Jan SYKULSKI[1]

High Temperature Superconducting Machines - the State of the Art

The paper is a brief summary of the talk which will provide the state of the art in power applications of high temperature superconductivity. It will be argued that the technology offers great potential for power devices such as generators, motors, transformers, fault current limiters and cables. Examples of demonstrators and working prototypes will be given with emphasis on work undertaken at Southampton University. Main achievements and remaining challenges will be highlighted.

1. Introduction

The discovery of high temperature superconductivity (HTS) in 1986 renewed interest in superconducting power devices. HTS coils are inherently more stable than low temperature superconducting (LTS) coils, especially when operated in a liquid nitrogen environment [3]. The cost of refrigeration is also significantly reduced; although the removal of losses is still a costly process, and installed refrigeration power required is typically 25 times the rate of heat removed at liquid nitrogen temperatures, this figure should be compared with a value of over a 1000 for LTS materials at liquid helium temperatures. Moreover, liquid nitrogen technology is cheaper and significantly easier to handle – it may be compared to the technology of water or compressed hydrogen cooling which is well established in electric power generation. Potential technical and economic advantages have been demonstrated and many small devices have been built in research and industrial laboratories [2, 4].

2. Superconductivity at Southampton

Interest in superconductivity has a long history at Southampton and resulted in several experimental rigs and small prototypes built to demonstrate power applications of HTS technology, including a transformer and a generator. The talk will review the state of the art of the technology with examples of applications. It will be shown that HTS materials offer great potential in electric power applications (generators, motors, fault current limiters, transformers, flywheels, cables), as losses and/or size of devices are significantly reduced. Last year saw a completion of a 100kVA HTS synchronous generator built in our laboratory under the government sponsored research project [1]. Figure 1 shows an overview whereas Figure 2 an incomplete rotor assembly. The HTS field winding is made of single-layer vacuum impregnated pancake coils connected in series. Each of the ten coils has 40 turns of silver sheathed BSCCO tape with nominal critical current 115A at 77K in self-field, wound on a stainless steel former and interleaved by a fibreglass sheet. The coils generate an air-gap

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[1] Professor and Head of Electrical Power Engineering, School of Electronics and Computer Science, University of Southampton, Southampton SO17 1BJ, UNITED KINGDOM,
tel. +(44 23) 80593448, fax: +(44 23) 80593709, e-mail: jks@soton.ac.uk,
http://www.ecs.soton.ac.uk/people/jks

flux density of about 0.6T at 77K, while producing a normal field of only 0.038T in the superconductor. One of the particularly difficult problems was to reach a satisfactory compromise between mechanical stiffness and thermal contraction requirements of the rotor support structure while preserving the required magnetic and heat leak constraints. The room temperature stainless steel stub shafts are linked to two 9% Ni steel plates using a novel design of fibreglass ‘torque tube’ to provide the mechanical support required and to reduce the heat intake to the generator cold space. To avoid excessive eddy-current losses in the rotor pole faces, a cold copper screen is placed around the rotor core.

