# POSSIBLE APPLICATION OF NBTI ARTIFICIAL PINNING CENTERS WIRE FOR INSERTION DEVICES

T. Holubek[1], S. Casalbuoni[1], S. Gerstl[1], A. Grau[1], D. Saez de Jauregui[1], M. Kläser[2], Th. Schneider[2], L. Motowidlo[3]
[1] ANKA, Karlsruhe Institute of Technology, Karlsruhe, Germany
[2] Institute for Technical Physics (ITEP), Karlsruhe Institute of Technology, Karlsruhe, Germany
[3] SupraMagnetics, Inc., USA

*Abstract*

Superconductive insertion devices (IDs) allow higher fields for a given gap and period length compared to the classical permanent magnet IDs. This technological concept enables an increase in the brilliance and/or the photon energy. The workhorse for superconducting magnets are multifilament NbTi wires, which are nowadays also used for superconducting insertion devices. Even higher magnetic fields can be reached by using a conductor with enhanced critical current density.

Here, we propose a possible application for superconducting undulators, wound with NbTi wire with artificial pinning centers, developed by SupraMagnetics, Inc. We report the critical current characteristic, $J_c(B)$, of a short wire measured in a liquid helium bath, and the load-line of a racetrack coil, designed to simulate the field configuration on the conductor as in a superconducting undulator. Based on the measured load line, we report on the simulations of the magnetic field on axis and of the spectrum in a third generation light source of a possible undulator wound with a wire having similar properties to the measured one.

## INTRODUCTION

In order to produce high brilliant X-ray beams, storage rings and linacs make use of insertion devices (IDs). The state of the art available today for IDs is the permanent magnet technology with magnet blocks placed inside the vacuum of the storage ring. Following an initial proposal at SPRING8 [1], the concept of cryogenic permanent magnet undulators (CPMU) is presently being considered as a possible evolution of in-vacuum undulators (IVU) [2-5]. Superconducting undulators can reach higher fields for the same gap and period length, even with respect to CPMU devices, allowing enhancement of the spectral range and the brilliance.

The workhorse for superconducting magnets are multifilament NbTi wires, which are nowadays also used for superconducting insertion devices. We investigate here the possible application of a conductor with enhanced critical current density, as the NbTi wire with artificial pinning centres (APCW), developed by SupraMagnetics, Inc. [6].

In section 1 we describe the main characteristics of the APCW and in section 2 the design and measurements of a small racetrack coil, whose design has been chosen to simulate the load-line of an undulator. Finally, we present the increased performance in terms of brilliance in a third generation light source that a superconducting undulator using an APCW would bring.

## NBTI WIRE WITH APC

The APCW has an outer diameter of 0.31 mm including insulation (30 µm), a copper to superconductor ratio of 2.125 and counts 37 filaments with diameter of 21 µm. An optical microscope image of its transverse cross section is shown in figure 1a. We could use for our test only 7m of wire. Part of the 7 m was used to measure the critical current of the APCW in the JUMBO facility at ITEP [7]. The results are presented in the next section in figure 2 (green line).

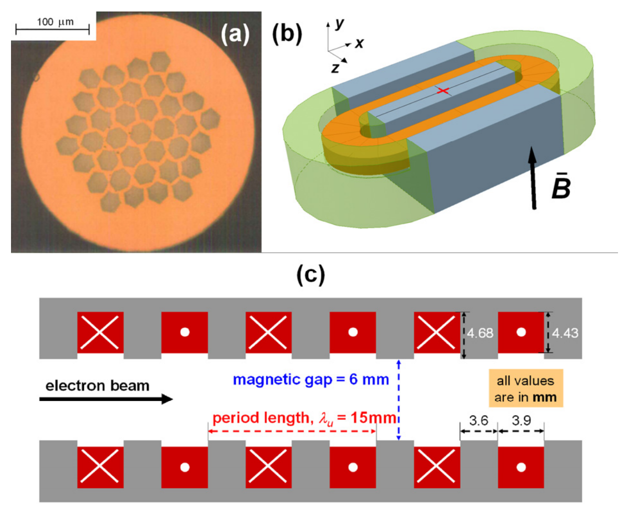


Figure 1: a) Optical microscope image of a transverse cross section of the NbTi APCW. b) Model of the half-filled racetrack. c) Sketch of the undulator geometry.

