NONLINEAR BEHAVIOR OF BETATRON OSCILLATION MEASURED WITH A WIDEBAND MAGNETIC BEAM SHAKER

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Abstract

A wideband beam shaker using a window-frame ferrite magnet has been designed and installed at the Photon Factory storage ring. The characteristic impedance of the magnet and the power-supply system was well adjusted to 50 Ohm in a frequency range up to 15 MHz. As a result, we obtain a flat response of the shaker around the low harmonics of the revolution frequency. The nonlinear response of betatron oscillation was investigated as a function of the excitation power. A broad resonance closely related to the beam loss phenomenon was observed. The resonance shape was changed depending upon the oscillation amplitude and the direction of the frequency scan.

INTRODUCTION

At the Photon Factory (PF) storage ring, we have several types of devices installed for the excitation of transverse oscillation. An RF knockout (RFKO) system using a stripline electrode is mainly used for the tune measurement and for killing the electrons in the surrounding bunches at the single-bunch operation [1]. A high-frequency quadrupole magnet (HFQM) system [2] can make the modulation of betatron tune from bunch to bunch. A fast kicker system is a pulsed deflector for the single-bunch beam. It is mainly used for the study of beam dynamics in conjunction with a phase-space monitor [3]. Both the HFQM and the fast kicker are constituted of window-frame ferrite cores and are excited in a frequency rage of a few MHz using dedicated high-power supply systems. The stripline electrode is a very wideband device as is often called the quarter-wave loop. The center frequency of the stripline was tuned to the RF frequency of 500 MHz. Hence the kicker function of the stripline near the revolution frequency (1.6 MHz) is low and no a flat one. The stripline is suitable for killing the electrons in surrounding bunches and the bunch feedback. Those functions need a wideband response around the RF frequency.

The beam shaker system described in this paper has been matched to 50 Ohm in a bandwidth up to 15 MHz and has a flat response in this range. Its principal operation is the excitation of the betatron oscillation near the low harmonics of revolution frequency. As it is well compatible with an all-purpose wideband RF amplifier, the waveform of the input signal can be precisely controlled in combination with an arbitrary waveform generator. In the following sections, we report the design and the construction of the shaker magnet. A preliminary experimental result of the nonlinear behavior of the betatron oscillation observed by using this beam shaker system is also described.

Table 1: Parameters of the beam shaker.

	Horizontal	Vertical
Magnetic length	130 mm	
Gap height	70 mm	140 mm
Gap width	140 mm	70 mm
Peak field	1×10^{-4} T	0.5×10^{-4} T
Inductance	2.47 μH	2.45 μH
Capacitor, C1	69 pF	147 pF
Capacitor, C2	100 pF	220 pF
Core material	Ferrite (TDK PE14)	

CONSTRUCTION OF THE BEAM SHAKER

The beam shaker has been designed as a window-frame ferrite-core type magnet with two set of double-turn coil. One coil is for the horizontal kick and the other for the vertical kick. The coils were made of a copper busbar of 5 mm width and 3 mm thickness. In order to suppress a cross talk between two coils, the width of the busbar was laid out rather narrow compared with the conventional design of the window frame magnet such as the injection kicker.

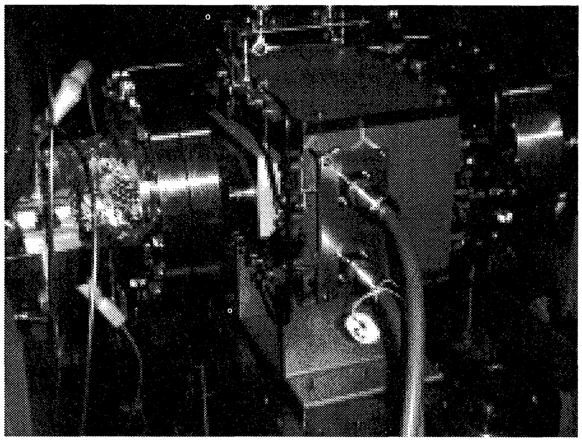

Figure 1: Photograph of the shaker magnet with the ceramic chamber.

Figure 1 shows a photograph of the shaker magnet installed in the PF ring with the ceramic vacuum chamber. The shaker was installed in one of the short spaces between the two quadrupole magnets in the arc section. The length of the ferrite core is 130 mm. The effective length of the ceramic duct is about 170 mm. The parameters of the shaker are summarized in table 1.

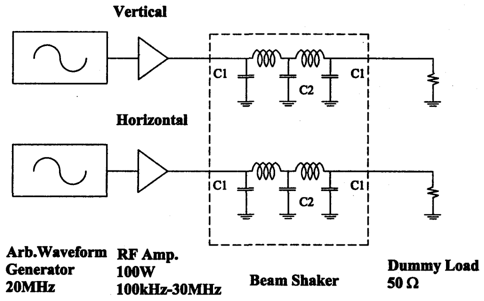

Figure 2: Block diagram of the beam shaker system.