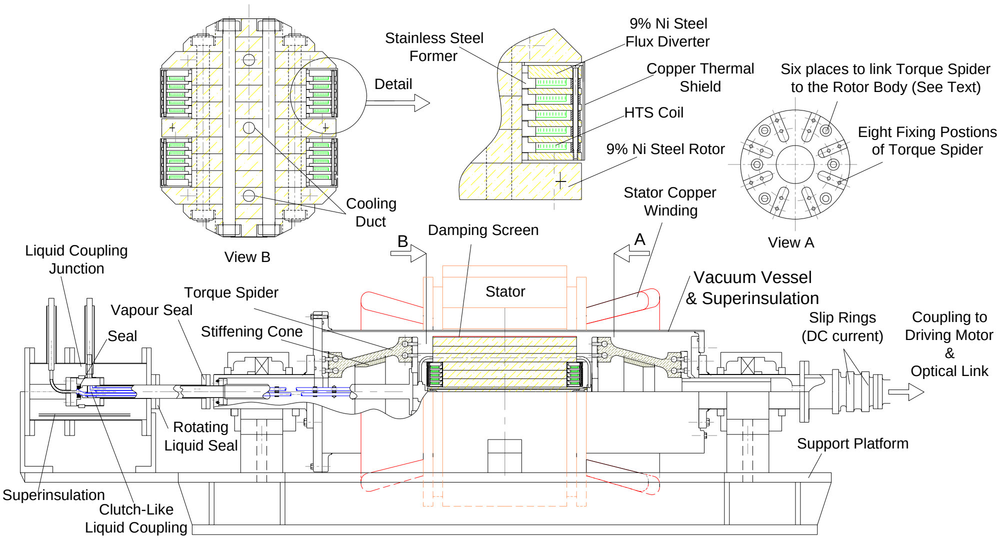

Figure 1. An overview of the 100kVA HTS generator built in Southampton.

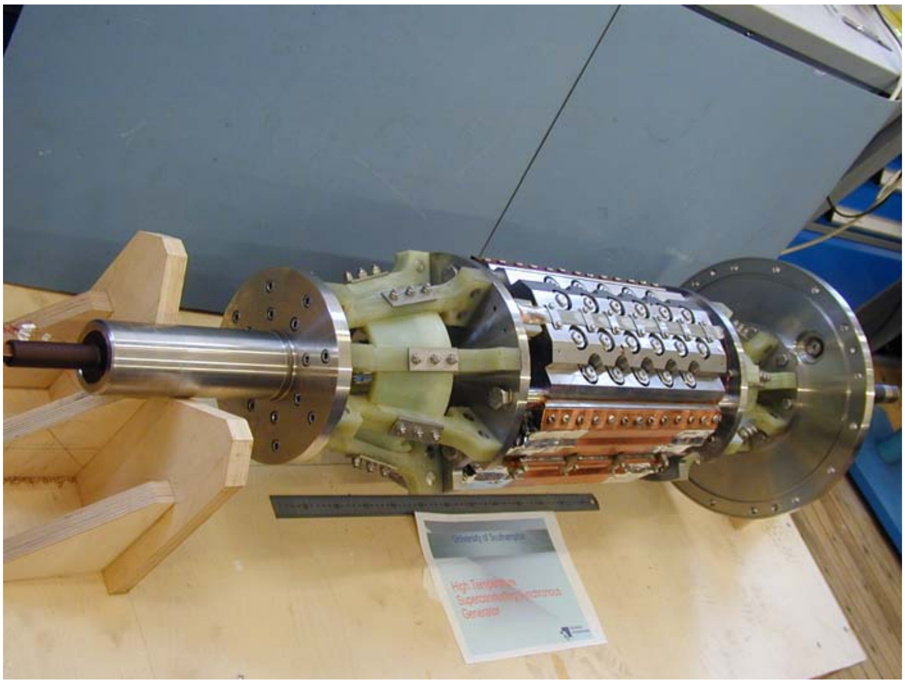

Figure 2. An incomplete rotor assembly of the 100kVA HTS generator.

Having made significant progress with the first design, demonstrated the feasibility of HTS generation, addressed and resolved a number of technical issues and established design principles for future designs, we considered the next step forward. The presence of the magnetic core was originally unavoidable simply because the properties of the tape at the time were insufficient to even consider a coreless solution while maintaining the cooling at 77K (rather than 25-30K) and still achieving reasonable air-gap flux density. Dramatic improvements in the technology of BSCCO tapes make it now possible to contemplate a coreless design at 77K or 65K (sub-cooled liquid nitrogen) or liquid air (57K). A new project has just started at Southampton under another government sponsored grant to address these issues. Preliminary design considerations reveal that it will be possible to use a ribbed fibreglass shell encapsulated in an external stainless steel cylinder as the main supporting structure so that the space inside the windings – filled with 9% nickel in the first design – may be void. The flux diverters no longer form part of the structure and could possibly be made from mild steel. The estimated savings in weight of the rotor are at least 60% (the mass of the main part of the rotor being now 75kg rather than the 170kg in the first design), but it is hoped that further reduction may be achieved through careful optimisation and better choice of materials. Figure 3 shows the magnetic flux distribution obtained from preliminary modelling. It is encouraging that the maximum flux density normal to the broad face of the tape is predicted to be below 0.07T, even if the air-gap density approaches 0.5T.

