DESIGN OF THE INJECTION SYSTEM BY HALF RESONANCE INTO A SUPERCONDUCTING ELECTRON STORAGE RING

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Abstract

A new injection scheme to the compact storage ring by a pulse quadrupole magnet was calculated. The pulse magnet was used to create half resonance condition during the injection period. The calculation indicates that the effective injection and the low emittance of the injected and stored beam after the injection period could be achieved by optimizing injection angle, pulse length, and timing. By this method the technical difficulties of pulse generator and field uniformity of bending magnet could be reduced.

Introduction

A compact electron storage ring using super conducting magnets has a lot of industrial applications and many types of the storage ring have been designed.[1] However, there are so many technical problems, such as large good field region of the magnetic field, etc.

One of these technical problems is the pulse magnet to create a bump orbit at the injection period. In case of small storage ring, the injection should be operated with a single pulse magnet and the kicking angle of the magnet should be large. As the results, the betatron oscillation of the injected and stored electrons become large after the injection.

Concerning the pulse generator of the pulse magnet, owing to the small circumference of the storage ring, the magnetic field should have the fast rising wave form to obtain the high injection efficiency. In order to generate rapid rising pulse with high peak current, the charging voltage of the pulse generator, consisting of P.F.N., should be high[2]. For examples, the pulse magnet for the storage ring, designed in our laboratory, should have the 10 mrad kicking angle with 60 nsec rising time. Considering the injection of 800MeV electron beam and assuming the magnet length of 200 mm, the charging voltage of the generator should be about 150 kV and there exist technical problems of switching devices, insulation and so on.

Another disadvantage of the usually used pulse magnet, having wide uniform magnetic field, is its disturbance on the stored beam during the injection period. By the magnetic field on the axis the stored particles are kicked and become to have a large betatron oscillation after the injection.

In this paper, we will suggest the other method of injection into the storage ring of race-track type, using the half-resonance.

The brief description of the injection theory is in the following. The pulse Q-magnet works to kick the beam upward and downward in phase space if it is in negative and positive position respectively. By adjusting the strength of the Q-magnet to resonance condition, beam will continue shrinking or blowing up rapidly depending on its initial position.

If the injected beam is in a proper condition, the beam will shrink fast enough to avoid the collision onto the septum wall after the injection and the high injection efficiency is obtained. And the beam continue shrinking during the injection period. In our designed storage ring, its tune in x-direction is nearly 1.4 to achieve the low emittance beam. As this tune is near to 1.5, the small quadruple magnet would be enough to create the half resonant condition.

As for the stored beam, the amplitude is going to blow up but it is not so fast owing to its initial small emittance. Then if the half resonance condition is terminated after the shrinking of the injected beam but before the blown-up of the stored beam, the high injection efficiency and the small emittance of the injected and stored beam will be achieved.

Calculation Method

The schematic drawing of the compact storage ring used in this calculation is shown in Fig.1.

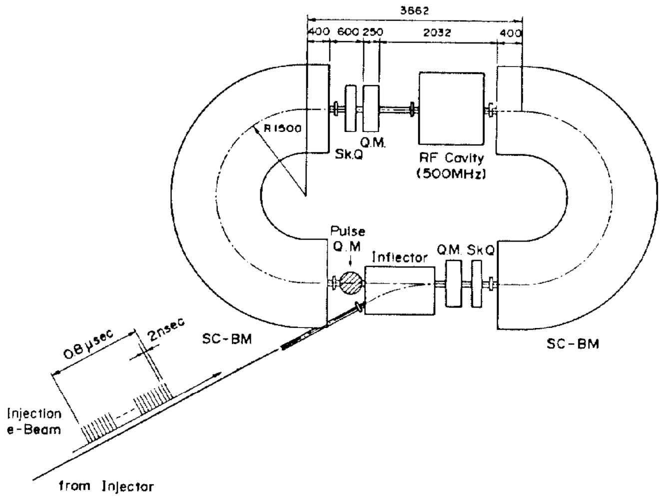

Fig.1 The compact storage ring used in this calculation.

The calculations were performed by tracking the injected and stored beam in phase space. In this calculation, we only considered the linear elements in the storage ring and the beam motion in x- and y-direction were treated independently. The beam loss was caused only by the collision on the septum wall. The effect of the dynamic aperture by higher order magnetic field was not included in this calculation.

The initial position of the injection beam with 4.8 mm of full beam width was +40.1 mm apart from the central orbit of the stored beam. The septum width of the injection magnet was 2.7mm. A linear accelerator was assumed as an injector and some characteristics of the beam are as follows. The rf frequency of the linear accelerator was 500 MHz, the pulse length of the beam was 0.8 micro-sec and the emittance of the beam was $3.0*10^{-6}$ pai-mrad. The emittance of the stored beam was $9.0*10^{-6}$ pai-mrad.

