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Super Conducting Electrical Machines

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Abstract

This paper introduces the advancement in electrical machines. An electrical machine runs on electricity. Every machine offers losses. Losses are reducing the efficiency of the machine. Now a day there is a growth of technology till now there are no 100% efficient electric machines. In order to increase the efficiency of machine there is a way to reduce the loss governs by the machine. The superconducting electrical machines offers high efficiency and so many advantages than ordinary electrical machines. At present the materials used in magnetic circuits are copper and aluminum. The copper is a good conductor and offers losses. The aluminum also a good conductor and it provides high efficiency than copper but the mechanical strength is poor. The Ceramic superconductor such as YBCO (composed of Yttrium, Barium, Copper and Oxygen) is high critical temperature ceramic superconductor having a transition temperature well above the boiling point of liquid nitrogen. It offers zero resistance and high mechanical strength. Researchers have estimated that the superconducting electrical machines provide more than 98 percent efficiency than ordinary electrical machines. The tremendous cost, size, weight and efficiency benefits of superconducting machines will significantly change the dynamics of the machine manufacturing industry and the machine end user market.

INDEX: ELECTRICAL MACHINES, CERAMIC SUPERCONDUCTOR, DESIGNING OF MACHINES, ADVANTAGES.

I. INTRODUCTION

The need for power generation, transmission and utilization requires conducting materials. The conductor plays a prominent role in the magnetic circuits. We know that the Generators, Motors and Transformers are magnetic circuits. The electric machine plays a major role in electric value chain. The efficiency of electric machines depends on losses in the machine. Among the losses I^2 R losses (copper loss) are reduce the efficiency of the machine. The principle behind to achieve high efficiency to make the value of resistance as zero such that the value of I^2R losses is zero

The superconducting materials used to design the electric machines makes the compact sized machine, high efficiency, reduced noise, potential energy saving, etc., when the superconducting machine needs where the demand of electricity.

II. ELECTRICAL MACHINES

Electricalmachine is synonymous with electric generator, all of which are electromechanical energy converters: converting electricity to mechanical power (i.e., electric motor) or mechanical power to electricity (i.e., electric generator). The movement involved in the mechanical power can be rotating or linear. The apparatus that converts energy in three categories:

- Generators which convert mechanical energy to electrical energy,
- Motors which convert electrical energy to mechanical energy, and
- Transformers which change the voltage level of an alternating current.

Electric machines (i.e., electric motors) consume approximately 60% of all electricity produced. Electric machines (i.e., electric generators) produce virtually all electricity consumed. Electric machines have become so ubiquitous that they are virtually overlooked as an integral component of the entire electricity infrastructure. Developing ever more efficient electric machine technology and influencing their use are crucial to any global conservation, green energy, or alternative energy strategy.

III. SUPERCONDUCTORS

A superconductor is an element or metallic alloy which, when cooled below a certain threshold temperature, the material dramatically loses all electrical resistance. In principle, superconductors can allow electrical current to flow without any energy loss (although, in practice, an ideal superconductor is very hard to produce). This type of current is called a supercurrent.

Superconductivity was first discovered in 1911, when mercury was cooled to approximately 4 degrees Kelvin by Dutch physicist Heike KamerlinghOnnes, which earned him the 1913 Nobel Prize in physics. In the years since, this field has greatly expanded and many other forms of superconductors have been discovered, including Type 2 superconductors in the 1930s.

The basic theory of superconductivity, BCS Theory, earned the scientists - John Bardeen, Leon Cooper, and John Schrieffer - the 1972 Nobel Prize in physics. A portion of the 1973 Nobel Prize in physics went to Brian Josephson, also for work with superconductivity. In January 1986, Karl Muller and Johannes Bednorz made a discovery that revolutionized how scientists thought of superconductors. Prior to this point, the understanding was that superconductivity manifested only when cooled to near absolute zero, but using an oxide of barium, lanthanum, and copper, they found that it became a superconductor at approximately 40 degrees Kelvin. This initiated a race to discover materials that functioned as superconductors at much higher temperatures.

IV. SUPERCONDUCTORS IN ELECTRICAL MACHINES

The ceramic based superconductors are used to manufacture the superconducting electrical machines. There are so many ceramic superconductors are available in the market. Out of those materials we choose **barium copper yttrium oxide** superconductor.

- Why barium copper yttrium oxide superconductor is used in electrical machines?

Although $YBa_2Cu_3O_7$ is a well-defined chemical compound with a specific structure and stoichiometry, materials with fewer than seven oxygen atoms per formula unit are non-stoichiometric compounds. although single crystals of YBCO have a very high critical current density, polycrystals have a very low critical current density: only a small current can be passed while maintaining superconductivity.

The $YBa_2Cu_3O_7$ is perfectly suitable for electrical machines because of their structure, high mechanical strength and its critical temperature (-195.8°C or -320.4°F) coincide with the temperature of liquid nitrogen (-196°C or -321°F) which is used as a medium for superconductivity of $YBa_2Cu_3O_7$ material.