## SMALL RACETRACK COIL DESIGN AND MEASUREMENT

Figure 1b shows a sketch of the racetrack coil used to simulate the load line of an undulator with 15 mm period length (figure 1c). The dimensions of the racetrack coil are shown in table 1. The yoke of the racetrack coil shown in figure 1b, is made of C10E steel (grey part) and of G10 material (light green parts). A 300 mm thick layer of G10 was placed at the bottom of the groove. The initial idea was to wind to fill the remaining space of the groove with APCW completely, but as not enough wire was available, just half of the groove was filled, as shown in figure 1b. The construction of the racetrack coil was carried out at the ITEP.

The critical current of the racetrack coil has been measured in the facility JUMBO at different external magnetic fields ranging from 0.5 up to 8 T. The external magnetic field was perpendicular to the racetrack plane, as shown in figure 1b. The quench current density of the groove of the racetrack coil compensated for the self field is plotted in figure 2 (red crosses).

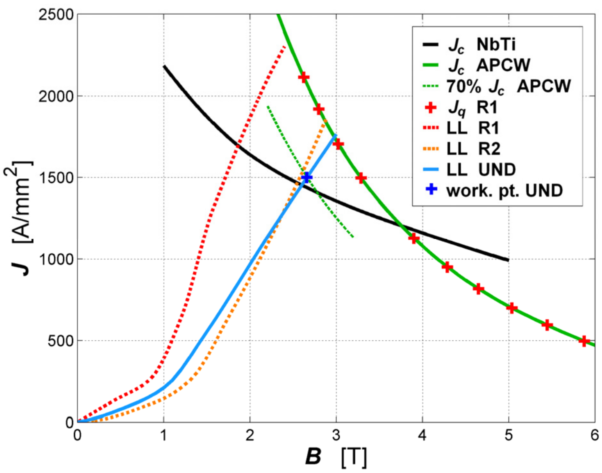


Figure 2: The measured groove critical current density of standard NbTi wire, short APCW and racetrack coil are shown. The simulated load lines (LL) of the racetrack coils R1 and R2 as well as the one of the undulator plus working point are also plotted.

Table 1: Dimensions of a half- (R1) and a fully-filled (R2) racetrack coil and the yoke.

| | R1 | R2 |
|---|---|---|
| Inner radius of racetrack coil [mm] | 1.8 | 1.8 |
| Straight part of racetrack [mm] | 16 | 16 |
| Groove width [mm] | 3.9 | 3.9 |
| Groove depth [mm] | 3.55 | 3.55 |
| Number of coil turns | 67 | 127 |

Table 2: Dimensions of the groove of the undulator with 15 mm period length.

| | |
|---|---|
| Groove width [mm] | 3.9 |
| Groove depth [mm] | 4.43 |
| Number of coil turns | 192 |

The load lines computed with the finite elements software Opera3D [8] of the coil half filled (red), fully filled (orange) and of the undulator (blue) are shown in figure 2. Here they are compared with the groove engineering critical current density for the APCW (green) and with the groove engineering critical current density for a standard NbTi wire (black). The green dotted line in figure 2 is 70% of the groove engineering critical current density for the APCW. The intersection of this line with the load line of the undulator gives the working point of the undulator at 4 K with 30 % safety margin.

