FAST STRIP LINE BASED INJECTION KICKER DEVELOPEMENT AT ESRF

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Abstract

This paper reports on the advancement of the design of a fast kicker device at ESRF. The kicker is based on a Strip-Line (SL) device fed by an ultra fast High Voltage (HV) power supply. These fast kickers allow to displace only one bunch instead of the full bunch train, reducing greatly the disturbance observed by users during injection. They are now operated in several institutes and under study in most modern light sources. We will report on the beam dynamics simulations to quantify the expected gain for injection, and describe the advancement of the hardware design and tests.

INTRODUCTION

For the last 15 years, pulsers providing tens of kV over sevral ns are available. The use of fast kickers combining these pulsers with SL is spreading in the accelerator community. The lake of reliability of the power supplies of the early days is now overcome, and some freshly commissioned light sources, like HEPS in China [1], or APS [2] in USA have their injection process relying on these devices. At ESRF, this technology had been tested in 2016 to inject the 200 Mev linac beam into the booster synchrotron. A single RF bucket could be injected in the booster with same efficiency as using the usual injection kicker. Nevertheless, the power supply failed after a few minutes of operation in the tunnel. Interest has risen again these past years even-thought the use of a Non Linear Kicker (NLK) is foreseen to target transparent injection [3, 4], mandatory feature to increase the top-up frequency.

These ultra fast kickers could be a backup solution to the NLK. The ”Kick and Cancel” (KC) scheme, proposed for the DIAMOND II light source [5], would indeed be an efficient scheme for accumulation in the main ring. Another interesting feature of the device, combined with the NLK, is its ability to drastically reduce injection losses on vertical low gap ID’s, a mandatory condition to close them further.

We will also report on some tests done in 2024, in collaboration with the PSI team, concerning the installation and test of a prototype SL kicker developed by PSI [6], on the ESRF storage ring.

PROTOTYPE DESIGN

The high frequency nature of the pulse traveling through the structure imposes a careful choice of geometry to keep the $50\,\Omega$ adaptation. The full setup consists of a HV HF pulser, followed by a low loss HV RF cable connected to the SL kicker. At the other end of the SL, the signal is extracted via another set of cables to an attenuator, in order to be damped and monitored on a scope. The transitions between air and vacuum at the entrance and exit of the SL structure will be ensured by commercial Feed-Throughs (FT). Different type of FT equipped with N and HN connectors will be tested:

- LESKER ref IFTNG012033M
- IFTHG013052
- VACCOM ref CF40R-N50-GS-SE-CE-SS
- CF40R-HN50-GS-SE-CE-NI.

We hope to be able to fully support the blades via their link with the FT, even-thought no solution has been found yet to ensure both, mechanical stiffness and absorption of the heat induced elongation of the blades. The transition between the upstream Vacuum Chamber (VC) profile and the inside of the SL is a complex shape meant to optimise both $50\,\Omega$ matching of the structure and beam/VC coupling impedance. We are aiming at making this transition inside of a wide flange, produced via Additive Manufacturing (AM), that will support the FT’s flanges. A sketch of a horizontal cut of the flange is shown in Fig. 1 as well as the central section of the kicker showing the blades/VC profile.

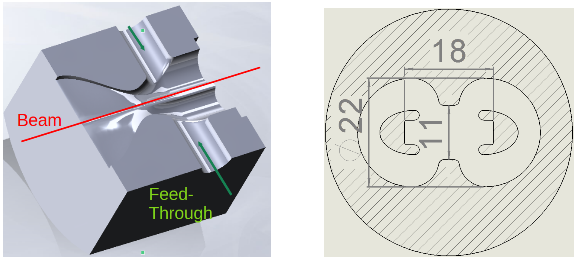

Figure 1: Left: Horizontal cut of the flange showing the complex shape of the transition. Right: Cross section of the central kicker part.

Ultra High Vacuum compatibility (UHV) of samples of three alloys produced via AM are being tested namely, CuCrZr, AS7G06, and TA6V grade 5. Some similar tests are reported in [7–9] The central part of the vacuum chamber and the blades will be machined to limit the size of parts produced by AM and optimize the vacuum property of the blades that are expected to reach temperatures above 120 °C. Optimisation of the blade/VC chamber geometry to minimise both coupling impedance and pulse reflection have been performed using the CST code [10]. Present design aims at assembling two devices as shown on Fig. 2. For

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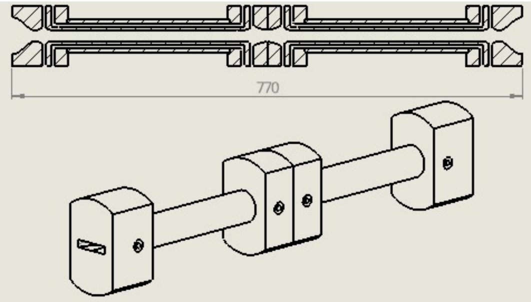

