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# Advancing superconductivity for future magnets

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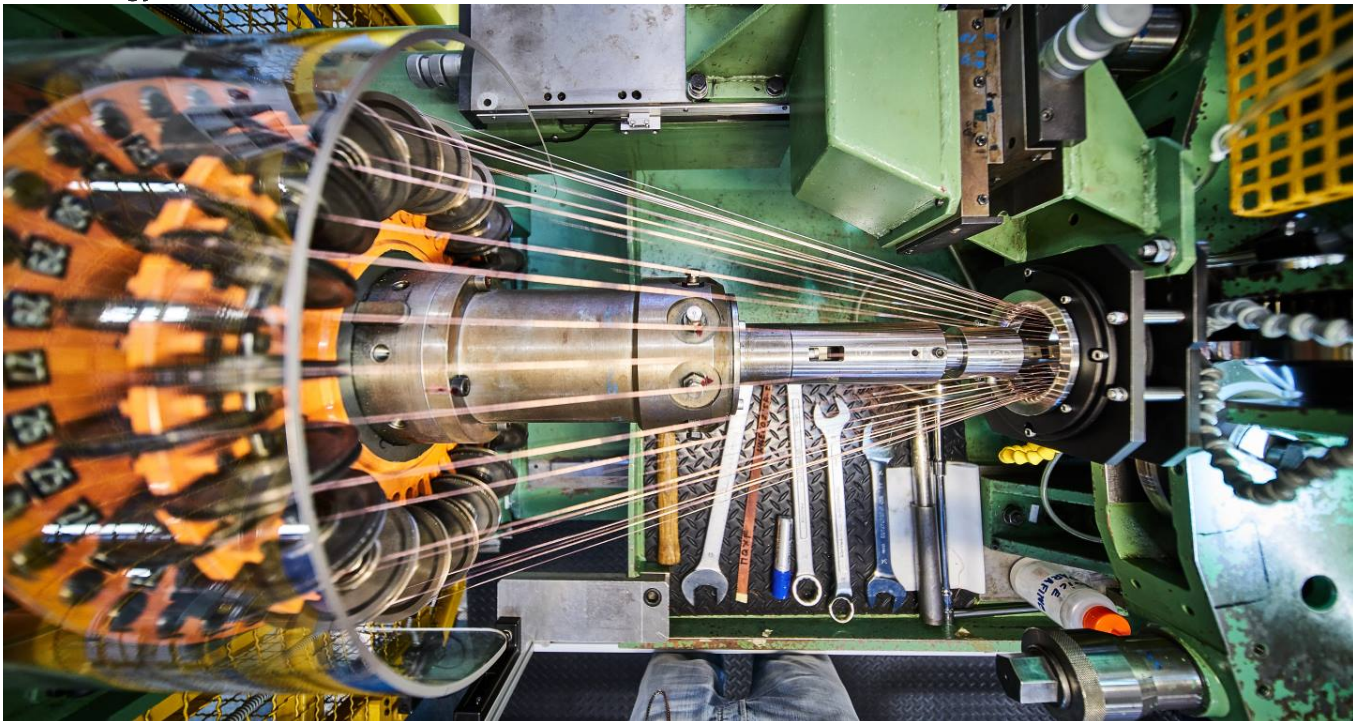
Collaboration between researchers and industry is key for unlocking the potential of this technology.



Superconductivity has been instrumental for the realization of large particle accelerators and is a key enabling technology for a future circular proton-proton collider (FCC-hh) reaching energies of 100 TeV.

The alloy Nb-Ti is undoubtedly the most successful practical superconductor, and it has been used in all superconducting particle accelerators and detectors built to date, but the higher magnetic fields required for the High Luminosity LHC (HL-LHC) upgrade and a future circular collider (FCC) call for new materials. An enabling superconducting technology for accelerator magnets beyond 10 tesla is the niobium-tin ($Nb_3Sn$) compound.

