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Small Enclosed Diesel Generator with a Multifunctional Brushless Exciter and Nanostructured Insulating Materials Used

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Abstract

The design and ventilation system features of a small enclosed diesel generator with a multi-functional brushless exciter suitable for application under extreme environmental service conditions as well as the results of the generator ventilation system calculation and the thermal stability analysis are presented in the paper.

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Keywords: small-scale power engineering; diesel generator; thermal calculations; severe service conditions; aluminum nitride; multifunctional brushless exciter

1. Introduction

The development of small-scale power industry in Russia has led to the development of low-power diesel generators which are able to work under various emergency and extreme climatic conditions, including fire hazard conditions during repairs of gas and oil pipelines, requiring a highly reliable power supply. It is appropriate to have a generator of a closed design with a combined brushless exciter to work under conditions mentioned above.

Low and medium power generators ranging from 60 to 200 kW for diesel power stations are being designed at the Electrical Machines Department of the Ural Federal University. The construction was designed on the basis of the Barahchinskiy Electro Mechanical Plant generators of the protected type. A number of changes were made on the prototype construction. The patent covered combined multifunctional brushless (SMBV) exciter designed at the Electrical Machines Department of the Ural Federal University is proposed as the exciter [1]. The characteristic

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feature of the SMBV is an unconventional magnetic and electric combination of several electromechanical transducers [2]: a four-phase synchronous exciter with combined magneto electric and electromagnetic excitation; an inductor pilot exciter; an induction pilot exciter; a power-supply source for the control system and exciter's initial excitation; an exciter's rotor current sensor; a rotating four-phase uncontrolled semiconductor converter; a controlled four-phase converter of induction and inductor pilot exciters; a semiconductor converter of initial excitation. Non-conventional combination methods being applied make it possible to impart new characteristics to the device, to reduce active materials consumption for the excitation device, to lower the cost price for its manufacturing.

Operating experience of the SMBV by high power synchronous generators has revealed the SMBV-based excitation system being a highly reliable and completely independent brushless excitation system both in terms of the power supply and control channels.

2. Design features

New insulating materials are recommended to be used in the generator and the excitation system.

The proposed selection of the excitation system and insulation materials will enable:

- Improving the reliability of the diesel power plant
- Ensuring the complete independence of the generator, including that of the control channel supply
- Automating the system completely and ensuring a high level of self-diagnostics
- Reducing operating costs
- Increasing the life of the generator
- Changing from protected to totally enclosed type without changing the height of the rotation axis of the device
- Being able to get implemented for the explosion and fire safety performance

While designing a new generator, retaining, first, the rotation axis height and the prototype's dimensions was set as the main aim. In changing from protected to totally enclosed design, changes in the generator construction are to be minimal in order to maintain the production technology and ensuring the possibility of using the magnetic system of the protected design diesel generators being produced.

The prototype has the exciter in cantilever located, i.e. outside the casing, which is denied to the enclosed generator. That is why the exciter was introduced into the body of the generator. Various designs of MBV generators have been examined. To intensify cooling, a 2-circuit system with the inner contour of the axial type is applied. The internal fan is located on the drive side and the SMBV - at the opposite end shield.

In connection with the changes in the design of the generator it is necessary to develop methods of heat and ventilation calculation. To determine the thermal state of the generator with the exciter, a complete equivalent thermal circuit (ETC) was developed taking into account different cooling conditions at the end shields [3]. In developing the ETC, the encapsulation of the coil ends of the generator and exciter windings, heating the air in ducts and cooling pipes are also taken into consideration. The power of heat sources was calculated using the program for calculating the electromagnetic synchronous generator, developed in the MathCAD package. Power loss in the SMBV was determined by the method developed at the Department of Electrical Machines of the former Ural State Technical University. Calculation of the thermal resistance and heat conductivity is made on the basis of approaches presented in technical literature. The thermal design of the installation is implemented using the capabilities of the MathCAD package.

Calculations performed in [4] showed that the use of the profile extrusion frames made of aluminum alloy with a higher degree of cooling fin to intensify the outer loop, while maintaining ventilation ducts between the frame and the stator core for the inner contour of the ventilation does not provide the necessary level of cooling intensification for the enclosed generator. Therefore, a number of measures to reduce windings overheating are proposed.