Figure 2: Horizontal cut of the full device with two sets of blades coupled, and general 3D view.

a 5 mm bunch, such structure has a longitudinal loss factor of 0.19 V/pC. Transmission of the HV pulse has been studied up to 3 GHz. The reflection coefficient S_{11} is below $-30/-20$ dB for odds/even modes up to 1.5 GHz. The field profile between the blades is presented on Fig. 3. Combined with a 2 ns, ±10 kV, half sin pulse, this assembly would give a deflection angle of 2×0.105 µrad. This prototype design is conservative and we target to reach deflection of 2×0.15 µrad. There is room to increase the field by enhancing the pulse voltage or reducing the blade spacing. 10% can be gained as well by closing the "U" shape on the inner blade, where no synchrotron radiation is present. In simulations, the degradation in the field homogeneity, and 50 Ω adaptation, has shown to be marginal.

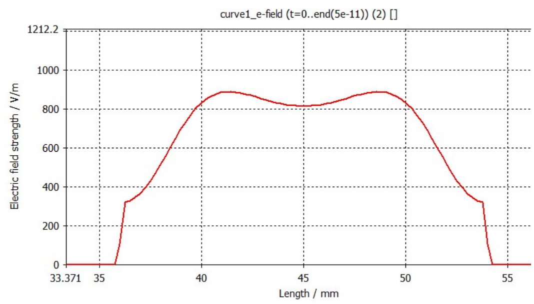

Figure 3: Field shape between blades in the symmetric case.

BEAM DYNAMICS SIMULATIONS

The Straight Section (SS) of cell 6, two cells downstream of the injection cell, can be partially freed to host the SL's array. The two sections are separated by a phase advance close to the optimal value of 90°. The horizontal beta function in the SS center is at 7 m, which is relatively high compared to the rest of the cell. It is therefore a good candidate to host the kickers. Simulations presented are based on the actual layout of injection section, adding SL kickers in the SS of cell 6.

Kick and Cancel for Injection

Several extensions of the basic "shared oscillation" injection with a single kicker have been studied. The KC scheme proposed by Diamond [5] is the most efficient one since generators able to produce two pulses separated by a few revolution periods can be purchased. Applied to ESRF, and considering a beam injected at 12.5 mm, consistent with present injection conditions, a kick of 450 µrad on the stored beam, followed two turns after by a kick of 650 µrad to the stored and freshly injected beam, would result in an injection efficiency of 99.5 %. Residual oscillations of the stored beam are then limited to a single RF bucket, and to a maximum amplitude of 2 mm. Phase space plots of the process are presented in Fig. 4. Limiting the oscillation is a good way to limit instabilities observed when kicking high charge bunches, we therefore believe the process is also suitable for time structure modes.

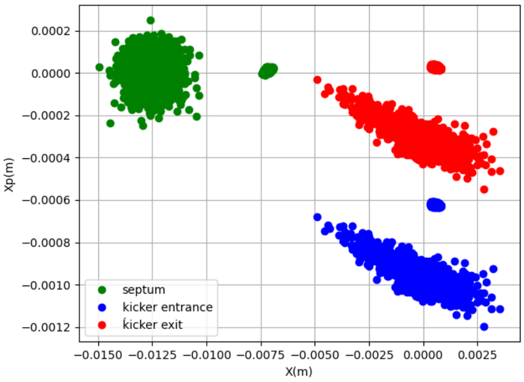

Figure 4: Phase space plot showing the injection process. Green: stored and injected beam at the septum. Stored beam has been kicked two turns ahead. Blue: beam at the SL kicker entrance. Red: beam at the kicker exit. The stored beam is almost back on axis.

Reduce Losses on Low Gaps IDs

To benefit from the full potential of EBS and be able to produce high flux of photons above 50 KeV, in-vacuum insertion devices optimised for a vertical gap of 4 mmare designed. The storage ring optics can be modified in specific straight sections in order to have the aperture reduction being transparent in term of lifetime. Nevertheless injection losses collimate on the low gaps and there is a relevant danger of demagnetising the low gap ID. To protect the magnets, horizontal collimators are routinely used. For present ID's, with full gaps of 6 mm the protection scheme is transparent in term of injection efficiency, but for 4 mm gaps it is not the case anymore [12]. Introducing a fast kicker to partially share the oscillations between injected and stored beam mitigates this problem, even using a relatively weak kicker. Simulations were performed on a machine with errors using the standard 4 kicker bump for injection. The ID is closed to 4 mm full gap, and a couple of collimators tuned to protect the low gap ID, with a criterion of less than 5% of the injected beam lost on the ID. Injection efficiency is then reduced to 81%. If a single SL kicker providing 0.15 m rad is added, with the same ID and collimators setting, injection efficiency rises to 99% with only 0.5% lost on the low gap, as illustrated in Fig. 5.

