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Coated Conductors Consultancy Pursuing Multilayer Coated Conductor Cylinders as Alternative to HTS Wire

Coated Conductors Consultancy Ltd. (3-Cs), in Watlington, UK, has developed a radically new approach to the fabrication of electrical devices based on HTS coated conductors. Instead of long lengths of superconducting wire being wound into coils in a conventional manner, the company is seeking to use superconducting multilayer coils that are manufactured directly onto a cylindrical substrate using thin film deposition and lithographic techniques.

With the exception of HTS cables, virtually all proposed applications for coated conductor involve coils. 3-Cs believes that multilayer coated cylinders can be commercially manufactured using processes largely already developed for 2G wire manufacture.

Patterned coated conductor cylinders could be configured in different ways to form a variety of superconducting electrical machines all based on highly manufacturable standard cylindrical modules with high engineering current density. Advantages to this approach include: bypassing many of the technological hurdles facing the development of long-length coated conductor wire, cost-saving benefits of coils that are mass-produced without the step of winding from wire, and the possibility of coils that are optimized for various applications in ways that would be impossible with coils wound from HTS wire.

Managing Director of 3-Cs, Eamonn Maher, commented: "I envision a new generation of electrical machines based on cylindrical modules of a standard size—say 15cm long and 8cm in diameter. These basic building blocks could be arranged to form, for example, a multi-module SMES unit, an array of magnets for one-sided MRI, a multi-module coaxial transformer, or an array of modules for a motor or generator.

3-Cs Seeking Funding and Partners

3-Cs business plan calls for the development of technology for niche applications in a pilot plant of its own, but ultimately hopes to license the technology for volume applications. To get the project past the concept stage, the company is seeking £500K in financing to demonstrate a prototype single layer device. The company is also seeking technology partners, and is currently working with the University of Birmingham.

Maher said that after a successful demonstration, 3-Cs will raise £2 million to build a multilayer demonstration capability. Maher believes a demonstration stage can be achieved within 12-18 months. Subsequent to this project, the company will raise a further £5 million to build a pilot plant that will develop specific prototypes for strategic partners in different applications areas such as energy, transport, science research, medical, and industrial processing. The pilot plant would take a further year to get up and running, Maher stated. Maher believes that if this ambitious agenda were realized on time, coated cylinder technology would be on a development schedule that parallels the more optimistic 2G wire development programs.

Maher said the company is seeking financing from a variety of sources: "We have had some support from private investors, and we are well advanced in our proposals for government funding, with one grant imminent. We also are in confidential discussions with several industry partners, large and small."

Maher believes 3-Cs is in a unique position to develop the coated cylinder concept. The company has a patent position started in 2001. Two Patent Cooperation Treaty (PCT) applications have been filed, and the first of these has reached European and U.S. filing. Maher commented: "We believe our position is unique. We think other groups will start working on this, but to date, no one else seems to have been thinking on these same lines."

Coil To Use Existing Coating Technology

Maher discussed the concept behind the coated cylinder concept: "The essential feature of all 2G wire technologies—the copying of biaxial texture from the substrate or buffer layer through to a single functional YBCO layer-is now capable of producing very high quality superconductor coatings. With this mission largely accomplished, further efforts to develop 2G wire are focused primarily on improving the technology to permit the manufacture of reproducible, homogeneous tapes in kilometer or greater lengths." Despite the fast pace of advances toward this goal, serious challenges remain.

Maher believes that as a result of these scale-up attempts, and the increased understanding of the key materials issues in the past five years, many of existing film deposition processes and multilayer architectures are actually well positioned to adopt an alternative approach based on a coaxial, essentially cylindrical geometry. The novel integrated design concept employs the simple expedient of producing a coil in situ by a multilayer deposition sequence onto a rotating cylindrical former.

To demonstrate the principle of the cylinder deposition process using existing coating deposition technology developed for 2G wire, the University of Birmingham has grown multilayer thin films of YBCO on curved nickel-based textured substrates by pulsed laser deposition (PLD). According to 3-Cs, this work successfully demonstrated the feasibility of fabricating, in situ, a multi-turn coil on a cylindrical former by continuous deposition of sequential layers of superconductor and insulator.

