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MATHEMATICAL SIMULATION OF THERMAL CONDITION OF A BRUSH CONTACT DEVICE IN A THREE-DIMENSIONAL SETTING

A detailed review of the existing design of brush-contact devices for 200 MW to 600 MW turbo-generators is performed. The main causes of damages are indicated and the ways of developing and improving the existing design are indicated. An analysis of the methods of calculating heat releases in a brush-contact device caused by heat releases of different nature was performed. The possibility of performing a three-dimensional computation, using the results of the analytical computation together with the CFD method, is shown. For the first time, a computation was performed and an improved method was developed for determining the thermal state of a brush contact device for high and medium-power turbo-generators.

Introduction

At present, a revision of the existing techniques for designing and calculating electrical machines is taking place. The most interesting and complex in designing is a brush contact device (BRCD). Its important feature is that when designing and calculating heat, it is necessary to solve the thermal problem with three types of heat generation: electrical losses in a classical setting, friction of the brushes on the slip ring, and additional losses caused by the action of parasitic currents. In the scientific works of Khutoretskyi G. M. [1], Alekseev A. Ye. [2], and Danilevich Ya. B. [3], the basic methods for designing and calculating electric machines of similar types are described, but the presented works do not provide a possibility to reconstruct the actual picture of the thermal state of a BRCD in a three-dimensional form. In this regard, to meet the requirements of reliability and operation, it is necessary to revise the existing methods for implementing solutions in software systems, using methods of computational fluid dynamics (CFD).

The objective of this paper is to create a technique for determining the thermal state of a BRCD in a three-dimensional setting, taking into account the heat generated by electrical and mechanical influences.

Description and design of a BRCD

A BRCD is a unit providing direct current from stationary current-carrying parts of an excitation circuit to the rotating winding of a generator rotor by means of a sliding contact.

The generator rotor has structures for fixing brush-holders. These structures are called brush-holder yokes. Each of these yokes is composed of two half-rings made from steel strips, with holes for fixing brush-holders.

A typical brush holder yoke includes brush holders and is equipped with sliding contact brushes. The number of the brushes installed at each pole of a BRCD is determined by the value of the maximum excitation current of the rotor winding and the permissible current of the brushes.

The scope of supply of the equipment usually includes one BRCD and a spare parts kit, including brush holders and electric brushes (if necessary).

The technical requirements for BRCDs are the following:

− both the arrangement of the brushes on the surface of the slip ring and pressure force of all the brushes throughout their operation shall be uniform;

− they shall be equipped with quick- detachable brackets with the use of an MC-axle box;

− they shall use two terminal panels for connecting the excitation busbar (3 lugs per pole);

− the brush-holder yoke bus shall provide transmission of the rated excitation current and have a corrosion resistant coating;

− the brushes shall be installed on the slip ring with offset (in chequered fashion);

− spaces shall be provided for installing an insulated brush at each polarity;

− the ventilation circuit shall be open;

− the intake of the cooling air shall be performed from the engine room, through the housing of the

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BRCD with discharging into the same the engine room.

Fig. 1 shows a general view of a 200 MW turbine generator manufactured at SE 'Plant 'Electrotyazhmash' with a BRCD.

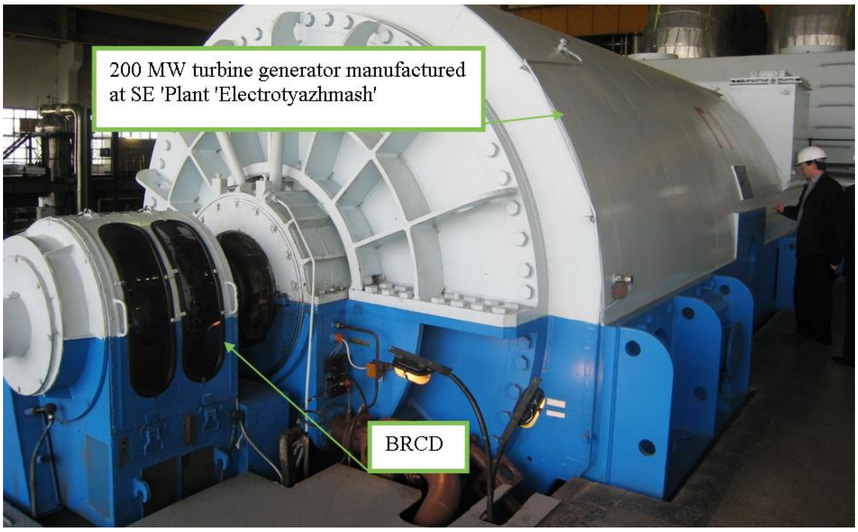


Fig. 1. General view of a turbo-generator

Table 1 presents a list of turbo-generators of various capacities manufactured in Ukraine and abroad, where at the moment MERSEN (France) has already installed the elaborated variants of the upgraded BRCD

