Study on Winding Force Distribution of Huge Nuclear Power Turbo-Generators

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Abstract. Unlike other polluted energies, the nuclear power is a novel energy which has the characteristics of clean, green and saving material. Due to the unbalanced power flow in the power system or on the load, the winding force appears large amount of harmonics and they are linked to the sound operation of the nuclear plant. In this paper, firstly the technology related nuclear power is discussed and the present central technology is reported. Then based on the experimental data, the finite element model of a third generation huge nuclear power turbo-generator is established. The arrangement of the field winding is given and the law of the field winding force distribution is discussed. And under unbalanced load, the constant forces of each field winding are found. This could bring new technology for the nuclear power turbo-generators safe running and fault diagnosis. The easiest damage part in field winding is shown and the conclusions in this paper give very useful information for future design of nuclear power turbo-generators.

Keywords: Nuclear power · Huge turbo-generators · Field winding force distribution · Easiest damage part

1 Introduction

1.1 Development of Nuclear Power Turbo-Generators

Since the nuclear power has been found, the replacement of nuclear material for traditional fuels becomes very practical and has great application value [1, 2]. Because compared with the traditional fuels, the nuclear material has the characteristics of saving space, clean and green. In the process of generating electricity, the nuclear power does not produce no air pollutants such as sulfur dioxide, nitrogen oxides, soot and so on. By the year of 2018, the nuclear power electricity took 4% of all electricity power in China. However, compared with the developed country especially France whose nuclear power takes 73% electricity generation rate and nuclear power has completely replaced

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the base load power plant of thermal power, in China in the field of nuclear power utilization rate there is large space to be developed.

So far, the nuclear power technology can be viewed as **four generations**. **First generation nuclear power plant:** They started from 1950s and belonged to the prototype nuclear power plant. **Second generation nuclear power plant:** They started from 1970s and the rising price of fuels pushed their fast development. In this stage, the economic factor is the first priority. **Third generation nuclear power plant:** The concept of safety and reliability had been brought out and took a very important role. **Fourth generation nuclear power plant:** The safety and economy of this kind of nuclear power plant would be more superior. The amount of waste would be very small, and there was no need for emergency measure outside the plant and an inherent ability to prevent nuclear proliferation.

Nowadays, the main technology used in China for nuclear power is the third generation nuclear power plant. In this paper, a AP1000 short for Advanced Passive PWR nuclear power turbo-generator is researched. Figure 1 is the first AP1000 nuclear power turbo-generator in the world. Usually, the nuclear power plants are created near the water.

Fig. 1. First AP1000 nuclear power turbo-generator in the world

1.2 Central Core Technology for Nuclear Power Turbo-Generators

As everyone knows, the generator is a core part of electric power system. Whether electric power system can operate safely or not is directly related to the stability and quality of power system, so the research concerning the turbo-generators is very important. Turbo-generators are operating under damp weather and rotating all the time. Therefore, the insulation fault and mechanical fault are the common reasons that the turbo-generators endure. When the turbo-generators experience failure, the whole electric power system is in danger. Typically the faults of turbo-generators can be classified into the following faults:

1) Stator core failure

In the process of manufacturing and in small turbo-generators due to self-vibration, if unluckily the stator core is damaged and short circuit between pieces, the circulating current flowing through the short circuit increases gradually with time and silicon steel sheets melt. The melting silicon steel sheets flow into the stator slot and burn the winding insulation [3].

2) Winding main insulation failure

These kinds of failures have two reasons. Firstly, it is insulation aging. Secondly, it is congenital defect of insulation [4].

3) Stator winding strand failure

Stator winding strand failure mostly consists of the strand short circuit failure. The stator bar is usually composed of multiple strands, moreover possessing insulation between strands and needing transposition. If vibrations in turbo-generators happen, it is most likely to damage insulation between strands. Then ground failure or phase to phase short circuit failure maybe occur [5].

4) Stator end winding failure

When the stator end winding endures large impact force, partial discharge occurs due to cracks in insulating materials [6].

5) Rotor winding failure

This failure happens when turn to turn short circuit in rotor happens. However, under external asymmetry, the field winding can make harmonic forces. As a result, it may burn the insulation of the field winding. Then, sometimes, turn to turn short circuit of rotor winding takes places. Therefore, the investigations on the harmonic and constant electromagnetic torque of turbo-generators are very important and deserves to be paid attentions [7].

6) Rotor body failure

In nuclear power turbo-generators, the rotor body is often made of mixed metal. Because of its material characteristics and turbo-generators running characteristics, the rotor body can suffer heat and torsional vibration [8].