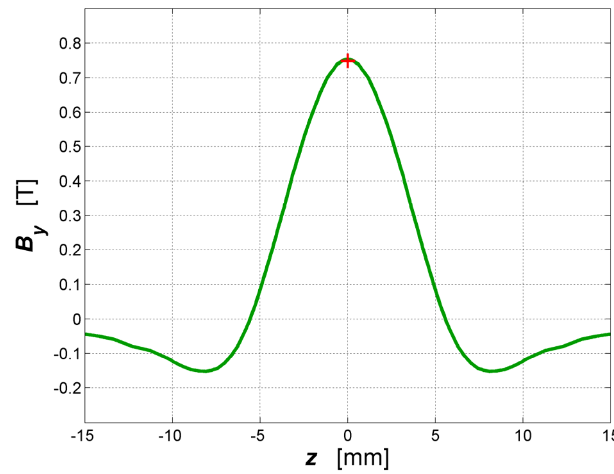


Figure 3: Field profile (green line) of the racetrack coil along z-axis located at 3 mm above the poles (y dir.) and measured point (red cross).

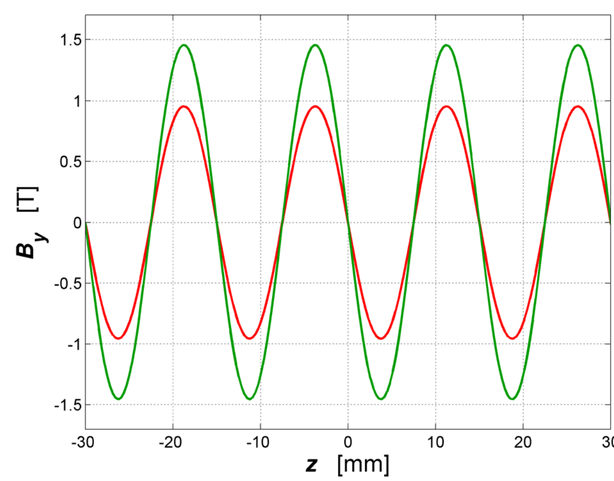


Figure 4: Field profiles of the undulator with engineering groove current density of 1500A/mm$^2$ for gap of 8mm (red) and of 6 mm (green).

In order to measure the magnetic field in the y direction, a Hall probe was located 3 mm above the centre of the middle pole of the racetrack as indicated in figure 1b by the red cross. In figure 3 the simulated field across the racetrack (along z line indicated in figure 1b) is compared with the measured field in JUMBO after having removed the applied external field.

The peak magnetic field on axis for the APC NbTi wire undulator calculated with OPERA 3D using geometry described in table 2, C10E steel as a yoke material and a groove engineering current density of 1500A/mm$^2$ (value of the crossing point of the load line with 70% of the groove engineering critical current density of the APCW) is shown in figure 4 for a magnetic gaps of 6 and 8 mm ($B_{max}$ = 1.46 and 0.95 T respectively).

## BRILLIANCE

Here the performance that could be reached by a superconducting undulator with 15 mm period length built using an APCW with the characteristics as reported in the previous sections was studied. The brilliance of this undulator was compared with the one of a superconducting undulator with the same geometry and same yoke material (C10E steel) built using standard NbTi wire and the competing technologies (see figure 5). The comparison was performed using the same magnetic length of 2 m (product of $N$ and $\lambda_u$) and the same vacuum gap of 5 mm. The following storage ring parameters have been used: beam energy $E$ = 3 GeV, beam current $I$ = 300 mA, energy spread $\Delta E/E$ = 0.1 %, horizontal $\varepsilon_x$ = 2.67 nm rad and vertical $\varepsilon_y$ = 0.027 nm rad emittance, horizontal $\beta_x$ = 4.8 m and vertical function $\beta_y$ = 1.43 m.

Table 3 shows that the APC NbTi wire undulator could reach a K = 2 allowing the superposition of the first and third harmonics, as demonstrated in figure 5.