The beam was divided into 10x10 in phase space (x-x' or y-y'). The weight function of these divided piece was constant. The shift of the beam orbit caused by the energy distribution and the energy difference between the injected and stored beam were not considered because it would be small compared with the betatron oscillation at the injection period.

The wave form of the pulse Q-magnet in this calculation was half-sine wave. The level of the peak current was set so as to create the half resonance condition.

The calculation was concerned with the injection efficiency, and betatron oscillation of the injected and stored beam after the injection period. And also the injection angle, the pulse Q-magnet position, pulse length were treated as the optimization parameter and also the effects of timing error and mis-alignment are calculated.

Calculation Results

In the following section, we will present the calculation results concerning the pulse Q-magnet position, injection angle, timing, and magnet mis-alignment. In the following "timing " is the time difference between the first injected bunch and the peak current and negative value of the timing means that the first beam is injected before the peak of the current . "Injection Efficiency" is the ratio of the captured particles to the total particles from the injector. "Emittance" is the maximum Courant-Schnyder invariant of the tracked particles.

Pulse Q-magnet magnet position

Three cases of the pulse Q-magnet position, 550, 650, and 750 mm upstream from the septum magnet, were studied. The effects of the pulse length, the injection efficiency and the emittance after the injection were calculated. The calculation was performed to obtain the long pulse length in so far as not to cause the stored beam loss and the optimized injection angle for the high injection efficiency. The calculation results are summarized in Table 1.

Table 1. The dependence of the beam parameter after the injection on the pulse Q-magnet position from the injection magnet.

Q-magnet position (mm)	Pulse length (μsec)	Injection efficiency (%)	Emittance injected (10^{-6} pai mrad)	stored
550	6.0	99.0	400.2	293.1
650	7.8	93.9	428.6	275.0
750	8.4	90.0	429.1	272.3

The table 1 indicates that the available pulse length becomes long but the injection efficiency decreases as the pulse Q-magnet is settled away from the septum magnet. As for the beam emittance, however, there is no clear difference between them.

By the practical compromise between pulse length and the injection efficiency, the position was set to be 650mm. Then the position of 650 mm from the septum magnet was used in the following calculations.

Injection Angle

The dependence of the pulse length, the injection efficiency and the emittance of the injected and stored beam on the injection angle were calculated and the results are shown in Fig. 2. The figure shows: 1) the pulse length becomes long as increasing the injection angle, 2) the emittance decreases as increasing the injection angle and , 3) the injection efficiency become maximum at the injection angle of -7mrad and decrease rapidly if the injection angle larger than -9mrad. The injection angle and the pulse length were chosen to be -8 mrad and 7.8 micro-sec respectively.

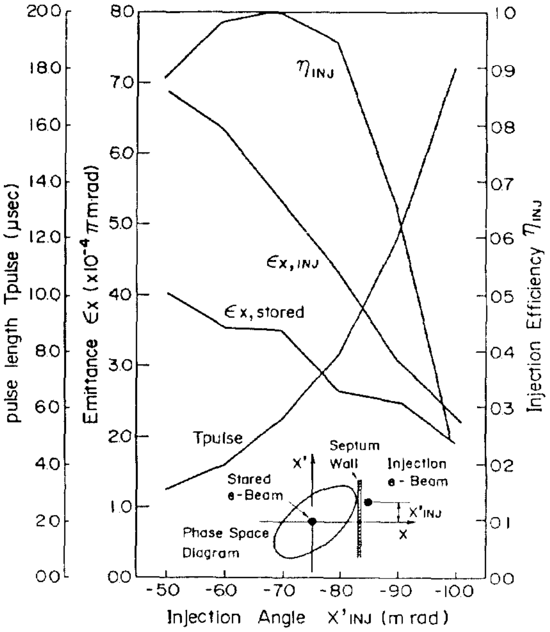

Fig.2 The dependence of the injection efficiency, emittance and pulse length on the injection angle.

Timing

The effects of the timing between the injected beam and pulse wave form were calculated and the results are shown in Fig.3. Fig.3 is the injection efficiency and the emittance of the injected beam. The stored beam is not affected by the injection timing. From Fig.3 the following results are obtained, 1) injection efficiency decreases when the beam injected before the peak of the pulse current and 2) the emittance of the injected beam has the minimum value when the injection starts 250nsec after the peak of the pulse current. ·The timing should be adjusted within several tens of nsec to obtain the low emittance of the injected beam. The timing of the current could be easily adjusted within several nsec by using a thyratron switching device for examples.

