MAGNETIC FIELD MEASUREMENT AND FINE-TUNING OF KICKERS

T.C. Fan*, F.Y. Lin, C.H. Fann, C.S. Hwang, C.H. Chang
NSRRC, Hsinchu, Taiwan

Abstract

We have demonstrated an algorithm which promisingly can tune the pulse shape of current and magnetic field of kicker systems in-situ. This algorithm includes gap shimming of the ferrite magnets to adjust the pulse width of the excitation current and changing the resistance of the secondary coils to modify the pulse curvatures of each kicker. With the empirical formula derived from the systematic measurement on the magnetic field and the pulse current in laboratory, we can reduce the pulse-shape difference among the kicker magnets in the injection section of the storage ring, with no need to do anything on the pulsers and high voltage power suppliers. This approach can efficiently increase the injection efficiency which is demanding in the top-up injection mode adopted by many new facilities of synchrotron radiation.

INTRODUCTION

The National Synchrotron Radiation Research Center (NSRRC) has replaced the kicker systems in the injection section of the storage ring with new ones. The first purpose of this replacement is to provide a wide horizontal aperture of the kicker magnet so as to reduce the shining on the ceramic chamber, which came from the synchrotron radiation of superconducting wavelength shifter. The second one is to reinforce the reliability and stability in order to facilitate the top-up mode injection which is in normal operation in NSRRC [1]. Due to the requirement of high efficiency of injections in top-up mode, we have to fine–tune the new kickers so that they have identical pulse shape.

The pulse shape of magnetic field is determined by the combination of individual properties of pulse-current circuit, kicker magnet and metallized ceramic chamber of each kicker system. To make the pulse shape of four kickers identical, an iterative but tedious tuning of each component, especially the pulser, is unavoidable. The new pulsers are enclosed in oil tanks with water cooling to meet the stringent requirement on the stabilization of environmental temperature in the storage ring. This made the tuning of pulser more complicated. Up to date, we can not rely on IGBT to provide high power pulse current.

On the other hand, swapping the individual elements can achieve a set of four kicker systems with almost the same pulse shape of the magnetic field, but the integrated condition in storage ring is still possibly different from that in laboratory. Therefore an efficient procedure of pulse-shape tuning at injection section was demanded. In ref [2], we reported the first step to work out an algorithm to tune the kicker magnets in situ. Here, we try to finish this algorithm by the second novel method.

fantc@nsrrc.org.tw

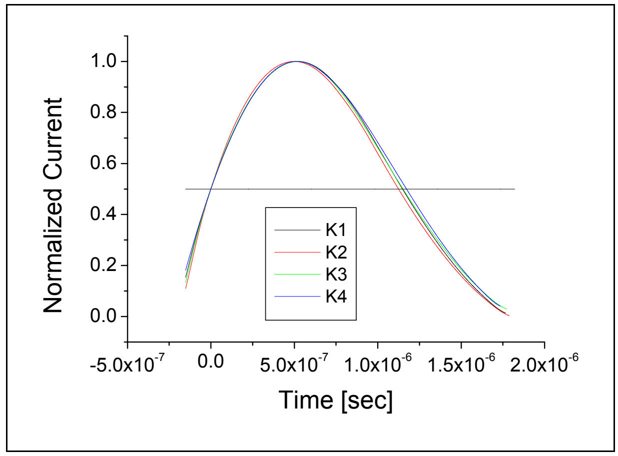

Figure 1: A typical measurement result of kicker current with normalization.

REVIEW OF PULSE WIDTH TUNING

A typical measurement result of pulse current at the injection section before tuning was included in ref [2] and is retrieved in Fig. 1 above. For the detail of the measurement on current and magnetic field pulses, please refer to the same reference. After normalization of the peak current, one can tell the pulse widths are very different among four kickers. Besides, the shape detail has a few differences. The first order difference of pulse shape among kickers can be characterized by the full width at half maximum (FWHM), which is independent of pulse amplitude. We proposed shimming the gaps of ferrite magnet of each kicker with Kapton® films to modify the inductance so as to fine-tune the FWHM of the current waveform. When we increases shim thickness, the magnet gap increases and its inductance decreases as well. This inductance variation can reduce the pulse widths of both current and magnetic field. However the amplitude of pulse current will increase, and that of magnetic field will decrease. If the gap change is small, the decrease of pulse width is linearly dependent on the shimming thickness. In these kickers, this method has an capability of pulse width tuning with 0.038 mm shimming per nanosecond. We use this method successfully to make the pulse width difference from ~50 ns down to several ns.