$Nb_3Sn$ wires suitable for producing the 11 T magnets required for the HL-LHC have been produced in industry, but the high-field magnets proposed for the FCC would require a substantial step forward in performance. In order to achieve this goal, a conductor development programme is under way at CERN.

To address the challenges of this project, a Conductor Development Workshop has bene launched by CERN. Amalia Ballarino, leader of the Superconductor and Superconducting Devices (SCD) section says: “It is the right time to create momentum for the FCC study and to bring together the current participants in our conductor development project to share recent progress and discuss future activities.”

The focus of the conductor development programme is on the development of $Nb_3Sn$ multi-filamentary wires able to meet the target non-copper critical current density ($J_c$) performance of 1,500 A/mm$^2$ at 16 T and at a temperature of 4.2 K (-268.95 °C). CERN is engaged in collaborative conductor development activities with a number of industrial and academic partners to achieve these challenging goals, and the initial phase of the programme will last four years.

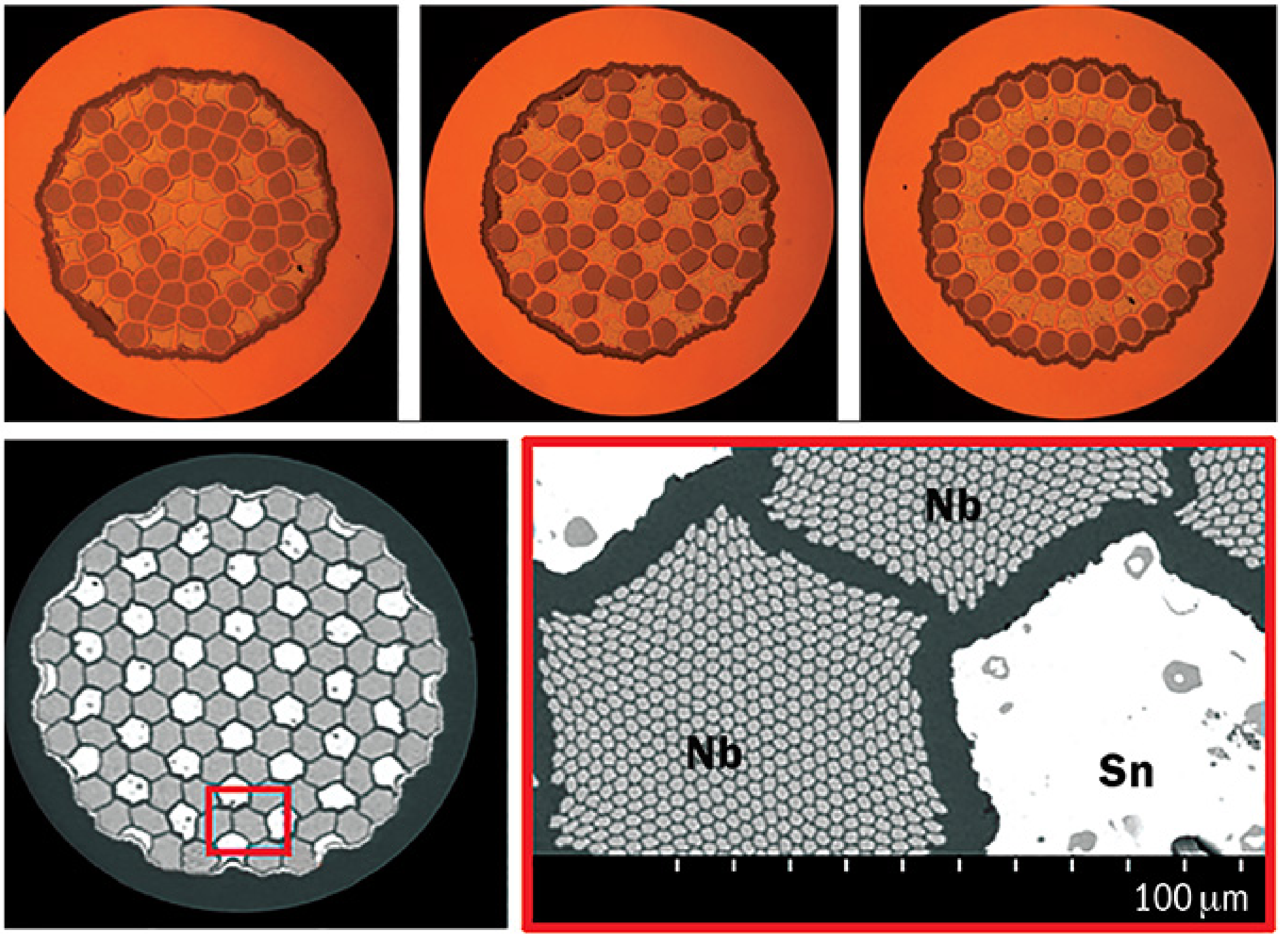
Presently, the conductor developed for HL-LHC reaches a performance of about 1,000–1200 A/mm$^2$ at 16 T and 4.2 K, and a significant R&D effort is needed to increase this by 30 to 50% to meet the requirements of 16 T magnets. “The magnets for future higher energy accelerators require fundamental research on superconductors to achieve the targets in performance and cost,” says Ballarino. For the FCC magnets, thousands of tonnes of superconductor will be required. Along with an increase in performance, a more competitive cost is needed, which calls for a wire design suitable for industrial-scale production at a considerably lower cost than the state-of-the-art conductor.

