UNUSUAL EDDY CURRENT STRAY FIELD OF PULSE SEPTUM OF NEWSUBARU

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Abstract

NewSUBARU, 1.5GeV storage ring, has a magnetic pulse to inject 1 GeV electron beam from the SPring-8 linac. Its maximum field is 0.36T with waveform of 1ms width half-sine. Behaviour of stored electron beam indicated an existence of a stray field which time structure was cosine like. A beam pipe for an injected beam and a beam duct for a circulating beam made an electric loop path of an eddy current induced by a magnetic field of the septum. Off-beam measurement of magnetic field and the induced current confirmed the existence and the path of eddy current. An electric insulation to a metal support of the beam pipe cut the loop path and reduced the cosine like stray field. There still existed a weak current, which runs long path along a beam transport line.

1 INTRODUCTION

The synchrotron radiation facility NewSUBARU is a VUV and Soft X-Ray light source at the SPring-8 site. Laboratory of Advanced Science and Technology for Industry (LASTI), at the Himeji Institute of Technology is in charge of its operation, collaborating with SPring-8. The main parameters of NewSUBARU are listed in Table 1. The ring has two operation modes for users. In the 1.5 GeV mode, the beam is accelerated to 1.5 GeV and stored, while in 1.0 GeV top-up mode, the beam current is kept at 250$\pm$0.15 mA by an occasional injection with the gaps of undulators closed.

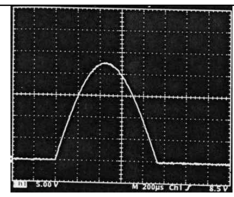
Two important points of top-up injection mode are the good injection efficiency and the stabilization of beam orbit during the injection. Lower efficiency means high radiation, which would damage the permanent magnets of the undulators. The injection efficiency of NewSUBARU is lower than 80% when the undulator gaps are closed, although at the present this is acceptable because NewSUBARU has no in-vacuum undulator.

In the early commissioning of the ring in 1998, we observed an unexpected beam loss at about 0.4ms after the injection. Later it became clear that the horizontal closed orbit distortion (COD) was changing with the septum field but its time structure was different from that of the pulse septum. Main parameters of the septum are listed in Table 2 and Fig.1 shows the flat view of the septum. The time structure of the strength of COD was almost the same as a differential function of the main septum field. We found that the beam pipe for the injected beam and the beam duct for the circulating beam made an electric loop. The main field of the septum for the injected beam induced a current along the loop and produced the abnormal stray field. We reduced this current by simply insulating the beam pipe to cut the loop. We will report our experience on this eddy current induced stray field.

Table 1: Main Parameters of the storage ring NewSUBARU.

Energy	0.5 ~ 1.5 GeV
Circumference	118.731 m
Injector	1.0GeV linac
RF frequency	499.956 MHz
Natural emittance	38 nm @ 1 GeV
Maximum current (at 1GeV)	single bunch 50 mA/bunch multi bunch 500 mA /ring
Lifetime (at 1.5GeV)	14 hours at 100mA
Tune ν_x / ν_y	6.30 / 2.23
Chromaticity ξ_x/ξ_y	3.2 / 5.8
Linear coupling	1 %

Table 2: Main Parameters of the pulse septum of NewSUBARU.

Length	1 m
Maximum field	0.36 T
Pulse width (T)	0.945 ms
Pulse Shape	half sine 
Maximum Voltage	382 V
Maximum current	4510 A
Thickness	3 mm
Inner duct size	ϕ11 mm

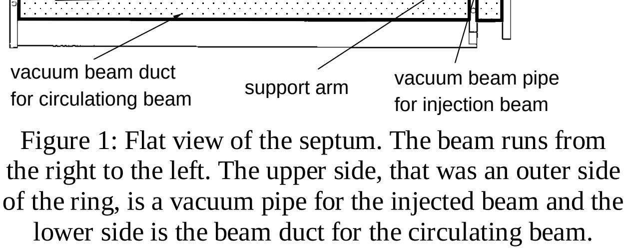


Figure 1: Flat view of the septum. The beam runs from the right to the left. The upper side, that was an outer side of the ring, is a vacuum pipe for the injected beam and the lower side is the beam duct for the circulating beam.

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2 EDDY CURRENT PATH

Fig.2 is a schematic flat view of the pulse septum and two possible current loops. We assume an ideal septum, which magnetic field, Bz, as a function of time, t, is

$$Bz(t) = B_0 \sin(\pi t/T) \qquad 0<x<2r,\ 0<s<L,\ 0<t<T$$
$$Bz(t) = 0 \qquad \text{other than the above condition .} \qquad (1)$$

Here B_0, T, r and L are peak magnetic field, the width of the half sine, radius of the inner pipe and the septum length, respectively. The space coordinate we use is x, z and s as shown in the figure.