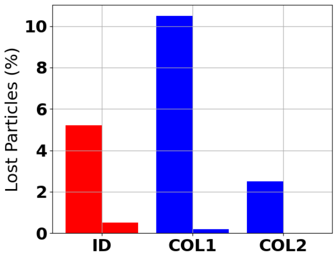

Figure 5: Left bars: injection loss ratio with present injection and collimators protecting the a gap ID. Right bars: Same losses adding one fast kicker device providing 0.15 µrad deflection.

TEST OF THE PSI PROTOTYPE AT ESRF

In the framework of a collaboration between ESRF and PSI, a prototype designed and assembled at PSI was tested on the ESRF machine. With a gap of 10mm between the blades, the device is not compatible with user operation. We therefore had to install, test and remove the set-up during a machine shutdown period. The 128 BPM's equipped with the Libera "Spark" electronics [11], allowed time resolved measurement of the deflection experienced by a single bunch with a µrad precision. As shown in Fig. 6, it is very close to the expected values of 30 µrad for the peak deflection, and 2 ns for the kick width in time. No relevant leakage or reflection was observed. Most interesting was the interaction between the electron beam and the SL. The limit in stored current was expected to come from out-gassing and temperature rise of the blades, due to the beam proximity and very little cooling ability. Indeed during the three days of the tests, and with a initial bake-out done at 120 °C, pressure increase was observed above 10 mA of stored uniform beam. We could inject up to 150 mA but then temperature and pressure were diverging and beam current had to be reduced. Figure 7 is a summary of the last current ramping attempt. It displays the pressure measured between the SL and the absorber placed at 5mm from the beam axis, the current stored and an evaluation of the blades temperature via IR camera measurement. It seems the limit is coming from the blades temperature that went above the 120 °C of the bake-out. Nevertheless, the absorber, that was poorly designed in term of coupling impedance, may as well have largely contributed to the pressure rise. The same temperature trend was observed on the outside of the absorber VC, that reached a relatively high level of 40 °C for 100 mA stored. For high charge single bunches no extensive study was carried out due to a lack of time, but 6 mA (17 nC) were stored during night conditioning, with no vacuum response, but still a visible increase in the absorber temperature.

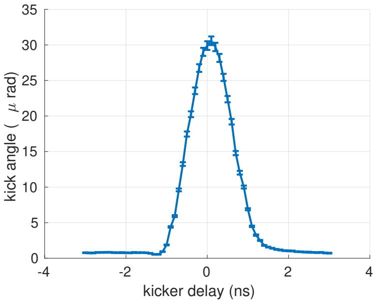

Figure 6: Kick experienced by a single bunch vs kicker timing.

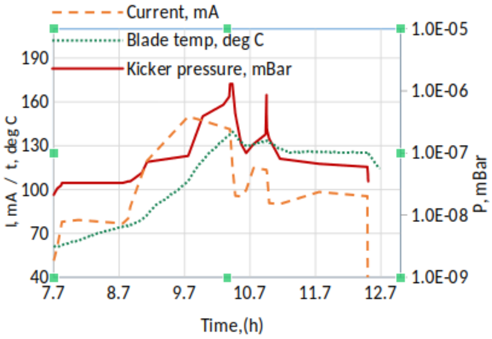

Figure 7: Summary of a current ramping attempt. Pressure between the SL and the absorber as well as blades temperature readings are reported.

CONCLUSION

The development of a stripline based ultra fast kicker, to optimise injection into the storage ring is under study at ESRF. The hardware design relying on the possibility to use metallic flanges produced via additive manufacturing is in it's early stage. It will enable the production of complex shapes enhancing RF performance of the device. The first step to validate the vacuum compatibility of the process is ongoing.

Beam dynamics simulations showed the numerous advantages we can expect if half of a 5 m straight section is dedicated to these kickers. The possibility to share the oscillations between stored beam and injected beam can be used either to inject or to reduce losses on vertical gaps, and protect ID's magnet arrays. The "kick-and-cancel" scheme proposed by the DIAMOND team could be applied to ESRF with the advantage of drastically reducing the stored beam disturbance and therefore mitigating potential instabilities.

We also had the chance to perform tests with the SL prototype for SLS II, installed on the ESRF storage ring. It validated the simulation predictions concerning pulse transmission and resulting beam deflection. It confirmed as well the limitations imposed by strong thermal stress induced by the beam on the blades, and stressed the care that should be given to the absorber design, a piece that cannot be avoided for such set-up.

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