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FURTHER CONSIDERATIONS ON
THE BEAM TRANSPORT SYSTEM ; LINAC-SYNCHROTRON INJECTOR

A beam transport system from the synchrotron injector has been proposed previously in MPS/int. LIN 68-3 by M. Weiss. This document was reviewed in SI parameters meetings No. 15 and 16.

In this note I wish to cover the following topics :

a) Review of the beam optics,
b) Choice of the vertical deflection system kicker,
c) The early establishment of the first section of the line from the linac to the shielding wall now in the linac-booster transfer tunnel,
d) The inflector to be installed in section 1 of the booster,
e) Beam observation and control.

a) REVIEW OF THE FOCUSING AND BENDING CHARACTERISTICS OF THE SYSTEM

The system should meet the following requirements : It should;

1. transport the linac beam contained in an emittance of $30\pi.10^{-6}$ rad for each of two transverse phase planes, to the booster;

2. match the emittance to the booster acceptance for monoturn injectio and be capable of optimum adjustment of the matching for multi-turn injection;

3. enable injection into either the PS or the booster without requiring parameter changes in the portion of the line common to the present PS injection path (i.e. up to IB1).

4. present a beam in the region of IB2 that is compatible with the emittance and momentum measuring equipment.

5. provide a vertical beam deflection system to steer the beam, sequen tially, into the four booster rings. Switching times should be an order of magnitude less than that required for injection.

In attempting to arrive at a basis for making a choice of parameters fo the design of the transfer line I found that it was convenient to break it down i four sections. There are indicated in Fig. 1 which shows some differences compa ed with the similar Fig. 1 /MPS/int. LIN-68-3. The first section is from the Linac to IB1, the second from IB1 to IB2, the third is from IB2 to IEV while the fourth completes the line to the booster.

The first section is that part of the line in common with the present PS injection path except that the pulsed magnet IB1 replaces IB11 to enable either injection directly into the PS or into the booster. The beam characteristics at the center of IB1 are governed by the focusing existing between IQ21 and PS straight section 26, assuming that the linac emittance is matched to the PS acceptance by the triplets IQ11 and IQ21. However, because of some doubt concerning the effect of the fringing field of the PS magnet block, it is difficult to make a firm estimate of the beam parameters as the beam leaves IQ2 Perhaps a better procedure would be to take the measured linac emittance and transform the beam parameters according to the actual currents in the triplets. However these currents are varied from day to day. Clearly some latitude must be allowed in defining the beam parameters used for transport calculation on the following sections of the transfer line.

Parameters used by M. Weiss are :

A	Horizontal	Vertical
a/b	13.33 m	5.77 m
c/b	-27.95 m	-0.42 m
$\dot{e}$	46.45 mm	13.2 mm

Another set that could be considered within the range of the doubts discussed above is :

B		
a/b	17.66 m	6.78 m
c/b	-20.93 m	o.0 m
e	35.69 mm	16.0 mm

One sees a difference of 21.5 mm in beam diameters for these two cases.

The pulsed bending magnet IB1 should have a vertical aperture of 50 mm a horizontal aperture of at least 25 cm, and a field of 0.2 T with a uniformity of 1‰ in the region traversed by the beam, i.e. over a radial width of 150mm. The bending angle required is 300 mrad. A rectangular pole piece is assumed because of the laminated construction.

The second section carries the beam from IB1 to the second pulsed horizontal bending magnet IB2, which can switch the beam into either the emitta or momentum measuring line as well as allow it to continue in a straight line.

IB2 has been shifted from the position indicated by M. Weiss to one inside the main PS tunnel so as to get sufficient length for the emittance measuring line which is blocked by the 6 m shielding block. This position also allows this measuring line to make a smaller angle (100 mr) with the main line, thereby reducing the effect of energy spread on the measurement of the horizontal emittance.

The emittance measure system is designed to have a displacement resolution of 0.5 mm and an resolution of 0.075 mR. This last figure is the same as the angular spread of the beam for a momentum error $\frac{dp}{p}$ of 3/4%. The beam should have a divergence of at least 3 mR to take maximum advantage o the angular resolution offered. This is not acheived in the system described by M. Weiss (divergence less than 1.25 mR).

Use can be made of the emittance measuring system to establish fixed beam descriptions at IB2. Provided at least four lenses are included between IB1 and IB2 it is possible to adjust these lenses to compensate for slow variations of linac emittance or any changes made to the operating currents of IQ21, IQ11. Furthermore, to make best use of a given lens aperture, the last two lenses should form a close doublet as near as possible to IB2, giving as wic range of beam conditions as possible in the emittance measuring system.