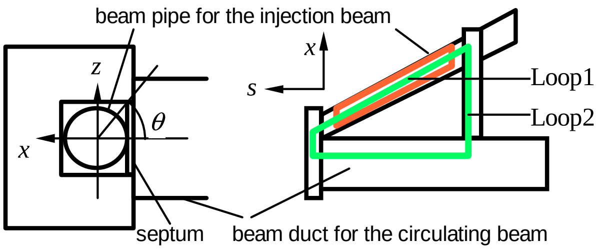

Figure 2: Schematic view of the pulse septum which shows three possible current loops.

Along one loop the current goes outer side of the beam pipe and goes back along the inner side of the same pipe (Loop 1 of the figure). The eddy current along this loop is well known to reduce the magnetic field that deflects the injected beam. The eddy current I as a function of time t is roughly given by

$$I(t) = (1/R) \int dBz/dt\, da \,. \qquad (2)$$

Here R and a are resistance along the loop and area, taking integration over the area enclosed by the loop. Along the second loop (Loop 2) the current goes the beam pipe and goes back along the beam duct, passing the metal support of the pipe. The current is also calculated by Eq. (2). We integrate the segmented current, $dI(t)$, around the circular beam pipe as shown in Fig.2. The $dI(t)$ is, using an angle of the segment θ,

$$dI(t) = \sigma (w/L_B) r d\theta (1-\cos\theta) rL\, (dBz/dt). \qquad (3)$$

The σ, L_B, r, w are conductivity of stainless steel ($1/\sigma = 7.4\text{X}10^{-7}\Omega$m), length of the beam pipe (L_B =1.2m), mean radius of the beam pipe (r=5.75mm) and thickness of the beam pipe (w=0.5mm). We ignored the resistances of the beam pipe support and the beam duct because they are negligibly small. The integration over θ gives the induced current of Loop2.

$$I(t) = \sigma (w/L_B) r^2 L\, (dBz/dt) \int_0^{2\pi} (1-\cos\theta) d\theta$$
$$= 2\pi^2 \sigma w r^2\, (L/L_B)(B_0/T) \cos(\pi t/T) \qquad 0<t<T. \quad (4)$$

For B_0= 0.36 T we obtain

$$I(t) = 140 \cos(t/\pi T) \text{ A} \quad 0<t<T. \qquad (5)$$

3 MEASUREMENTS

3.1 COD change

We measured the change of the horizontal COD as a function of time using the single-pass beam position monitor. At that time the pulse septum was fired but the pulse bump system was not, neither the electron gun trigger was. The analysis of COD at a time gave the location and strength of the error dipole field which produced that COD. Fig. 3 is an example of the observed COD, which showed that the error field existed at the location indicated by an arrow, where the septum was.

Fig.4 shows the calculated deflection by the error field as a function of timing. The main time structure component was cosine-like form.

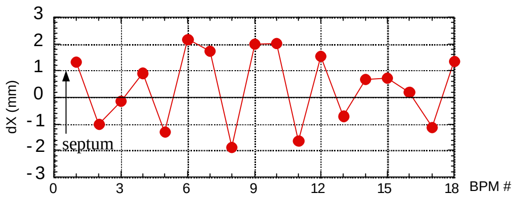

Figure 3: Example of horizontal closed orbit distortion around the ring produced by an error kick at the location indicated by the arrow.

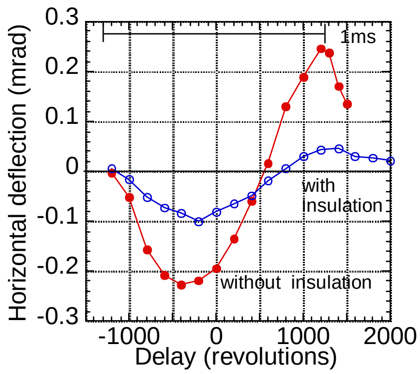

Figure 4: The deflection by the stray field of the septum as a function of time, counted by a number of revolutions. The solid line and the broken line are deflections without and with the electric insulator.

Later we insulated the injection beam pipe from the support arm. The result of the same measurement is over written in Fig.4. The cosine-like component was remarkably reduced but was still existed. The injection beam pipe and the ring was still weakly connected by water cooling pipes, beam duct support and so on.

3.2 Measurement of Eddy Current

The AC current along various electrically conductive lines were measured using crampon probe. The results with and without the insulation of the injection beam pipe is shown in Fig.5 The measured current had cosine-like form and the current without the insulation was 260 A p-p, which almost agreed with the calculation of section 2.

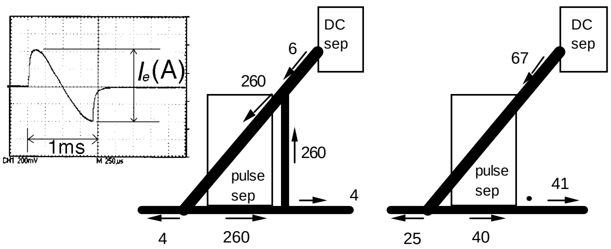

Figure 5: The septum induced AC current without (left) and with (right) the insulator between the beam pipe and the supporting arm. The peak to peak current (*Ie*) and its initial direction are shown.