Table 1. Turbo-generators (TG) with BRCDs

TG type	TG manufacturer	Slip ring diameter, mm	Current, A	Remark
TBF-63	ELSIB, Electrosila	463	1350	open-type BRCD, without forced ventilation
TBF -110	ELSIB, Electrosila	463	1750	open-type BRCD, without forced ventilation
TBF -63	ELSIB, Electrosila	320	1350	closed-type BRCD, fan between poles
TBF -110	ELSIB, Electrosila	320	1750	closed-type BRCD, fan between poles
TZFP-110	ELSIB, Electrosila	320	2000	closed-type BRCD, fan between poles
TZFP -160	ELSIB, Electrosila	320	2000	closed-type BRCD, fan between poles
TVV-220	ELSIB, Electrosila	460	2750	open-type BRCD, without forced ventilation
TGV-200	SE 'Plant 'Electrotyazhmash'	450	2100	closed-type BRCD, fan at shaft end
TVV-320	ELSIB, Electrosila	460	2750	closed-type BRCD, fan at pole tips
TVV-800	ELSIB, Electrosila	400	3850	closed-type BRCD, fan between poles

Monitoring systems

To ensure the optimal temperature state of the entire system with the purpose of avoiding emergency situations of categories I and II, thermal systems for automatic control of the state of a BRCD are installed.

The absolute error of the device is verified by comparing its readings with those of control DC bridges connected to the resistance temperature transducers instead of a standard device. The deviation of the measured values of the air temperature difference shall not exceed ±1 °C.

The BRCDs of the TGV-series turbine generators are equipped with the TCM-0879-01 cold and hot air temperature sensors.

Turbo-generators with a power of 63 MW and above use either bipolar electrical brushes of grade EG4 or unipolar brushes of grade 611OM at the positive pole and those of grade EG2AF − at the negative pole. Brief physico-technical specifications of these electric brushes meet the ILEA 685211.037 technical specifications [4].

Regulation and control of the pressing force on the electric brushes are made by an indirect method according to the compression ratio of a spring.

In work [5] the statistics of the causes of a turbo-generator failure are given, one fourth of which is a BRCD failure (see Fig. 2). This allows one to assert that the phenomena occurring during the operation of a BRCD are rather complex and poorly understood.

The main reasons for BRCD failures of are:

– circular fire;

– heating of the slip rings above the maximum permissible value;

– uneven wear of the brushes;

– local breakage;

– vibration and chips of the brushes;

– insulation resistance below the maximum permissible value.

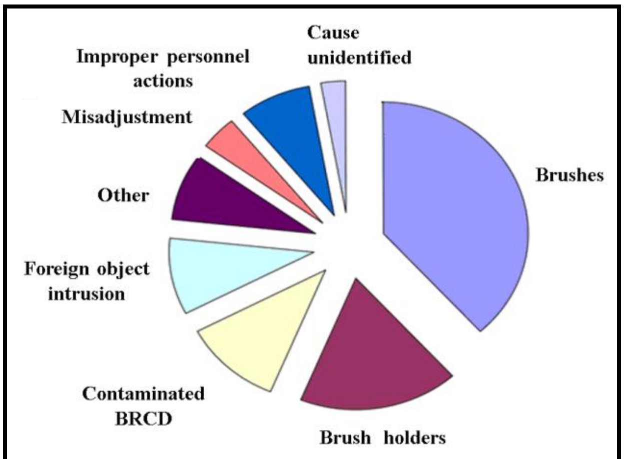


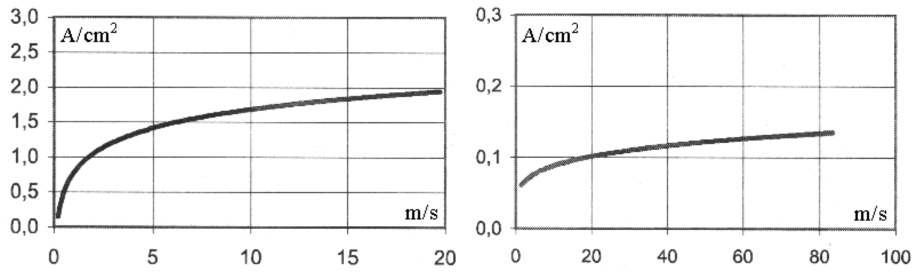
Fig. 2. Statistics of operational failures