A block diagram of the power supply for the shaker is shown in figure 2. The input signal from the arbitrary waveform generator is amplified by a 100-W RF amplifier of 30-MHz bandwidth. The RF amplifier has a fixed gain of 50 dB. The current after passing through the shaker is terminated by a 50-Ohm dummy load. The same driving systems are prepared for the both coils of the shaker.

In order to match the impedance of the magnet in a wide frequency range, we applied a simple filter design theory known as the constant-K design for the circuit designing. A 5th-ordrer low pass filter was made by the inductance L and the shunt capacitors at the both ends (C1) and the center (C2) of the coil as shown in the figure 2. We determined the values of both C1 and C2 by calculation to match the impedance by using the measured values of inductances of coils. The cut-off frequency was also estimated by the calculation. A comparison of the transmission loss (S_{21}) of the shaker with and without the capacitors is shown in figure 3. When the capacitor was applied, the cut-off frequency was extended to 17 MHz for the horizontal and 14 MHz for the vertical, respectively. These values agreed well with the estimated values.

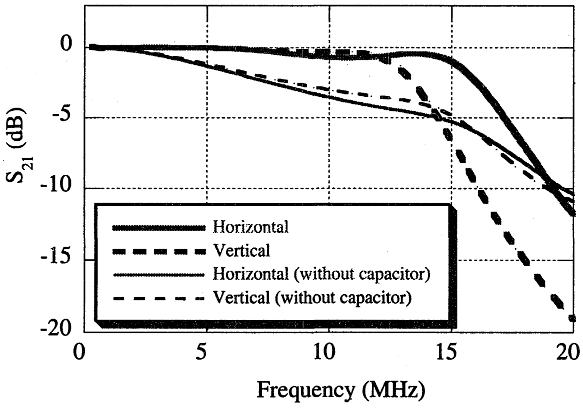

Figure 3: Measurement of the transmission loss, S_{21}, without the ceramic chamber.

When the shaker magnet was set with the ceramic duct in the storage ring, the transmission loss was deteriorated in the lower frequency range. The origin of this deterioration was the stray capacitance between the coil and the environmental metallic structure such as the coating inside of the ceramic duct, the beam duct and the vacuum flanges. The values of capacitors were adjusted to make transmission loss smaller and to extend the cut-off frequency larger. The smaller capacitance than the calculated one was better for the impedance matching, and it also extended the cut-off frequency up to 24 MHz for the horizontal and 18 MHz for the vertical, respectively.

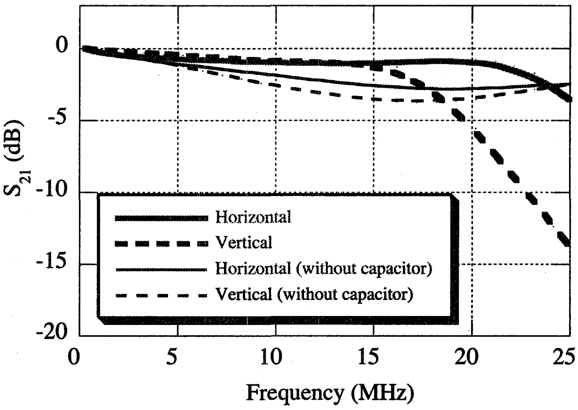

Figure 4: A result of the adjustment of the transmission loss after installed in the storage ring.

The current in the coil was measured using a current transformer (PEASON 2100). Figure 5 shows the magnetic field converted from the measured current as a function of output power of the arbitrary waveform generator. The good linearity is obtained over the power level of -6 dBm. Beyond this level, output power of the RF amplifier reached to the saturation, we observed a little deformation of the output waveform.

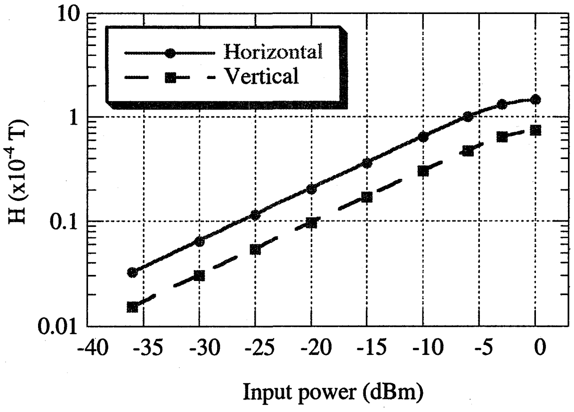

Figure 5: Magnetic field as a function of the output power of the arbitrary waveform generator at a frequency of 1 MHz.

Hence the vertical gap is a half of the horizontal gap, the vertical field strength is twice as much as the horizontal one. At the installation point of the beam shaker, the square root of the β-function in the horizontal direction is about one half of that in the vertical direction, so the effective kick angles in the both directions are almost same for the same input power.

