

Global thermal analysis of air-air cooled motor based on thermal network

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Abstract. The air-air cooled motors with high efficiency, large starting torque, strong overload capacity, low noise, small vibration and other characteristics, are widely used in different department of national industry, but its cooling structure is complex, it requires the motor thermal management technology should be high. The thermal network method is a common method to calculate the temperature field of the motor, it has the advantages of small computation time and short time consuming, it can save a lot of time in the initial design phase of the motor. The domain analysis of air-air cooled motor and its cooler was based on thermal network method, the combined thermal network model was based, the main components of motor internal and external cooler temperature were calculated and analyzed, and the temperature rise test results were compared to verify the correctness of the combined thermal network model, the calculation method can satisfy the need of engineering design, and provide a reference for the initial and optimum design of the motor.

1. Introduction

Air-air cooling medium asynchronous motor is widely used in various fields of national production, it has many advantages, as energy saving, environmental protection, high efficiency, large starting torque, strong overload capacity, low noise, small vibration[1].

In recent years, with the capacity of motor is getting larger, the motor temperature rise problem is more prominent, the cooling structure of air to air cooling medium of asynchronous motor complex formation cycles continuously between the external and internal cooler motor cooling itself, coupled with considering the rotation of the rotor, the temperature calculation has certain difficulty the field of the motor[2].

At present, the general methods for calculating the temperature field of a motor include simplified formula method, equivalent heat network method and finite element method[3]. The simplified formula is simple, but it can only calculate the average temperature of each part of the motor rises, and the precision is relatively rough, generally only briefly in the motor temperature rise calculation, and the finite element method while the calculation is accurate, but it requires a lot of accurate modelling work as the basis, in addition to calculating a long time the calculation ability of computer, also put forward higher requirements, not suitable for fast calculation analysis of various schemes and under various conditions in the design stage[4].

The thermal network method is to take the network structure of the temperature field of equivalent transformation to the equivalent circuit of the similar way, through the establishment of network topology inside the motor, and the equivalent of the network structure, and through the grid



temperature field equivalent after analysis, reached the final of the internal temperature field of the motor research method. The heat source in the thermal network calculation comes from the loss of each part of the motor, where the loss is considered uniform in the calculation of the thermal network, the loss is averaged over the medium it produces[5]. The heat generated by the loss is radiated outside the motor and is transmitted by heat source to other cooling medium to form a complex heat network. The equivalent heat network method is similar to the ordinary circuit solution method[6]. The nodes in each network have clear physical concept and simple meshing, which are easy to be familiar with and mastered by engineers and technicians. Therefore, it is still widely used in motor design.

At present, the motor internal cooling are computed and compared with common thermal network method, but most of them did not consider the influence of external and internal circulation cooler generated by the motor, this paper using a YKK630-4TH air-air cooling medium asynchronous motor as the research object, the establishment of the global thermal network model of the motor and the external cooler, the cooler outside the same as the node into the motor thermal network equation, and based on MATLAB developed thermal network calculation program, through the comparison with the experimental results, verify the correctness of the equivalent thermal network analysis method[7].

2. The prototype of air-air cooled medium scale induction motor

The ventilation cooling structure of the air-air cooled medium type asynchronous motor is shown in Figure 1. The internal structure of motor is shown in Figure 2.

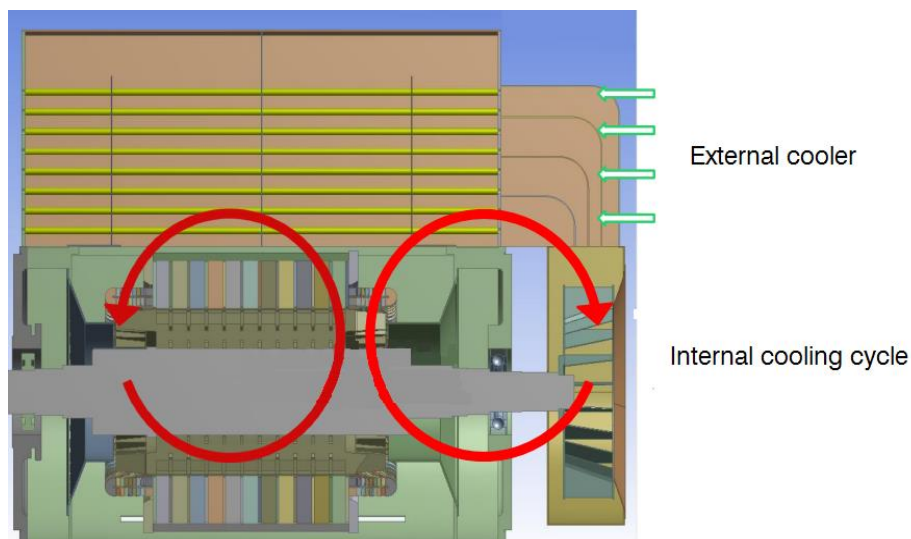


Figure 1.
Schematic diagram
of motor ventilation
system.