7) Cooling water system failure

Mostly, it is because of unclean cooling water. As seen in Fig. 2, the cooling water is directly emitting to the large river or ocean systems [9].

2 Model Establishment

In this paper, a huge capacity turbo-generator is served as a researching object. The huge turbo-generators are quite long and own a relative thin shape. For the physical characteristic of turbo-generators and also for the simplest way to achieve the simulation result, the two-dimensional finite element model of the third generations of nuclear power turbo-generators AP1000 is built up. Its physical model after division in finite element model is shown in Fig. 3.

Fig. 2. Cooling water directly emits to waters

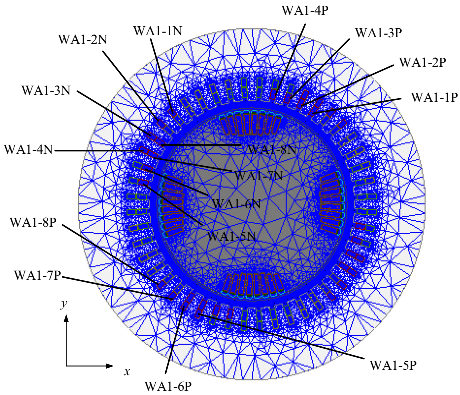


Fig. 3. Physical model after subdivision

In the division part in Fig. 3, the manual division method is adopted. And P presents the current flow direction which is paper inward and N presents the current flow direction which is paper outward. Clearly as seen in Fig. 3, the stator winding WA1-1, WA1-2, WA1-3, WA1-4, WA1-5, WA1-6, WA1-7 and WA1-8 is displayed and WA2-1, WA2-2, WA2-3, WA2-4, WA2-5, WA2-6, WA2-7 and WA1-8 are mechanical 180° away from WA1-1, WA1-2, WA1-3, WA1-4, WA1-5, WA1-6, WA1-7 and WA1-8. The rotor is moving in the anti-clockwise direction. The phasor B and phasor C differ 120° and 240° anti-clockwise electrical degree from the phasor A.

Further, the distributions of field windings are detailed displayed in Fig. 4. In each pole, the field winding has very good symmetry. The distribution and excitation of the field winding guarantees to keep the air-gap waveform at sinusoidal wave. So the field winding current in field winding slot is not the same to give the armature winding sinusoidal voltage. For instance, in field winding 3 and 4, the field current is bigger than field winding 1 and 8.

The huge nuclear power turbo-generator is 4 poles and the pole distribution in the rotor is shown vividly in Fig. 5. According to the China power grid frequency and the 1400 MV nuclear power turbo-generator's pole numbers, the rotor is rotating at the speed of 1500 r/min. In this paper, the field winding tangential electromagnetic force

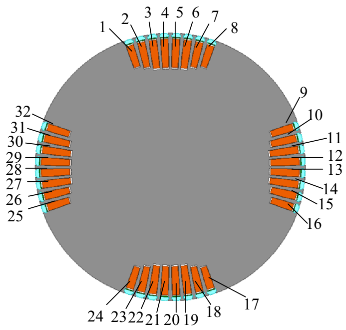


Fig. 4. Field winding number sequence of each slot

is calculated by finite element method, when the damper winding and damper wedge winding is present or not at different current asymmetrical degree.