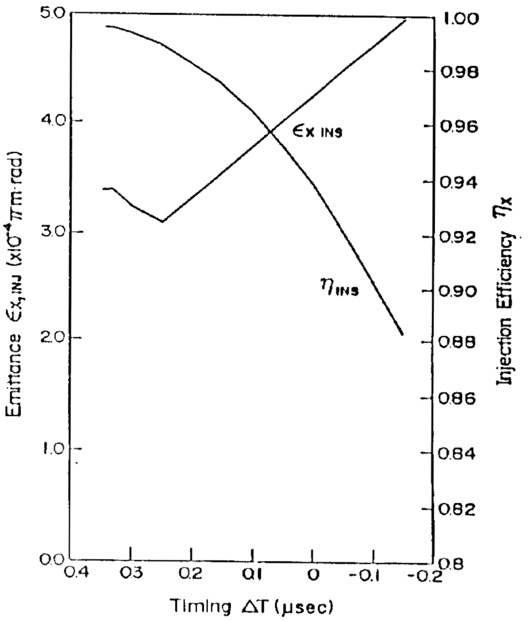

Fig.3 The dependence of the injection efficiency and the emittance on the timing between the pulse magnet and injected beam

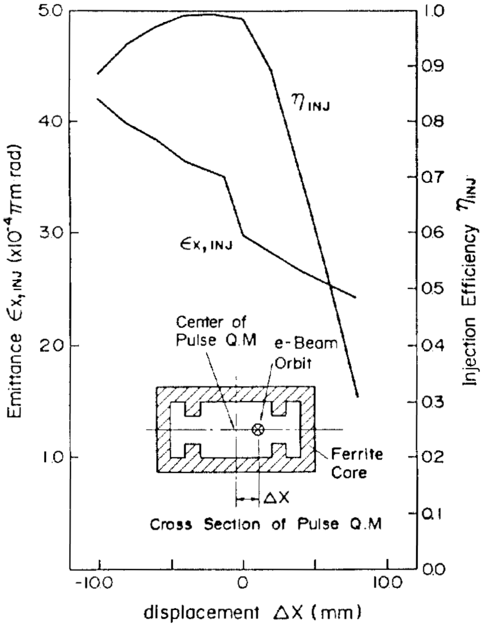

Fig.4 The effects of the mis-setting of the pulse magnet on the injection efficiency and the emittance.

Magnet mis-alignment

The effects of the magnet mis-alignment in x direction were calculated. "Displacement" means the distance between the stored beam center and the Q-magnet center. Fig.4 is the results of the calculation. The injection efficiency becomes worse when the magnet is displaced on the positive direction. The emittance is also decreased as the magnet moves toward the same direction. As for the stored beam, the remaining ratio and the emittance were not severely affected by the displacement. From Fig.4 the pulse Q-magnet should be adjusted within 1mm to obtain the injection efficiency of more than 90%. The setting within 1mm is not thought to be practically difficult.

Discussion

The technical feasibility of the pulse Q-magnet system will be discussed. The K value (field gradient) of the Q-magnet to create the half resonance condition was 400 G/cm and it is not so difficult to construct the Q-magnet having such a K-value by ferrite core. Assuming the magnet length of 240 mm, the inductance of the magnet is about 0.7 micro-H per pole and the peak current of 4500 AT per pole is necessary. Considering the pulse generator of L-C discharging circuit, the charging voltage of the pulse generator can be calculated by inductance, frequency, and discharging current and it is only 1.3 kV, about one hundredth of the voltage for the ordinary injection magnet system.

The maximum emittance after the injection was about $2.7*10^{-4}$ pai-mrad for stored beam and $3.1*10^{-4}$ pai-mrad for injected beam. The maximum beta-x in bending magnet was 1.3 m. The maximum beam size is about 20 mm in the bending magnet. Hence the good field region of the bending magnet necessary for the injection is only 40mm (-20mm < x < 20mm).

Conclusion

The injection scheme using the half-resonance condition into the compact storage ring was calculated. The calculation showed that the high injection efficiency, more than 90%, was possible from the linear accelerator of 0.8 micro-sec pulse length by the pulse Q-magnet of about 8 micro-sec pulse length. The injection efficiency would be reduced by the injection angle, the timing of the injection beam ,the displacement of the pulse Q-magnet. However these adjustment could be obtained without practical difficulties.

As for the pulse generator the charging voltage of the pulse generator could be reduced to be about 1.3 kV owing to the long pulse length.

The betatron oscillation in bending magnet was 20mm after the injection by this method and would be smaller than that by the usual system. Hence the good field region of the super-conducting magnet necessary for injection can be reduced.

Acknowledgments

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