Study on Thermal Analysis and Cooling System of Mine Flameproof Inverter

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Abstract. At present, the underground environment is humid and complex, and there are a lot of flammable and explosive gases. The electric control equipment such as underground roadheader and shearer all adopt frequency conversion technology. Temperature rise is very important for the service life and working stability of the core components of underground flameproof frequency converter. The cooling systems of IGBT, capacitor and driving unit can be roughly divided into air cooling, cooling medium circulation and natural cooling.

Keywords: IGBT, Capacitors and frequency converter driving components, Fan cooling, Cooling medium circulation system.

1. Introduction
The underground environment is humid and complex, and the underground gas is full of inflammable and explosive mixed gases such as dust and gas, so the products of common civil structures on the well cannot be directly applied to the underground. The general electronic devices shall be placed in the explosion-proof chamber meeting the explosion-proof standard (GB3836-2010), and the electrical performance technical parameters of the electrical equipment shall meet the relevant requirements of the national standard or the corresponding mine underground industry standard. With the rapid development of domestic economy, the vigorous promotion of environmental protection and energy-saving technology and the gradual increase of market demand, frequency conversion technology is widely used in mining transportation, coal mining, winch, permanent magnet synchronous motor and other equipment. According to a large number of data statistics, its energy saving effect is more than 30% compared with the traditional form.

2. Application of frequency conversion technology
At present, taking coal mine as an example, frequency conversion technology is widely used in electric control equipment such as road header, shearer, scraper, conveyor and ventilator. Frequency conversion technology performs well in controlling high-power motor, starting under heavy load, reducing starting current of motor, adjusting speed by permanent magnet direct drive, protecting motor and so on. However, the underground space is limited, the environment is complex, and it is difficult to install, transport and debug. This requires that the design of the flameproof cabinet of underground electrical
equipment meet the requirements of flameproof, and its internal structure should be as reasonable and compact as possible. But for the frequency conversion technology, the internal space becomes smaller, and the ventilation and heat dissipation problems come into being. Among them, the temperature rises of IGBT and capacitor of underground frequency converter directly affects the safety and stability of frequency converter and its subordinate motors, and it directly affects the service life of frequency converter, so the temperature rise problem has always been the top priority of frequency converter. The temperature of IGBT inverter unit, internal conductor and cavity is clearly specified in international IEC, national standards, coal mine safety regulations and industry standards. Therefore, the cooling mode and the temperature of cooling medium have become the primary problems faced by the wide application of frequency converters in mines.

The temperature rise of frequency converter is closely related to the ambient temperature and the temperature of rectifier and inverter unit, capacitor, internal cavity and cooling medium. Therefore, the cooling scheme matching with the power of the frequency converter came into being.

3. Heat loss of frequency converter
Many tests data show that to solve the heat dissipation problem of downhole frequency converter, not only the designer of downhole electrical products should consider the application performance of frequency converter, but also the structural design of its explosion-proof cavity should meet many explosion-proof requirements such as electrical clearance, creepage distance and cavity thickness. Users of underground electrical appliances need to use and install them in strict accordance with explosion-proof requirements. Underground, especially coal mine, dust is serious. Enough ventilation space is needed for dust removal of cooling air duct and cavity of frequency converter to ensure the temperature requirement of cooling medium, and regular maintenance is carried out according to regulations, so as to make the cooling system of IGBT of frequency converter play a normal role, ensure IGBT of frequency converter, keep the temperature rise of capacitor and internal cavity within the standard range, and ensure reliable operation of equipment.

The heating source of the frequency converter mainly comes from IGBT (combination of insulated gate field effect transistor and bipolar transistor), circuit capacitance and internal wires. However, the reason of IGBT tube heating mainly focuses on the saturation turn-on and turn-off moment of internal transistor PN node. Considering the power design and the withstand voltage level of IGBT, a frequency converter equipment forms two-level and three-level modes after series and parallel processing of IGBT. Therefore, when the switching frequency of the tubes in the inverter unit is high, the heat generated by IGBT is large.

In the whole module (IGBT tube and driving circuit) of frequency converter, the main circuit accounts for 98% of the heat, while the control circuit only accounts for 2%. The power consumption of inverter IGBT is about 5% of its power capacity. Among them, the inverter unit composed of several IGBT tubes accounts for about 50%, the rectifier circuit and DC bus account for about 40%, and the control drive circuit and protection circuit account for 5 ~ 15%. Among them, the frequency converter abides by the rule of 10℃, and when the temperature of electronic circuit devices decreases by 10℃, the working reliability of devices will double.