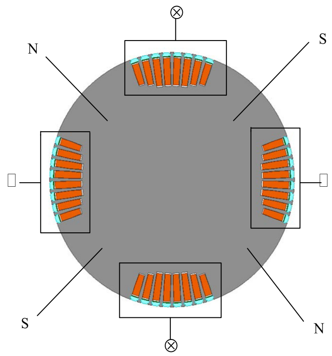
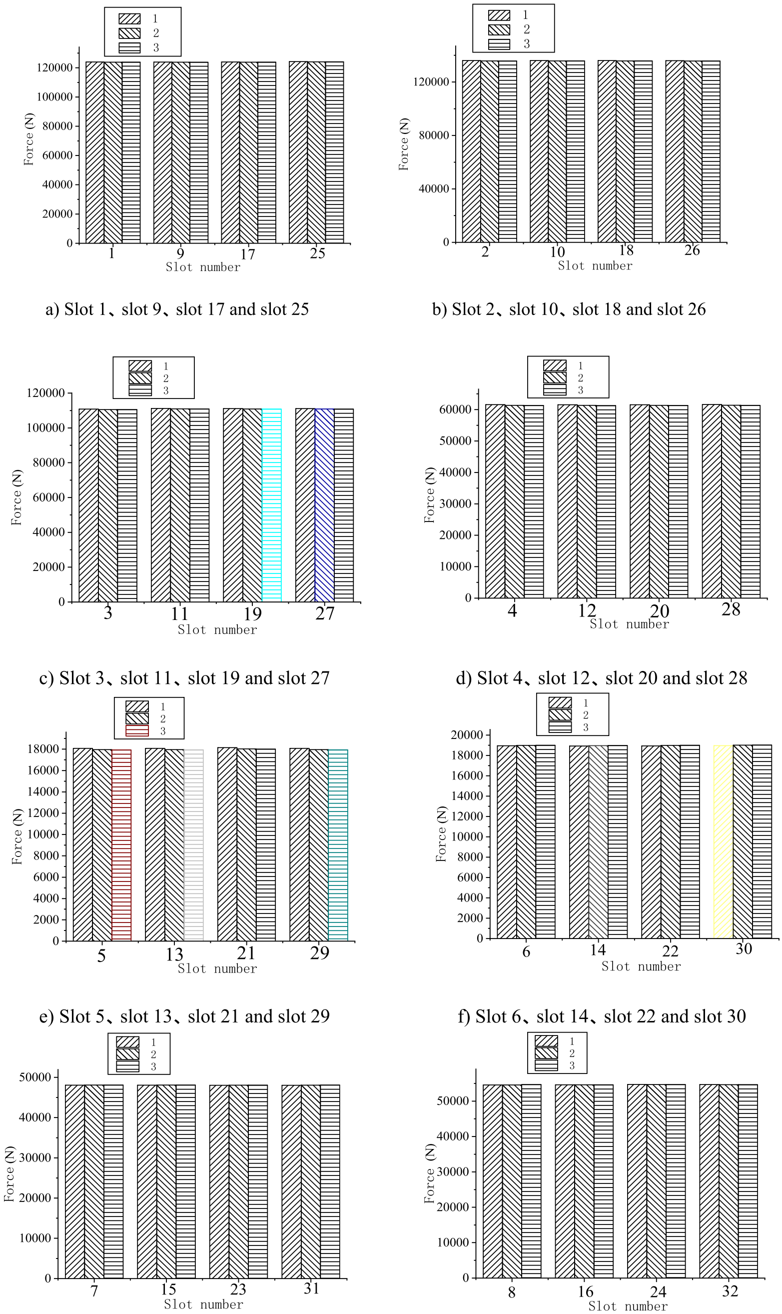


Fig. 5. Position of N-pole and S-pole of rotor

3 Results

When the positive sequence network is 1/2 rated load and 4% current asymmetry, in Fig. 6 the finite element simulation results show the constant component of tangential electromagnetic force of field winding that there is no damper winding and damper wedge, there is no damper wedge but damper winding, and there is both damper wedge winding and damper wedge at the same time. When the positive sequence network is rated load and 6% current asymmetry, in Fig. 7 the finite element simulation results show the constant component of tangential electromagnetic force of field winding that there is no damper winding and damper wedge coded 1, there is no damper wedge but damper winding coded 2, and there is both damper wedge winding and damper wedge at the same time coded 3.

From Fig. 6 and Fig. 7, due to the symmetry of the magnetic field in the nuclear power turbo-generator, under the condition of asymmetric external load the constant component



a) Slot 1、slot 9、slot 17 and slot 25

b) Slot 2、slot 10、slot 18 and slot 26

c) Slot 3、slot 11、slot 19 and slot 27

d) Slot 4、slot 12、slot 20 and slot 28

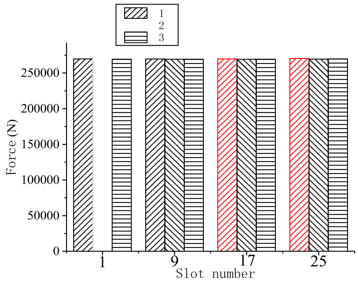
e) Slot 5、slot 13、slot 21 and slot 29

f) Slot 6、slot 14、slot 22 and slot 30

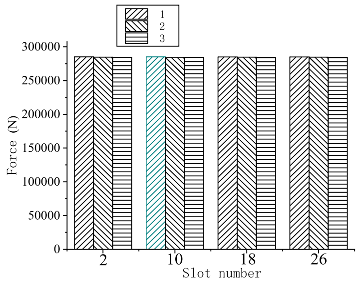
g) Slot 7、slot 15、slot 23 and slot 31

h) Slot 8、slot 16、slot 24 and slot 32

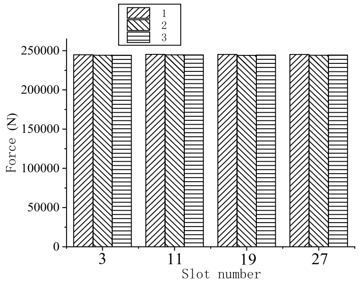
Fig. 6. Constant component of tangential electromagnetic force of field winding when positive sequence network is 1/2 rated condition and asymmetrical degree is 4%