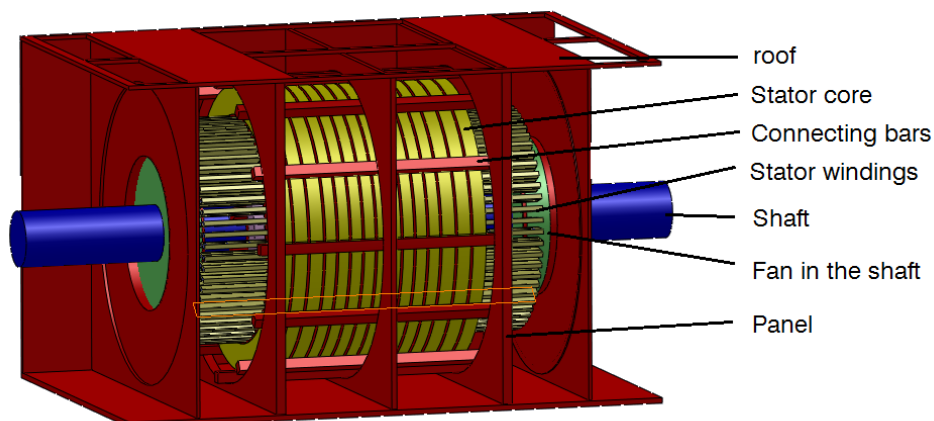


Figure 2. Internal
structure of motor.

The motor has two air cooling circulation, circulation from on top of the frame mounted air cooler, a left and right end into the air duct, inner fan, rotor hub, rotor, stator radial ventilation ducts, stator coil end, a ventilation hole is composed of ring plate. The outer loop air route is composed of an outer fan and an air-air cooler. The specific parameters of the motor are shown in Table 1:

Table 1. Motor parameters.

Name	Numerical Value	Name	Numerical Value
Rated power /kW	2500	Rotor inside diameter /mm	350
Rated speed / r·min ⁻¹	1494	Air gap length /mm	2.8
Base diameter /mm	1280	Rated voltage /V	6000
Stator outside diameter /mm	1060	Rated current /A	276
Stator inside diameter /mm	700	Efficiency /%	96.9

3. Global thermal network of electric machines

3.1. Global thermal network analysis model

When calculating the temperature field of the motor by using the heat network method, the motor is divided into grids, and some necessary simplifications are made according to the actual conditions and operating conditions:

- (1) It is assumed that the cavity on both sides of the motor is completely symmetrical and the temperature is as same as that in the inner space of the motor body structure.
- (2) The thermal conductivity of copper is not considered to be infinite, then the axial winding of the stator can be equivalent to non-isothermal.
- (3) The physical structure of the motor is axially symmetrical in the circumferential direction, that is, the cooling boundary conditions of the motor in the circumferential direction are identical.
- (4) Because the skin effect in the stator slot is weaker, the winding is not affected.

Based on the actual physical structure of motor, and taking into account the above assumptions, the network topology of the physical model of the motor is divided into a plurality of orthogonal, and the definition of the centre node network unit grid for temperature, the dispersion parameters are converted to lumped parameter. The final division of the motor whole area thermal network is shown in Figure 3:

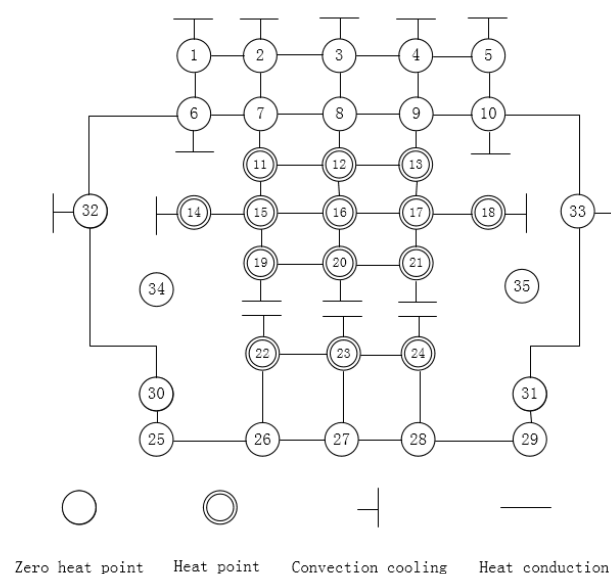


Figure 3. Schematic diagram of motor ventilation system

The node 1 to 5 on behalf of the external cooler; node 6 to 10 representative case, 11 to 13 nodes represent the stator yoke, node 19 to 21 on behalf of the teeth of the stator core, 14 to 18 nodes represent the winding, node 14 and node 18 to end winding, node 22 to 24 on behalf of the rotor, node 25 to 29 on behalf of the axis, The joint 30 and 31 is the bearing; the node 32~33 represents the back cover, the node 34~35 is the temperature inside the chamber.