In this approach, layers may be uniformly deposited and subsequently patterned to define the conducting tracks, to mimic a helical winding, or in some cases direct beam writing or masking processes may be employed to define the coil.

According to Maher, the key principle of the multi-layer approach is that, if the biaxial texture can be transmitted through the buffer layer architecture into an initial YBCO layer, it should also be possible to continue copying this texture through subsequent layers. The result would be a multilayer structure of electrically isolated superconducting elements which, on a cylindrical former, could provide the basis of a multi-turn, multi-layered, helical superconducting coil.

Little Research Exists for Cylinder Concept

While epitaxial YBCO multilayers have been routinely deposited on single-crystal substrates, on the scale of tens of nanometers to produce research and device structures for electronic applications, little or no work has been reported on growing multiple layers of YBCO on biaxially textured metallic substrates for power applications. For this reason, a great deal more materials research will be required, particularly for the joining technology between layers, according to Maher.

Maher added: "Other than such materials research, the fabrication of superconducting coils in situ would use materials already widely investigated for 2G wire. In principle, a single cylindrical textured base substrate, with an integral heater, can serve as both the former and the template for the whole process. For example, a textured IBAD YSZ coating on a cylindrical base substrate, or an ISD textured layer could serve as the template. In a simpler 'half-way house' scenario, the base substrate could be a helically wound textured RABiTS Ni tape, or an ex situ prepared IBAD tape of textured YSZ on Hastelloy."

Maher described the process: "By rotating a substrate with an integral heater, buffer layers and/or superconducting layers can be deposited, followed by a textured overlayer shunt. A lattice-matched insulating layer is subsequently deposited, followed by another YBCO layer. This combination is then repeated to provide a multilayer YBCO coil, with each layer electrically isolated. If necessary, each layer could be protected by a metallic shunt layer. In the ideal scenario, only one layer of base substrate is required to provide the initial texture, thus reducing cost."

According to Maher, an additional benefit is an increase in engineering current density (J_e) of the coil, compared with a coil made of YBCO tape. This is because the base substrate is the largest component by far of conventional single-YBCO-layer coated conductor tapes, in terms of cross-sectional area. Maher commented: "Increased J_e would relax the strict requirement on texture-copying through the layers to some extent. However, if degradation of epitaxy is observed as the number of layers is increased, it could be necessary to add a new template layer at intervals."

Potential Manufacturing Advantages of Coil

3-Cs contends that there are two key processing simplifications that would potentially be gained in a cylindrical processing scenario where there is no moving tape. The first is that, although the materials requirements are quite similar, the process control aspects become easier. For example, a major problem with most tape scale-up routes is the difficulty in holding the substrate temperature constant throughout the deposition area and throughout the deposition processes.

In the case of film deposition on cylindrical substrates, there is no moving tape and no particular necessity for radiative heating. Also, the increased mass of the substrate would lend thermal stability to the coil surface. Maher says that the use of a cylindrical substrate, with its integral heater, would give coaxial symmetry, resulting in a high degree of temperature uniformity, and much greater thermal mass of the substrate compared with the tape processing case, such that the effect of any local temperature fluctuations during processing would be minimized. Radiative heating could be used to give additional tuning of the temperature control.

The second important process simplification is another direct result of the coaxial symmetry, and the simple ability to rotate the cylinder over a wide range of speeds dependent on the particular process being carried out. Maher explained: "In a sense, each layer operation is a batch operation, capable of in situ verification before proceeding to the next layer, rather than attempting to process long lengths continually. For some processes, the cylinder may be rotated slowly, for example during a laser machining process to 'scribe' a helical coil. For others it may be rotated fast, for example during thermal evaporation of YBCO when oxygenation may be taking place at the rear surface of the rotating cylinder."

Systems Designers Benefit from Coils

Maher believes that the ability to define the geometry of conductor tracks on the surface of the cylinder, rather than being constrained by the tape geometry, would potentially give design engineers increased degrees of freedom. Maher said: "Two more important advantages of the cylindrical processing approach from a systems viewpoint are that it would allow higher engineering current densities and reduced AC losses. This is because there is no repetitive wasted substrate to reduce J_c and add to the losses, unlike conventional tape winding."

