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DESIGN OF A LIQUID COOLER FOR A 100 KW SEMICONDUCTOR POWER CONVERTER

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ПРОЕКТ ЖИДКОСТНОГО ОХЛАДИТЕЛЯ ПОЛУПРОВОДНИКОВОГО СИЛОВОГО ПРЕОБРАЗОВАТЕЛЯ МОЩНОСТЬЮ 100 КВТ

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Abstract. The focus of this research in this paper is to design a 100 kW power liquid cooler, semiconductor converter liquid cooler, thus using pulsed thermal medium circulation to increase the capacity of the cooling system on the surface of the power semiconductor device. Based on comparing the parameters of conventional and pulsed coolant circulation mode, the liquid cooling system of power semiconductor converter is studied by physical method. In laboratory testing, experiments are planned according to the order and frequency of changing device operating modes. Finally, the experimental research results are processed, and the relationship between the discharge heat power and the temperature drop and the coolant flow is established by using the mathematical statistics method. Result: Depending on the exhaust heat power and the coolant flow in the range of 3–1.5 L/min, the pulsating heat transfer enhancement in the liquid cooling system of the power semiconductor converter can increase the thermal capacity and the current load of the power semiconductor converter by a factor of almost 2.5 times, respectively. At the same time, the circulation of the coolant in the inner circuit is carried out by a hydraulic powered film pump.

Аннотация. Основное внимание в исследовании уделяется разработке жидкостного охладителя полупроводникового преобразователя, мощностью 100 кВт, с использованием импульсной циркуляции теплоносителя для увеличения мощности системы охлаждения на поверхности силового полупроводникового устройства. На основе сравнения параметров обычного и импульсного режимов циркуляции теплоносителя физическим методом исследована жидкостная система охлаждения силового полупроводникового преобразователя. При лабораторных испытаниях эксперименты планировались по порядку и частоте смены режимов работы прибора. Наконец, результаты экспериментальных исследований обрабатывались, и методом математической статистики устанавливалась связь между тепловой мощностью разряда, падением температуры и расходом теплоносителя. Результат: в зависимости от мощности выхлопа и расхода теплоносителя в диапазоне 3–1,5 л/мин пульсирующее усиление теплообмена в системе жидкостного охлаждения силового полупроводникового преобразователя может увеличить тепловую мощность и токовую нагрузку силового агрегата полупроводникового преобразователя почти в 2,5 раза. При этом циркуляция теплоносителя во внутреннем контуре осуществляется пленочным насосом с гидравлическим приводом.

Keywords: liquid cooler, semiconductor converter, pulsating heat transfer.

Ключевые слова: жидкостный охладитель, полупроводниковый преобразователь, пульсирующий теплообмен.

Introduction

In recent years, with the rapid development of power electronic technology, the power level of power electronic converters has been greatly improved. The increase in the power level of the frequency converter will increase the junction temperature of the power electronic system, which directly threatens the reliable operation of the frequency converter, especially in high-power electronic frequency converters. For high-power electronic converters, the generation, transfer and distribution of heat directly affect the working efficiency of the converter, and the heat transfer process is closely related to the temperature of power electronic devices. Studies have shown that during the operation of the inverter, the failure rate of the chip increases exponentially with the increase of temperature. Therefore, effective thermal design of converter equipment is very necessary. Thermal design is an important part of power electronic converter design, and thermal design is directly related to the reliability and efficiency of equipment operation.

In this paper, three basic heat transfer methods are used to establish the heat transfer mathematical model of the circulating water-cooling system of the frequency converter. Through analysis, when the inside of the two copper busbars and the water-cooled radiator are designed as toothed pin wings, the heat exchange area is not only increased in theory, but the simulation results show that the internal fluid flow is relatively stable and can withstand more much heat loss. At the same time, it can also reduce the junction temperature of the power electronic device without causing local overheating and damaging the device, which is beneficial to improve the heat dissipation effect. In addition, verifying and controlling the research speed of the heat dissipation technology of the inlet flow high-power power electronic converter of each flow loop in the liquid cooling radiator can enhance the heat dissipation. Therefore, in engineering applications, we can design the structure of the radiator and control the inlet flow rate according to the actual needs of the circulating cooling system to improve the efficiency of the inverter equipment and save energy.