CURVATURE TUNING

There is still another pulse shape difference among the four kickers called piecewise curvature difference. We propose to characterize this curvature by 7 check points, as shown in Fig. 2, at various timing points with the current (or magnetic field) 25%, 50%, 75%, … of peak value of the pulse of each kicker. The pulse width at 25%, 50% and 75% are taken accordingly. If one can shift the timing of any check points, one can modify the curvature.

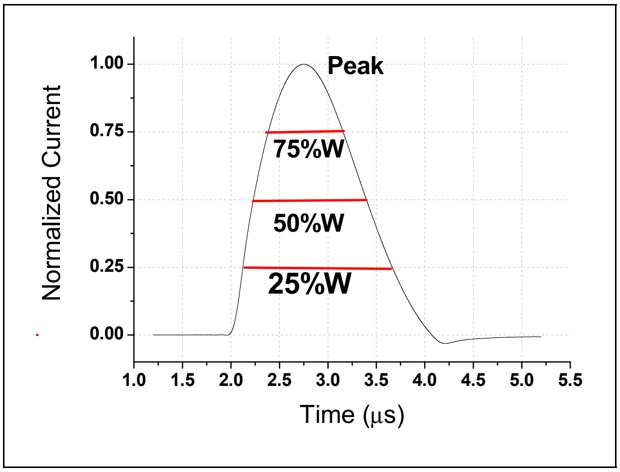

Figure 2: The proposed check points and pulse widths characterizing the shape of each pulse.

Basic Idea of Curvature Tuning

As depicted in Fig.3, we wired a secondary copper coil coincidently along the main coil of a kicker and shunted the secondary one with different resistors. The picture in Fig. 4 is the real testing set-up. The resistors are to be selected carefully in terms of high voltage capacity and good heat dissipation.

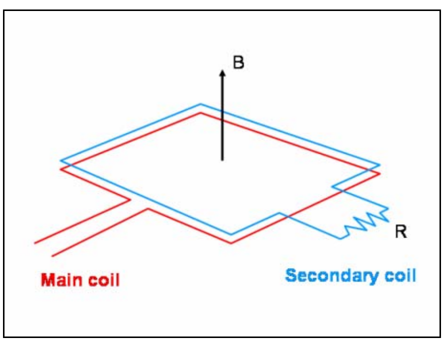

Figure 3: The secondary coil (cyan) with a resistor shunted to modify the magnetic field caused by the main coil (red).

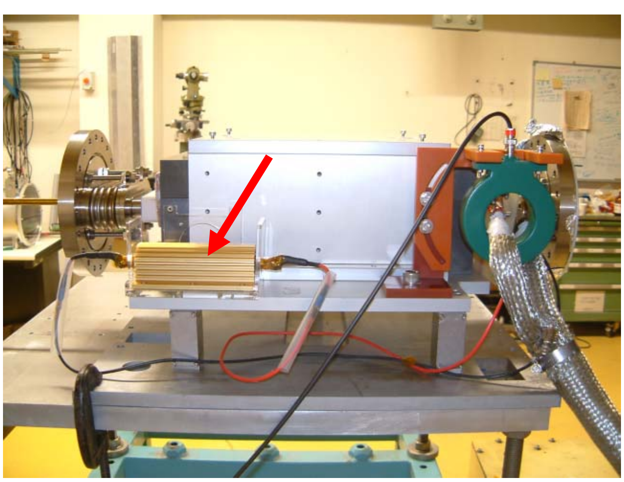

Figure 4: The real testing set-up of the secondary coil upon the main coil. The resistor is pointed.

We first imagine the following scenario. When the main coil is excited with a pulse current, a pulse magnetic field occurs at the gap of the kicker. If there is a secondary coil with closed-loop in the same gap, an electromotive force (emf)

$$\varepsilon = -M\frac{di_1}{dt}, \quad (1)$$

would be induced, where M is the mutual inductance between the secondary coil and the whole kicker, di_1/dt is the first time derivative of the current on the main coil. This emf will cause a current in the secondary coil,

$$i_2 = \frac{\varepsilon}{R}, \quad (2)$$

where R is the resistance of the resistor. In turn, the induced current will cause a magnetic field, with a shape proportional to the first derivative of the main coil current, modifying the field caused by the main coil in some way. Fig. 5 shows a typical pulse shape of the current, its first derivative of time and the modified pulse shape due to the subtraction of the first derivative multiplied by an arbitrary constant factor. The resistance will determine this factor.

