td>
<td>150 x 52</td>
<td>450</td>
<td>80</td>
<td>180</td>
<td>-</td>
<td>45</td>
<td>165</td>
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<tr>
<td>LEAR</td>
<td>Injection</td>
<td>Delay line 15.7 G</td>
<td>150 x 46</td>
<td>2</td>
<td>450</td>
<td>80</td>
<td>87</td>
<td>83</td>
</tr>
<tr>
<td></td>
<td>Injection</td>
<td>Delay line 15.7 G</td>
<td>150 x 46</td>
<td>1</td>
<td>120</td>
<td>33</td>
<td>86</td>
<td>83</td>
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<tr>
<td>Antiproton Rings</td>
<td>Collector</td>
<td>Delay line 15 G</td>
<td>140 x 72</td>
<td>2</td>
<td>2842</td>
<td>80</td>
<td>185</td>
<td>185</td>
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<tr>
<td></td>
<td>Collector</td>
<td>Delay line 15 G</td>
<td>140 x 72</td>
<td>2</td>
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<td>185</td>
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<td>Delay line 15 G</td>
<td>140 x 72</td>
<td>2</td>
<td>2842</td>
<td>80</td>
<td>185</td>
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<td>Collector</td>
<td>Delay line 15 G</td>
<td>140 x 72</td>
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<td>Delay line 15 G</td>
<td>140 x 72</td>
<td>2</td>
<td>2842</td>
<td>80</td>
<td>185</td>
<td>185</td>
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<tr>
<td></td>
<td>Collector</td>
<td>Delay line 15 G</td>
<td>140 x 72</td>
<td>2</td>
<td>2842</td>
<td>80</td>
<td>185</td>
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<tr>
<td></td>
<td>Collector</td>
<td>Delay line 15 G</td>
<td>140 x 72</td>
<td>2</td>
<td>2842</td>
<td>80</td>
<td>185</td>
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<tr>
<td></td>
<td>Collector</td>
<td>Delay line 15 G</td>
<td>140 x 72</td>
<td>2</td>
<td>2842</td>
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<tr>
<td></td>
<td>Collector</td>
<td>Delay line 15 G</td>
<td>140 x 72</td>
<td>2</td>
<td>2842</td>
<td>80</td>
<td>185</td>
<td>185</td>
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</tbody>
</table>

magnets use solid cores, others laminated, particularly for storage rings. Until about 5 years ago laminated circuits comprised epoxy glued stacks. Recent practice has been to use transil steel, an inorganic insulated material, in pressure held stacks which can be vacuum baked in situ up to 150°C. The ultimate outgassing of this newer conception is lower but bakeout is essential for reasonable pump down time.

Most PS septa have performed extremely well and the average service life of a magnet is probably around 10 years. The most significant difficulty has been blockage of d.c. septa by copper oxide deposits from the interaction of dissolved oxygen in the demineralised cooling water with their copper conductors. A solution has been found
by cooling the most dissipative d.c. septa with low oxygen (< 100 ppb) demineralised water. Typical current density and water velocity in these magnets are 70 A/mm² and 12 m/s respectively. There is only one recorded case of coil failure from cavitation, perhaps 3 or 4 from oxide blockage although prior to the introduction of low oxygen water.

Table 2. Ratings of present PS complex septa.

<table>
<thead>
<tr>
<th>Machine</th>
<th>Application</th>
<th>Type</th>
<th>No. in service</th>
<th>Bd (Tm)</th>
<th>Max. I (kA)</th>
<th>No. of turns</th>
<th>Length (mm)</th>
<th>Gap w x h (mm x mm)</th>
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<tr>
<td>Booster</td>
<td>Distributor</td>
<td>P.V.F</td>
<td>4</td>
<td>0.004</td>
<td>0.5</td>
<td>1</td>
<td>354</td>
<td>80 x 50</td>
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<tr>
<td></td>
<td>Injection</td>
<td>P.V.F</td>
<td>1</td>
<td>0.172</td>
<td>20</td>
<td>1</td>
<td>860</td>
<td>32 x 12</td>
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<td></td>
<td>P.V.T</td>
<td>2</td>
<td>0.138</td>
<td>15</td>
<td>1</td>
<td>1</td>
<td>850</td>
<td>32 x 12</td>
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<tr>
<td></td>
<td>P.V.F</td>
<td>4</td>
<td>0.071</td>
<td>4</td>
<td>1</td>
<td>710</td>
<td>60</td>
<td>40</td>
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<tr>
<td>Ejection</td>
<td>DC.V.SS</td>
<td>4</td>
<td>0.238</td>
<td>4</td>
<td>1</td>
<td>1170</td>
<td>60</td>
<td>24 x 5</td>
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<tr>
<td>Transfer</td>
<td>DC.V.SS</td>
<td>3</td>
<td>0.359</td>
<td>2.0</td>
<td>12</td>
<td>950</td>
<td>100 x 60</td>
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<tr>
<td></td>
<td>P.V.F</td>
<td>2</td>
<td>0.013</td>
<td>5.1</td>
<td>1</td>
<td>400</td>
<td>70</td>
<td>60</td>
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<td>PS Ring</td>
<td>Injection</td>
<td>DC.V.SS</td>
<td>1</td>
<td>0.25</td>
<td>1.8</td>
<td>12</td>
<td>700</td>
<td>100 x 60</td>
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<tr>
<td></td>
<td>Injection *</td>
<td>P.V.TS</td>
<td>1</td>
<td>0.588</td>
<td>13.9</td>
<td>1</td>
<td>400</td>
<td>70 x 10</td>
</tr>
<tr>
<td></td>
<td>Injection *</td>
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P = Pulsed  A = Air mounted  F = Ferrite  LS = Laminated steel
DC = Continuously powered  V = In machine vacuum  SS = Solid steel  TS =Transit steel

frequent rinsing with sulfamic acid was needed. All pulsed septa are operated at low repetition rate (< 1 Hz) and present no characteristic weaknesses although those with most water circuit joints within the vacuum envelope, a principle to be avoided if possible, have been least reliable.

CONCLUSION

The range, performance and reliability of the CERN PS septa and kickers may serve as encouragement for the kaon factory project. However the PS complex is a slow cycling facility.