The main source of heat inside the power semiconductor device is the conversion of the loss inside the chip from electrical energy to thermal energy, and the heat generated at this time needs to be dissipated through an effective heat flow path. Power semiconductor devices work in the switching state, and there are power losses in the switching process and in the on and off states; including the on-state power consumption and off-state power consumption that occur in static state, and the turn-on power consumption generated in the dynamic process [1]. and turn-off power consumption, the most accurate method should be calculated according to the actual current and voltage waveforms of each stage obtained from the test. Power semiconductors consume a lot of energy when working, and this part of the energy is converted into heat, which will cause the temperature of the chip to rise. If the heat dissipation problem of the chip cannot be solved well, it will not only affect the full performance of the device, but also may cause damage to the device [2]. Studies have shown that the failure rate of the device changes exponentially with increasing temperature, while the heat dissipation of the device is achieved through solid conduction including the printed circuit board and air convection [3]. Therefore, in the circuit design stage [4], it is very important to the reliability of the product to correctly estimate the temperature distribution on the printed circuit board and the junction temperature of the device under various heat dissipation and layout conditions to ensure the normal operation of the circuit [5-7].

Power semiconductor devices, also known as power electronic devices, are the basis of power electronic technology and the core devices that constitute power electronic conversion circuits. Power semiconductor devices are used in almost all electronic products and electronic equipment manufacturing [8]. Power semiconductor devices are more sensitive to high temperature, low temperature or temperature alternation, because such devices undertake the main power regulation function in the circuit and undertake most of the power regulation electrical stress [9]. Therefore, high attention must be paid to the thermal management of power semiconductor devices to improve the reliability of the circuit. The application scope of power semiconductor devices has expanded from traditional aerospace electronics, industrial control and 4C industries (computers, communications, consumer electronics and automobiles) to new fields such as new energy, rail transit, and smart grids [10]. When power semiconductor devices are in the working state of high current and high voltage in the circuit, the power density and local temperature in a small area of the device are very high, resulting in a hot spot effect. Therefore, great attention must be paid to the thermal management of power semiconductors, focusing on reducing device The operating junction temperature can improve the reliability of circuits and products. Electronics manufacturers specify the maximum allowable temperature for operation, above which they do not guarantee expected performance and longevity. With the wide application of high-performance microelectronic products in the market, the heat dissipation of the products is larger, and more efficient cooling technology is required to ensure that the equipment works within the allowable temperature.

Material and research methods

Modeling of oscillations in the circuit of indirect heating of the heat exchanger is expedient on the basis of the frequency solution of differential equations, in the preparation of which it is convenient to use an energy circuit. The energy circuit is compiled on the basis of a model that includes a hot water boiler, a circulation pump, a coil.

The energy circuit of the heating heat exchanger of indirect heating includes three links: the first link is a converter link, it converts the torque μ and the angular velocity ω into motion p and volume flow v at the pump outlet; the second link is hydraulic, it takes into account friction losses with the help of active resistance r1 and compliance of the pipeline l1; the third link is hydraulic, reflecting the mass of water in the heat exchanger (coil) M1, its compliance l2 and active resistance r2 (Figure 1).

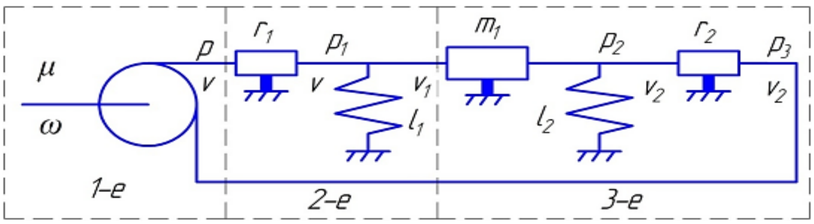

Figure 1. Energy circuit of the heating circuit of the heat exchanger for indirect hot water heating

To obtain these dependencies, an experiment plan was drawn up, which includes:

1) Preparation of experimental installation and testing of equipment

2) Testing the installation in test mode

3) Determination of the required number of modes depending on the step of discrediting the flow rate and temperature of the heating medium

4) Determination of the mode setting time

5) Determination of the frequency of operation of the shock unit and data recording of the experimental installation

6) Determination of the repeatability of the experiment

Preparation of the experimental installation involves connection to the laboratory heat network of the educational and scientific laboratory and installation

of flow, temperature and pressure sensors.