Representatives from five research institutes and seven companies, from the US, Japan, Korea, Russia, China and Europe, travelled to CERN in March 2018 to attend the first Conductor Development Workshop. “Our aim is to open up a space where collaborators can discuss the current status and review different approaches to meet the target performance and cost. The meeting also serves as an invitation to potential new partners interested in joining this effort”. Two new companies attended the workshop to discuss their possible future involvement in the project, namely Luvata and Western Superconducting Technologies (WST).

The workshop started with a plenary session followed by closed meetings during which companies engaged in fruitful discussions.  “Presentations in the plenary session gave a valuable overview of progress and future directions,” observed Simon Hopkins, a CERN expert on superconductivity and scientific secretary of the workshop, “but we recognise the commercial sensitivity of some of these developments. It was essential to provide an environment in which our industrial partners were free to discuss the details openly: both their proposed technical solutions and a realistic assessment of the challenges ahead.”


First Future Circular Collider conductor development workshop (Credit: Athina Papageorgiou-Koufidou).

The early involvement of industry, and their investment in developing new technologies, is crucial for the success of the programme. One of the positive outcomes of this meeting has been that, according to Amalia Ballarino: “Thanks to their commitment to the programme, and with CERN’s support, companies are now investing in a transition to internal tin processes. It was impressive to see achievements after only one year of activity”. Several partners have produced wire with $J_C$ performance close to or exceeding the HL-LHC specification, and all of the companies that attended the workshop had new designs to present, some of which are very innovative.