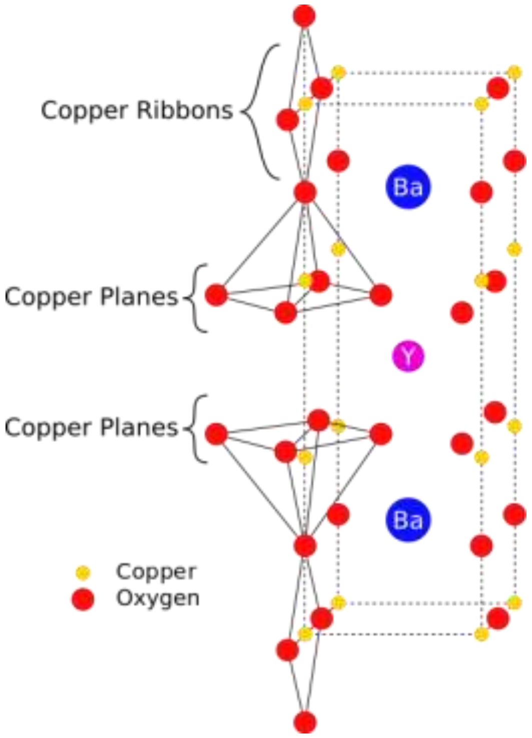
A. **Yttrium Barium Copper Oxide ($YBa_2Cu_3O_7$)**

Yttrium barium copper oxide (YBCO) is a family of crystalline chemical compounds, famous for displaying "high-temperature superconductivity". It includes the first material ever discovered to become superconducting above the boiling point of liquid nitrogen (77 K) at about 90 K.Relatively pure YBCO was first synthesized by heating a mixture of the metal carbonates at temperatures between 1000 and 1300 K.

$$4\ BaCO_3 + Y_2(CO_3)_3 + 6\ CuCO_3 + (1/2-x)\ O_2 \rightarrow 2\ YBa_2Cu_3O_{7-x} + 13\ CO_2$$

Modern syntheses of YBCO use the corresponding oxides and nitrates.

YBCO crystallises in a defect perovskite structure consisting of layers. The boundary of each layer is defined by planes of square planar CuO_4 units sharing 4 vertices. The planes can sometimes be slightly puckered. Perpendicular to these CuO_2 planes is CuO_4 ribbons sharing 2 vertices. The yttrium atoms are found between the CuO_2 planes, while the barium atoms are found between the CuO_4 ribbons and the CuO_2 planes. This structural feature is illustrated in the figure below.



Pervoskite structure of YBCO

B. **Annealing Technique for Manufacture of YBCO**

Annealing is a technique used in manufacturing process to withstand the ceramic material in high mechanical strength. It usually follows sintering and is done in an oxygen rich atmosphere to restore oxygen lost during calcination. The oxygen content of a ceramic superconductor is critical for example YBCO with 6.4 atoms of oxygen will not super conduct but 6.5 atoms of oxygen will super conduct.

V. **esign of superconducting electrical machines**

Superconucting electrical machines should have zero resistance, low power consumption and high efficiency.

Some consequences of zero resistance are as follows:

- When a current is induced in a ring-shaped SC, the current will continue to circulate in the ring until an external influence causes it to stop. In the 1950s, 'persistent currents' in SC rings immersed in liquid helium were maintained for more than five years without the addition of any further electrical input.
- A SC cannot be shorted out, e.g., a copper conductor across a SC will have no effect at all. In fact, by comparison to the SC, copper is a perfect insulator.
- The diamagnetic effect that causes a magnet to levitate above a SC is a consequence of zero resistance and of the fact that a SC cannot be shorted out. The act of moving a magnet toward a

SC induces circulating persistent currents in domains in the material. These circulating currents cannot be sustained in a material of finite electrical resistance. For this reason, the levitating magnet test is one of the most accurate methods of confirming superconductivity.

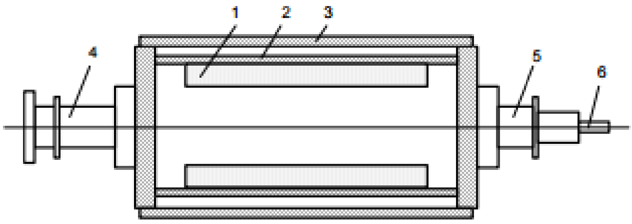
- Circulating persistent currents form an array of electromagnets that are always aligned in such as way as to oppose the external magnetic field. In effect, a mirror image of the magnet is formed in the SC with a North pole below a North pole and a South pole below a South pole.

The main factor limiting the field strength of the conventional (Cu or Al wire) electromagnet is the I^2R power losses in the winding when sufficiently high current is applied. In a SC, in which R = 0, the I^2R power losses practically do not exist.