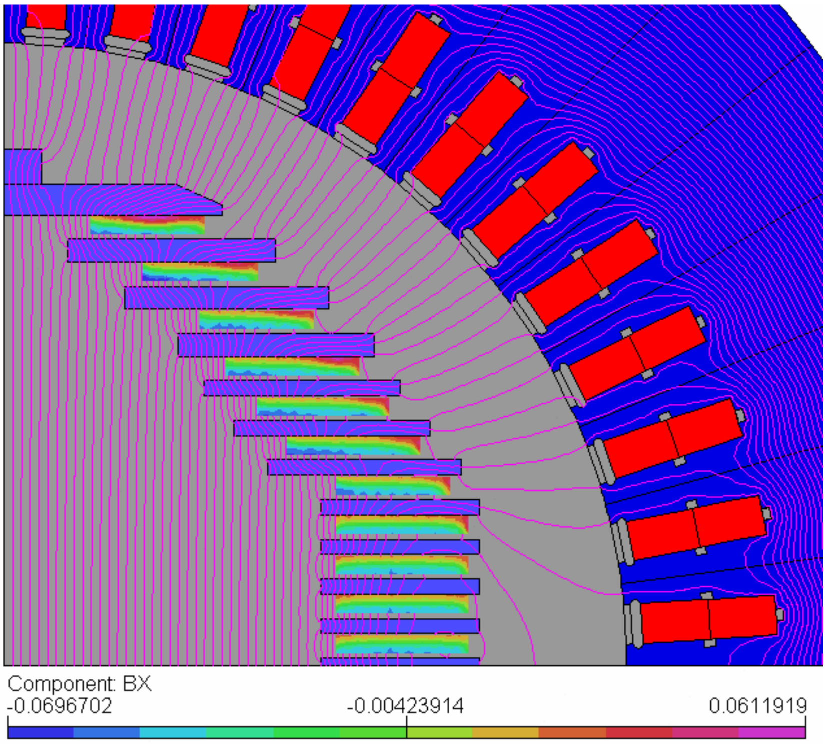

Figure 3. Preliminary field modelling results (using finite elements) showing flux distribution and magnitude levels of field 'normal' to the broad face of the tape in the HTS winding region.

Simulating current flow and magnetic field in the HTS tapes presents a significant challenge because of very highly non-linearity and anisotropic properties of materials. Several models have been developed, including some based on the idea of applying non-linear diffusion equation for a.c. field penetration [5, 6]. A typical current distribution is depicted by the graph in Figure 3; the level of non-linearity is so severe that the local conductivity may change by up to six orders of magnitude within one a.c. cycle which puts severe pressure on the computational scheme. It has also been found that using a simplified critical state model – which is quite popular in literature – does not yield accurate results.

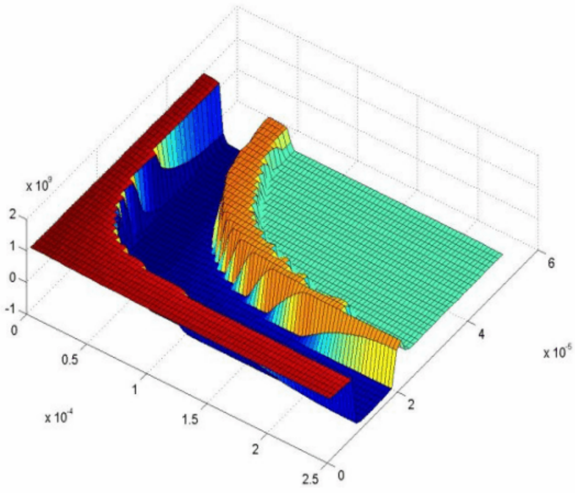

Figure 3. Current penetration into HTS tape obtained from a highly non-linear diffusion model.

3. Concluding remarks

The talk will review the work summarised above and other similar projects undertaken at Southampton and other research establishments. The main challenges and achievements will be emphasised. It will be argued that the technology has matured and that HTS power devices are technically viable and may also be economically competitive.

References

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