Composite materials in high efficient sleeve applications of electric machines

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***Abstract*— This paper describes the potential of composite materials for sleeves of electric machines. Composite retention sleeves are used to retain magnets on high speed rotors used in electric motors and generators. Filament wound composite retention sleeves offer the perfect technical solution for magnet retention on high speed magnetic rotors due to high strength in combination with magnetic field transparency. Due to the outstanding characteristics composite sleeves can be designed very thin and the space between outer diameter of rotor magnets and inner diameter of stator can be minimized. In addition, composite materials have very good transparency for the magnetic field. This paper describes benefits together with several fields of application for composite sleeves.**

Keywords*— *Composite materials, sleeves, cans, filament-winding

I. Introduction

Electric machines with stator or rotor sleeves have a wide range of application. Rotating sleeves for example are used for high speed rotors to protect magnets against centrifugal forces. Stator sleeves can be used to shield machine components from the process fluid, also called canned motor pumps.

Metallic rotor sleeves are used extensively in high-speed permanent-magnet machines for fastening the permanent magnets. Metallic materials are also extensively used for manufacturing of cans in canned motor pumps. It is evident that eddy-current losses are generated in such metallic sleeves and leads to reduced machine efficiency and may also lead to overheat the electric machines.

Recently composite rotor sleeves and cans are coming up. Composites are the first choice for such applications as they are almost transparent for magnetic field, have an excellent stiffness, strength and are easy to machine. In order to reduce the rotor eddy-current losses, this paper focuses on composite materials, composite manufacturing technologies and composite sleeve applications.

II. Composite sleeve and can manufacturing technology

Several publication analyses rotor eddy-current losses as a function of sleeve material, sleeve thickness, rotor speed and drive frequency. Efficiency of electric machines can be predicted by simple mathematic models [1] as well as by finite element method (FEM) of eddy current losses in conductive non-magnetic sleeves (cans) [2]. Depending on electric machine design and revolution speed the efficiency of electrical machines is predicted to be increased by >30% [3] using composite sleeves compared to metallic sleeves.

As conclusion composite sleeves and cans can be assumed as very efficient. Therefor there is a high potential of composite materials for application of electric machines.

Composite material for sleeves and cans are manly made by combining two materials – fibres and matrix materials. The two materials work together to give the composite unique properties. The biggest advantage of modern composite materials is that they are light as well as strong. By choosing an appropriate combination of matrix and reinforcement material, a material can be made that exactly meets the requirements of a particular sleeve and can applications. The higher cost of composite materials compared to some metallic materials can be over compensated by more efficient electric machines.

One manufacturing method of composite rotor sleeves and cans for motor pumps is filament winding technology. Filament winding technology shown in Fig. 1 is an automated CNC controlled process of wrapping resin impregnated continuous filaments in a geometric pattern over a rotating male mandrel.

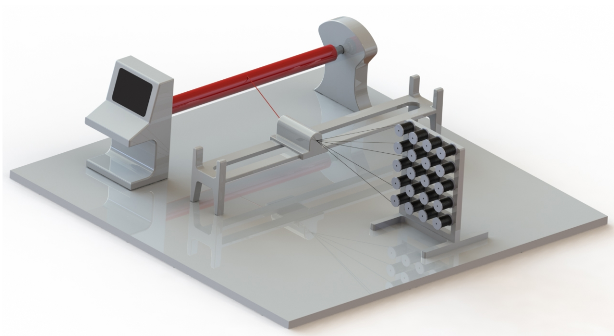

Fig. 1. Filament winding technology.

Typical filament materials used for sleeve applications are carbon-, glass- or aramid-fibres. The combination of the fibres and matrix leads to glass fibre reinforced platic (GFRP), carbon fibre reinforced plastic (CFRP) and aramid fibre reinforced plastic (AFRP). A wide range of certified composite thermoset and thermoplastic materials from low temperatures up to high temperatures of 400 °C are available on the market. Table 1 shows significant properties of typical composite materials compared to metallic materials.

The filament winding process has considerable advantages over conventional techniques leading to superior outcomes in strength and consistency. Filament winding can achieve these results because of:

- high material strength
- precise fibre orientations
- high fibre-to-resin ratios
- straight, un-crimped fibre paths
- high consistency and repeatability
- adjustable and controlled fibre tension

Filament winding can be stated as an important technology for composite sleeve, composite can and composite rotor housing manufacturing.

