ON-AXIS INJECTION USING A *SIN* WAVE RF KICKER

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Abstract

On-axis injection is one of the critical issues for an ultra-low emittance storage ring which holds a rather small dynamic aperture. In order to reduce the challenges of the fast pulsed kicker design, a *sin* wave RF kicker is studied which is suitable for longitudinal on-axis injection. Since the injected bunch is longitudinally apart from the stored bunches, the location of the stored bunches can be at the π knot of the *sin* wave, while the injected bunches are launched at a phase around π/2+n·π. At this situation the injected bunches will receive a transverse kick, however the store bunches are almost un-affected.

INTRODUCTION

The brightness of the synchrotron radiation is inversely proportional to the transverse emittance of the electron beam in a storage ring. The next generation ring based synchrotron light source pursues an ultra-low emittance which is generally through applying a multi-bend archromat (MBA) lattice[1]. For the MBA lattice, the focusing strength of the quadrupole is much stronger than that of the third generation light sources, as well as sextupoles, which will greatly reduce the dynamic aperture. Some of the MBA lattices only get few millimetres dynamic apertures, leave great challenges for injection [2,3,4]. On-axis injection is then proposed. There are two types of on-axis injection, one is so called swap-out injection[5,6], which replaces the stored bunches with the fresh bunches either from an accumulation ring or from an injector, the other one is longitudinal on-axis injection, for which case, the injected bunches are longitudinally apart from the stored bunches. The injected bunches are longitudinally merged into the stored bunches either through radiation damping [7] or through RF system manipulation [8].

For swap-out on-axis injection, a pulsed kicker is required. If an individual bunch replacement is required, the pulsed kicker will be quite challenging. The pulse rising and falling time should shorter than the bunch spacings. The pulsed kicker is also working for the longitudinal on-axis injection scheme. However we will show bellow a *sin* wave kicker is also adaptive for the longitudinal on-axis injection. Comparing to the pulsed kicker, the *sin* wave kicker is much easier to design and gets less challenges for pursuing a large deflecting angle.

SIN WAVE TRANSVERSE KICK FOR LONGITUDINAL ON-AXIS INJECTION

For longitudinal on-axis injection, the injected bunches are longitudinally separated from the stored bunches. A transient transverse dipole kick should be given to the injected bunches in order to correct the x’ to zero. As to achieve accumulation, the stored bunches should not be affected remarkably by the kicker. After injected bunches are captured in the transverse phase space, they will longitudinally merge into stored bunches either through the radiation damping [7] or through the RF system manipulation [8].

To reduce the challenge of the transverse kicker, we propose using a *sin* wave RF kicker for on-axis injection. The frequency of the RF kicker is $n/2{\cdot}f_{rf}$ where n is an integer, f_{rf} is the accelerating RF frequency. The stored bunches is located at the π kont of the wave. For this setting up, the stored bunches will receive a transverse *x-z* correlated kick which is similar to the effect of a deflecting cavity to generate short pulses in a storage ring [9]. At the RF kicker phase π/2 depart to the stored bunches, there will be a large transverse kick, if the injected bunches are lunched around this phase, they can be on-axis injected to the closed orbit.

Fig. 1 shows how the *sin* wave kicker plays in the on-axis injection scheme. The storage ring gets two RF systems, one is 500MHz and the other on is 250MHz as has explained in [8], the injected bunch is launched at a bucket created by the RF system manipulation which is 2ns apart from the stored bunches at both sides. A 125MHz transverse electrical field kicks the injected bunch on to the closed orbit while gives the stored bunches a *x-z* deflecting. After injection, the accelerating RF systems manipulate a reverse process to merge the injected bunch into the stored bunch as shown in Fig. 1 b and Fig 1. c. For this case only charges in the odd index buckets can be complemented. To complement even index buckets, the phase of the kicker needs a π adjustment.

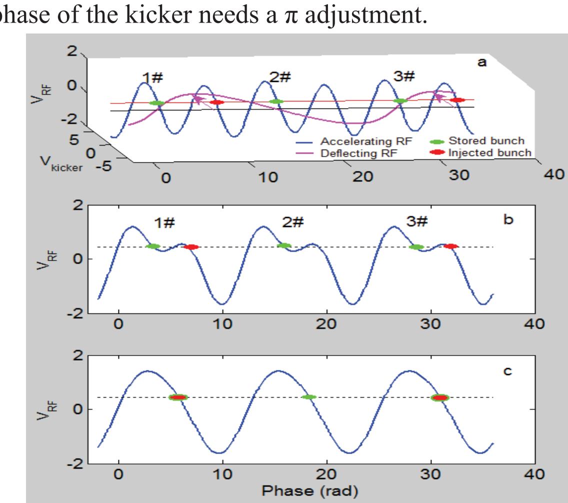

Figure 1: Sketch of the *sin* wave kicker play in longitudinal on axis injection (Fig 1a 500MHz RF is 1.5MV, 250MHz RF is 0.15MV, Fig 1b 500MHz RF is 0.6MV, 250MHz RF is 1.05MV, Fig 1c 500MHz RF is 0.15MV, 250MHz RF is 1.5MV).

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For such a *sin* wave kick, the pulse duration can be at the order of revolution time which is in micro-second range, much longer than *ns* pulse proposed in [10]. Take SSRF storage ring for example, the revolution time is 1.44μs, if the injected bunch is at the peak voltage of the pulse, the total pulse duration can be 2.88μs as shown in Fig. 2.