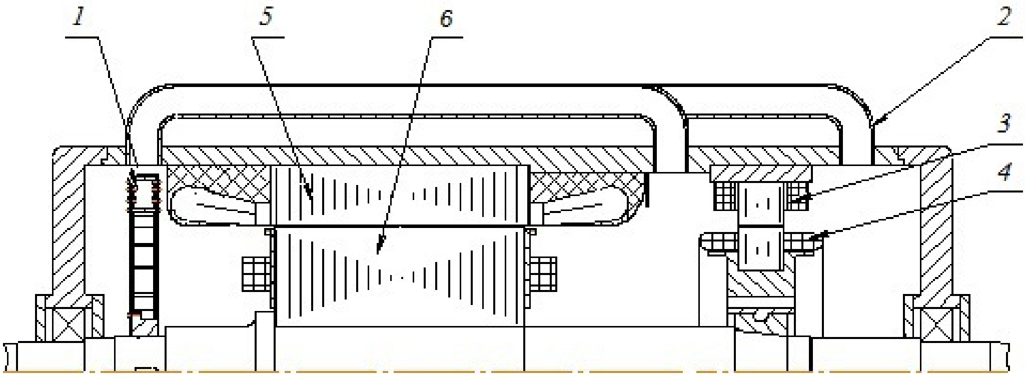

Fig. 1. Structural diagram of the enclosed diesel generator: 1 - centrifugal fan; 2 - cooling pipe; 3 - SMBV inducer; 4 – SMBV armature; 5 - generator stator; 6 - generator inductor.

In the new design, the ventilation ducts formed between the frame and the stator core by means of internal ribs on the frame, are removed from the machine into the ventilation external loop and are made in the form of pipes of varying lengths, welded to the outer surface of the casing (Fig. 1). Some of them transfer the cooling air into the space between the bearing shield and the causative agent, another part - into the space between the driver and the frontal part of the stator winding to intensify cooling of the coil. There are also additional parallel air flows introduced through the axial channels in the SMBV armature poles [5].

Such a solution ensures a more intensive heat exchange between the stator core and the casing (since they are in an immediate contact), as well as eliminates the blowing the outer surface of the stator core by hot air, which could cause undesirable heating of the magnetic circuit. The total cross section of the pipe is selected depending on the interpole windows' cross-sectional area in accordance with the guidelines given in the literature [6]. The disadvantage of this design is a significant increase of the total hydraulic resistance of the ventilation path due to the local hydraulic resistance occurring at the inlet and outlet of the cooling air from the pipes and the frictional resistance along the length of the pipes. To reduce its value and intensify the cooling of the excitation coil, axial ventilation channels are introduced into the rim of the inductor core.

A centrifugal fan (Fig. 1) having radial blades placed on the side of the working end of the shaft has been selected as a pressure element. Under the conditions of a lack of space at the outlet of the inter-blade space, this fan is the best option as compared the a forward bladed fan (the blades of which are bent in the rotation direction) as the increased dynamic pressure produced by the latter fan is not virtually transformed into an effective (useful) static one due to the absence of a straightener [4].

A preliminary fan calculation was performed using the method of equivalent hydraulic circuits. The air flow was 0.098 m^3/s in the internal loop and 0.964 m^3/s in the external one. Peculiarities of the fan calculation are given in [5].

The check calculation of both ventilation circuits was then performed using the final volume method in Ansys CFX. The inner circuit discharge was determined by the total mass flow rate in the cross-section of cooling tubes, divided by the air density and was equal to 0.101 m^3/s. The air flow of the outer circuit was determined in the cross-section at the fan enclosure inlet and was equal 1.01 m^3/s. As a result, the classical analytical calculation error appeared to be the value of 3% as to the internal circuit discharge and 4.5% as to the external one. Fig 2 shows the contours of the air absolute velocities' distribution, obtained in CFX.

The operational effectiveness of the ventilation path was evaluated by calculating the thermal state, using the method of equivalent heat balance diagrams. The results of the thermal state calculation showed that the rotor winding overheating exceeded the permissible values for Class H.

To reduce the overheating of the generator and exciter windings a number of measures are proposed. In manufacturing the generator and exciter windings, it is advisable to use impregnating compounds with the addition of highly heat-conductive powder materials [8]. Such compounds can be made using aluminum nitride, the use of which will ensure values of thermal conductivity of not lower than 2-2.5 W / (m · K) to be reached. This will enable obtaining the equivalent coefficient of impregnation slot insulation up to values of 1 W / (m · K).

Another measure to reduce the overheating of the windings is filling (encapsulation) the cavity coil ends of the stator windings with highly heat conducting compound. Evaluating the efficiency of this measure was done in [9].

