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# IMPROVED FREQUENCY CHARACTERISTICS USING MULTIPLE STRIPLINE KICKERS*

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*Abstract*

One of the important ingredient in the intra-bunch transverse feedback is a kicker. The frequency characteristics of the kicker suffers from the transit-time factor, sin(kl)/kl. We examine the frequency characteristics of multiple kickers system. Relation between the excitation patterns of the multiple kickers and the frequency characteristics are presented.

## INTRODUCTION

In the MR (Main Ring synchrotron) of J-PARC (Japan Proton Accelerator Research Complex), a transverse intra-bunch feedback system is running at the sampling clock frequency of 64th harmonic of the acceleration RF, 107 - 110 MHz [1]. During a recent high-power beam test, we observe a transverse instability signal oscillating close to the Nyquist frequency (Fig. 1). Therefore, we intend to increase the frequency higher enough than the Nyquist frequency. The feedback system comprises a position monitor, controller, RF power amplifier and kicker. We need upgrade the controller and kicker for higher frequency response. Present kicker is a stripline kicker which has a node (= zero gain) at 200 MHz. Improvement possibilities are discussed using multiple stripline kickers.

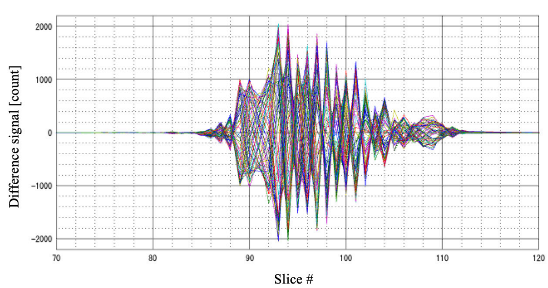


Figure 1: Horizontal difference signal sampled by iGp12-H [2], the intra-bunch feedback controller. Data of 51 consecutive turns are superimposed.

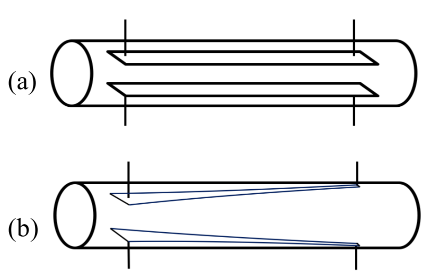


Figure 2: Stripline kickers.

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## SINGLE AND MULTIPLE KICKER SYSTEM

In case of single kicker, ordinary stripline electrode and tapered electrode are considered. The Faltin type kicker [3], [4] is not examined in this paper.

### *Single Stripline Kicker*

Ordinary stripline kicker is depicted in Fig. 2 (a). The kick angle Δx' is evaluated by integrating the Lorentz force along the beam path.

$$\Delta x' = \frac{1}{p_z}\int_{-l/2v_z}^{l/2v_z} \mathrm{e}(\mathrm{E}_x - v_z B_y)\, dt$$
$$\sim \frac{2}{p_z}\int_{-l/2v_z}^{l/2v_z} \mathrm{e}\bar{\mathrm{E}}_x\, e^{2j\omega t}\, dt$$
$$= \frac{2e}{p_z}\bar{\mathrm{E}}_x \frac{l}{v_z}\frac{\sin(\omega l/v_z)}{\omega l/v_z}$$

where $p_z$, e and $v_z$ are the momentum, charge and velocity of the charged particle, respectively, and $E_x$ and $B_y$ are the electric and magnetic field of the injected RF, respectively. Subscripts indicate the vector components projected on the indicated axes. $v_z$ is assumed to be close to the light velocity, c. The last part of the right-hand-side, sinc function, is the transit time factor [5]. Using this result the frequency response of the kick angle is plotted by a blue curve in Fig. 3, with the kicker length of the J-PARC MR, 750 mm. The nodes are located periodically and no gain at these frequencies. Using tapered coupler (Fig. 2 (b)), the frequency response becomes smoother as a red curve in Fig. 3. But the gain decreases as the frequency goes higher.

