THE ADJUSTING AND MECHANISM OF THE HCE FOR THE COMMISSIONING OF NSRL

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Abstract

It is discovered that the accumulated current in injection can be raised easily from 200mA to 300mA with the increase of the storage current in the ring, as long as the current of the septum is increased constantly in small quantities, during the commissioning of National Synchrotron Radiation Lab.(NSRL). A tentative exploration is also conducted concerning the mechanism of this high current effect(HCE).

Key words: high current effect, synchritron radiation, pulse septum megnet, DeQ circuit.

1. INTROUDUCTION

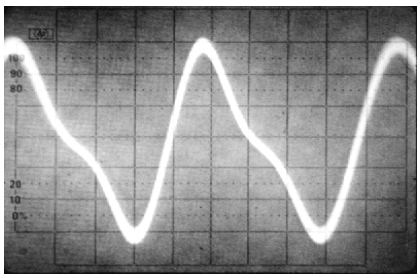
Hefei Electron Storage Ring is a facility dedicated to synchrotron radiation. A beam from the transport is deflected by an angle of 22.5° in a vertical direction through a DC septum magenet, descending on the midplane of the storage ring, and then the beam is deflected outward by an angle of 6° in a horizontal direction through a PS (pulsed septum magnet), making it parallel to the local bumped orbit produced by three Kicker magenets[1].

The designed injection electron energy for the storage ring of NSRL is 200MeV and the operational energy, after the beam is accelerated slowly, up to 800MeV. Consider to the effect of the beam's loss in the ramping, thus require the accumulated current $I_R \geq 230$mA in injection for insuring the current of operation $I \geq 200$mA in the 800MeV. However, when we adjusted the related parameters of the ring according to the normal steps, I_R hesitate to increase further after the beam raised to 200mA for a long period. It was found by the first author that, just at this time, the I_R will increase rapidly from 200mA to 300mA, as long as the PS current(I_S) is increased continously in small quantities. It make NSRL accelerator rapidly reached and surpassed its design value. We name it as HCE.

2. THE PHENOMENON AND ADJUSTMENT OF TEST

It is found in the experiment that when a storage beam runs in the equilibrium orbit but without injection, i.e., the PS coil is not charged, there is an alternate current in the PS coil. The photograph of the wave is Figure 1.

We think that alternate current is the result of the high frequency induction, which is produced when bunchs in the ring travel at a near the speed of light to pass by the strip (the strip is a part of the PS coil) . Reference see Figure 3.



I_R =110mA, March 18, 1993
X=1 ns / div, Y=0.01 V / div

Figure 1: The measuring voltage wave induced in the PS coil

A PS coil is a single turn coil made of copper. It is inlaid in a gap of a magnet laminated of silicon steel sheets with a hole. Its length is 50cm, the width is 5cm and the height is 1cm of the hole. For detail see Figure 3. They are placed horizontally in the longitudinal direction in the septum vacuum chamber which connects directly with the ultra-high vacuum chamber of the ring. The HCE is closely related with this structure. The coil is driven by a pulse current source, which provides a half sine-wave pulse current(I_S) with a base width of 18ms and amplitude of 1kA ~ 4.5kA and one time every 2 seconds. The fine adjustment of the I_S is completed by a DeQ circuit with the adjustable precision of 0.3‰ by a computer. During commissioning, to make the incoming beam deflect of 6^0, I_S is needed about 1.15kA with an amplitude stability $\leq \pm 1‰$[2] . However, in the actual injection test, it was discovered that when accompanied by the increase of the I_R in the ring, so long as we increase appropriately the simulation quantity PS_{012}, which corresponds to the I_S increase linearly, the I_R will continuously increase. In a different time, The relative curve of the adjusting

quantity of the PS_{012} versus the storage current with injection is shown in Figure 2.