The determination of the installation in the test mode is carried out in the temperature range of the heating medium from 60 to 70 degrees and the flow rate from 100 to 300 liters per minute.

The number of modes was selected based on the minimum number of points on the experimental graph. To ensure information, take the minimum number of points equal to 7. The sampling step according to the heating temperature was taken 50, 60, 70 degrees. The consumption of the heating medium was taken depending on the stable slave of the shock unit.

The end time of transients was controlled by setting the temperature at the outlet of the heating medium. The frequency of operation of the shock unit is one of the most important parameters of the mode, the power reserve was selected from the installation operation of the shock unit in the range from 0.5 to 5 Hz different speeds of air movement through the heat exchanger created by the fan were taken as the load of the modes.

Temperature measurement: by the heating medium was determined by the temperature sensor, by the heated medium (air)...

Purpose of the experiment: The purpose of the experiment is to obtain experimental dependences: the temperature difference at the inlet and outlet of the heat exchanger on the heating and heated temperature.

Figure 2. Experimental device

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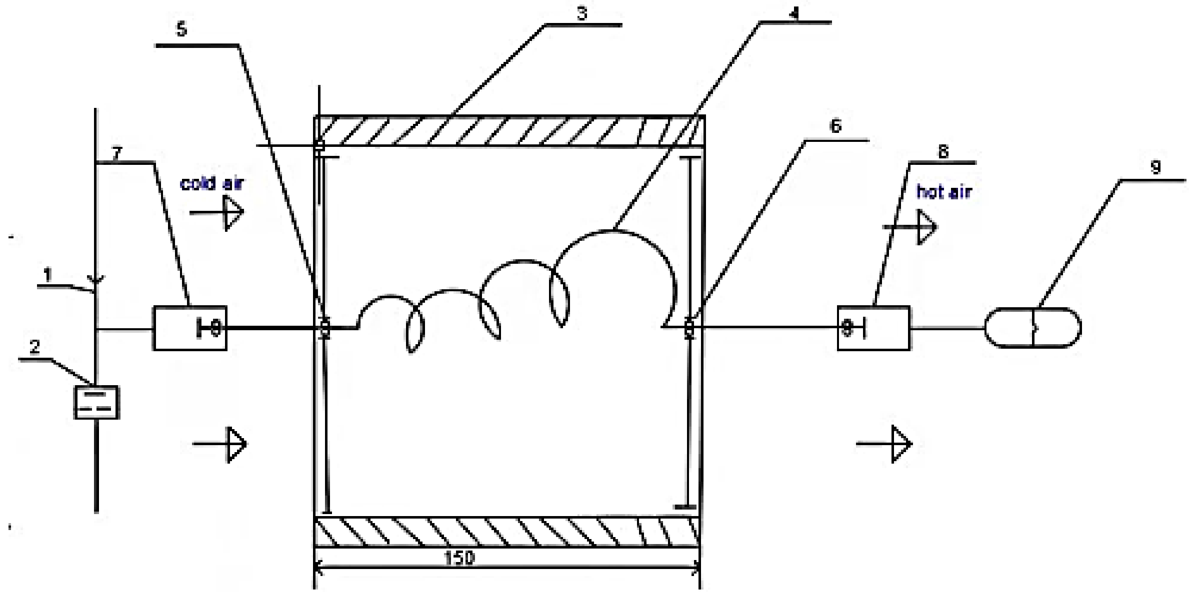

Figure 3. Scheme of experimental setup:1 — hot water pipeline; 2 — Shock valve; 3 — Body; 4 — Coil; 5, 6 — bearings; 7, 8 — movable couplings; 9 — hydraulic accumulator

Table 1

PULSE MODE READINGS WITH VALVE OPENING FREQUENCY 3 Hz. Experiment №3

Fuel consumption, l/m	*Temperature of the heat carrier in the heating circuit*		*Temperature in the heated circuit*	
	At the inlet to the heat exchanger (T1), °C	*At the outlet of the heat exchanger (T2), °C*	*Initial temperature of air (T3), °C*	*Temperature of heated air (T4), °C*
0.82	71.1	68.2	21.0	43.5
0.78	70.8	68.3	21.1	40.7
0.74	70.8	67.9	21.0	42.8
0.68	72.1	68.5	21.0	43.2

Further, on the basis of the obtained data, a graphical dependence of the temperatures of the heat carriers in the stationary mode is constructed.

