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Research on Properties of Fluid Pressure Drop for Electric Vehicle IGPT Pin Fin Heat Sink

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ABSTRACT

The performance of electric vehicle IGPT pin fin heat sink can be measured by the temperature field and fluid pressure and other parameters. In order to improve the cooling effect of pin fin heat sink, diameter, length and distance of the fin was optimizedin combination. The relationship between pressure drop of the water inlet, outlet and pin fin parameters was analyzed and calculated. Pressure drop effect on different parameters of 9 groups of pin fin heat sink structures was analyzed using the orthogonal design. Among the pressure drop curves of 9 schemes, results ofschemes 1,5,6 and9 were moderate and in favor of improving comprehensive property of heat sink. According to the optimum structure parameters, experimental cooling system platform was set up and experiments were carried on. The optimum structure of electric vehicle IGPT pin fin heat sink was produced.

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1. INTRODUCTION

Research on the development of electric car is a new interest in modern industry aiming atsolving the problem of automobile energy saving and reducing the emission [1]. Electric car in the type of energy saving and environmental protection, the economical and practical type or the luxurious and honorable type has the advantages of low pollution and no fuel consumption, which is an important technical means of easing short supply of oil natural resources and lowering the increasing price [2]. The high power device called IGBT is the electrical component of great importance in electric vehicle control system. Under the condition of normal working, the power loss of IGBT is mainly through conduction or radiated in the form of heat. The conduction or radiation of heat may cause serious effects on working performance and life of other electric devices. So, the high power device IGBT needs the reduction of thermal radiation and conduction through cooling [3-4]. As a result, the thermal emission performance of cooling device can affect the quality, the performance and the working life of electric vehicle control system in electric car, which will influence the stationary and safety of electric car.The performance of heat sink is reflected not only in heat transfer performance but also in the property of pressure drop in the heat sink [5-6]. For this reason, at the stage of the heat sink structure design, the premise of determining the best flow, optimization of heat sink in structure, as well as pressure drop property are the major technical methods in the performance study of heat sink, and it is one of the main ways in the safety study of the electric car [7-8]. Due to the rapid development of computer technology, optimization design in engineering could be solved. A solid platform was build for the optimization engineering problem by MATLAB [6]. The linear program, non-linear program and multi-objective programcan be solved by MATLAB tools function. Linear minimization problem, nonlinear minimization and quadratic programming not only could be solved

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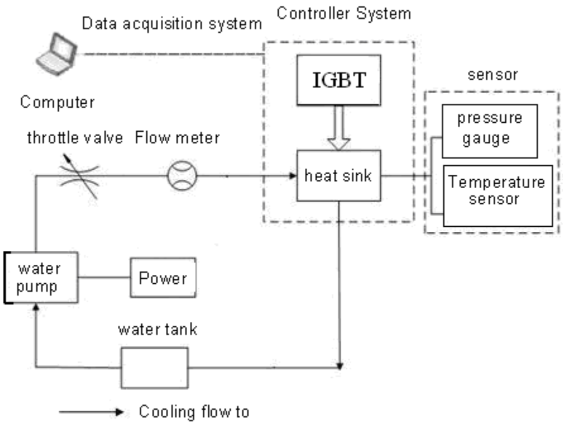
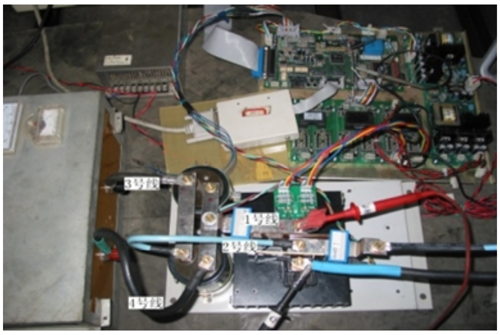
but also solution of large engineering project could be provided by the kit [7].

