RESONANT STRIP-LINE TYPE LONGITUDINAL KICKER

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Abstract

The new type of longitudinal kicker for bunch-by-bunch feedback based on the resonant strip-line shape is proposed and the prototype model was tested with low power. Waveguide over-loaded cavity type kickers are widely used for this purpose, however, the length of the new kicker is less then half of them, therefore, the higher shunt impedance per length is expected, which is necessary for large and high energy storage ring like SPring-8.

INTRODUCTION

Longitudinal multi-bunch instability is observed in the SPring-8 storage ring at the test of the low energy operation below 6 GeV. The instability is driven by a higher order mode of acceleration cavities and the instability was suppressed by introduction of Landau damping with introducing synchrotron tune spread by driving one of the four RF acceleration station by one revolution higher frequency than RF acceleration frequency. However, the freedom of the filling pattern, which is indispensable for user operation, was lost with such scheme. Therefore, the longitudinal bunch-by-bunch feedback is now under consideration for alternative solution for the suppression of the longitudinal instability. However, for the SPring-8 storage ring, the circumference and energy are larger, thus, larger kick is necessary to suppress the instability, but the installation length for the feedback is limited to just one meter long as the other rings. Therefore, the high efficiency longitudinal kicker: high shunt impedance per length is needed for the ring. Also the RF frequency of the ring is 508.58MHz, which is also highest frequency in the light sources.

To fulfil the requirements above, we proposed the resonant strip-line type longitudinal kicker [1], of which length is less than half of the length of waveguide overloaded cavity type kickers [2-6] widely used in the bunch-by-bunch feedback, therefore the new kicker is expected to have larger shunt impedance / length.

RESONANT STRIP-LINE KICKER

A prototype of the resonant strip-line type longitudinal kicker (RSL kicker) was designed and constructed as shown in Fig. 1, with the inner shape of the kicker in Fig. 2. The total length of the kicker inner structure is just 100mm, which is less than half of the length of waveguide over-loaded cavity kickers (WOC kickers) widely used in the bunch-by-bunch feedback.

The kicker has six ports: two input ports, two horizontal ports, and two vertical ports as shown in Fig. 2. The RF power is fed through the input ports, and the most of the power come back from the input port. The H-ports and V-ports are for damping of trapped modes in the kicker.

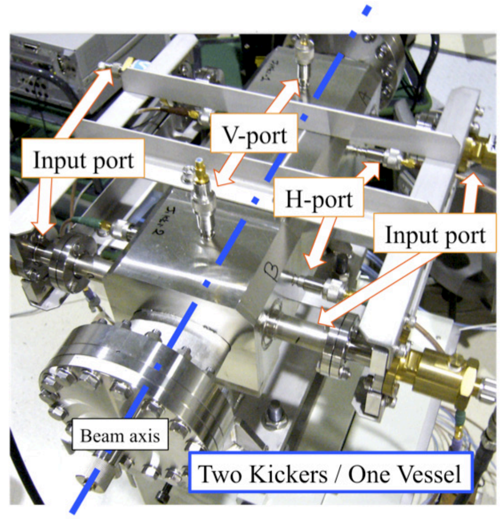

Figure 1: Prototype of longitudinal kicker. Two kickers are contained in the vacuum vessel; with their input ports are set far sides each other. The distance or wall thickness between two kickers in the vessel is 169 mm. However, this can be shorten to tens mm in principle, thus the reduction of the vessel size, or the increase of the number of kickers in a vessel are possible.

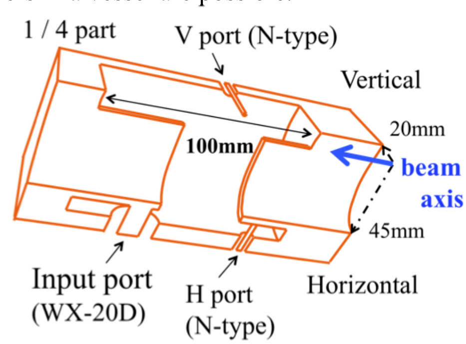

Figure 2: Inner shape of one of the kickers (simulation model for MAFIA T3). One quarter part is shown in the figure.

The center frequency of the RSL kicker is defined by the length of the stripline, not the outer radius as WOC kickers, therefore, the center frequency can be set higher than WOC kickers, of which center frequency is usually set to ~ 1.4 GHz, or (3-1/4) f_{RF} for ~500MHz RF acceleration frequency. For the RSL kicker, the center frequency of the kicker is set to

$$f = (3+1/4)\, f_{RF} = 1.65 \text{ GHz},$$

where f_{RF} = 508.58MHz is the RF frequency of the ring. With such higher frequency, three waves can be input to the kicker during one RF period (~2ns). Also the kicker length can be shorten with high frequency. However, the drive frequency is extend to the cut-off frequency of the beam pipe (40×90) : ~2GHz, and some part of the input power propagate through the beam pipe. Also the sensitivity to jitter or drift of the timing is higher.