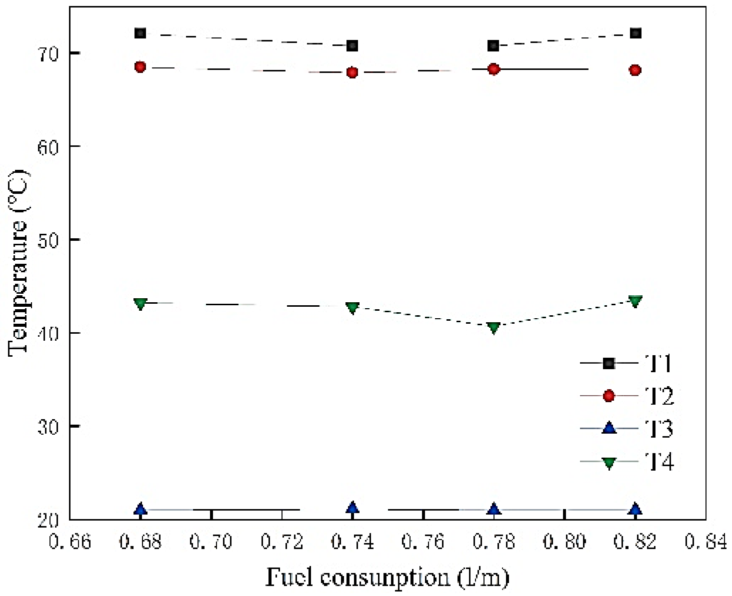

Figure 4. Temperatures of heat carriers in the stationary mode

Table 2

STEADY-STATE READINGS. Experiment №1

Fuel consumption, l / m	*Temperature of the heat carrier in the heating circuit*		*Temperature in the heated circuit*	
	At the inlet to the heat exchanger (T1), °C	*At the outlet of the heat exchanger (T2), °C*	*Initial temperature of air (T3), °C*	*Temperature of heated air (T4), °C*
1	66.2	59.0	21.5	39.8
0.95	66.4	59.5	21.6	41.2
0.85	66.3	59.7	21.7	43.3
0.73	66.8	61.8	21.8	46.2

Further, on the basis of the obtained data, a graphical dependence of the temperatures of the heat carriers in the pulse mode, with a frequency of 4 hertz, is constructed. The relationship is shown in the graph below.

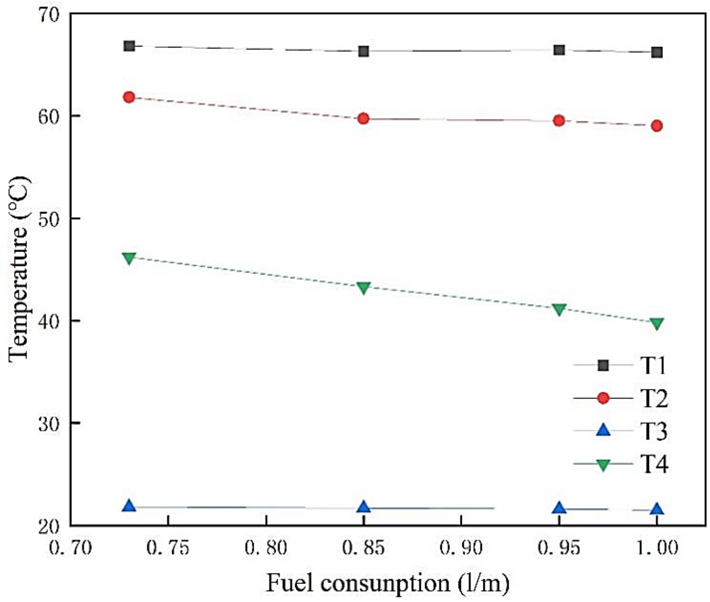

Figure 5. Temperatures of heat carriers in the pulse mode with frequency 4 Hz

Judging by the graph, we can conclude that the heated coolant has the highest point at a flow rate of 0.68 l / m. The temperature of the air at the inlet to the heat exchanger is almost unchanged.

