Pulsed Electrostatic Kickers with Low Beam Impedance for AmPS

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Abstract

During 3-turn injection into AmPS, the Amsterdam Pulse Stretcher ring, two identical electrostatic kickers create a local vertical displacement of the closed orbit of the ring by a 2.75 mrad bend. Within 10 μs, the 1570 mm long parallel plates of the kickers are charged to + and -35 kV by a triode switch. The fast discharge of the plates, required at the end of the injection cycle of 2.1 μs, is achieved by using very fast thyratrons. A discharge time of less than 100 ns is shown in bench tests.

The synchronous discharge of the two kickers requires a timing error of less than 1 ns. Timing jitter is reduced by the improved stability of the thyratron adjustments.

The measured longitudinal broadband impedance $|Z/n|$ of the kicker is $(0.21 \pm 0.05)\ \Omega$.

1. INTRODUCTION

The AmPS ring aims at a 100% duty cycle operation by means of a slow extraction of injected electron beam pulses of 2.1 μs, as described by Luijckx et.al. [1]. The maximum beam energy is 900 MeV and the maximum current is 80 mA. Used as a storage ring, the maximum beam energy will be 1 GeV.

The two injection kickers in the ring have a symmetrical location with respect to the injection septum magnet [2], as is illustrated in Figure 1. The septum injects beam "off-axis" but parallel to the ring-axis. The first kicker (K1), downstream of the septum, bends the injected beam downward into the horizontal plane of the ring. Upstream of the septum, the second kicker (K2) bends the returning beam downwards to bring it "off-axis" again. Due to the horizontal betatron oscillation of the beam, characterized by a 120° phase shift per turn of the beam position, the injected beam passes the septum from aside at its first and second return. The first kicker directs both the injected and the returning beam back into the horizontal plane.

This scheme allows a 3-turn injection process for AmPS. Just before the third return of the injected beam the two kickers are switched off to avoid beam to hit the septum. The 3-turn injection efficiency is determined by the kicker falltime.

2. KICKER DESIGN REQUIREMENTS

2.1. Optical requirements

Maas [3,4] optimized the optics of the injection process. This resulted in a vertical bending angle of 2.75 mrad for both kickers. The total length of the kicker construction, located in between two ring quadrupoles, is restricted to 2120 mm. For ring operation, the beam stay clear requirements are 40 mm in the vertical direction and 80 mm in the horizontal direction.

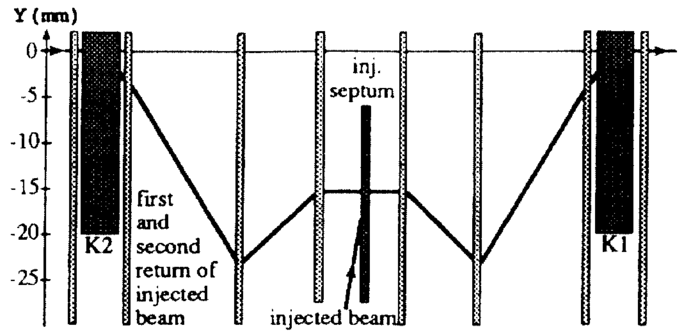

Figure 1 - Schematic layout of the AmPS 3-turn injection process using the kickers (K1,K2) and the injection septum.

In the multiturn injection process, the second kicker must be discharged 77.5 ns earlier than the first kicker. During the discharge, as characterized by the falltime, beam arriving at the kicker will be missteered in the vertical plane. To minimize an increase of the vertical emittance the two kickers must be discharged synchronously. The timing accuracy must be about 1% of the falltime, assuming a linear discharge.

In stretcher mode the time for slow extraction is at least 2.5 ms. The required maximum repetition rate for the kicker operation is 400 Hz.

Storage mode operation is sensitive for bunch lengthening effects. The longitudinal broadband impedance $|Z/n|$ of the kickers is required to be less than 1 Ω per kicker.

2.2. Pulse requirements

The 3-turn injection process requires the flattop length of the kicker pulse to be 2.1 μs. The risetime of the kicker pulse is allowed to be of the order of 10 μs. This is less than 1% of the minimum time for extraction.

To achieve almost complete 3-turn injection the falltime is required to be less than 10% of one turn revolution time. This restricts the falltime to 70 ns. The relative timing accuracy for the two kickers should be less than 1 ns.

2.3. Design principles

Both optical and pulse requirements are regarded to be more suitable for electrostatic than for magnetic kickers. Firstly, the required bending strength is small enough to be realized by an electrostatic deflection. Secondly, for a vertical bending of the kickers, the required large horizontal clearance allows the gap height for electrostatic deflection to be two times smaller than for magnetic deflection. Finally, because the risetime requirement is not critical, the AmPS kicker design can concentrate on the flattop and fast discharge of an electrostatic kicker.