The AC current along various electrically conductive lines were measured using clamp-on probe. The results with and without the insulation of the injection is shown in Fig.5. The measured current had cosine-like form and the current without the insulation was 260 Ap-p, which almost agreed with the calculation of Section 2.
The insulation reduced the eddy current. Fig.6 shows a complicated paths of induced current with the insulation.

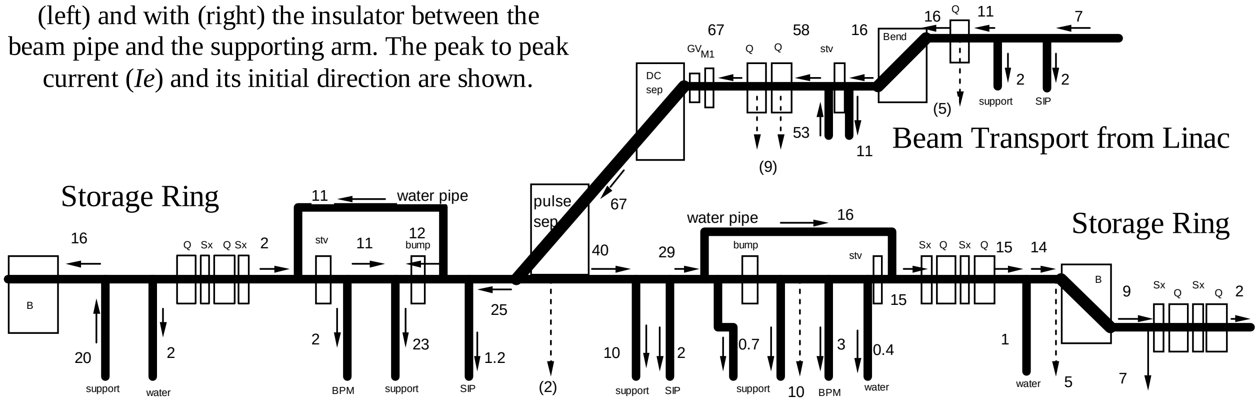

Figure 6: The septum induced AC current with the insulator of the beam pipe.

3.3 Magnetic Field Measurement

The magnetic stray field in the ring beam duct with the pulse septum was measured using a pick up coil. During the measurement the septum was replaced from the ring, which meant that the septum was isolated from the weak current path shown in Fig.6. The pulse shapes of the induced voltage at the pick up coil with and without the insulator are shown in Fig.7. The magnetic field also confirmed the existence and the disappearance of the eddy current field.

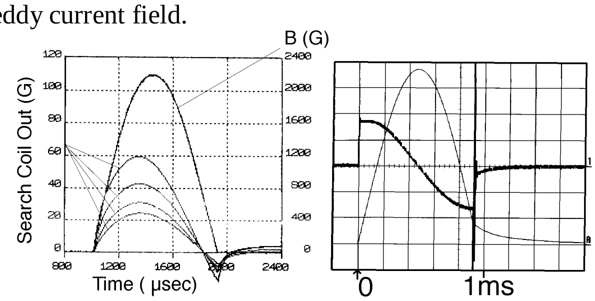

Figure 7: The pulse shapes of the induced voltage at the search coil without (left) and with (right) the insulator. In the left main magnetic field and the integrated shape of the search coil voltage (=current) is shown. In the right the cosine-like shape was the induced voltage and the sine-like shape was the integration of the voltage.

The distribution of the stray field without the insulator near the edge of the septum was shown in Fig. 8. The shapes shown in Fig.7 (left) were separated into cosine-like component and sine like component. The sine-like stray field existed only at the edge of the septum. On the other hand the cosine-like (eddy current induced) component existed along the septum.

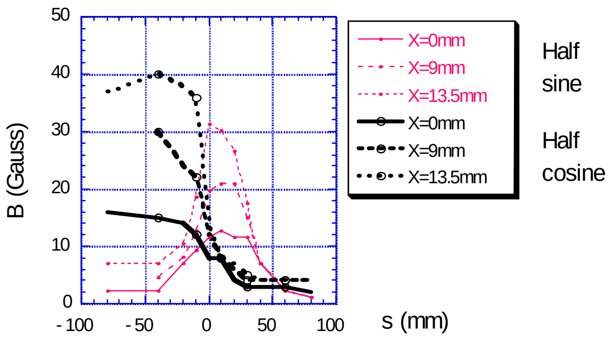

Figure 8: Distribution of the stray field. We defined x=0 at the designed centre of the circulating beam, where the wall of the vacuum duct is at x=21mm. The septum exists at s<0 and ends at s=0. The thick lines are cosine-like components and the thin lines are sine-like components of the stray field.

4 SUMMARY

We show some proofs of the existence of the eddy current induced stray field in the pulse septum of NewSUBARU.

We succeeded to reduce the stray field just by the insulation of the beam pipe from the support arm. The new septum was already constructed and is waiting for the installation. It is capable of insulation from the long beam transport line and shall not have eddy current induced stray field.