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BEAM DYNAMICS, INJECTION AND IMPEDANCE STUDIES FOR THE PROPOSED SINGLE PULSED NONLINEAR INJECTION KICKER AT THE AUSTRALIAN SYNCHROTRON

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Abstract

The Australian Synchrotron are currently investigating the use of a single pulsed nonlinear injection kicker (NLK) to free floor space within the ring for future beamline development. The NLK has a zero and flat magnetic field at the stored beam to leave the stored beam undisturbed but has a maximum field off-axis where the injected beam is located. After the kick, the injected beam is stored.

While NLKs have been prototyped at many facilities around the world, injection efficiency and heat loading have been the main impediment to deployment of the NLK. The wakefields that pass through the ceramic chamber aperture can cause severe heat loading and impedance. Despite achieving impressive injection efficiencies, a previous prototype at BESSY II [1] showed that strong interactions of the stored beam resulted in high heat load causing the thin 5 µm Titanium coated ceramic chamber to reach temperatures over 500 °C and fail.

To avoid beam induced heat loads, this paper presents studies of the wake impedance and thermal behaviour for our proposed NLK design. Injection simulations and future considerations for installation and operation at the Australian Synchrotron will be discussed.

THE AUSTRALIAN SYNCHROTRON AND NEW BRIGHT BEAMLINES

The AS is a 3rd generation facility in Melbourne, Australia. Recently, the second stage of beamline development under the BRIGHT beamlines project was announced. Over the next 3 to 5 years, 7 beamlines are planned to meet the user demand for beamlines in medical and advanced material research.

THE CURRENT KICKER CONFIGURATION

New beamlines require new space within the storage ring, stable beam and transparent top-up. Currently, the AS employs a conventional 4 dipole kicker configuration located in Sectors 2 and 14; taking up 4 meters of valuable space where future BRIGHT beamline development is planned. This setup will be operationally insufficient for future beamlines as this injection method introduces perturbation in the beam upon top-up which reduces the injection efficiency.

A SINGLE NONLINEAR KICKER

To reduce the space taken in the storage ring and remove the jitter in the beam on top-up, the construction and commissioning of a single nonlinear injection kicker (NLK) has been proposed. A NLK is comprised of a ceramic chamber and magnetic conductors (Fig. 1 left) that produces a nonlinear field that kicks the injected beam (Figure 1, right) while leaving the stored beam untouched. This ensures the beam is transparent in top-up as the stored beam is unaltered, providing the users with stable, perturbation free light.

DESIGN CONSIDERATIONS

Although NLKs have been proposed and implemented by several facilities to date, there are several design considerations that need to be addressed before deployment at the AS. Other facilities have shown that the stored beam produces image currents along the ceramic chamber, necessitating a conductive coating of either Titanium (Ti) or Titanium Nitride (TiN) be applied on the inside of the chamber [2]. The conductive coating will decrease any beam induced impedance and unwanted wakefields, prevent significant charge accumulation across the ceramic surface, dissipate heat load from the stored beam on the ceramic chamber and guide the image currents.

To produce a full prototype for deployment at the AS, many features need to be characterized and optimized for our facility as the interplay of these factors will impact the final performance. To fully characterise the impact of the induced impedance from our stored beam interacting with the NLK ceramic chamber needs to be assessed with respect to:

- The material and thicknesses of conductive coating applied inside the ceramic chamber
- Selected aperture and length of ceramic chamber
- Power deposition along the ceramic chamber
- Field distortion induced by the selected conductive coating thickness
- The thermal load on the ceramic chamber

PRELIMINARY DESIGN OF THE NLK

Our initial NLK design is shown in Fig. 1 and the magnetic fields generated were characterized using the finite element method magnetics (FEMM) program [3]. This is a 8 conductor design with a Al_2O_3 ceramic chamber (Kyocera) – chamber dimensions (H x V x L) 74 mm x 20 mm x 330 mm with a chamber aperture (H x V x L) 64 mm x 10 mm x 330 mm. An internal Ti or TiN coating of 1 µm to 10 µm will be investigated. The 8 copper conductors will be