Methods for calculating the thermal state of a BRCD

The main material from which the brushes are made is LFC 554. This material consists of graphite and coal tar. To obtain a good consistency, this mixture is baked in an oven at 1000 °C, and the resulting material has a light structure, low density and a relatively low resistance.

The physical characteristics of the material are the following: density – 1.25 g/cm^3; resistance – 2,000 μ′Ω; bending force – 10 MPa.

In Fig. 3 it is stated that when operating one and the same BRCD the electrical and thermal characteristics will vary depending on the technical condition of the brushes. Thus, the thermal calculation shall ensure reliable operation with a sufficiently long life of the brushes. Herewith, the voltage drop shall be insignificant to avoid overheating and abnormal electrical losses, which can damage the sliding contact and affect the current distribution between the brushes.



a b

Fig. 3. Dependencies of the current density:
a – and friction coefficient: b – on the circumferential velocity

Let's consider the scheme of calculation of a BRCD brush contact (see Fig. 4).

This important characteristic depends on the class of the carbon brush, the electrical contact and the film. The latter is a complex mixture of metal oxides, carbon and water applied to the slip ring, or commutator.

Hence, there follows the conclusion that the quality of the contact is influenced by the following factors:

– temperature, pressure, and humidity of the environment;

– contaminants;

– sliding speed;

– pressure on the brushes;

– current.

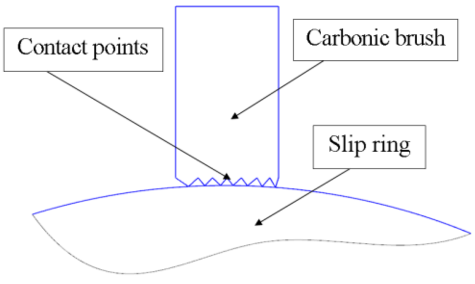
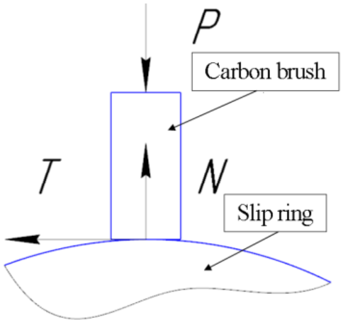


Fig. 4. Contact spot design scheme

Tables 2 show the typical contact reduction values obtained under the specific operating conditions of the Mersen brushes. The data are indicated for each brush type and are grouped into five categories: from 'extreme low' to 'high'.

Table 2. The values of contact drop and friction coefficient

Symbol	Signification	Contact drop [sum of both polarities]	Friction μ
E/H	high	>3 V	μ>0.20
M	medium	2.3 V – 3 V	0.12<μ<0.20
B/L	low	1.4 V – 2.3 V	μ<0.12
TB/VL	very low	0.5 V – 1.4 V	–
EB/EL	extreme low	<0.5 V	–



Friction coefficient μ=*T*/*N*

Fig. 5. Scheme for calculating the friction coefficient of a carbon brush

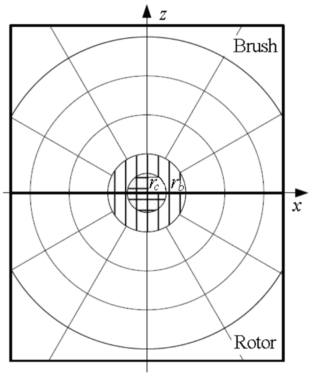


Fig. 6. Model of a microcontact spot

For the operation of a carbon brush without overheating it is necessary that its friction coefficient μ be low and remain unchanged with time. This coefficient has no constant value and is the result of many factors (see Fig. 5), depending on the quality of the carbon brush, rotor speed, collector operational conditions, and environmental conditions. The wear of brushes is determined by the method of GOST 9506.7-74 and is no more than 0.4–0.6 mm, which determines the value of the friction coefficient.