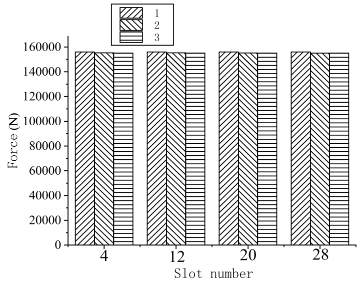
a) Slot 1、slot 9、slot 17 and slot 25



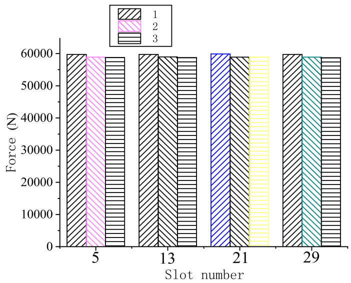
b) Slot 2、slot 10、slot 18 and slot 26



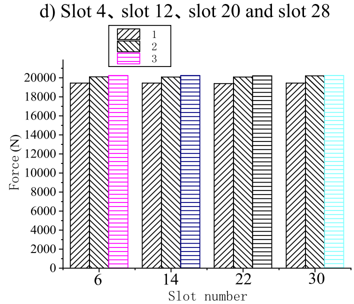
c) Slot 3、slot 11、slot 19 and slot 27



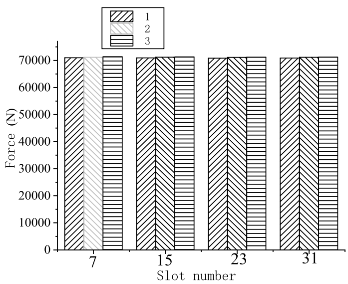
d) Slot 4、slot 12、slot 20 and slot 28



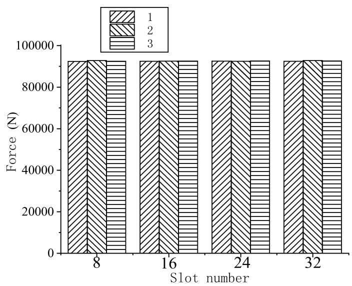
e) Slot 5、slot 13、slot 21 and slot 29



f) Slot 6、slot 14、slot 22 and slot 30



g) Slot 7、slot 15、slot 23 and slot 31



h) Slot 8、slot 16、slot 24 and slot 32

Fig. 7. Constant component of tangential electromagnetic force of field winding when positive sequence network is rated condition and asymmetrical degree is 6%

of the tangential electromagnetic force in the composite magnetic field is approximately equal when the slot number difference is the total slot number of each pole field winding pole. In this case, field winding slot 1, field winding slot 9, field winding slot 17 and field winding slot 25 take the same constant tangential electromagnetic force. Field winding slot 2, field winding slot 10, field winding slot 18 and field winding slot 26 take the same constant tangential electromagnetic force. Field winding slot 3, field winding slot 11, field winding slot 19 and field winding slot 27 take the same constant tangential electromagnetic force. Field winding slot 4, field winding slot 12, field winding slot 20 and field winding slot 28 take the same constant tangential electromagnetic force. Field winding slot 5, field winding slot 13, field winding slot 21 and field winding slot 29 take the same constant tangential electromagnetic force. Field winding slot 6, field winding slot 14, field winding slot 22 and field winding slot 30 take the same constant tangential electromagnetic force. Field winding slot 7, field winding slot 15, field winding slot 23 and field winding slot 31 take the same constant tangential electromagnetic force. Field winding slot 8, field winding slot 16, field winding slot 24 and field winding slot 32 take the same constant tangential electromagnetic force.

The damper winding and damper wedge show no influence on constant tangential electromagnetic force in huge nuclear power turbo-generators. The front slot number of field winding bear large constant forces as seen in Fig. 6 and Fig. 7.

4 Conclusions

In this paper, the beneficial effect of nuclear power technology is discussed. And the factors that the nuclear power turbo-generators may encounter are displayed. Then the finite element model of a 4 pole nuclear power turbo-generator is established.

The damper winding and damper wedge show no influence on constant tangential electromagnetic force in huge nuclear power turbo-generators. The front slot number of field winding bear large forces.

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