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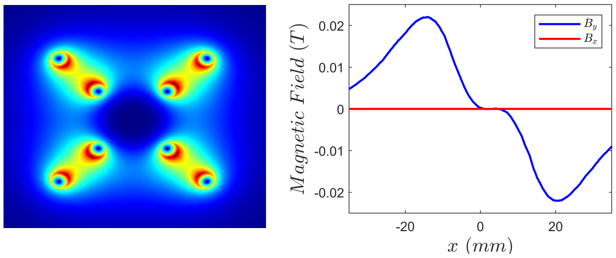

Figure 1: NLK preliminary design 8 conductor configuration and the nonlinear magnetic field B_y.

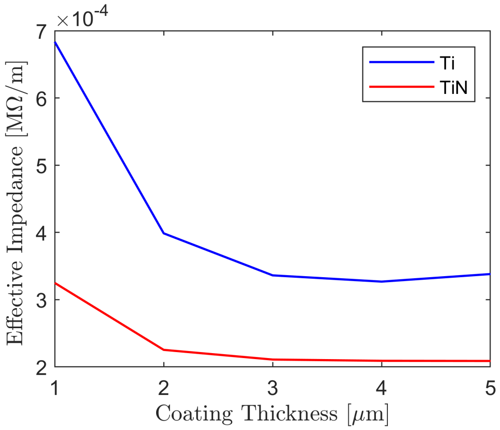

Figure 2: The effective impedance of 1 μm to 5 μm Titanium (blue) and Titanium Nitride (red) conductive coatings on the NLK chamber for the AS beam.

arranged symmetrically; two opposing wires on each quadrant to produce a flat magnetic field gradient at the stored beam to ensure no perturbation of the beam upon injection.

PLACEMENT IN THE STORAGE RING

The optimal location for the NLK placement in the facility is in Sector 5. Engineering studies conduced showed that the maximal length of the NLK that can fit into the Sector 5 straight with crotch absorbers downstream is 330 mm. We note that in the future, an IVU could be installed downstream of the NLK in Sector 5. This could produce a resonant cavity and this will need to be investigated in future work.

CHOICE OF CONDUCTIVE COATING

In this paper, we investigate several options for the conductive coating for the inside of the ceramic NLK chamber. The selected coating must guide the image currents, decrease the beam impedance to an acceptable value, reduce charge accumulation across the chamber while also taking into account the trade-offs between power deposition from the stored beam on the chamber, the thermal load on the chamber and finally, the implications on the injection efficiency that can be obtained by the NLK. In the next sections, we present our investigations into the impedance obtained for our design with various conductive coatings.

IMPEDANCE STUDIES FOR TITANIUM AND TITANIUM NITRIDE COATINGS

The impedance studies for our NLK design were conducted using the 3D Computer Simulation Technology (CST) software [4] and the 2D ImpedanceWake2D (IW2D) code [5] developed by the impedance working group at CERN.

Figure 2 shows the effective impedance of various Ti and TiN coatings for our NLK ceramic chamber as a function of our beam parameters (seen in Table 1). The longitudinal (Z_{long}) and transverse (Z_t) impedances for Ti coatings and TiN coatings are shown in Fig. 3. Z_{long} and Z_t were calculated using IW2D assuming a flat geometry of Al_2O_3 with the corresponding Ti (6 x 10^{-7} Ω/m) or TiN (2 x 10^{-5} Ω/m) conductive coating. The effective impedance of the bare NLK chamber is 0.29 MΩ-m which decreases substantially to 6.8 x 10^{-4} MΩ-m and 3.3 x 10^{-4} MΩ-m when 1 μm of Ti and TiN coating is applied, respectively. This is expected as the effective impedance is proportional to electrical resistivity.