SC field excitation winding can provide high magnetic flux density in the air gap at zero excitation losses. Such field excitation systems lead to performance characteristics not achievable so far by classical field excitation systems, e.g., with copper coils or PMs. A PM motor rated at 7 MW for marine pod propulsor weighs about 120 t. An HTS synchronous motor concept would drastically reduce the weight of a podded electromechanical drive by 50%.

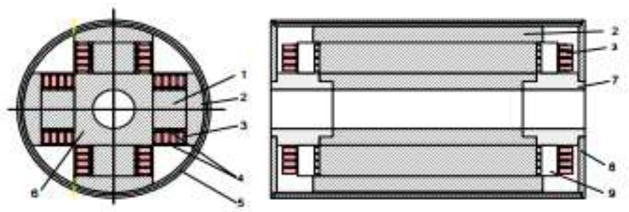
SUPERCONDUCTING ELECTRICAL MOTOR.

By using an SC wire for the field excitation winding, the field winding losses $I_f^2R_f$can be practically eliminated, since the field winding resistance R_f = 0. The magnetic flux excited in the stator (armature) winding by the rotor excitation system is not limited by saturation magnetic flux density of the ferromagnetic core, because the stator system can be constructed without stator ferromagnetic teeth. Slot less armature system means that losses in the armature teeth do not exist and the distribution of the stator air gap magnetic flux density waveform can be sinusoidal.



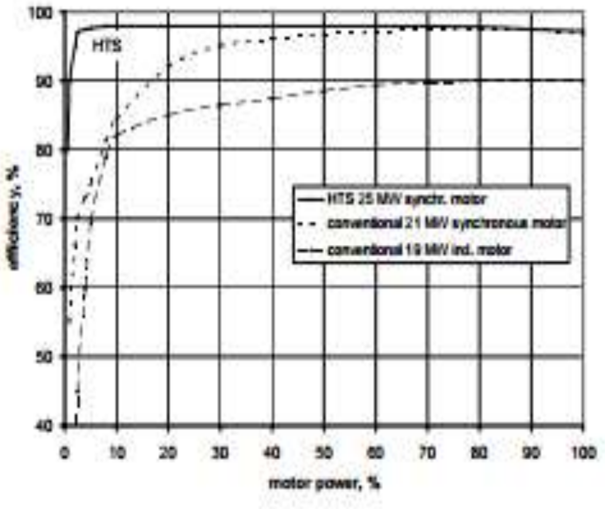
Air core rotor of a superconducting synchronous machine.

1 — HTS coil, 2 — torque tube 3 — electromagnetic shield, 4 — turbine end shaft, 5 — collector end shaft, 6 — transfer coupling.



Salient pole rotor with HTS excitation winding:

1 — pole core (ferromagnetic material), 2 — pole shoe (ferromagnetic material), 3 — HTS coil, 4 — coil spacers, 5 — cold electromagnetic shield (oxygen free Cu Inconnel 718), 6 — rotor yoke (ferromagnetic material), 7 — stainless nonmagnetic bushing, 8 — end disk (stainless nonmagnetic steel), 9 — support of HTS end connections (nonmagnetic and nonconductive material).



VII. **CONCLUSION**

Superconductivity is the upcoming technology in the field of electrical machines which is under experimental stage. This seems like a very promising direction that will eventually allow for superconductors promise to be more fully harnessed. It helps in increasing the efficiency, reliability of the electrical drives.

REFERENCES

[1] American Superconductors (AMSC), Westborough, MA, USA, http://www.amsuper.com/ J. Clerk Maxwell, A Treatise on Electricity and Magnetism, 3rd ed., vol. 2. Oxford: Clarendon, 1892, pp.68–73.

[2] Bardeen J., Cooper, L.N., and Schrieffer J.R. (1957). Theory of superconductivity, Phys. Review, 108:1175–1204.

[3] Barnes P.N. (2007). Advancing YBCO-coated conductors for use on air platforms, Int. Journal of Appl. Ceramic Technology, 4(3):242-249R. Nicole, "Title of paper with only first word capitalized," J. Name Stand. Abbrev., in press.

[4] Bednorz J.G., and Mueller K.A. (1986). Possible high Tc superconductivity in the Ba-La-Cu-O system, Zeitschrift fur Physics B – Condensed ¨ Matter, 64:189–193.

[5] A.J. Dekker, Electrical Engineering Materials (Prentice Hall, 1988).

Efficiency versus power of conventional and HTS synchronous motors for marine propulsion.

VI. **SYNCHRONOUS MACHINES WITH HTS ROTOR FIELD**

VII. **EXCITATION WINDINGS**

SHOW THE FOLLOWING GENERAL ADVANTAGES:

• Higher power density than that of classical synchronous machines;

• Reduced mass;

• Increase in machine efficiency beyond 99% by reducing power losses by as much as 50% over conventional machines;

• High efficiency at all loads - down to 5% of full load;

• Low noise;

• Superior negative sequence capability;

• Excellent transient stability;

• Low synchronous reactance – small load angle;

• Enhanced grid stability;

• Low harmonic content;

• Reduced acoustic noise;

• require less maintenance than classical synchronous machines.