It seems that one can modify the pulse shape according to above scenario. However, if the pulse shape is very close to an upper part of a sinusoid wave and the hysteresis is negligible, the modified pulse should be almost the same with the original pulse except a time lag and some modulation of the amplitude. One can understand this argument by the formulae below,

$$A\sin\omega t - B\cos\omega t = \sqrt{A^2 + B^2}\sin(\omega t - \delta), \quad (3)$$

and the calculation of δ/ω will get the time lag. Apparently it is hopeless to modify the curvature this way. On the other hand, addition of high harmonics can really change the shape of the sinusoidal wave as well known, like

$$A_1 \sin\omega t + A_2 \sin 2\omega t + A_3 \sin 3\omega t. \quad (4)$$

Nevertheless, in Fig. 5, because of the asymmetry of the pulse shape, one does have a modification.

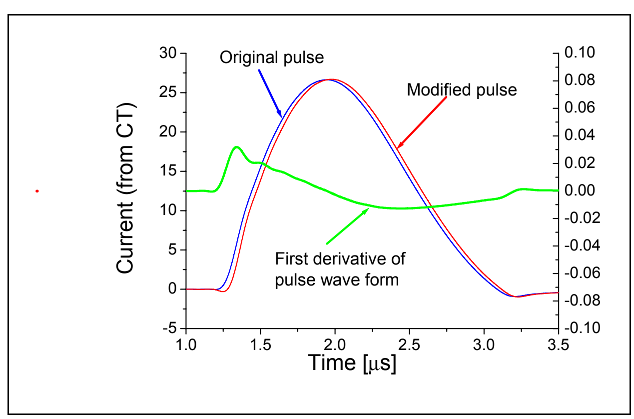

Figure 5: A typical pulse shape of the current and its modification

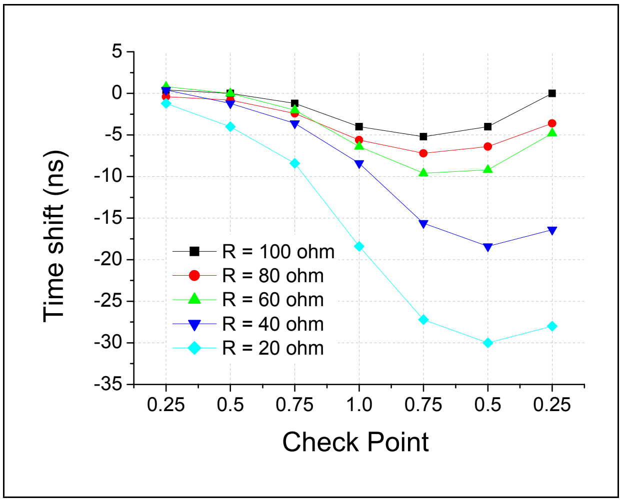

Figure 6: The real pulse shape modification observed from the check points.

Real Test of Curvature Tuning

To our surprise, in real test, the pulse shape is indeed deformed by the secondary coil. This deformation is recognized by the check points described before, as shown in Fig. 6. The reason is not clear yet, but one can modify the shape using the deformation pattern in Fig. 6. The good thing is that the amplitude change of the magnetic field pulse is proportional to that of current pulse [3], unlike the situation in pulse width tuning by shimming gap. The disadvantage is that the secondary coil also affects the pulse width on both field and current pulses.

DISCUSSION

By understanding the behaviour of the shimming gap and the secondary coil, we can modify the pulse shape as we wish. Since the shimming gap does not affect the curvature of the pulse shape, we can deform the pulse shape using the secondary coil first and then tune the pulse width by shimming gap. Be aware that in control room only the current pulse but not the field pulse can be detected. Therefore one has to tune the kicker in situ according the empirical formula derived from both current and field measurement in lab.

REFERENCES

[1] G. H. Luo et al., “The status of Top-Up Injection at NSRRRC”, Proceedings of APAC 2004, Gyeongju, Korea, p. 224.
[2] T.C. Fan et al., “Magnetic Field Measurement on a Refined Kicker”, Proceedings of PAC 2005, p.1682
[3] T.C. Fan et al., “Magnetic Field Measurement on New Kickers”, NSRRC internal report MMGFAN200601