Higher J_c could result in electrical machines of greatly reduced size and weight. Also, as a result of the increased structural integrity and the integrated manufacturing approach, refrigeration may be integrated into the coil, with liquid nitrogen or gaseous helium circulated through pathways within the cylinder and its shaft.

For more information, visit www.3-Cs.co.uk or write EFMaher@3-Cs.co.uk ❍

References

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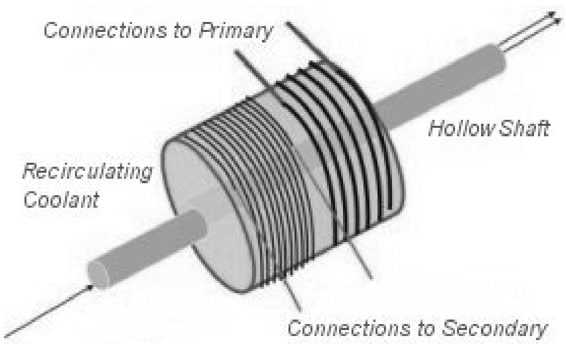
2) *Coated Conductor Cylinders – an Alternative Approach*, E.F. Maher CCA 2003 Workshop, Milan
3) *Multi-layer coated conductor cylinders—an alternative approach to superconducting coil fabrication* E Maher, J S Abell, R I Chakalova, Y L Cheung,T W Button and P Tixador Supercond. Sci. Technol. 17 (2004) 1440–1445

Coated Conductors Consultancy Ltd

3-Cs is developing revolutionary concepts for the fabrication of superconducting machines and systems. In addition, we offer products and services for materials characterization and the evaluation of superconductivity in HTS tapes.

3-Cs demonstrator

3-Cs is developing a radically new approach for the fabrication of a new generation of superconducting electrical machines and is seeking collaborations and strategic partnerships to demonstrate prototypes in different applications and market sectors.



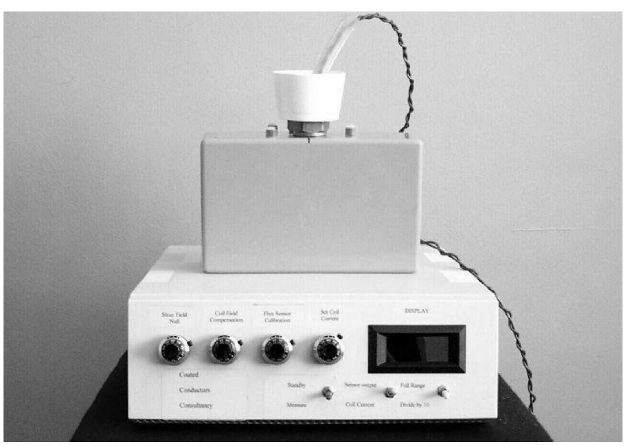
Proposed single layer test structure for a step-up transformer. Similar structures could be used to demonstrate FCL devices (resistive and inductive), SMES modules and a linear motor module

Superconducting electrical machines are usually designed in the same way as conventional machines operating at normal temperatures - with long lengths of conductor wound into coils. However, suitable lengths of high temperature superconducting tape are not yet available for building other than relatively simple demonstration equipment and this is likely to remain the case for some years to come.

The 3-Cs concept eliminates the need for long lengths of conductor and utilises film deposition and lithographic techniques widely used in the semiconductor industry, but in three dimensions. The superconducting layers are deposited directly onto cylindrical formers. Superconducting tracks are then patterned using, for example, laser scribing or etching of the superconducting layer. In this way multilayer superconducting structures will be built up directly into the cylindrical geometry required by the final electrical machine.

Please contact 3-Cs for further information and a copy of the investment proposal.

Inspector Hall



Inspector Hall equipment showing the controller, magnetic sensor unit and sample holder.

Is the optimisation of your HTS process parameters being slowed down by delays in measuring electrical properties?

Do you want to reduce the reliance on four-terminal transport current measurements and using costly and complex electrical and magnetic property measuring instruments?

If so you will be interested in the 3-Cs "Inspector Hall" rapid test equipment which gives a simple, inexpensive estimate of J_c and T_c .

Please contact 3-Cs or visit our web site www.3-Cs.co.uk for more information.

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