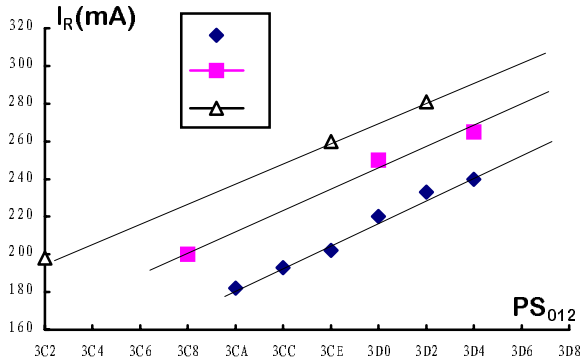


Figure 2: The relation curve of the adjustment quantity of the PS_{012} versus the storage current with injection in a different time

From Figure 2, we can see that, when the PS_{012} is increased 20 hexadecimal, which correspond to PS current I_S increases approximately 3% and the increment of the deflecting angle of needed correction angle is $\triangle\theta \approx 0.2^0$, the injection accumulation I_R will raise from 200mA to 300mA. From Figure 2, we can see that there is nearly linear relation between the increase of the I_R in ring and the increase of the I_S in PS coil. Certainly, if the initial value is different, the final value will also be different. The initial value is closely related to the setting and adjusting of the other parameters of the machine, such as the quality of the beam from the transport line, the RF capture efficiency, the match of the lattice parameter of the ring and the work condition of the current source, etc. After all those parameters are determined once and the current of the ring can't be accumulated further, one can make the storage current increase by about 1/3 by increasing the PS current properly.

3. THE MECHANISM OF THE HCE

3.1 The Analysis for the Induction Wave Pattern

The results of many actual measurements show that the induced voltage increase is in succession with the increase of the storage current in the ring. However, there is a general rule worth paying attention to, i.e., its area of negative and positive semiperiod as well as its front and back porch which are asymmetric. After integrating for the area, we can obtain an equivalent nonzero negative average ΔU, which correspond to a negative bias ΔI=ΔU/ R_m (R_m is the signal resistance). The bias will be superposed on I_S and will decrease the value of I_S, causing the deflected angle to reduce. It not only produces a disdurbance to the incoming beam to cause transverse vibration, but also the negative average DC will make the central line of the incoming beam closed to the strip, resulting in loss of the injection beam. Just at this time, if the I_S is increased properly to offset the average negative DC induced, it makes the central line of the incoming beam returne to the previous designed position and thus the injection accumulation will proceed normally. The higher the storage current, the greater the increase of I_S.

3.2 The Calculation of the Induced Voltage in PS Coil

The perimeter of the NSRL electron storage ring is 66m, and there are 45 bunchs in the ring. The relative position between a single bunch on the equilibrium orbit and PS coil is shown in Figure 3.

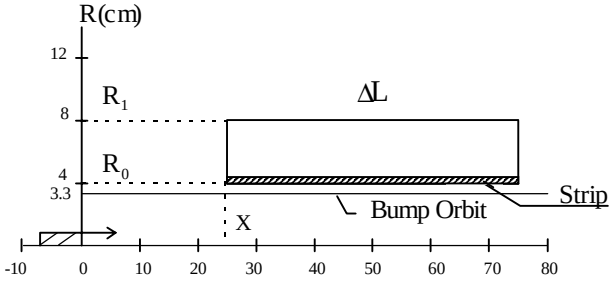


Figure 3: The relative position between a single bunch on the equilibrium orbit and PS coil. R_0: distance between the equilibrium orbit and the strip; R_1-R_0: the width of PS coil; ΔL: the lenth of PS coil

Suppose the length of the bunch is $l = 6\text{cm}$[3]. We take a little current element $I_l dl$ which moves from left to right near the speed of light. The distance between the lower-left corner of the PS coil and the origin of the coordinate is x, then $dx/dt \approx c$, we obtain the induced voltage produced by the $I_l dl$ which position relative to the coil is varied continuously, according to the Biot-Savart law is:

$$U_m = \frac{d\Phi}{dt} = \frac{\mu_0 \times I_l}{4\pi}\left[Ln\frac{(x+l)+\sqrt{(x+l)^2+(R_1)^2}}{x+\sqrt{x^2+(R_1)^2}} - Ln\frac{(x+l)+\sqrt{(x+l)^2+(R_0)^2}}{x+\sqrt{x^2+(R_0)^2}} + Ln\frac{(x+\Delta L+l)+\sqrt{(x+\Delta l+l)^2+(R_0)^2}}{(x+\Delta L)+\sqrt{(x+\Delta L)^2+(R_0)^2}} - Ln\frac{(x+\Delta L+l)+\sqrt{(x+\Delta L+l)^2+(R_1)^2}}{(x+\Delta L)+\sqrt{(x+\Delta L)^2+(R_1)^2}}\right]\frac{dx}{dt} \quad \textbf{(1)}$$

where $\mu_0 = 4\pi \times 10^{-7}$ H/m, $dx/dt \approx c$ (3×10^8 m/s), $d\Phi/dt$ is change ratio of the induced magnetic flux in the PS coil.