Therefore; the principle design of the AmPS kicker is a parallel plate construction, in analogy to the kicker design of Figley [5]. Considering the pulse requirements, the plates are capacitively charged by a current source, the injected beam is deflected by an electrostatic field and the plates are discharged like a transmission line.

3. Kicker Construction Design

3.1. Design parameters

The combined fast switching of high currents and hold-off of high voltages to charge and discharge the kicker plates requires the use of electron tubes. To ensure a long life time of the tubes, the maximum lower and upper plate voltage is restricted to +35 kV and -35 kV respectively. This enables the use of the EEV B1510 triode as the charging switch and the EEV CX1154D thyratron as the discharging switch.

With regard to the vertical beam stay clear requirements the gap distance between the plates is determined as 40 mm. The maximum electric field strength is then 17.5 kV/cm. To create a bending angle of 2.75 mrad for the maximum beam energy of 1 GeV, the plate length is required to be 1570 mm. This is less than the limit of 2120 mm. For an ideal transmission line discharge the calculated minimum falltime is 10.5 ns.

3.2. Mechanical construction

For reasons of mechanical rigidity, the parallel plate kicker construction consists of standard U-profile aluminum beams of 150 mm width, 50 mm height and 10 mm thickness. The two plates are connected by ceramic bridges to withstand 70 kV. Stand-offs for 25 kV d.c. are used in the hanging construction between the upper plate and the kicker tank of Ø 253 mm, as shown in Figure 2. To minimize contributions to the $| Z / n |$, the change in beam pipe diameter from Ø 90 mm to Ø 253 mm is made by conical tapers. The taper angle is 20°.

The electrical feedthroughs for the two plates are located aside of the kicker tank to create a short electrical length.

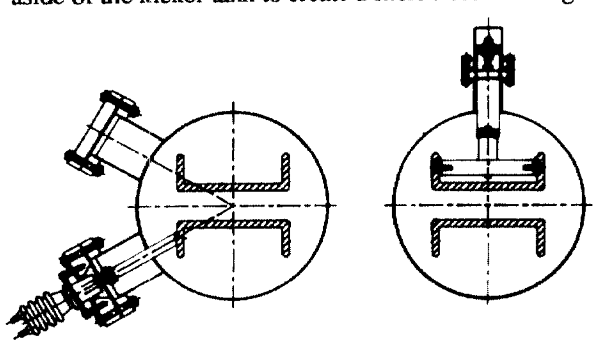

Figure 2 - Cross-sections of the mechanical kicker design.

Having determined the cross-section of the construction, the transmission line impedance of the kicker plates has been simulated using printed circuit board with a resistive layer. Assuming the horizontal symmetry plane is at ground potential, the line impedance of a kicker plate is about 20 Ω.

4. Pulsed Power Supply Design

4.1. System design and mechanical construction

The power supply design is schematically shown in Figure 3. A positive and negative d.c. supply continuously charge separate 250 nF capacitors, which are housed in an oil tank together with the electron tubes and the local timing boards and the control voltage supplies. Oil is used for cooling and insulation, in order to allow a compact construction, with short electrical lengths for fast switching, and to reduce electromagnetic interference. If possible, the use of semiconductors in the tank is avoided to minimize failures due to radiation damage.

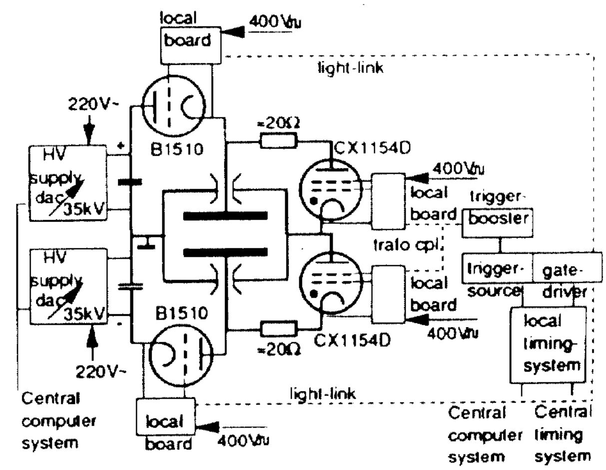

Figure 3 - Schematic layout of the kicker pulsed power supply

4.2. Charging circuit

The kicker plates are capacitively charged from the 250 nF capacitors using the light-link controlled EEV B1510 triode as high current, high voltage switch. The triode filament voltage is adjustable to operate the circuit as a constant current source of 1 A at maximum voltage. The required performance is well below the maximum ratings [6], while the minimum charging time is less than 10 µs. Cooling of this glass type electron tube is strongly recommended.