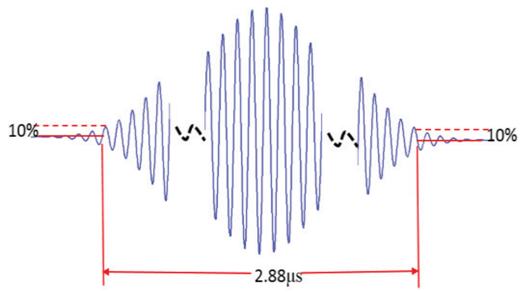

Figure 2: *Sin* wave pulse duration for SSRF storage ring.

INJECTION SIMULATION FOR SSRF-U

Taking SSRF-U[11] lattice as an example for injection tracing. The main parameters of the storage ring and the booster are listed in Table 1.

Table 1: Main Parameters of SSRF-U Storage Ring and Booster

Ring	Parameters	Value
Storage ring	Lattice	7BA
	E_0	3.0 GeV
	C	432 m
	$\nu_{x/y}$	43.22/17.32
	V_{RF}	1.75 MV
	f_{RF}	500 MHz, 250 MHz
	Emittance	202 pm rad
	Transverse emittance ratio	10%
	Damping time (x,y,z)	9.6ms, 19.6ms, 20.3ms
	Bunch charge	0.4mA/bunch (3.6e9 electrons)
	Momentum compaction factor	2.0e-4
	Energy spread	0.09%
	U0	0.44 MeV
	Bunch length	3.5mm@500MHz, 5.0mm @ 250MHz
Booster	Emittance	42nm rad
	Bunch length	11.6mm
	Energy spread	0.077%

A brief design of the injection section located at a 12m straight section is as shown in Fig.3. The injected bunch needs a 1.5mrad kick. As the strip-line is 0.75m, the peak electric field should be 6MV/m. The effect of the kick to the stored beam is simulated as shown in Fig. 4, the oscillation amplitude in horizontal plane is far smaller than the dynamic aperture. Fig. 5 shows the tracking results of injected bunch, the oscillation caused by the kick field uniformity received by the head and tail of the bunch is negligible.

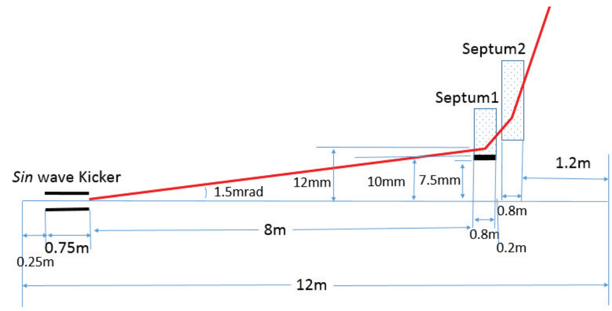

Figure 3: Injection section design for SSRF-U.

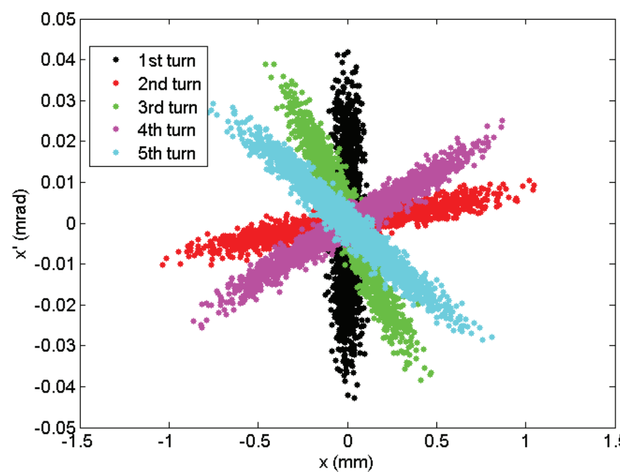

Figure 4: Beam motion of the stored bunch after injection.

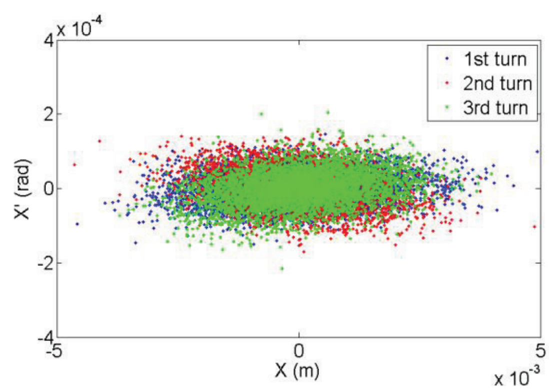

Figure5: Beam motion of the injected bunch.

KICKER DESIGN

A preliminary kicker design is as shown in Fig. 6. The system consists an arbitrary waveform generator (AWG) based on FPGA which generate 125MHz *sin* wave pulse triggered by the timing system. A time delay controller

(TDC) is used for phase adjustment. The signal is amplified by a narrow-band power amplifier and fed to the strip line kicker.

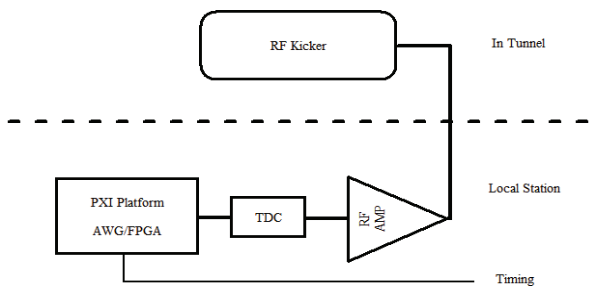

Figure 6: RF kicker design.

DISCUSSIONS

For *sin* wave kicker, the perturbation to the stored beam is inevitable. Which acts as deflecting cavity in a storage ring. Lower the frequency, less the perturbation, since the slope of the deflecting is proportional to the frequency.

The kicker can also be a low Q deflecting cavity. The pulsed high power RF source for the deflecting cavity is mature. However the cavity need a special design to decrease the Q factor to around 10^3.

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