Synchronous motor with HTS-2G wires

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Abstract. One of the applications of new high-temperature superconductor materials (HTS) is field coils for synchronous electrical machines. The use of YBCO 2G HTS tapes (HTS-2G) allows increasing of magnetic flux density in the air gap, which will increase the output power and reduce the dimensions of the motor. Such motors with improved characteristics can be successfully used in transportation as traction motor. In MAI-based "Center of Superconducting machines and devices" with the support of "Rosatom" has been designed and tested a prototype of the 50 kW synchronous motor with radial magnetic flux from a field-coils based on HTS-2G tapes. The experimental and theoretical results are presented.

1. Introduction

Analysis of existing developments showed that the world is gradually moving from internal combustion engines to the use electric motors as traction drive for transport applications. This is due to high efficiency of electric motors, reduction of the size of the traction drive, absence of harmful emissions etc.

We can make a prediction that the next transition in the application of traction motors will use superconducting motor. This is evidenced by numerous examples of the use of superconducting motors for large-scale, powerful traction drives, and, for example, in the automobile industry.

They may provide a number of advantages, such as reducing the size and increasing the efficiency of up to 99% own efficiency (excluding cooling) for large machines.

Many years of experience in the field of creation of cryogenic electrical machines was put in a basis of development of the electric motor with 2G HTS tapes for transport applications.

Currently, the most promising are the following areas of application of powerful high-performance superconducting electric motors as drive:

- Propellers large vessels;
- The leading wheel pairs of electric locomotives;
- Cargo electric cars and electric buses;
- Propellers helicopters and hovercrafts etc.

Preferred area of application for future HTS motor was selected the electric transport. In future will planed to install a new HTS motor on the electrical bus.
2. **A small test model of HTSC-2G motor with power of 50 kW has been produced**

To gain experience with work with new HTS-2G tapes was designed and produced a small scale model of a synchronous motor. Its power is equal to 50 kW (see figure 1).

Designed synchronous motor has 10 poles, 3 phases, a nominal phase voltage 220 V and nominal current about of 80 Amps. Nominal rotation speed of this electrical motor is 300 rpm. Its calculated efficiency with account for losses in the stator winding, losses in steel and mechanical losses amounted a near to 97% (without cooling).

![Figure 1. Experimental model of 50 kW HTS motor.](image)

Field coils were made of SuperPower HTS-2G tape (4 mm, Ic = 100 A SF) at the Institute for High Energy Physics (Protvino). HTS coils were made according to the technology of "double pancake". At the one pole were located two coils with 120 turns in each. For the convenience of winding and further use, winding was made on the steel core (see figure 2). Then, it was fastened to the iron yoke of rotor. The electrical ends of coils were brought out and soldered to the copper wire (see figure 3).

![Figure 2. The winding process of HTS-2G tapes in IHEP (Protvino).](image)  
![Figure 3. Field-coils was made of HTS-2G tapes with iron core inside.](image)

Cooling of synchronous 50 kW motor was performed by the use of liquid nitrogen. The housing of the motor was a cryostat. Thermal insulation was mounted to the outside of the motor. For the protection from the leakage of liquid nitrogen between the housing and the shaft were used special o-rings.

Electrical power for excitation of field coils was transmitted to the rotor by the use of the slip rings. To prevent the formation of frost, nitrogen vapors were filed to the place of the slip rings.
3. Experimental studies of 50 kW HTS-2G motor were conducted

Experimental studies of 50 kW synchronous motor with HTS-2G field-coils were held on summer 2013. They performed on the test bench of Research Institute of Electromechanics (Istra).

Starting and speedup of the motor were performed by the use of frequency inverter. The load was performed by the using of a high-speed DC machine with gearbox.

Field coils were powered from a DC power supply. Current in the field-coils for safety reasons (related with the critical current), do not exceed 22 A. Due to the high inductance HTS-2G coils, input current increased with the rate of ~1 A/sec. HTS field coils were are not specially shielded from alternate magnetic fields of stator winding.

Some results of the performed test of the 50 kW HTS-2G motor are shown on figure 4 and figure 5. It is seen that due to the limitations of the current in the excitation winding of rotor, voltage in the stator winding was slightly below than calculated. Maximum output power was 42 kW at the speed of motor 300 rpm. Tested electrical motor showed high efficiency (above 96 %) and high power factor in the wide range of loads.

![Figure 4. No-load characteristic for the 22 A of excitation current and 300 rpm.](image)

![Figure 5. Load characteristics of the 50 kW HTS-2G motor.](image)

The gained successful experience in developing of 50 kW motor with HTS-2G tapes was used to design a new traction motor for transport.

4. Currently in development 200 kW HTS-2G motor for transport applications

At present in the "Russian Center of cryogenic electrical machines" (MAI, Moscow) 200 kW synchronous motor with HTS-2G field-coils is developing. Future motor is designed for installation on electrical bus.

For the decrease of cooling power of motor, its stator will be located at ambient temperature. Field-coils located on the rotor will be made from HTS-2G tapes. Rotor will be placed in a rotating cryostat for cooling of HTS-2G excitation coils. In this regard, the air gap of HTS motor will be increased for placing thermal insulation of the cryostat.

Increased air gap demanded increase of magneto motive force of excitation winding. For these purposes the number of double-pancake HTS coils will be increased up to 3 on one pole.

Stator of 200kW HTS motor will be cooled with water. It will provide to increase of stator current density and reduce the thickness of stator yoke.

Currently checking calculations of the magnetic state of stator are carried out, choosing the most rational scheme for cooling HTS windings, investigate the possibility of the contactless current transfer into the excitation winding.

Main parameters of future 200 kW HTS motor shown in Table 1.
Production of 200 kW HTS motor planned on 2014-2015. The first tests must be conducted in 2015.

**Table 1. Parameters of future 200 kW synchronous HTS motor**

| List of Parameters                               | Identification | Value  |
|--------------------------------------------------|----------------|--------|
| Nominal Output Power (kW)                        | P              | 200    |
| Phase voltage (V)                                | U              | 450    |
| Nominal Speed (rpm)                              | n              | 1500   |
| Maximal Speed (rpm)                              | \( n_{\text{max}} \) | 4000   |
| Nominal moment (N\( \cdot \)m)                  | M              | 1300   |
| Maximal moment (N\( \cdot \)m)                  | \( M_{\text{max}} \) | 2600   |
| Phase number                                     | m              | 3      |
| Pole number                                      | p              | 6      |
| Nominal current (A)                              | I              | 165    |
| Inner diameter of stator (mm)                    | D              | 340    |
| Active light (mm)                                | L              | 220    |
| Material of stator winding                       | –              | Cu     |
| Operating temperature of stator winding (K)      | \( T \)        | \( \sim 300 \) |
| Material of field-coils                          | –              | HTS 2G tape |
| Operating temperature of field-coils (K)         | \( T_{\text{FC}} \) | 77     |
| Nominal current in field-coils (A)               | \( I_{\text{FC}} \) | 34     |
| Number of turn per one pole                      | \( w_{\text{FC}} \) | 252    |
| Operating Power factor                           | \( \cos \varphi \) | 0.95 – 0.99 |
| Full load efficiency (%)                         | \( \eta \)    | 96.3   |

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