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FIELD SIMULATION

The kicker was designed with the three-dimensional electromagnetic field simulation with MAFIA-T3. The kick voltage on the beam including the transit-time factor was obtained with the wake function calculation function of MAFIA-T3 by setting the beam charge so small that the wake field is negligible compared with the kick field.

In the simulation, the output signals at each ports (input port, H-port and V-port) and kick on the beam was calculated for the short input signal of Gaussian shape of 17ps (rms) to the input ports. Then, using these responses as Green functions, the responses to the arbitrary input wave shapes were calculated.

The input signals for the simulation: single-wave, three-waves, and ten-waves pulses, are shown in Fig. 3. The three-wave pulse is the nominal drive signal to the kicker. The kick and the output signal of the H-port are shown in Fig. 5. The shapes of the signals are similar but the kick voltage is 15 times higher than the H-port signal voltage. This ratio of the voltage also holds for the 10-waves pulse. With this result, the kick voltage is easily estimated from the H-port output signal at the bench measurement.

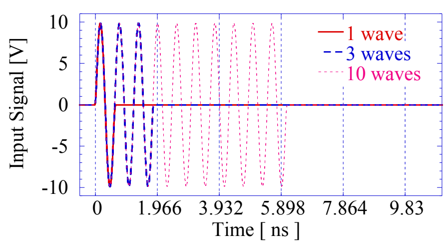

Figure 3: Input signal to one of the input ports; single-wave (1 wave), three-waves (3 waves), and ten-waves (10 waves) pulses. The same signal was also fed to the other input port. Bunch spacing is 1.966 ns.

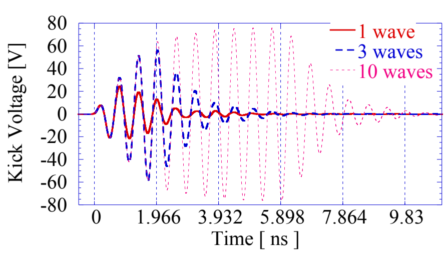

Figure 4: Kick voltage produced by the input signal in Fig. 3.

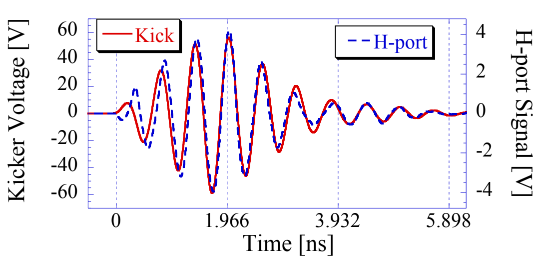

Figure 5: Kick and H-port output signal for the input signal of three-waves pulse: standard drive signal to the kicker.

The shunt impedance $R = V_k^2/(2P)$: (V_k and P are peak kick voltage and total input peak power, respectively), calculated with the result is 1.4 kΩ for CW drive with a ten-waves pulse, and 880 Ω for a three-wave pulse. Those values are comparable to those of WOC kickers, but the length is less than half.

The calculated wake fields are shown in Fig. 6 and 7. Due to the H-ports and V-ports, the wake fields decay in a few nano seconds. The longitudinal loss factor is 0.64 V/pC for 5mm (rms) bunch; comparable to WOC kickers.

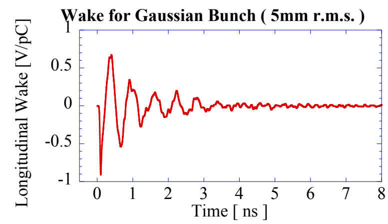

Figure 6: Longitudinal wake field for Gaussian bunch of 5mm (rms).

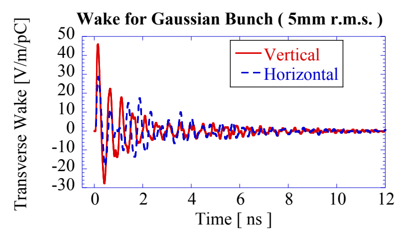

Figure 7: Horizontal and vertical wake field.

MEASUREMENT

Low power RF measurement was performed with the kicker. The input signal is produced by the circuit in Fig. 8. A rectangular pulse of duration ~ 500ps, locked to the RF reference signal, is generated by a signal generator. The pulse is amplitude-modulated with a feedback signal by a mixer, then is differentiated by an impulse forming network (IFN) to form a bipolar pulse. The INF can be replaced by a SMA T-junction with one port is shorted and the other are padded with attenuators. After the IFN, the pulse is divided to three signals; each signal passes the delay and the attenuator, then combined to form a pulse with three waves (three-wave pulse). The amount of the delays and attenuators can be chosen for the signal shape for maximum efficiency. The three-wave pulse is amplified and divided to the two input ports of the kicker. The circulators are placed at the input ports because the most power to the input ports is reflects back.