Figure 1 below shows the internal design of IGBT module and the temperature characteristic curves of IGBT chip, substrate and heat sink under periodic alternating current load.

According to Figure 1, the influence of temperature on IGBT module is as follows:
Figure 1. Temperature characteristics of IGBT under periodic alternating current load

Because several layers of different materials are used in the mechanical design of IGBT, there is a relatively high thermal resistance between IGBT chip and substrate. This heat is transferred to the radiator on the power module through the IGBT substrate and absorbed. Therefore, there is a great temperature fluctuation in IGBT chip when the current is periodically alternated, while the temperature of substrate and heat sink is relatively constant. Under certain operating conditions, there may be high temperature fluctuation $\Delta T_{\text{Chip}}$, so that IGBT module bears high thermal stress, thus greatly shortening its service life.

In actual operation, the inverter with IGBT runs at low frequency and high output current (typical periodic alternating current load). When the output current is in the positive half cycle, the output current only flows through the IGBT connected to the DC positive bus for a long time, so the temperature of the IGBT chip continues to rise, while the IGBT chip connected to the DC negative bus is cooled. In the control program, the temperature monitoring model will trigger an overload reaction when the IGBT reaches the allowable limit temperature, which can reliably avoid the damage caused by excessive chip temperature. In the configuration stage, measures must be taken to ensure that the temperature fluctuation of IGBT does not exceed the allowable temperature fluctuation range of IGBT, or only accounts for a small part (< 2%) of the whole operation time, that is, it exceeds the allowable limit value in a short time. For example, when driving or braking, it is acceptable if these operating conditions are less than 2% of the running time of the whole frequency converter.

Generally, when the temperature of IGBT radiator reaches 75°C, the inverter will give an alarm of overheating, and when it reaches 90°C, it will protect and stop working. According to practical experience, when the radiator temperature reaches 80°C, the junction temperature of the chip has already reached about 110°C, and when it reaches 90°C, the junction temperature has reached or exceeded the allowable limit value.

4. Choice of heat dissipation

4.1. Forced air cooling and circulating water cooling are usually used in mine flameproof and intrinsically safe frequency converters

4.1.1. Air cooling

1) Built in fan

Generally, for low-power inverter, the heat dissipation capacity of the built-in fan of inverter IGBT can be optimized through correct installation. The cooling air medium can take away a part of the heat inside IGBT through the heat dissipation mode of the built-in fan. IGBT dissipates heat through the heat dissipation iron plate of the flameproof box. Downhole frequency converter is suitable for single
frequency converter or equipment with few control circuit components and sufficient heat dissipation space in flame-proof cavity by cooling with built-in cooling fan. If several IGBTs and driving circuits, or other circuits and internal wires have a large amount of heat dissipation in the downhole frequency converter, variable frequency speed regulating device or combined frequency converter, the heat dissipation mode of the built-in fan is difficult to meet the requirements.

2) External fan

Underground frequency converter can adopt the cooling mode of external fan. The heat dissipation of the frequency converter is estimated. According to the data experience of general frequency converters, it can be calculated that the exhaust air volume of cooling fan is 360m³/h (or specified by relevant standards), and the power consumption of IGBT and driving circuit is about 5% of the total capacity of underground flameproof frequency converters.

4.2. Circulating water cooling

Circulating water (coolant) cooling system can be divided into active water cooling and passive water cooling.

The active water (coolant) cooling system consists of two parts: water-cooled radiator fittings and cooling fans (auxiliary cooling), and the ambient temperature generally does not exceed 40°C. These two parts are carried out at the same time, which can make the heat dissipation effect of inverter IGBT best. Passive water (cooling liquid) cooling system, without auxiliary cooling fan, only relies on water (cooling liquid) cooling radiator itself for IGBT cooling, or adds more cooling fins to assist cooling. The function of circulating liquid is similar to the air of cooling medium, and it can absorb most of the heat so as to keep the temperature of IGBT unchanged.

The cooling system consists of multiple units. The function of the circulating pump is to push the cooling medium to flow according to the specified flow rate, and reduce the temperature of the cooling medium through the circulating system, thus absorbing the heat of IGBT and other heating electronic components. The cooling medium takes away the heat of IGBT package module through circulation, and the new low-temperature cooling liquid after circulation will continue to absorb the heat of heating elements. The cooling medium pipeline is connected with the water pump, water cooling block and water tank, and its function is to make the cooling liquid circulate in a closed channel without leakage, so that the cooling system can run normally.

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