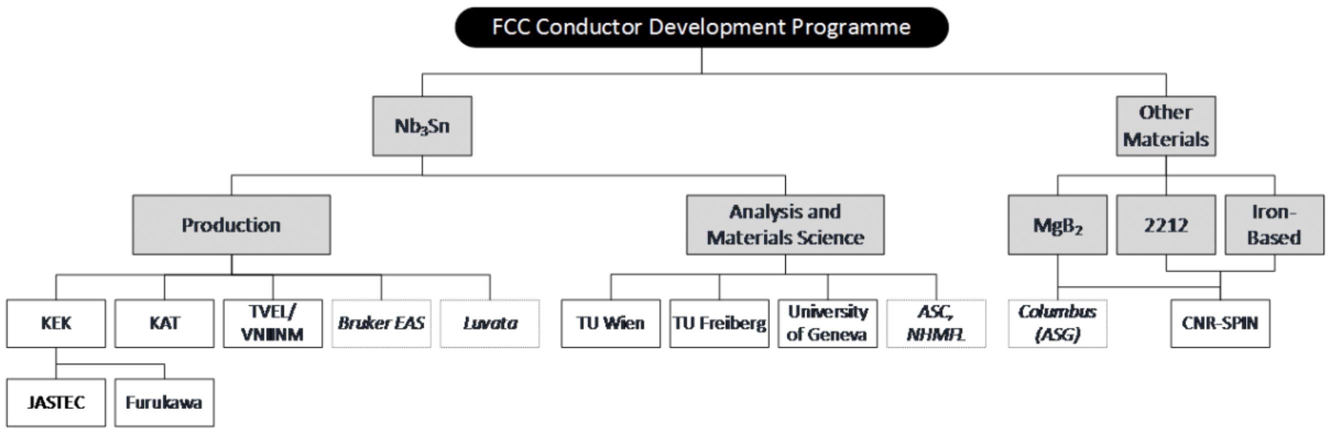

Cross-sections of prototype Nb3Sn wires developed in collaboration with CERN as part of the FCC conductor development programme.Top: optical micrographs of wires from Kiswire Advanced Technology. Bottom: electron micrographs showing a wire developed by JASTEC in collaboration with KEK. Both show the unreacted wire before the heat treatment to form the Nb3Sn compound from the niobium filaments and tin. (Credit: KAT/JASTEC. The image originally appeared in the CERN Courier, June, 2018).

The companies already producing $Nb_3Sn$ superconducting wire for the programme are Kiswire Advanced Technology Co., Ltd. (KAT); TVEL Fuel Company supported by the Bochvar Institute (JSC VNIINM); and from Japan, Furukawa Electric Co. Ltd. and Japan Superconductor Technology Inc. (JASTEC), coordinated by the Japanese High Energy Accelerator Research Organisation, KEK. Columbus Superconductor SpA will participate in the programme for other superconducting materials.  Arrangements are now being finalised for Luvata and another manufacturer, Bruker EAS, to join the programme; and the participation of our Russian partner, TVEL, has been renewed.

Moreover, the organizers acknowledged the contribution of the academic partners, who are developing innovative approaches for the characterization of superconducting wires, as well as investigating new materials and processes that could help meet the required targets. Developments include the correlation of microstructures, compositional variations and superconducting properties in TU Wien; research into promising internal oxidation routes in the University of Geneva; the study of phase transformations at TU

Bergakademie Freiberg; and conductors based on novel superconductors at CNR-SPIN.

Finally, during the two-day workshop a panel of experts reviewed the conductor programme and offered their invaluable insights during the last session of the workshop. Their recommendations centred on the scope and focus of the programme, encouraging an emphasis on novel approaches to achieve a breakthrough in performance, with the broadest possible participation of industrial partners, underpinned by close long-term partnerships with research institutions. “We fully share the panel’s ambition for developing novel approaches with our industrial partners,” agreed Hopkins. “Improving our understanding of the materials science of Nb3Sn wires is also essential for developing new and optimised processing methods, and we welcome the contribution of new research institutes”. A US research institute, the Applied Superconductivity Center based in the National High Magnetic Field Laboratory (Florida State University) has also joined the programme.




The structure of the FCC Conductor Development Programme, showing the activities (shaded boxes) and partners. A dotted outline and italic text indicate pending participants, whose participation is currently being finalised. (Credit: CERN)
Since the workshop, partners in the conductor development programme have continued to make good progress: the latest results will be presented at the Applied Superconductivity Conference in October 2018 (Seattle, USA), and a second edition of the workshop is planned in 2019.

We are confident that this will result in a new class of high-performance Nb3Sn material suitable not only for accelerator magnets, but also for other large-scale applications such as high field NMR and laboratory solenoids or MRI scanners for medical research.

Top image:  High-performance Nb3Sn cables are being assembled by a Rutherford cabling machine in CERN's superconducting laboratory (Credits: CERN).