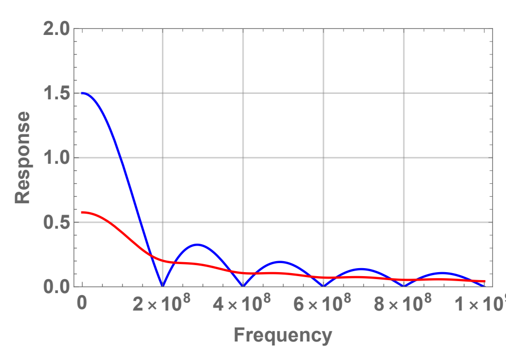


Figure 3: The responses of two kinds of stripline kickers. Blue curve: ordinary stripline, red curve: tapered stripline.

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### *Multiple Stripline Kickers*

Consider 2N+1 kickers with the kicker length of $l_k$ and the spacing is $l$ as shown in Fig. 4. The kick angle is evaluated by the same procedure but an integration interval is from $(-l_k/2+nl)/v_z$ to $(l_k/2+nl)/v_z$ for the n-th kicker.

$$\Delta x' = \sum_{n=-N}^{N} 2\frac{e}{p_z}\int_{(-l_k/2+nl)/v_z}^{(l_k/2+nl)/v_z} \overline{E}_z e^{-2j\omega\Delta t} e^{-2j\omega t_0(n)}\, e^{2j\omega t}\, dt$$

$$= 2\frac{e}{p_z}\frac{l_k}{v_z}\sum_{n=-N}^{N} \overline{E}_z(n)\, e^{-2j\omega t_0(n)}\frac{\sin(\omega l_k/v_z)}{\omega l_k/v_z}\, e^{2nj\omega l/v_z}$$

$$\sim 2\frac{e}{p_z}\frac{l_k}{v_z}\sum_{n=-N}^{N} \overline{E}_z(n)\, e^{-2j\omega t_0(n)}\, e^{2nj\omega l/v_z}$$

At the final step the sinc function is approximated with the delta function. This final expression expresses the Fourier transform of the kicker amplitude variation, $\overline{E}_z(n)e^{-2j\omega t_0(n)}$ as a function of n. Therefore, a flat frequency response (rectangular window) is obtained if the kicker amplitude variation is the sinc function of n. The example amplitude variation is plotted with blue dots in Fig. 5. The frequency response is obtained with the exact equation and using the kicker length of 0.15 m and spacing of 0.15 m, the blue curve in Fig. 6. Using the constant kicker amplitude as red dots in Fig. 5, the frequency response shows very narrow bandwidth as the red curve in Fig. 6. These two amplitude setups are using a constant RF phase, $\omega t_0(n) = 0$ and total RF power is normalized to 1. There is no phase variation in the frequency response.

Adopting the phases so as to synchronize the beam with the RF, which means $n\omega l/v_z = \omega t_0(n)$, the frequency response amplitude becomes highest as a dark red curve in Fig. 6. This is 2N+1 times of single kicker transit time factor.

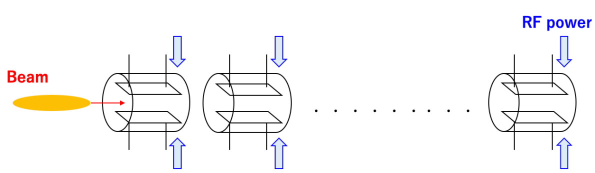


Figure 4: Multiple stripline kickers.

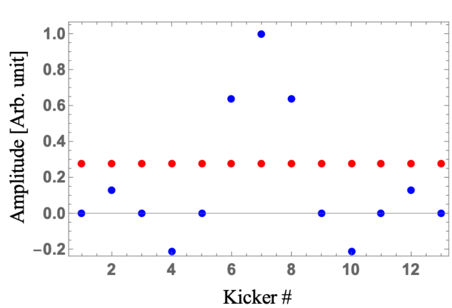


Figure 5: The amplitude variation of the multiple stripline kickers.

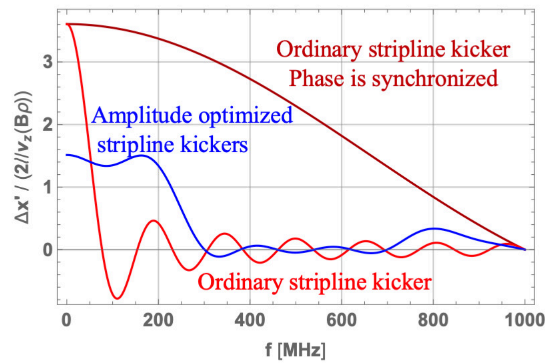


Figure 6: Frequency responses of the multiple stripline kickers.