Table 3

PULSE MODE READINGS WITH VALVE OPENING FREQUENCY 4 HZ. Experiment №2

Fuel consumption, l/m	*Temperature of the heat carrier in the heating circuit*		*Temperature in the heated circuit*	
	At the inlet to the heat exchanger (T1), °C	*At the outlet of the heat exchanger (T2), °C*	*Initial temperature of air (T3), °C*	*Temperature of heated air (T4), °C*
0.90	66.1	58.8	20.5	38.4
0.84	66.6	59.9	20.6	41.4
0.82	66.7	60.7	20.7	44.7
0.79	66.5	60.3	20.6	43.3

Further, on the basis of the obtained data, a graphical dependence of the temperatures of the heat carriers in the pulse mode, with a frequency of 3 hertz, is constructed. The relationship is shown in the graph below.

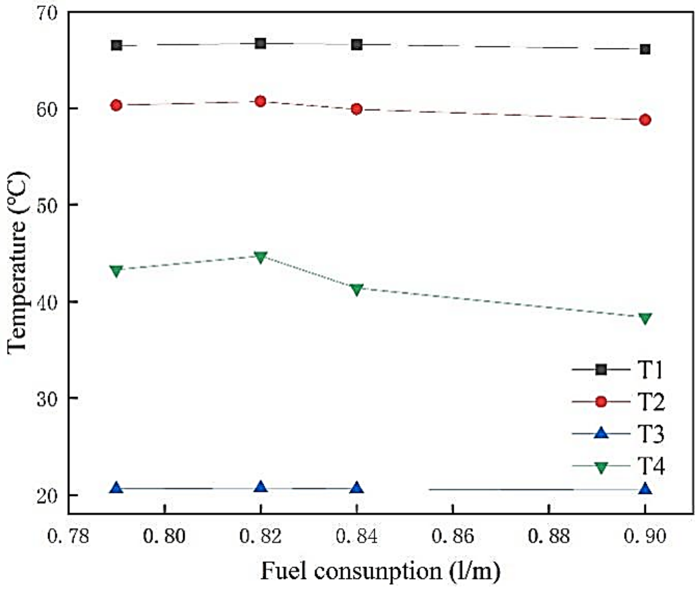

Figure 6. Temperatures of heat carriers in the pulse mode with frequency 3 Hz

Judging by the graph, it can be concluded that the heated coolant has the highest point at a flow rate of 0.73 l / m. The temperature of the air at the inlet to the heat exchanger is almost unchanged.

Conclusion

Referring to a large number of relevant literatures, studying various thermal design methods and cooling methods, understanding the principle of heat transfer and conducting thermal design. After comparing many heat dissipation methods, and then according to the actual requirements of the actual project, it is determined that the laboratory should adopt a circulating water-cooling system, and the main heat dissipation components are optimized.

According to the experimental design, select the required experimental equipment and build the experimental bench, carry out the experiment according to the design plan, and record the experimental data.

Amplitude-frequency response decreases as the speed of rotation increases, and when the speed of rotation increases to around 18, the rate of decrease gets smaller sharply. Phase-frequency response increases as the speed increases, and the rate of increase gets great.

A protocol was developed for a laboratory setup, a circuit with pulsed circulation of coolant independent of the heat source. This setup allows to test heat exchanger-superchargers with different performances at a coolant fluctuation frequency of 3 to 4 Hz.

Increasing the water flow velocity of each water flow loop of the liquid cooling radiator can enhance the heat dissipation effect. In engineering applications, the speed of the water inlet can be considered according to the actual needs of the circulating cooling system, so as to achieve high efficiency and energy saving.

When analyzing the calculation results of power loss and efficiency per unit time, it is further verified that the structure of the main heat dissipation components of the heat dissipation system and the inlet water flow speed are closely related to the power loss and efficiency of the converter equipment. These factors should be fully considered when designing the cooling system.

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