2. COOLING TEST SYSTEM

Electronic devices are components sensitive to temperature. If the working environment is extremely bad, the properties of the electrical device will be much reduced. As a result, the working performance of the controller will be affected. To ensure the safety and reliability of the operation of the electronic device, the cooling methods of the heat sink directly determines the design scheme of the components, instruments and equipment, and some other technical parameter selection, such as the reliability of the main control system and the cost of the heat sink [7]. The forced water cooling method was adopted in this research for the IGBT cooling heat sink system. The heat transfer process included the aluminum plate thermal conductivity and the convection heat transfer between the secondary heat exchange surface and the fluid [12-13].



a. Heat sink cooling system chart



b. Experimental scene

Figure 1. Heat sink cooling system

The heat sink conducted the generated heat from the upper panel to the secondary heat exchange surface through the aluminum plate. The generated heat from the upper panel to the secondary heat exchange surface through the aluminum plate was transmitted by the heat sink, and then the heat conduction out was performed through the convective heat transfer between the second heat exchange surface and coolant to reduce the temperature of IGBT [9-11]. The heat sink cooling system diagram is shown in Figure 1.

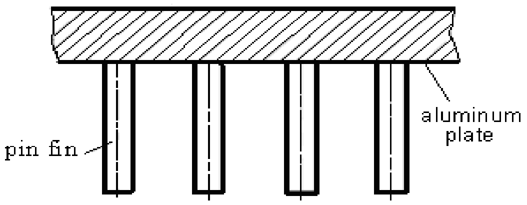
The cooling system consisted of water pump, throttle valve, flow meter,pressure gauge, water tank,sensor, controller system and data acquisition system. Part of experimentalscene is shown in Figure 1b. The heat sink channel was sealed up by type of sealing ring, and the coolant added up with anti-freeze. The pump coolant was supplied by the tank. The coolant flowed out from the pump, passed through the throttle valve, and then was adjusted to the required actual flow in the glass rotor flow meter. Next, the coolant entered the heat sink channel and removed the heat by the convection heat transfer between the secondary heat exchange surface.

The ZRN1151DP capacitance tolerance transmitter was used to detect the pressure difference between the inlet and the outlet. The temperature in upper surface of the aluminum plate and temperature between the inlet and the outlet was detected by glass liquid temperature sensor [7]. The coolant from the heat sink was sent back to the tank. As a result, the tank kept the liquid temperature in outlet the same as the original level. At last, the goal of transferring the heat generated by IGBT was achieved [11].

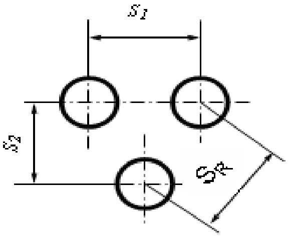
3. THE PIN FIN STRUCTURE

To keep the working environment temperature of the electron device at a constant level effectively, it was necessary to use the optimization design in the structure and size of the heat sink. The inner structure of the heat sink was adopted to be a pin fin snake type channel. The pin fin structure is shown in Figure 2. The pin fin distribution schematic diagram isalso presented in Figure 2. In this research, the distribution of the pin fin was fork row, and the shape of the pin was circle.

It could enhance the conduction ability of heat sink to increase the pin fin length and reduce the space among the pin fin. However, as the pin fin length increased, the pressure drop could increase. In the premise of certain channel size, the reduction of pin fin space limited the range of pin fin diameter, which caused the liquid stagnation among the pin fin, so that, the boundary layer thickness increased [14-16].



The pin fin structure



s_1 The pin fin circumferential center distance, m;

s_2 The pin fin longitudinal center distance, m;

S_R The pin fin oblique spacing, m.

Figure 2. The pin fin distribution schematic diagram

The performance of the heat sink was measured by the temperature field and the fluid pressure drop or other parameters. To achieve better fluid pressure drop performance, it was needed to optimize the combination of the length, diameter and space and to design the best structure scheme and to select the best flow.

4. FLUID PRESSURE DROPS

4. 1. Analysis of Fluid Pressure Drop Backflow phenomenon appeared in some flow processes; some fluid moved along the flow direction, and constantly impacted the pin fin and such loss of pressure drop was caused . The change of interval S, length l, and diameter d of the pin fin caused different flow pressure drops. The parameter and distribution of pin fin greatly influenced the pressure drop of coolant. So research on the fluid pressure drop was of significant importance. Simulation of pressure drop of heat sink with different structural parameters and research on optimum structure of heat sink parameters made it feasible to provide specific parameters for actually building the controller test bench and thus underlay the choice of water pump, flow meter and relief valve [7, 17].