When the coating thickness is greater than the skin depth, the fields cannot not escape as the image currents are not close to the beam. When this occurs, the effective impedance is saturated as the fields resemble the bulk substrate. For our NLK design, the thickness is greater than the skin depth at 3 μm where the impedance levels out where the 3 μm coating acts like bulk Ti. From this figure, we rule out the suitability of Ti and TiN coatings >3-10 μm as the effective impedance reaches its minimum at 3 μm.

The NLK chamber wake potential and wake-loss factors for Ti conductive coatings of 1-3 μm were calculated using the Wakefield simulator in CST Studio Suite. The wake loss factor ($k_{\parallel}$) for the Ti 2 μm coating $k_{\parallel}$ was 0.01085 V/pC. A previous study by Dressler et al. [1] showed that their first NLK design which had issues with heat load and conductor shielding had a longitudinal $k_{\parallel}$ of 4.8 V/pC. Dressler et al. then produced a revised NLK that has avoided any heating issues and has a $k_{\parallel}$ of 0.411 V/pC. For our design, additional simulations for coatings of 1 μm - 3 μm Ti and TiN were not calculated in CST as the addition of a thin film of Ti or TiN coating significantly increased the number of mesh cells and the computational time. However, as our Ti 2 μm $k_{\parallel}$ is significantly less than 4.8 V/pC, the longitudinal wake loss factor should not pose a problem. In order to decide between the 1-3 μm conductive coatings, we now turn to power and heat simulations.

Table 1: AS Machine Parameters

Beam Energy, E	3.03 GeV
Current, I	200 mA
Revolution, f_{rev}	720.467 ns (1.38799 MHz)
Bunch length, σ_z	29.85 ps, 8.94 mm

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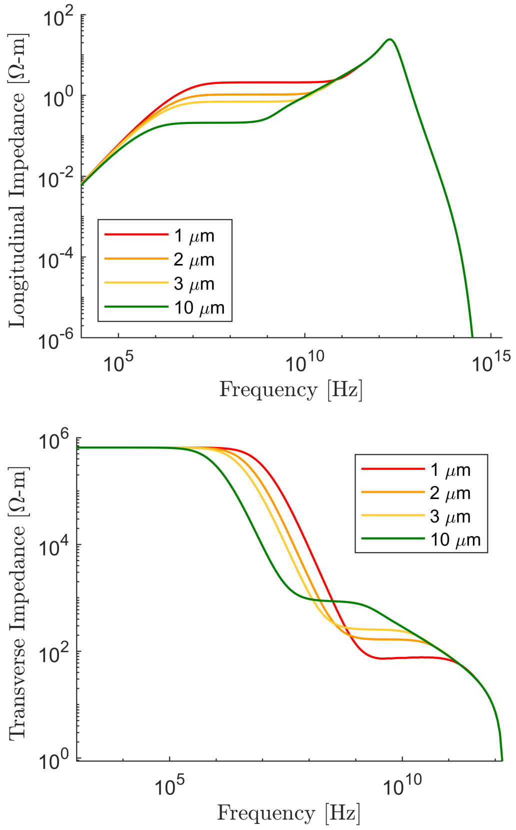

Figure 3: Real longitudinal impedance, Z_{long}, and imaginary transverse impedance, Z_t, for 1 - 10 µm Titanium Nitride conductive coatings on the NLK chamber.

POWER AND HEAT LOAD FROM BEAM

The power deposited across the ceramic chamber from the stored beam induces a heat load on the ceramic chamber. As previous facilities have noted problems with the NLK chamber heating up, we calculated the maximum temperature deposited on the chamber at 400 mA current with 240 bunches. We note that normal operations consists of 200 mA with 300 bunches, so the power and heat calculations shown below represent the maximum ”worst-case” scenario. The power deposited and the corresponding heat load for various Ti and TiN coatings are shown in Table 2.