EXPERIMENTAL

By using the shaker, we measure the betatron tune shift as a function of amplitude of the betatron oscillation. The principal parameters of the PF ring during the measurement were as follows: E = 2.5 GeV, f_{rf} = 500.1 MHz, f_r = 1.602 MHz, $\nu_x = 9.60$, $\nu_y = 4.28$ and $\nu_s = 0.013$. Where E is the electron energy, f_r the revolution frequency, ν_x and ν_y are the horizontal and vertical betatron tunes, respectively, and ν_s the synchrotron tune. The vertical fractional betatron frequency was 441 kHz and the synchrotron frequency 21 kHz. The beam current was about 400 mA, and the octupole field was applied for suppression of the transverse instability. The amplitude of the oscillation was observed at an upper side-band of the f_{rf} in the signal from a button electrode. The result of the betatron tune shift is shown in figure 6. The abscissa is the observed amplitude of the betatron oscillation. The both data for the vertical and horizontal tune shift are plotted together in the figure 6. The amount of tune shift has a similar tendency in the both directions.

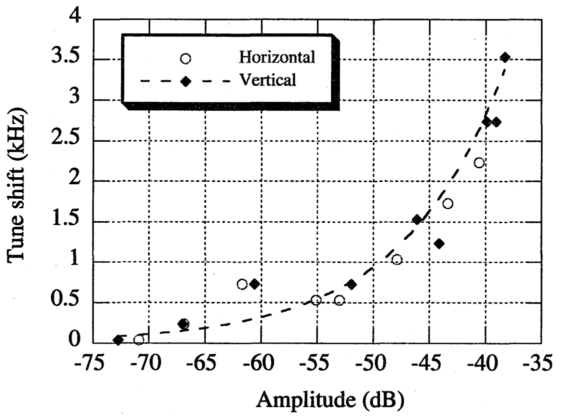

Figure 6: Tune shift as a function of the amplitude of betatron oscillation.

For the vertical direction, we observed a change of resonance shape in the spectrum when the input power was increased as shown in figure 7. The left spectrum in the figure 7 shows a sharp resonance at the center and this spectrum is usually observed at the lower input power. Also in the left spectrum, the small peak was observed at the frequency that is about 20 kHz above the betatron peak. It corresponds to the synchrotron sideband. At the higher input power, the resonance peak was started at the same frequency as in the lower power and it continued until f_β+20 kHz as shown in the right spectrum. This broad resonance shape was only appeared in the upward frequency scan. Two results of spectrum taken by a downward frequency scan using the same input levels are shown in figure 8. Two spectra in figure 8 are almost same in the shape, and the distinctive broad resonance shape did not appear in the downward scan. When the frequency scan reached to the broad resonance, the beam loss or the drop of the beam lifetime was observed. In other hand, no beam loss was observed in the downward scan even using a maximum input. We have not yet understand how such broad resonance continues in the upward scan, and why it is related to the beam loss. We are planning to investigate the instantaneous transverse and longitudinal beam profile during the resonance.

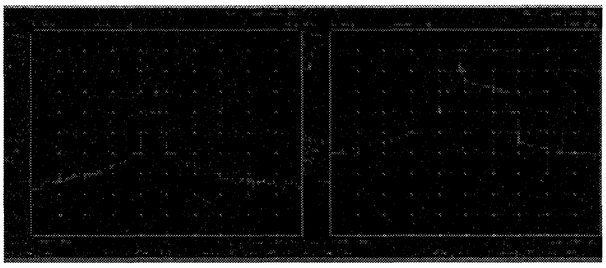

Figure 7: The resonance spectrum for the upward frequency. The input power was -20 dBm for the left and -3 dBm for the right.

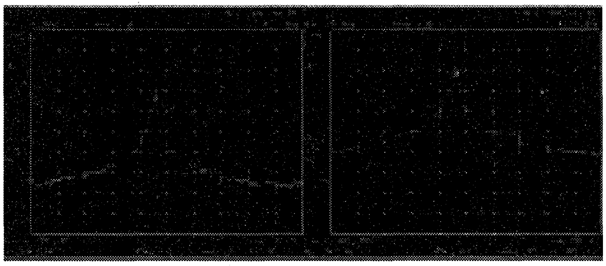

Figure 8: The resonance spectrum for the downward frequency scan. The input power was -20 dBm for the left and -3 dBm for the right.

SUMMARY

A wideband beam shaker using a magnet with a ferrite core was newly constructed and installed in the Photon Factory storage ring. As the impedance could be well matched in the wide frequency range, it was suitable for the precisely controlled beam excitation around the low harmonics of the revolution frequency. The preliminary experimental results showed that it was useful for the investigation of nonlinear behaviour of the betatron oscillation.

REFERENCES

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