It is impossible to specify the exact value of μ for the presented value of brush types, but only the approximate range of the spread in values. However, this is sufficient for most numerical calculations or projects.

The problem of an analytical solution to the problem of calculating the unsteady temperature field in the region of the microcontact was considered in [6]. When creating a simulation model of electrofraction interaction, the problem of unsteady heat transfer for each contact element of the spot transition surface was solved. Fig. 6 shows the diagram for determining the microcontact spot.

Using the COMSOL Multiphysics software environment, the authors developed an unsteady three-dimensional model of the electronic microcontact (see Fig. 7) and presented the results of the numerical experiment that showed the fundamental possibility of constructing a multifactor model.

However, at present, this problem can be solved only for a particular case and can not be extended to the entire BRCD.

The solution to the problem of determining the thermal state of the BRCD was performed in several stages:

1. Determination of heat emissions.
2. Determination of pressure characteristics of the supercharger.
3. Development of a three-dimensional model.
4. Calculation of the thermal state.

The calculated resistivity of copper was $1.75 \cdot 10^{-8}$ Oh·m, and the resistivity of steel was $1.3 \cdot 10^{-7}$ Oh·m.

The heat release caused by the rubbing of the brushes against the slip ring was 10050 W. The calculation was performed by the method in [6].

The calculation of the fan pressure characteristics was performed by the analytical method according to [7, 8].

The calculation parameters of a centrifugal fan are:

– static blower pressure is 1800 Pa,
– nominal air flow rate is 2.26 m^3/s,
– air velocity at fan inlet is 23 m/s,
– air velocity at fan scroll housing outlet is 65 m/s.