Figure 4 shows the injection and particle distribution calculations for the 2-µm Ti coated NLK design. Recent work by Bennetto and Giansiracusa, 2019 [6] has quantified the beam dynamics of the storage ring. Future work will use these results and the particle distribution shown in Fig. 4 to estimate the injection efficiency of the NLK design when placed in Sector 5.

Table 2: Power deposited by stored beam on the inside of the nonlinear kicker for various Ti and TiN conductive coatings with the corresponding heat load. Temperature calculations were completed using the Matlab PDE toolbox.

Thickness (µm)	P_{Ti} (W/m^2)	P_{TiN} (W/m^2)	T_{Ti} ($^\circ C$)	T_{TiN} ($^\circ C$)
1	625.8	512.6	150.3	127.7
2	312.9	256.3	87.7	76.4
3	208.6	170.9	66.9	59.33

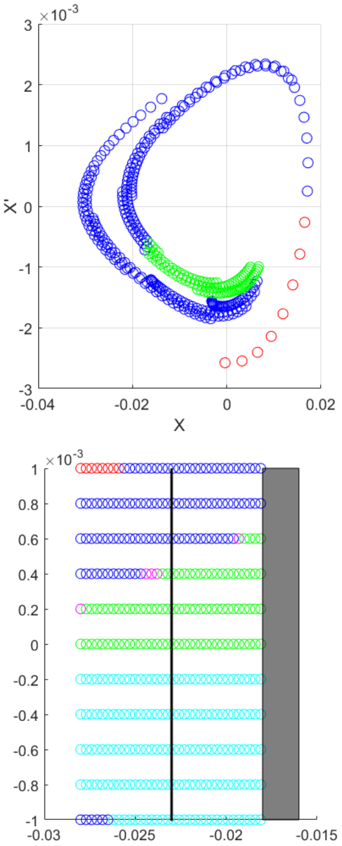

Figure 4: Injection studies and particle distribution for the 2-µm Ti coated NLK design. The initial particle distribution is shown in red while the subsequent turns are shown in blue (1st turn), cyan (2nd turn), magenta (3rd turn) and green (8th and last turn).

CONCLUSION

This work has investigated the conductive coating impact on the impedance of a nonlinear kicker ceramic chamber designed for installation at the Australian Synchrotron. We have shown that based on the power deposited on the chamber, the effective impedance and induced heat load across the chamber, a 2-µm Titanium or Titanium-Nitride conductive coating is suitable for our beam. The final choice between Ti and TiN will be determined based on manufacturability and cost. Construction and commissioning of the NLK will commence in the second half of 2019. Future studies are warranted to fully characterize the injection efficiencies we can obtain with the NLK design described in this paper.

REFERENCES

[1] O. Dressler, T. Atkinson, M. Dirsat, P. Kuske, and H. Rast, "Development of a Non-Linear Kicker System to Facilitate a New Injection Scheme for the BESSY II Storage Ring", in *Proc. 2nd Int. Particle Accelerator Conf. (IPAC'11)*, San Sebastian, Spain, Sep. 2011, paper THPO024, pp. 3394–3396.

[2] A. Piwinski, "Penetration of the field of a bunched beam through a ceramic vacuum chamber with metallic coating", in *IEEE Transactions on Nuclear Science* 3, no. 24, June 1977, paper THPO024, pp. 1364–1366.

[3] D. Meeker, Finite Element Method Magnetics, Version 4.2 (28Feb2018 Build). `http://www.femm.info`

[4] Computer Simulation Technology (CST) Studio Suite 2019. `https://www.cst.com`

[5] N. Mounet, ImpedanceWake2D. `http://impedance.web/cern.ch/impedance/Codes/ImpedanceWake2D/`

[6] P. Bennetto and P. J. Giansiracusa, "Characterising Injected Beam Dynamics in the Australian Synchrotron Storage Ring", presented at the 10th Int. Particle Accelerator Conf. (IPAC'19), Melbourne, Australia, May 2019, paper WEPGW001, this conference.