4.3. Discharging circuit

The EEV deuterium filled ceramic thyratron CX1154D is chosen as very fast high current, high voltage discharge switch because, being a one gap-thyratron, it is characterized by a very high rates of rise of current of more than 120 kA/µs. Assuming an ideal transmission line discharge of a kicker plate at the maximum voltage of 35 kV, the peak current is 875 A and the average current is 3.67 mA, which is well below the maximum ratings [7].

The reservoir heating voltage is adjustable in order to find a compromise with respect to voltage hold-off and rate of rise of current as well as for reasons of thyratron life time. The high power trigger pulse is delivered by a small CX1548 thyratron, used as booster, and amplified by a trigger transformer. To maximize the trigger pulse energy, the grid circuit involves a differentiator without coupling between control and bias grid.

Jitter in triggering is reduced by the d.c. filament voltage supply in order to avoid electromagnetic fields at the cathode.

An optimal transmission line discharge of the kicker plates is achieved by tuning the matched load in the discharge circuits during the final development of the power supply system.

4.4. *Timing*

The charging of the kickers is timed by the delayed pulse generator (dpg) of the linac beam switch yard. The timing of the discharge makes use of the dpg of the ring timing system. Finally, the timing of the relative discharge of the two kickers is adjustable within the integrated kicker control system with the aim of reducing relative timing errors.

4.5. *Test results*

The charging and discharging of one kicker plate, with the other plate at ground potential, has been tested up to 20 kV in air, including a test of the prototype timing system. As shown in Figure 4 a fast falltime of less than 100 ns, similar to the discharge of a transmission line, has been achieved.

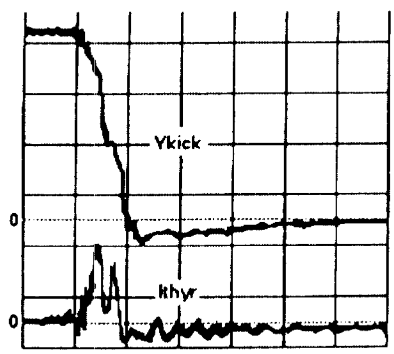

Figure 4 - Measured kicker plate discharge in bench test. Scale is 5 kV/div, 106 A/div and 50 ns/div respectively.

5. KICKER BROADBAND IMPEDANCE

The longitudinal coupling impedance Z of the kicker, with respect to the standard ring beampipe, is determined in coaxial wire measurements, involving a small centred conductor, that simulates the beam position in storage mode. A 20 GHz HP network analyzer is used to send calibrated signals along the centred conductor and to measure the signal transmission. According to Hahn and Pedersen [8]:

$$|Z| = 2Z_0 \cdot \left(\frac{S_{21,\,\text{beampipe}}}{S_{21,\,\text{kicker}}} - 1 \right) \quad (1)$$

S_{21} is the measured transmission in S-parameters; Z_0 is the transmission line impedance of beampipe and centre conductor.

The frequency spectrum of Z is used to determine an upper limit of the parasitic mode loss factor K:

$$K(\sigma, f_0) < 2f_0 \cdot \sum_{n=1,2,\ldots} |Z(n.f_0)| \cdot e^{-(n.2\pi f_0 \sigma)^2} \quad (2)$$

where σ is the bunch length and f_0 is the revolution frequency.

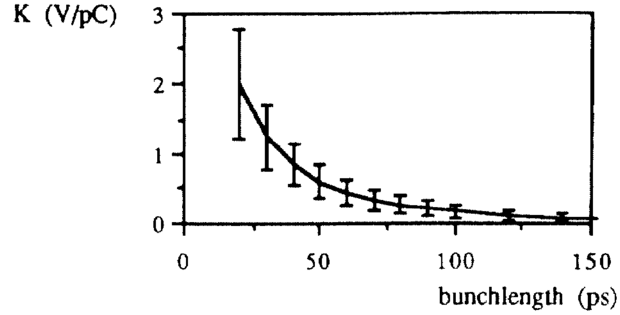

Figure 5 - Parasitic mode loss factor K of a kicker, calculated as a function of the bunchlength.

As shown in Figure 5, K is calculated for the revolution frequency of 1.41666 MHz and for bunch lengths of 20 ps and higher. The data are fitted with a broadband resonator model by Maas [9]. As result for the | Z / n |, the longitudinal broadband impedance of the kicker is calculated as (0.21 ± 0.05) Ω.

6. PROJECT STATUS

Both kicker tanks have already been installed in the ring. The construction and system test of the power supply tank is in its finishing stage. Before the summer of 1992 the first kicker will be used for single turn injection into AmPS.

7. ACKNOWLEDGEMENTS

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