These results show that within the constant RF phase the sinc-function weighted kicker amplitude produces better frequency response, but in terms of efficiency the beam-synchronized RF phase is the best.

## APPLICATION TO THE THREE KICKER SYSTEM FOR THE SLOW EXTRACTION

In the slow beam extraction in the J-PARC MR, three serial-connected kickers are used as the "transverse RF" [6] for reducing spill fluctuation. The schematic view is depicted in Fig. 7. The number of kickers has been increased step by step. When the kickers are used for intra-bunch feedback, only one kicker is connected with the RF source and the other kickers are just terminated to 50 Ω loads.

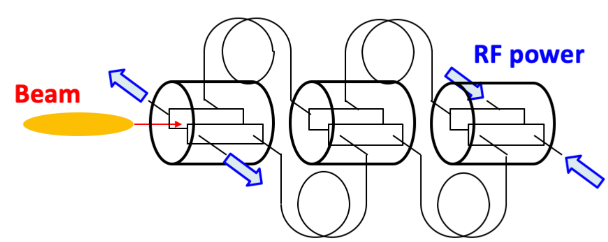


Figure 7: Serial connected stripline kickers.

The expression of the kick angle is rewritten with the RF phase variation with the aid of Fig. 8,

$$\Delta x' = 2\frac{e}{p_z}\frac{l_k}{v_z}\overline{E}_z\frac{\sin(\omega l_k/v_z)}{\omega l_k/v_z}\{e^{-2j\omega(-\Delta t)}e^{-2j\omega l/v_z} + 1 + e^{-2j\omega\Delta t}e^{+2j\omega l/v_z}\}.$$

The RF phase is measured with reference to the center input port. If the phases of the three input ports, $2\omega l/v_z - \omega\Delta t$, taking account of the transit time of the RF between the kickers, $\omega l/v_z$, are the integer multiples of π, the inside of the parentheses becomes 3 and the kick angle becomes the maximum. With the kicker length $l_k$ = 0.75 m, the spacing $l$ = 1.05 m, the frequency = 47.47 MHz and Δt = 7.11 ns, the frequency response is obtained as shown with the blue curve in Fig. 9. The green curve is for the case of the beam-synchronized RF phase, which is

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just as a reference and cannot be realized by serial-connection.

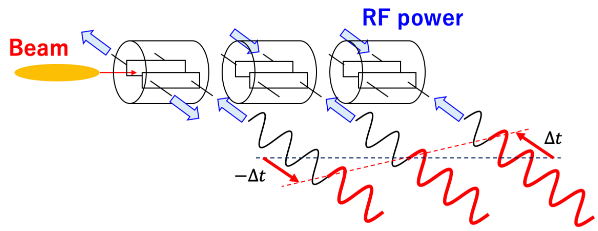


Figure 8: Three stripline kickers with variable RF phases.

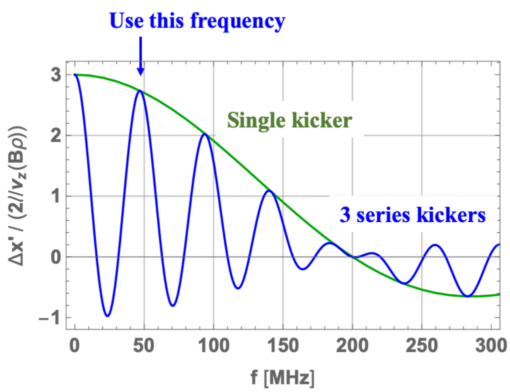


Figure 9: Three-kicker response tuned to the 47.47 MHz.

## CONCLUSION

Multiple kickers with variable amplitudes and phases gives intended response, using inverse Fourier transform. But comparing with the same input RF power, the constant amplitude setup with beam synchronization gives the best efficiency which is the kick angle with the same input RF power.

Using the same formula, the response of three-series-connected kickers is evaluated.

The Faltin type kicker will be examined and compared to this results for the next step.

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