In this measurement, the power of the amplifier was reduced to the level shown in Fig. 10 by an attenuator just after the amplifier (not shown in the Fig. 8).

The input power is expected not to propagate in the beam pipe because the cut-off frequency for horizontal electric field is ~4GHz and only horizontal electric field is driven by the input signal with its symmetry. However, the transmission of the level of -60dB was observed form the input port to the V-port in the next kicker with the nominal input signal. Therefore, some care might be necessary for high sensitivity devices around.

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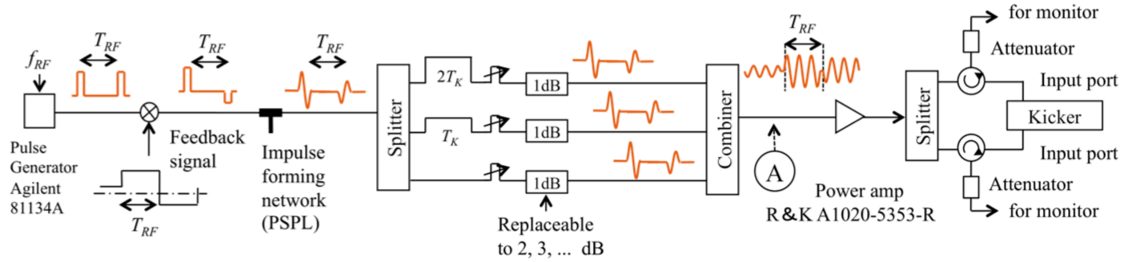

Figure 8: Drive signal generation circuit. The amplitude-modulated mono rectangular pulse is processed to the train of bipolar pulse with simple analogue circuit.

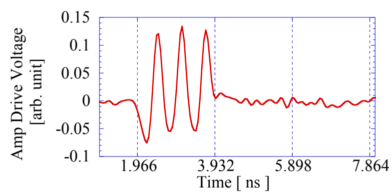

Figure 9: Signal to the input of the power amplifier (point A in Fig. 8).

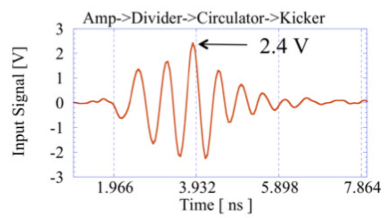

Figure 10: Signal to the input port of the kicker.

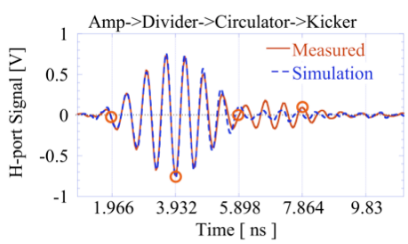

Figure 11: Output signal of the H-port: The measured signal (solid) and the simulation result (dashed) based on the measured input signal in Fig. 10.

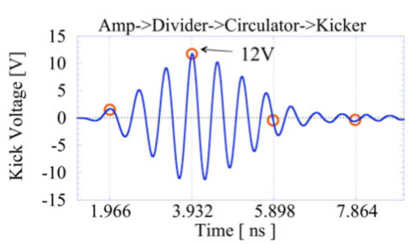

Figure 12: Kick voltage for the input in Fig. 10 estimated by the simulation result. The circles are the timing of the bunch passage.

The measured input signal to the amplifier is shown in Fig. 9. The three-wave pulse is obtained as expected. The input to the kicker is shown in Fig. 10 and suffers the deformation by the limited frequency response of the amplifier, power splitter and circulators. The output signal of the H-port is shown in Fig. 11. For the comparison, the signal estimated by the Green function by simulation with the input pulse in Fig. 10 is also shown.

The kick voltage for the input in Fig. 10 is estimated with the Green function obtained by the simulation. The result is shown in Fig. 12. The kick voltage is V_K = 12V for the peak input voltage 2.4 V in Fig. 10, corresponding to 0.058 W/port, and total power is P = 0.115 W. With these values, the shut impedance $P = V_k^2/(2P)$ is expected to be 625 Ω, slightly lower than the simulation result. One of the possible reasons is that the deformation of the input voltage to the kicker shown in Fig.10, therefore, the correction by the attenuators and delays might improve the signal shape and the peak input power.

The kicker was excited with sinusoidal CW wave of 0.1V peak at the center frequency 1.65 GHz. The voltage of the output signal from the H-port was observed to be 0.05Vpeak. With the ratio of the kick voltage, 15, obtained with the simulation, the kick voltage is 0.75V and the shunt impedance of the kicker is 1.4 kΩ for a CW signal at the center frequency.

SUMMAY

The resonant strip-line type longitudinal kicker is proposed and, from the simulation and the bench measurement result, the higher shunt impedance per length than waveguide overloaded cavity type kickers is expected. The beam test for the kick voltage measurement is expected.

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