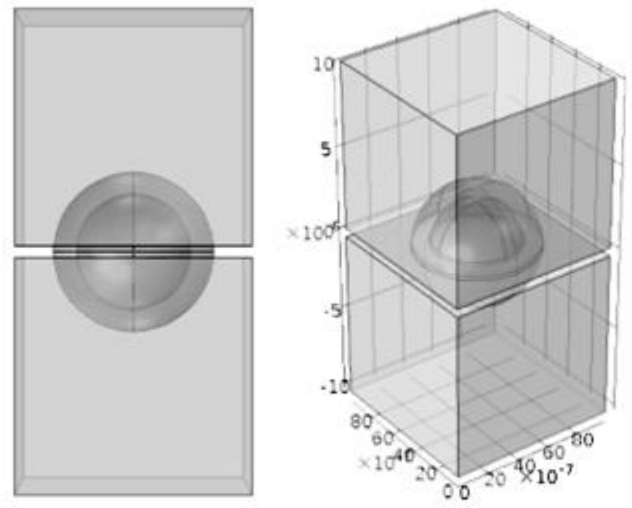


Fig. 7. A three-dimensional model of the microcontact in COMSOL

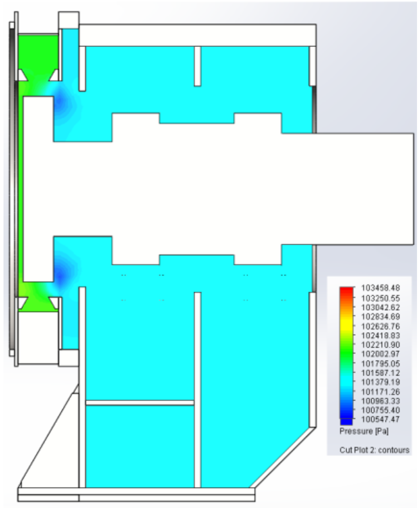


Fig. 8. Cooling air pressure diagram at the steady-state operation mode

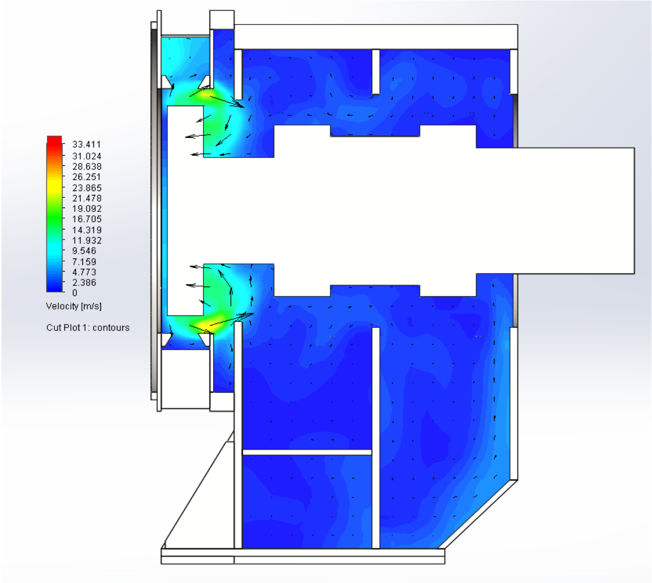


Fig. 9. Cooling air velocity diagram at the steady-state operation mode

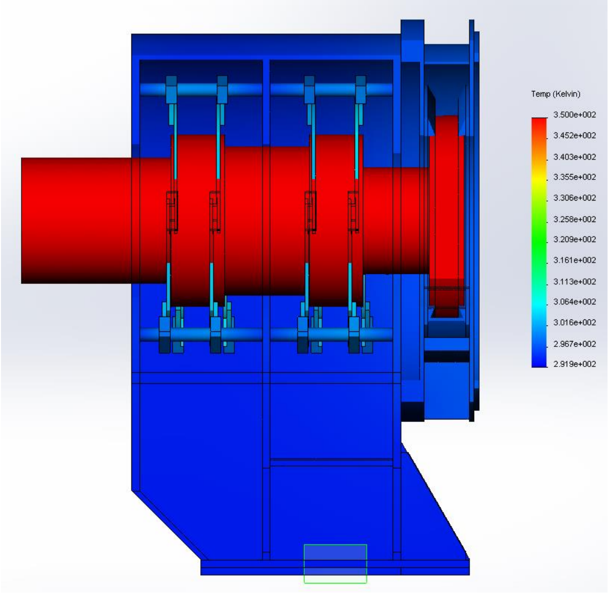


Fig. 10. Temperature diagram at the steady-state operation mode

The calculation of the thermal state of a BRCD was performed in a three-dimensional setting, using SolidWorks Flow Simulation.

The SolidWorks software package contains the Flow Simulation application module that allows numerical modeling of both the internal and external flows of fluids or gases. To simulate flow, we use the solution to the 3D Reynolds averaged Navier-Stokes equations for the motion of a viscous fluid and supplemented by the k- ε model of turbulence. The sufficient accuracy of this module makes it possible to apply it to solve most of engineering problems. The basic methods and description of the mathematical apparatus used in SolidWorks FlowSimulation are presented in [9].

The simulation of air movement in the the hydrogenerator housing was performed at standard settings of computational grid detailing with additional thickening in the narrow channels. Such settings allow one to sufficiently accurately determine the flow features due to the complexity of the flow path.

As criteria for the convergence of the solution, the following values for volume were chosen: minimum, average, and maximum static pressure; average mass flow rate; average heat flux on the indicated surfaces. The calculation was performed until the convergence criterion was reached and at least three purges of the computation area were executed.

Figs. 8−10 show the diagrams of pressures, speeds of cooling air and temperatures at the steady-state operating mode of a 200 MW turbo-generator for the nominal operating mode. The flow inside the BRCD is turbulent. There are no locking zones.

The temperature values obtained as a result of modeling the thermal state of the BRCD in the SolidWorks Flow Simulation environment meet the requirements for newly designed electric machines. The calculated error does not exceed the measuring error, which makes it possible to evaluate the operability of the BRCD at the design stages, and the values obtained do not exceed the maximum permissible temperatures in accordance with GOST 183-74 for collectors and slip rings.

Conclusion

The problem of determining the thermal state of the BRCD in a three-dimensional setting is solved for the first time. A combination of an analytical calculation method with a solution in a three-dimensional setting, using the SolidWorks FlowSimulation software package, is proposed. A technique was developed to determine the thermal state of the BRCD in a three-dimensional setting, taking into account the heat generated by electrical and mechanical influences. The calculation is based on the combination of the three-dimensional solution by the CFD method and the analytical solution of the thermal problem. This technique was tested on the BRCDs of serial 200 MW and 300 MW TGV turbo generators manufactured at SE 'Plant 'Electrotyazhmash'.

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