In developing the technology of encapsulation of the induction motors stator end-winding with highly heat conducting compound, it is taken into account that more than a half (in a number of sizes up to 70%) of the electrical losses in the stator winding is developed in the end parts, but only 4-10% of these losses are transferred from the coil ends of the stator winding to the frame via the internal air. The main part of the heat developed in the end winding is removed through the slot part of the core (60% of the machines at 3000 rpm and 80% - at 750 rpm).

Filling (encapsulation) the end winding cavity with highly heat conducting compound enables increasing the heat transfer between the coil ends and the frame, thereby reducing the outflow of heat into the slot part and reducing the overall coil heating, and, hence, reducing electrical losses and increasing the insulation life and reliability of the engine. The rotor winding of the generator is characterized by the greatest overheating level exceeding the allowable values for the insulation class H in the diesel generator. Increasing the number of pipes while reducing the number of ribs of the housing tend to reduce the imbalance in the armature and field windings overheating and reduce overheating of the excitation winding to the desired level (Fig 3) [10]. The proposed measures reduce overheating of the enclosed generators windings by 15-20%. As a result, diesel generator sets of enclosed design can be made in the sizes of the plants of protected design.

3. Conclusion

It is known that enclosed electric machines have mass-scale indices exceeding than those of the corresponding machines of protected construction, which are of the same capacity. However, in developing diesel generators of low and medium power with SMBV, the above mentioned technological solutions were applied which allowed diesel generators with SMBV of the enclosed type to be manufactured in sizes (by the rotation axis height) of diesel generators of the protected design. Such decisions should include the use of nanostructured insulating and impregnating materials, based on the use of heat-conducting fillers, which manifests a new approach to windings manufacturing technology both of the generator and brushless exciter, based on the encapsulation of the front and grooving parts, as well as speeding up the internal and external ventilation.

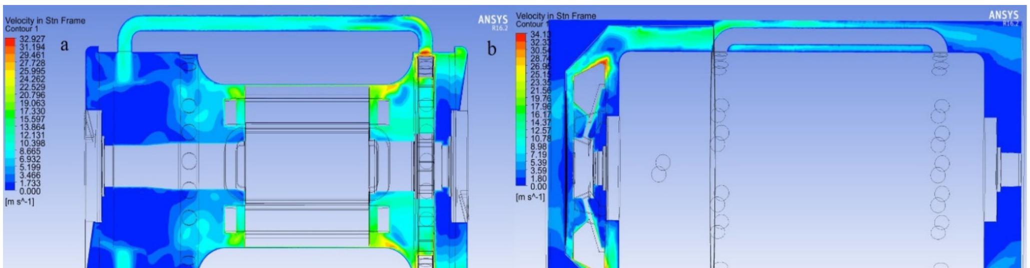

Fig. 2. (a) Inner circuit absolute air velocities' distribution at the axial cut; (b) Outer circuit absolute air velocities' distribution at the cut along the cooling tube.

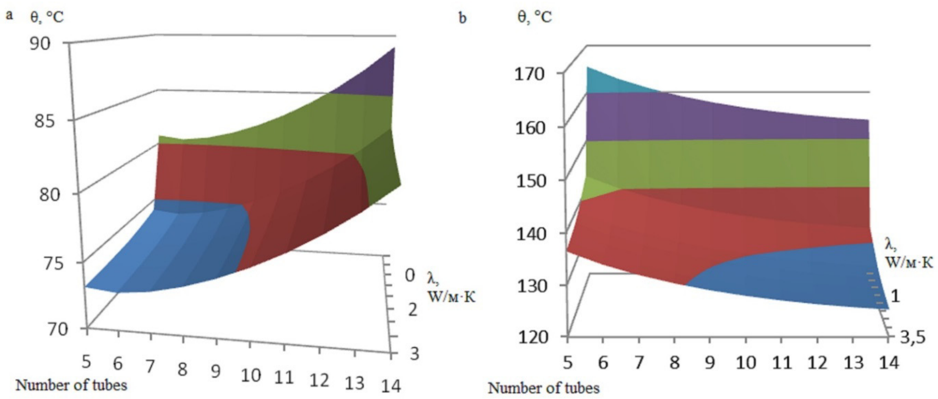

Fig. 3. (a) The dependence of the stator winding overheating upon the number of tubes and the slot insulation thermal conductivity coefficient; (b) The dependence of the rotor winding overheating upon the number of tubes and the slot insulation thermal conductivity coefficient.

Taken together, these factors allowed designing diesel generators with a new excitation system with improved technical and economic parameters that meet requirements imposed.

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