Composite sleeves are offered as tight fit solution, assembled by the manufacturer or assembled by the customer as well as composite sleeves applied by directly winding onto the rotors.

In order to achieve best efficiency and minimum wall thickness, the fibre tension during filament winding is of particular importance. Filament winding technology provides an extreme pre-tensioning of the rotor magnets in radial direction which leads to extraordinary thin sleeve material. Low clearance between rotor and stator combined with the transparency of composite materials for the magnetic field in combination with the high mechanical properties and non-corrosive properties leads to high efficient electric machines using filament winding technology.

To apply process capable radial pretension on magnets assembled on big diameter rotors or magnets assembled on long rotors is challenging using metallic sleeve technology. Using filament winding technology leads to a save and repeatable process to apply radial pretension on magnets assembled on big diameter rotors or magnets assembled on long rotors. Due to a high tensioning braking device developed at CirComp, glass-, carbon-, aramid- and other fibres can be processed with extremely high and constant pretension which leads to high radial pretension on the magnets. Properties of composite sleeve materials are given in Table 1.

TABLE I. PROPERTIES OF COMPOSITE SLEEVE MATERIALS

Sleeve Material		***GFRP DW210***	***AFRP DW152***	***CFRP DW231***	***CFRP DW260***
Tensile strength *	MPa	1,440	1.880	2,420	2,420
Density	g/cm^3	2.1	1.33	1.52	1.52
Eddy current loss		low	low	low	low
Max. application temperature	°C	<110°C	<140°C	<140°C	>300°C
Coefficient of thermal expansion *		~ 7	< 0.2	< 0.2	< 0.2

* in fibre direction

Composite sleeves applied by directly filament winding with fibre pretension on rotors can be applied on rough and uneven magnet surface which significantly reduces costs as complex machining and grinding of magnet surfaces is not required. Due to the CNC controlled winding and tensioning process the manufacturing is very accurate and repeatable. In addition to thermoset composites, all kinds of thermoplastic composite tapes as for example carbon fibre PEEK (CF/PEEK), carbon fibre PPS (CF/PPS) or aramid fibre PA12 (AF/PA12) tape can be processed with the high tensioning braking device developed at CirComp.

Composite sleeves have outstanding characteristics for electric machines due to high strength of the composite material compared to metallic materials the sleeves can be designed very thin and the space between outer diameter of rotor magnets and inner diameter of stator can be minimized. In addition, composite materials have very good transparency for the magnetic field. Comparing metallic sleeves leads already to significant differences in magnetic field losses. The difference of stator can losses using Hastelloy C cans compared to stator can losses using Hastelloy 1.4571 is about a factor of 3 [4]. Properties of metallic sleeve materials are given in Table 2. Typical values of increase in efficiency using composite materials as rotor sleeves or cans are between 2-5% compared to optimized metallic materials. Several high speed applications can only be implemented by use of composite material sleeves, as metallic material sleeves do not have enough strength and cannot apply the required pretension.

TABLE II. PROPERTIES OF METALLIC SLEEVE MATERIALS

Sleeve Material		***Carbon steel***	***Hastelloy 1.4571***	***Hastelloy C4***
Tensile strength	MPa	280 – 1,900	~ 600	~ 700
Density	g/cm^3	7.8	7.98	8.64
Eddy current loss		very high	high	middle
Max. application temperature	°C	>300°C	>300°C	>300°C
Coefficient of thermal expansion		11 - 17	~ 16	~ 11

III. CONCLUSIONS

A. Outrunner motor housing

Electric motors that include an outer rotating rotor may also be referred to as outrunner motors [5]. Electric motors of a typical outrunner design include an outer rotor housing that spins around an inner stator that carries coils or windings. The outer rotor housing includes permanent magnets and may be connected to a drive shaft that is located on the axial centerline of the motor. In general, outrunner motors produce more torque than their inrunner counterparts. Outrunner motors are often chosen for specific applications due to their size and power-to-weight ratios.

Composite materials are used as rotor housing for such application in order to reduce heating induced by magnetic fields of the electric machines and to reduce the accelerated mass and total weight of electric machines.