The analysis of pressure drop indicated that pressure drop between the exit and entrance of heat sink was related to pin fin array parameters, flow condition of coolant and fluid physical properties. So the Euler number [7, 18] is:

$$Eu = F(Re, s_1 / d, s_2 / d, N) \tag{1}$$

where, Re——Reynolds number,

d——diameter of pin fin, meter,

N——pin fin quantity of each column.

s_1——the pin fin circumferential center distance, m;

s_2——the pin fin longitudinal center distance, m;

For fixed heat sink, $s_1/d, s_2/d$ and N were constant, so:

$$Eu = k\mathrm{Re}^m \tag{2}$$

Pressure drop of transverse flow in pin fin [13] is:

$$\Delta p_f = \xi \cdot \frac{u^2}{2} = c_s \cdot R_e^{0.27}(NN+1) \tag{3}$$

herein, NN——bay quantity of pin fin;

C_s——geometrical factor of pin fin, determined by s_1 / d and φ .

$$\varphi = (s_1 - d)/(s_R - d)^2 \tag{4}$$

$$\mathrm{Re} = \frac{u_{\max} d}{v} \tag{5}$$

herein, $u_{\max}$——flow velocity of the most narrow sectional area $A_{\min}$ in the flow channel, m/s ;

v——fluid motion viscosity, m^2/s.

According to

$$u_{\max} = \frac{Q_v}{A_{\min}} \tag{6}$$

herein, Q_v——volume flow rate, m^3/s;

$A_{\min}$——the most narrow sectional area, m^2.

$$A_{\min} = \frac{s_1 - d}{s_1} \omega l \tag{7}$$

where, s_1——the pin fin circumferential center distance, m;

d——diameter of the pin fin, m ;

ω——channel width, m;

l——length or height of pin fin, m.

Heat sink pressure drop Δp_f was related to length l, diameter d and spacing s of the pin fin. There were three standards for each factor, so if all the working conditions were simulated, 27 simulation schemes were needed, so on the basis of the guarantee that all the working conditions were taken into account comprehensively, the key to design heat sink structure was to improve work efficiencyand establish efficient and comprehensive optimization simulation scheme.

TABLE 1. Radiator factors and level parameter

Factor	Level		
	1	**2**	**3**
Diameter *d*／mm	3	4	5
Spaces /mm	10	11	12
Length *l*／mm	15	17	19

TABLE 2. Structure parameters and orthogonal results analysis of heat sink

Schemes	Length *l* / mm	Spaces/mm	Diameter *d*／mm	Pressure drop /Pa
1	1（15）	1（10）	1（3）	2278.34
2	2（17）	2（11）	1	2098.36
3	3（19）	3（12）	1	1916.67
4	2	1	2（4）	2591.11
5	3	2	2	2280.32
6	1	3	2	2276.56
7	3	1	3（5）	2720.34
8	1	2	3	2692.56
9	2	3	3	2270.78

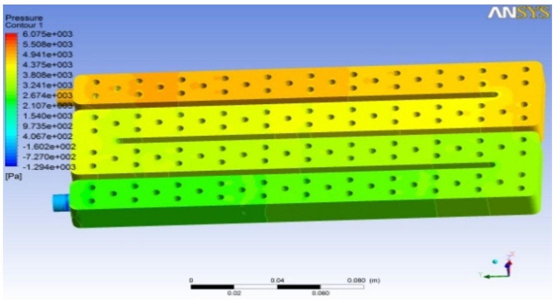


Figure 3. Vectogram of coolant pressure drop

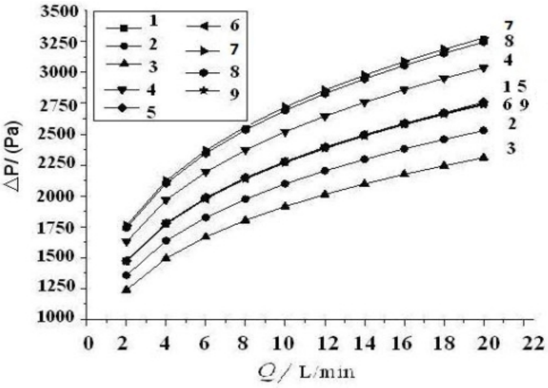


Figure 4. Comparison and analysis of pressure drop

According to orthogonal design thought, three factors of d, l, s and each with three levels were considered in the design of radiator; besides, reciprocal bond was thought. The factors and level parametersare summarized in Table 1.