The aperture requirements and field gradients for the lens IQ1 - IQ4 were calculated for a system that gives beam waists at points 3 m and 9 m downstreamd from IQ4. They are given in table I. The divergences were fixed t be ± 3 mR, giving a waist diameter of 2cm. The aperture of this second part of the system should be liberal so as to allow some flexibility in beam design not necessarily for the main task of transporting the beam to the booster but to allow some variations in the beam measuring lines. A lens aperture of 14 cm is proposed, i.e. the calculated beam sizes are < 70 % of the lens aperture. This is without an allowance for steering errors,

IB2 should have a vertical gap consistent with this size, viz, 12 cm . The horizontal pole width should be 35 cm. The magnet should have an equivalen length of 1.2 m. IB2 then works at the same current as IB1 when switching into the emittance measuring line. The inductance of IB2 is then about 1/2 that for IB1 (for the same number of turns for the different coils).

An alternative possibility for IB1 and IB2 is to make both magnets ide tical (with the dimensions given above for IB2). This has a decided advantage from the point of view of the cost of these laminated magnets, but entails increasing the power supplied to IB1 by a factor of five. The voltage required to switch on the field, however only increases by a factor of 1.2.

It is proposed to have only one power supply to operate IB1 and IB2. It will have a switching cycle period of 1 sec. There will be times in this cycle, separated by 0.5 sec., at wich the magent will be on, and off. The pow supply will be commutated between IB1 and IB2 (including current reversal in IB2) as required. For a linac repetition rate of 2/sec, only every second pul can be delfected, either into the PS or into one of the measuring lines. Both bending magnets should be capable of DC operation.

Some boundary conditions governing the design of the remainder of the transfer line come from the components of the beam switching system that gives vertical separation to the portions of a linac pulse go to the different booster rings. There is, in general, conflict between the wish to have small apertures leading to lower operating currents and voltages for the pulsed kicke and DC septum magnets, and to have moderately sized apertures in the rest of the system eg. in quadrupole magnets, beam transformers, position monitors and vacuum valves. M. Weiss has given a design based on minimizing the switching voltage for an electrostatic kicker system. A compromise between minimum volta and aperture requirement in the remainder of the system was reached. Ther has been a further study of an electrostatic system by R. Featherstone (MPS-SI/Int. LIN 68-1). In addition it has been thought worth while to conside a magnetic kicker. This is the subject of the appended note by H. Haseroth. A discussion of these alternative is given later,only the beam optical considerations are dealt with here.

If one takes a deflection system of a kicker followed by a drift space to a DC septum magnet to complete the bending and a further DC magnet to bring the beam to a horizontal line again, and place lens at each end of this section, then the important parameters in the design of the system are the drift space length and the lens apertures. The requirements for a magnet and an electrostatic kicker system differ. In both cases one should design for a small kicker angle. However in the electrostatic case this is tempered by th need to have a small vertical size for the beam in the kicker. One then has a balance between the beam vertical divergence and the vertical size at the waist formed in the drift space. M. Weiss has given an analysis of the optimization of the kicker voltage. It depends on the beam vertical size (for a fixed septum width) and does not depend on the beam horizontal size or lens apertures

The case for the magnetic kicker is more complicated. The voltage required to establish the magnetic field is proportional to the voltage require in the electrostatic case. For the same kicker vertical aperture and bending angle, and assuming a single turn window frame magnet,

$$V_m = V_E \; . \; 10^{-8} \; le/\tau m$$

where V_m, V_E are the voltages for a magnetic and an electri kicker, le is the length of the electrostatic deflecting plates in meters and τ m is the curren rise time of the magnetic kicker in seconds.

The minimum for V_m then occurs with the same conditions for the minimum of V_E However, if the minimum current for the magnetic inflector is required, the beam should have a small vertical size near the DC septum and a small horizonta size near the center of the kicker. If, in addition, the beam sizes at the lenses are fixed there is little advantage in increasing the drift space and, in fact, for a set of parameters suitable for the transfer line, it is found that the required current curve has a shallow minimum for a drift space of about 10 m. Increasing the permisible aperture in the lenses at both ends also leads to a reduction of the current required.

It is not necessary to operate the system with these minimum currents or voltages. For the beam given by M. Weiss, it is possible to have a magnetic kicker. So far it has been assumed that any beam configuration in the region of the deflection system could be matched to the booster acceptance. It is not proposed to include sufficient lenses to enable this. In the Weiss solutic a doublet only is used. The solution he presents already gives the minimum horizontal size at the kicker possible with a doublet. It is proposed now to use instead a symmetric triplet. In this solution , the horizontal size is almost unchanged . A further reduction of more than 10% seems unlikely. The inclusion of the extra lenses is justified because of the reduction in horizontal aperture at the DC septum vertically deflecting magnets A total power saving of 35 kW is possible.

The lens combination now proposed to meet the requirements of phase space matching and the vertical deflection system consists of section three which takes the beam from IB2 to IEV and section four which completes the path to the booster.