When the storage current is 100mA, without consideration of the effect of ferrimagnet, the curves computed are shown in Figure 4.

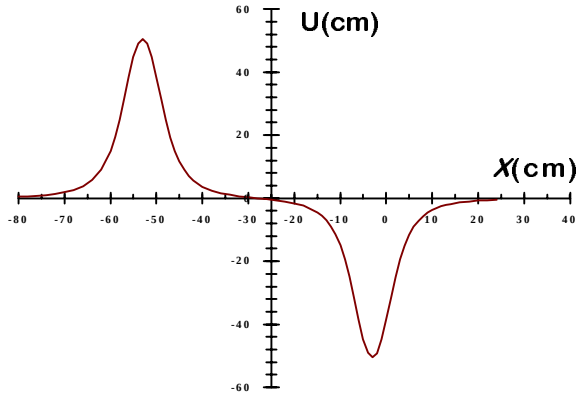


Figure 4: The induced voltage wave of calculation in the PS coil

3.3 The Analysis for Computed and Measured Results

From Figure 1 and Fig4, we can see that, the wave pattern measured and the diagram of curves computed are almost the same. But the amplitude computed by our theory is larger than measured by three orders. This difference with three orders is mainly caused by the destortion effect of septum ferrimagnet for the magnetic flux produced by the storage beam. Due to the complexity of the construction and for the sake of computing approximate effect, we gain result calculated roughly according to the model of two magnetic paths with resistance paralleled, see Figure 5.

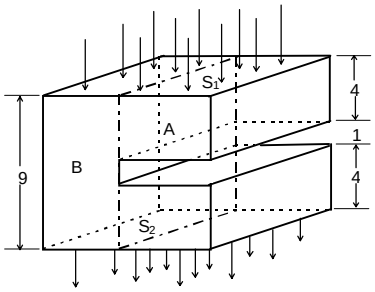


Figure 5: Diagramatic sketch of PS of induced flux through

We consider the section of the septum magnetic as a magnetic circuit of a rectangle, which consist of two paralleled branches A and B. If a uniform magnetic flux is loaded to iron's both ends of S_1 and S_2, suppose Φ'_A and Φ_A represent respectively the magenetic flux through magnetic circuit A, in which either there is or is not an air gap. Making use of the magenetic circuit law, we can gain the ratio of Φ_A/Φ_A. The value can represent approximate times reduced by the magnetic flux through the PS coil due to existance of ferrimagnet

$$\frac{\Phi'_A}{\Phi_A} = \frac{S_A + S_B}{S_A}\left(\frac{L_B S_A}{L_B S_A + 2S_B L_A + S_B L'_A \mu_r}\right) \quad (2)$$

Φ_A: magnetic flux through magnetic circuit A;
S_A, S_B: the section area of the magnetic circuit A and B especively;
$2L_A$, L_A: the length of Φ_A through the ferrimagnet and the air gap respectively;
L_B: the length of Φ_B through the ferrimagnet.

we gain $\Phi_A/\Phi_A \approx 7.3‰$. thus we'll further discuss this result in the next chapter.

4. DISCUSSION OF THE RESULT

The HCE and the effectiveness of the method adopted for increasing current, have been verified in the commissioning and the operating of the NSRL accelerator for years. In the paper, authors gave a probable exploration about the mechanism for the effect. From above calculation, we can see that the exploration is reasonable. Because the voltage value computed is consistent with those obtained in actual measuring in principle after considering the factor of the ferrimagnet effect. Along the other line, the exploration obtain to prove further. Because of the work property of PS is that it only deflect to injection beam current, but not affect storage current as far as possible. Therefore, we required the ratio of its stray magnetic field B_S in strip outer space to the main magnetic field B_0 of PS is of the less three orders of magnitude, which were realized by the magnetic shield of the strip and the field shape fill. This shown that field produced from outer storage current affect to main magnetic field of PS is of the less three orders of magnitude also. This three orders difference is coincident with difference between computed and observed result.

5. ACKNOWLEDGMENTS

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6. REFERENCES

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