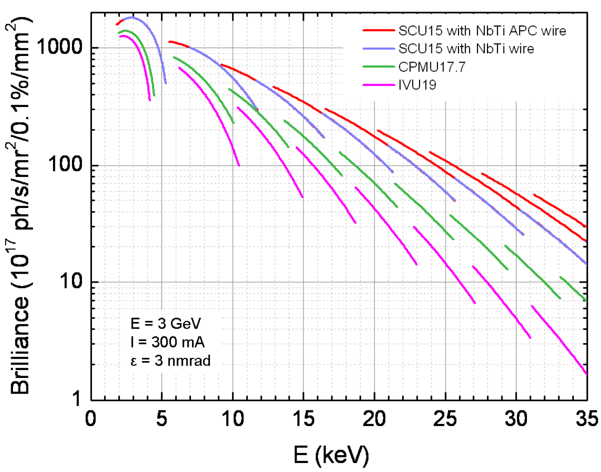


Figure 5: Comparison of the tuning curves calculated with SPECTRA [11] of different undulators with the parameters as in Table 3.

Table 3: Parameters used to calculate the brilliance of undulators to be realized using different technologies.

| | **IVU** [9] | **CPMU** [10] | **SCU NbTi wire** | **SCU APCW** [6] |
|---|---|---|---|---|
| $\lambda_u$ [mm] | 19 | 17.7 | 15 | 15 |
| $N$ | 105 | 112 | 133 | 133 |
| *gap* [mm] | 5 | 5.2 | 6 | 6 |
| $B$ [T] | 0.86 | 1.04 | 1.2 | 1.46 |
| $K$ | 1.53 | 1.72 | 1.7 | 2.05 |

## CONCLUSIONS AND OUTLOOK

A preliminary study on the application of APCW in superconducting undulators has been presented here. Such a wire would enable a 15 mm period length undulator with 30% margin from the critical current density measured at 4.2 K, with a $K$ = 2 at a magnetic (vacuum) gap of 6(5) mm, allowing full tunability of the undulator. A thicker wire is expected to be produced by SupraMagnetics, Inc. More tests will follow as soon as this wire becomes available.

## REFERENCES

[1] T. Hara, T. Tanaka, H. Kitamura, T. Bizen, X. Marchal, T. Seike, T. Kohda, and Y. Matsuura, Phys. Rev. ST Accel. Beams 7, 050702 (2004).

[2] C. Kitegi, J. Chavanne, D. Cognie, P. Elleaume, F. Revol,C. Penel, B. Plan, and M. Rossat, in Proceedings of the10th European Particle Accelerator Conference, Edinburgh, Scotland, 2006 (EPS-AG, Edinburgh, Scotland, 2006).

[3] T. Tanabe, D. A. Harder, G. Rakowsky, T. Shaftan, and J. Skaritka, in Proceedings of the 2007 Particle Accelerator Conference, Albuquerque, New Mexico (IEEE, Albuquerque, New Mexico, 2007).

[4] C. Benabderrahmane, N. Bchu, P. Berteaud, M. E. Couprie, J. M. Filhol, C. Herbeaux, C. Kitegi, J. L. Marlats, K. Tavakoli, and A. Mary, in Proceedings of the 11th European Particle Accelerator Conference, Genoa, 2008 (EPS-AG, Genoa, Italy, 2008).

[5] J. Chavanne, M. Hahn, R. Kersevan, C. Kitegi, C. Penel, and F. Revol, in Proceedings of the 11th European Particle Accelerator Conference, Genoa, Italy,2008 (EPS-AG, Genoa, Italy, 2008).

[6] http://www.supramagnetics.com/

[7] Th. Schneider, M. Beckenbach, R. Ernst, F. Hornung, M. Klaser, H. Lahn, P. Leys, C. Ruf, H. Neumann,M. Stamm, IEEE Transaction on applied Superconductivity, Vol. 20-3, June 2010, 624-627

[8] OPERA-3D, Vector Fields Limited, Oxford, England.

[9] F. Bødker, M.N. Pedersen, C.W. Ostenfeld, E. Juul, E.B. Christensen, T.L. Svendsen, H. Bach, in Proceedings of the 10th European Particle Accelerator Conference, Edinburgh, Scotland, 2010.

[10] C.W. Ostenfeld and M. Pedersen, in Proceedings of the 1st International Particle Accelerator Conference, Kyoto, Japan, 2010.

[11] T. Tanaka, H. Kitamura, Journal of Synchrotron Radiation, **8**, (2001), 1221-1228