4. 2. Fluid Properties and Boundary Conditions

Pin fin heat sink watercourse was designed as a snakelike flow channel, which consisted of three tandem water channels, and the design of flow channel structure was optimized. Through the orthogonal design, with Fluent software, heat sink structure temperature field and pressure drop of nine schemes were simulated and analyzed. 9 kinds of schemes and specific parameters are shown in Table 2.

Boundary condition was set as: $k-\varepsilon$ viscous model; coolant temperature at water inlet was 20°C, outlet pressure was 0 Pa.Due to the complicated structure of pin fin heat sink, tetrahedral grid partition was chosen, the heat transfer and flow was compatible with the basic control equation, and 9 pin fin heat sinks fluid pressure drop schemes were respectively simulated.

The coolant medium was water; physical parameters were constant at equivalent temperature. With different structures and different flow rates, the flow state of coolant in heat sinks was different; laminar conditions with little rate, and along with the flow increased gradually and changed into turbulent layer. Therefore, fluid states differed with different fluid velocities.Cooling efficiency and pressure drop of pin fin heat sink is reflected in Table 2.

4. 3. Numerical Simulations Vectogram of coolant pressure drop is shown in Figure 3. Boundary condition was defined as the outlet pressure which was 0Pa and average pressure drop at water inlet and outlet was about 2400Pa according to the experimental measurement.

The pressure gradually reduced along the flow direction from water inlet to water outlet because the snakelike water channel was long, the final pressure drop loss was strong due to the fluid resistance caused by pin fin that gradually increased.

4. 4. Pressure Drop Curve It was indicated that the bigger pressure drop, the bigger resistance coefficient, the more evident inhibition; the smaller the pressure drop, the smaller the resistance coefficient as observe in Figure 4. Structure with big fluid pressure drop lead to a small flow velocity, the heat taken by fluid in unit time was much. On the contrary, the smaller fluid pressures drop, the faster flow velocity, the smaller heat removal. Therefore, it was of vital importance to choose the appropriate pressure drop curve to improve the cooling efficiency.

Structural parameters in scheme 7 caused a bigger fluid pressure drop than scheme 8. Pressure drop in scheme 7, 8 and 4 was big, the fluid resistance caused by structure size was big, and these schemes prevented the improvement of comprehensive performance of heat sink. So the pressure drop curves did not meet the requirements. Too small pressure drop indicated that the flow velocity was too fast, it went against heat dissipation. Fluid pressure drop in scheme 2 and 3 were smallest, it prevented the improvement of comprehensive performance of heat sink as well. Pressure drop curves of scheme 1, 5, 6, 9 were almost coincident, and pressure drop were moderate, so they were reasonable [7].

5. RESULTS COMPARATIVE ANALYSIS AND STRUCTURAL PRODUCTS

5. 1. Results Analysis of Orthogonal Design The coolant flow in this research was changed at the range 2～20L/min.The orthogonal design result of pin fin heat sink was analyzed. The analysis results by flow parameter $Q=10\,L/m$ are shown in Table 2.

The pressure drop in scheme 8 achieved the maximum 2692.56Pa in Table 2. The maximum value of Δk of the results of subtraction caused by every factor level is shown in Table 3. According to the range Δk, the primary and secondary order of the factor were inferred as, $B(s)>C(s)>A(s)$, which affected the pressure drop. Thus among the three selected factors which were influential to the fluid pressure drop property, the pin fin spacing was the most sensitive with highest influence.

5. 2. Experimental Test Value and Numerical Simulation Value Analysis and Comparison Structure of heat sink was designed by the parameter scheme 5. According to Equations (5) and (6), the expression of pressure drop between the entrance and outlet was: $\Delta p_f=246.4\times\mathrm{Re}^{0.27}$.The change trend of experimental test value, the theoretical value and the numerical simulation value along with Re changes is shown in Table 4.

The contrast curve of the experimental test value, the numerical simulation value and the theoretical value are shown in Figure 5. The pressure drop error ratebetween experimental test value and numerical simulation value was below 7.5%, and the one between experimental test value and theoretical value was below 5%.It was proved that numerical simulation was correct.