B. Separating Stator Cans for Pumps

The ever-increasing demand for environmental safety at a reasonable cost presents a unique challenge to the process industries: find and utilize equipment that, while operating leak-free, performs reliably and efficiently. Canned motor pumps also known as stator sleeve pumps meet and exceed this challenge. Canned motor pumps offer many remarkable operating, maintenance and performance advantages. Designed to enable long periods of time between pre-planned maintenance intervals, these pumps have a minimum of components that need to be monitored and serviced. Costly alignment procedures or external lubrication are never required. And, because they are seal-less, canned motor pumps eliminate required dynamic seal adjustments and maintenance as well as the demands of complicated and maintenance intensive seal support systems.

Composite cans for canned motor pumps are typically made of two layers. The inner barrier layer assures gas and fluid tightness and the thin composite layer takes up internal pressure forces. As composite materials are characterized by high strength, composite layers can be designed very thin.

Stator composite sleeves in canned motor pumps offer the perfect technical solution due to their transparency for the magnetic field in combination with the high mechanical properties and non-corrosive property. Typical lot sizes at CirComp for composite canned motor pump sleeve manufacturing are between 10,000 to over 200,000 units.

As the main magnetic flux permeate the stator can in rotational motion, magnetic flux losses are even more significant than in rotor sleeve application. Significantly less eddy current losses can be achieved by the implementation of composite can materials. Thin composite cans offer advantages compared to any metallic cans to achieve high efficiency and to consume much less power.

C. Rotor Sleeves

Composite retention sleeves (Fig. 2) offer the perfect technical solution as magnet retention sleeves due to their transparency for the magnetic field in combination with the high mechanical properties and low weight.

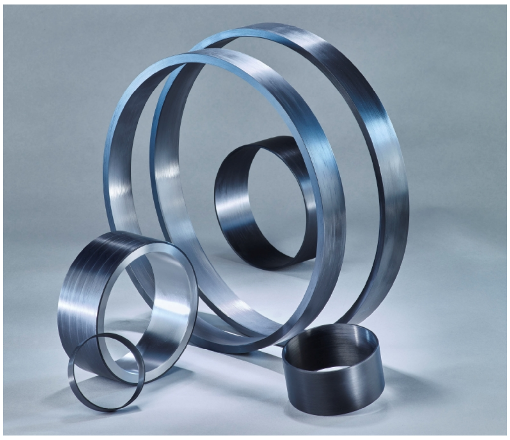

Fig. 2. Composite retention sleeves.

In a wide range of applications the magnets are typically bonded to the rotor. In certain cases, bonded magnets are taking off the rotor and cause significant damage to the machines. Reasons for “magnet take off” are for example missing adhesive due to failure in bonding process, poor adhesion between magnets and rotor, low mechanical property or ageing of the adhesive.

In order to overcome these drawbacks, magnets are additionally covered with sleeves.

Motor and generator units with composite sleeves are used in a variety of applications to improve speed and energy efficiency across all sectors. Fig. 3 shows a high speed rotor with CFRP composite sleeve.

Composites are the first choice for such applications as they have an excellent stiffness, strength, low weight and are easy to machine.

Composite sleeves can be assembled as tight fit solutions or can be applied by direct winding onto the rotors. One main advantage of direct filament winding onto rotor magnets is achieved by the elimination of machining the magnet outer surface of the rotor. Minor surface roughness of magnets and minor misalignment of magnets can be compensated by direct filament winding onto rotor magnets.

Fig. 3. High speed rotor with CFRP composite sleeve.

The range of applications includes all kinds of high speed motor and generators as well as Kinetic Energy Recovery Systems (KERS), micro gas turbine engines as well as for turbo energy recovery systems and electric hybrid turbo charger. An electric hybrid turbo charger consists of high speed turbine generator and high speed electric air compressor. The turbine and compressor in this case are high speed aero machines, as in a conventional turbocharger. The electrical motors run at speeds in excess of 100,000 rpm. With hybrid turbocharger compressors, speed and power are independent from turbine speed and power. This design leads to higher efficiency of turbocharged engines. With latest process technologies composite sleeves withstand application temperatures over 300°C [6].

All mentioned composite sleeves and cans are provided by CirComp. Typical lot sizes for composite sleeve manufacturing are between 1 rotor sleeve to over 200,000 rotor sleeves with dimensions between 20mm of diameter to 1,000mm of diameter.

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