3.2. Thermal network parameters and thermal resistance analysis

In the calculation of the temperature rise of a motor, heat conduction and heat convection are the two basic forms of heat transfer, in which the formula of conduction heat conductivity can be expressed as follows:

$$G_d = \frac{S_d \lambda}{L_i} \quad (1)$$

The convection heat conductivity is calculated as follows:

$$G_v = \alpha_v S_v \quad (2)$$

In the equation, G_d is the thermal conductivity, G_v is convection thermal conductivity, L_i is the distance between two nodes of the thermal network, α_v is the convective heat transfer coefficient, S_v is the surface area of convection contact, S_d is the contact surface area for heat conduction, λ is the thermal conductivity of materials in thermal conduction.

The temperature rise of the motor is caused by the loss in the operation of each part. In the whole thermal network, the mode of load loss is shown in Table 2. The data of loss are derived from simulation calculations using correlated parameters.

Table 2. Loss value of each part of motor.

Loss name	Loss value
Stator yoke loss	11.11 kW
Lead loss	10.198 kW
Stator copper loss	17.675 kW
Stator tooth loss	8.73 kW
Mechanical loss	19.89 kW
Stray loss	12.50 kW

The thermal conductivity of each part of the motor is shown in Table 3[6]. This is based on the sixth literature.

Table 3. The thermal conductivity of each part of the motor.

Part name	Thermal conductivity / W·(m·K)-1		
	X direction	Y direction	Z direction
Stator tooth	39	39	4.43
Stator yoke	39	39	4.43
Internal air	0.0305	0.0305	0.0305
Winding copper wire	385	385	385
Rotor core	39	39	4.43

Convection can be divided into forced convection heat convection and natural convection heat transfer, depending on whether the fluid motion is aided by external means. The internal air of the motor is forced convection heat in the cooling process.

The node 1 to 5 of cooler has no heat source, they can be equivalent to the same constant temperature heat source and temperature, but the cooling air will emit absorption inside the motor during cooling of heat, will produce a certain temperature gradient, the temperature at different nodes are different, so the actual temperature of each node will be higher than the ambient temperature, such as the formation of equivalent heat source. The equivalent heat source is equal to the convective heat conductivity, multiplied by the air temperature.

3.3. Solving global thermal networks

According to the thermal network model, each node of the heat transfer between the analysis, and lists the corresponding heat balance equation respectively, then the heat balance equation of simultaneous corresponding to 35 nodes, can get the motor heat balance equations, the matrix form is as follow:

$$GT = W \quad (3)$$

In the equation, G is the thermal conductivity matrix, which has 32 order. The thermal network calculation program is programmed by using MATLAB software. After calculation, the temperature of each node is calculated as follows:

Table 4. Equivalent thermal network temperature rise calculation
(The room temperature is 18 degrees centigrade).

Part	Node temperature rise (K)				
External cooler	1)20.2	2)36.5	3)37.8	4)36.7	5)35.4
Shell	6)35.3	7)38.4	8)39.5	9)38.8	10)35.4
Stator yoke		11)64.9	12)68.4	13)64.3	
Winding	14)88.0	15)74.6	16)72.5	17)74.1	18)79.6
Stator tooth		19)58.8	20)62.9	21)58.5	
Rotor		22)65.0	23)67.3	24)64.8	
Shaft	25)31.2	26)33.8	27)35.9	28)33.4	29)31.3
Bearing		30)30.7	31)30.5		
End cap		32)34.2	33)33.6		

4. Experimental verification and result analysis

From the calculation results in Table 4, it can be seen that the highest temperature rise of the motor appears at the end of the winding, 88.0K, the minimum temperature of the winding appears in the middle of the winding, and the average temperature of the winding is 77.8K. The temperature rise of the stator tooth is lower than that of the yoke, and the temperature rise of the motor is symmetrical in the axial direction.

In order to verify the correctness of the global thermal network analysis method, the temperature rise test is carried out on the actual prototype. The results of temperature rise test are compared with the results of the global thermal network calculation as shown in Table 5:

Table 5. Comparison of temperature rise test and calculation result.

Part	Calculated value /K	Experimental value /K
Stator core	62.9	58.00
Stator winding	77.8	76.35
Rotor core	65.7	60.2

Through the comparison of the results shown in Table 5, it can be found that the global thermal network method is used to solve the temperature rise of the main parts of the motor, and the calculation results are not very different from the experimental values. The method is effective.

Cooler heat above the motor of motor internal exchange has played an important role, the shortage is above the cooling air temperature gradient exists in the simulation to the actual distribution, according to the actual situation to fully equivalent, thus the calculation results and the experimental results have a certain difference.

5. Results

In this paper, an equivalent thermal network of the motor was established, the thermal network node was divided according to the characteristics of the motor. According to the principle of heat transfer, an equivalent thermal network calculation program was compiled to calculate the temperature rise.

The results of temperature rise show that the highest temperature rise occurs at the end of the winding, the value is 88.0K, the lowest temperature rise of the winding appears in the middle of the winding, and the average temperature rise of the winding is 72.5K. The temperature rise of the stator tooth is lower than that the stator yoke.

The calculation results are close to the experimental values of temperature rise, which proves the feasibility of the method for temperature rise of global thermal network. This method can provide some help in the design of motor and the optimization of cooling system.

Acknowledgment

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