5.3. Optimized Structure Heat Sink Product Experimental cooling system test platform was established. The scheme of structure parameter was adopted. The heat sink was produced through optimizing structure designand analysis on comprehensive properties of heat sink. The product is shown in Figure 6.

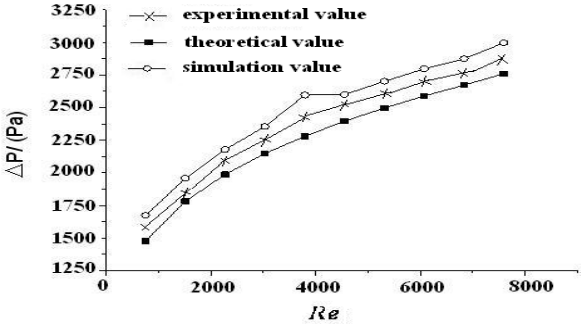


Figure 5. The fluid pressure drop comparison

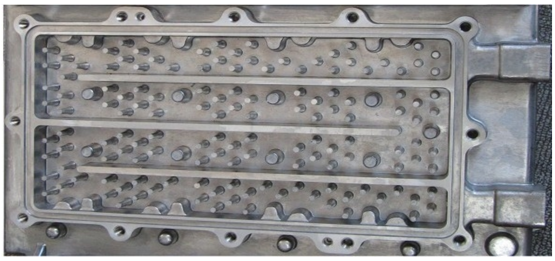


Figure 6. Heat sink product

TABLE 3. The calculation results of the range

Factors	A(*l*)	B(s)	C(*d*)
k_{1j}	7246	7517	6292
k_{2j}	6589	7070	7075
k_{3j}	6916	6164	7384
Δk	657	1353	1092

TABLE 4. Analysis and comparison on pressure drop experimental value

Fluid flow (L/min)	2	4	6	8	10
Re	759.1	1518.4	2277.5	3036.2	3795.4
Experimental value (Pa)	1542.23	1831.29	2059.18	2247.79	2378.58
Theoretical value (Pa)	1477.34	1781.54	1987.56	2149.41	2280.32
Simulation value (Pa)	1672.31	1958.22	2178.14	2356.65	2569.15

6. CONCLUSION

1) Coolant pressure drophas enormous influence on the parameter and arrangement of the pin fin. Among the parameters, the pin fin diameter, spacing and length, which affected fluid pressure drop, the spacing had the most influence. The second influential factor was the diameter, and the last factor was the pin fin length.

2) Among the pressure drop curves of 9 schemes, results in scheme 1, 5, 6, 9 were moderate and were in favor of improvement of comprehensive property of heat sink.
3) When the fluid flow Q was changed in the range of 2L/min to 20L/min, the pressure drop of heat sink using different structure parameters was disparate. The value of pressure drop reflected that the pin fin of heat sink hindered the fluid.
4) Through the error rate comparison of experimental test value and the numerical simulation value or the theoretical value, the reliability of theoretical calculation and the feasibility and correctness of simulation methodswas proved.

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چکیده

عملکرد سینک گرمایی پین پرهخودرو الکتریکی IGBT را می توان بادما و فشارسیال و پارامترهای دیگر اندازه گیری کرد. به منظور بهبود اثر خنک کننده سینک گرمایی پین پره ، قطر، طول و فاصله پره بهینه سازی شد.رابطه بین افت فشارآب ورودی، خروجی و پین پره تجزیه و تحلیل و محاسبه شد.ا ثر افت فشار روی پارامترهای مختلف از۹ گروه ساختارهای سینک گرمایی پین پره با استفاده ازطراحی متعامد تجزیه و تحلیل شد. در میان منحنی های افت فشار از ۹ طرح، نتایج حاصل ازطرح های۱، ۵، ٦و ۹ در حد متوسط بوده ودر جهت بهبود خواص جامع سینک گرمایی بودند. با توجه به پارامترهای ساختاری بهینه، پلت فرم آزمایشگاهی سیستم خنک کننده راه اندازی شد وآزمایش روی آن انجام شد. ساختار بهینه سینک گرمایی پین پره خودرو الکتریکی IGBT تولید شد.

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