Section three consists of two doublets, one on each side of the concrete shielding block. The upstream doublet, IQ4A, IQ4B has been added. It, together with IQ5 and IQ6, form the main phase space matching group. Beam sizes and gradients in these lenses are shown in table I. They should be of the same type as those used in section 1.

Section four contains the triplet discussed above. Because there is a triplet in each of the verticaly displaced lines, some independent adjustmen the vertical match for each ring is possible. However, these lenses can be considered as fixed in focussing strength. Gradients and apertures are shown in table I. Since the aperture requirements for these lenses are smaller and the vertical distance between centres must be 36 cm, it is expected that thi group of 12 lenses will be of different design from the other lenses.

b) CHOICE OF THE VERTICAL DEFLECTION SYSTEM KICKER

It is proposed to build an electrostatic kicker based on the design described by Featherstone.

Cost estimates for both this kicker and a magnetic device as described by Haseroth show that the magnetic system is probably slightly more expensive. The voltage required to establish the magnetic field is an appreciable function of that used for the electrostatic plates, unless rise time is sacrified.

The largest deflection angle should remain constant to 0.5% over the pulse. This poses a serious problem for the magnet pulser although it is thoug possible to achieve this result, it is not clear how much effort would be invol or more importantly, how much more maintenance this circuit would require, after the system is operational when compared with the pulser for the electrostatic plates.

The chief disadvantage of the electronic design given by Featherstone is that the thyratrons operate with high potentials on their cathodes. This could be overcome by using a three pair plate system and 50% increase in voltage. This alternative requires moving to a more expensive set of thyratr

c) THE EARLY ESTABLISHMENT OF THE TRANSFER LINE BETWEEN IB1 and IB2

The construction of the first part of the extension of the linac line as soon as possible has been proposed. This would create a test facility, bot for the linac and for study of beam monitoring and control devices to be used for injection into the booster. The completion of this section is scheduled for November 1970. By this time the linac should be capable of two pulses per second so that parasite operation with the PS will be possible. The section t be installed will include IB1, IQ1-IQ4, position monitors, beam transformer, steering coils, a vacuum station near IB2., and the emittance measuring syste If IB2 is ready it can also be installed and powered with DC.

It is intended to investigate automatic control of beam steering and, possibly, automatic control of phase space matching, using the emittance measuring device as a monitor. The experience gained in these investigations will be useful in deciding how such systems could be used when the time comes to inject into the booster rings.

As most of this section passes over a portion of the PS ring floor where it consists of cable ducts and loose concrete slabs it is necessary to start a study now of the mechanical structure to support the line. Any engineering work for these structures should be scheduled for the summer shutdown 1969.

d) THE INFLECTOR FOR BOOSTER STRAIGHT SECTION 1

As a result of discussions concerning the clearance between the injection line and the booster ring bending magnet consideration has been given to the use of septum magnets in place of the electrostatic inflector discussed by M. Weiss.

The recent modification to the geometrical position of the center of the booster allows both types of inflector. No choice need be made immediately Both types are designed to give a bending angle of 66 mR. An electrostatic inflector would be similar to that recently installed in the PS and would have the same operating voltage for the worst case i.e. monoturn injection. However clearance between the plates and the incoming beam would be small. Furthermore with multiturn injection, it is almost impossible to prevent beam from striking the septum with beam injected in previous turns. From all accounts, beam on the electrodes can lead to trouble. Another disadvantage of the electrostatic inflector is that it uses up a considerable fraction of the straight section leaving little room for the injection dipole also located in this straight sec

In a recent memorandum by Geisch, Weisse and Sherwood, a septum magne inflector was described. Each ring has an inflector consisting of two septum magnets in series. The downstream one has a 0.5 mm thick septum while the sec has a 4 turn septum 5 mm thick. The pair occupy 1100 mm of straight section length compared with 1800 for the electrostatic inflector, and less distance is needed between inflector and tank. The required current is 1155 A.

The inflectors for the 4 rings can be housed in a common tank with only one pair of feed throughs for current and water the remaining connections can be made inside the tank.

e) BEAM CONTROL AND OBSERVATION

In addition to the position monitors and steering coils shown by Weiss, it is considered necessary to have another set just before IB2, so that the bea position and direction coming into the measuring lines is well determined.

It is planned to use the steering coils to maintain the beam on fixed lines at critical points. The first is following IB1 so that the effect of any residual field can be cancelled, the next is before IB2, another position monit before the concrete shield checks for residual field in IB2. After the shield, another set establish a beam line with respect to the booster as well as indicating the beam position as it approaches the vertical kicker. Any misalignment between lines and each side of the shield can be detected and compensated. The final set of monitors and steering coils are used for guidanc into the inflector and to move the beam line between the positions for monoturn and multiturn injection. Beam transformers will be included before the vertica delfection system and each of the four separated lines as near to the inflector as possible.

Some thought needs to be given to the placing of limiting apertures in each of the injection lines in such a way as to check the phase space ellipses, on line, before injection.

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