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Experimental study on hydraulic expansion of tube-fin heat exchanger

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Experimental study on hydraulic expansion of tube-fin heat exchanger

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Abstract: The tube-fin heat exchanger is the core equipment in the whole air-conditioning system, the thermal resistance of copper tube and fin contact accounts for 10%-20% of the total thermal resistance of the heat exchanger, and the thermal contact with the fin increases. Therefore, reducing the contact gap of the heat exchanger is extremely important to improve the overall heat exchange efficiency. In this paper, for the high-efficiency heat exchanger composed of seamless internal thread copper pipe, the heat exchange tube and the fin are expanded by hydraulic expansion and the liquid pressure range, reasonable pressure holding time and pull-off force are guaranteed by a large number of experiments. In this paper, the heat transfer tube and the fins are expanded by hydraulic expansion, and the relationship between the liquid pressure range, the reasonable pressure holding time and the pull-off force and the dwell time is measured through a large number of experiments. Finally, the effect of different liquid pressure expansion joints on the contact gap was further observed by a microscope.

1. Introduction
With the fierce competition between the air-conditioning industry and the multi-level development of consumer demand, people are increasingly demanding the performance of air conditioners. A large number of experimental studies have shown that the tube-fin contact thermal resistance accounts for 6%-18% of the total heat resistance of the entire heat exchanger [1]. Among them, the heat exchange tube is a key component of the heat exchanger. Besides the excellent features of the smooth copper tubes, the heat transfer effect is the smooth tube 2- 2.5 times, saving one third of copper [2]. Therefore, the seamless internal thread copper tube is widely used. Due to the structural characteristics of the seamless internal thread copper tube, the mechanical expansion tube method will cause the drawing of the inner wall thread and the defects such as work hardening, which will reduce the overall transmission. However, the non-contact uniform expansion method of hydraulic pressure to expand the heat exchanger can effectively solve the disadvantages caused by mechanical expansion. Therefore, it is extremely

important to study the new expansion method to improve the development and innovation of the current heat exchanger to low power consumption and high performance.

In order to better observe the contact gap of the heat exchanger, we need to know the factors related to the contact gap, such as the magnitude of the hydraulic pressure, the specific holding time and the relationship between the pull-off force and the holding time. The contact gap between the entire heat transfer tube and the fin was observed through a microscope.

In 2003, EIsherbini et al. studied the contact of aluminum fins without flanged copper tubes, and measured the contact thermal resistance under tube fin brazing and direct expansion contact [3] Jeong is equal to the correlation between the thermal resistance and the expansion joint forming of the indirect contact between the 9.52mm and 7mm copper tubes and the aluminum fins in 2004 and 2006 respectively[4.5].In 2009, Tang Ding et al. studied the contact state of tube-fin heat exchangers, and proposed reasonable improvement of the expansion joint process by finite element method and test method [6]. However, the relationship between the contact thermal resistance and the thermal expansion of the hydraulic expansion tube is rare.

In this paper, the optimal expansion pressure range of the heat exchanger and the relationship between the dwell time and the pull-off force are obtained through a large number of experiments. Under the different hydraulic pressures obtained through experiments, the results of local contact of the heat exchanger tubes and fins were observed. A new measurement direction related to contact thermal resistance is proposed to analyze the influence of the hydraulic expansion process on the thermal resistance of the heat exchanger, which provides a new idea for the entire tube-fin heat exchanger in the case of hydraulic expansion.

2. Determination of the range of hydraulic pressure

2.1. experiment system

The whole experiment consists of three parts, the first part of the hydraulic power system, the second part of the data measurement part, and the third part is the self-designed hydraulic bulging device combination to complete the whole experiment process. the sampling rate of the data acquisition system is set to 10 Sps/s for uninterrupted sampling. Finally, different hydraulic pressure experiments were completed under the same holding time, and the high pressure liquid in the heat exchanger was released by hydraulic device to complete the expansion process of the entire heat exchanger.

2.2. Expansion pressure determination

In order to make the fins of the tube-fin heat exchanger and the heat exchange tube expand tightly, we need to know in advance the reasonable pressure of the liquid pressure expansion in the case of hydraulic expansion, using the corresponding theoretical calculation as a guide, the specific experimental phase Combine the way to determine the reasonable expansion pressure under this specification. The specific assembly and parameters of the selected hydrophilic aluminum foil fins and seamless internal thread copper tubes are shown in Figure1. The liquid belongs to a homogeneous medium. According to the calculation, the optimum expansion pressure range of the gap between the fin and the heat exchange tube and the yield of the fin just after yielding is between 8 MPa and 11 MPa.

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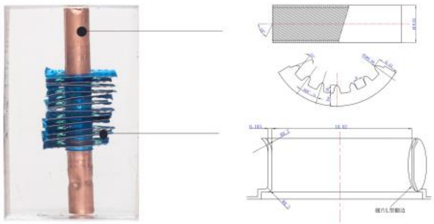

Figure 1. Schematic diagram of heat exchange tube and fin structure.

The range of the expansion pressure is tested by the previously calculated reference value under different expansion pressures, and the indentation on the surface of the heat exchange tube is used to determine whether the expansion joint phenomenon has occurred to determine whether the expansion has occurred. Finally, a liquid pressure range from 9 MPa to 11.5 MPa when the expansion joint is just expanded until the heat exchange tube is broken.

3. Determination of holding time

3.1 Expansion test and pull-off test

The experiment was arranged under the condition of 10MPa liquid pressure expansion joint, and the effective expansion time was carried out under the conditions of holding pressure for 2s, 4s, 6s, 8s, 10s, 12s and 14s respectively. The expansion of the three sets of samples was carried out under each dwell time, and the expansion of the whole experiment was completed by a hydraulic expansion joint device. The pull-off force test is carried out according to the heat exchanger's independent design of the corresponding fixture. The pull-off force test was carried out by a self-designed tube-fin fixture and a Shimadzu AX-G electronic universal testing machine to measure the pull-out force under different dwell time. After the measurement of the pull-off force reaches the maximum value, the average pull-off force value of the 0.5 mm continues to slide is the pull-out force value of the heat exchanger. The pull-off force and displacement parameters measured at different dwell times were obtained as shown in Table 1.

Table 1. Pull-down force and displacement test parameters for different dwell time.

Measurement type	Numbering	4s	6s	8s	10s	12s	14s
Pull force /N	No1	40.22	244.56	64.50	185.80	183.06	129.17
	No2	43.75	85.66	119.58	295.04	145.65	94.81
	No3	20.85	72.11	306.20	188.98	124.49	112.44
Pull force average /N		34.94	78.86	119.58	223.27	151.07	112.14
Displacement /mm	No1	0.36	14.05	3.90	15.31	7.82	5.88
	No2	4.47	8.23	6.24	31.25	6.67	3.32
	No3	0.38	5.62	10.32	3.52	4.95	9.26
Average displacement /mm		1.74	6.93	6.24	16.69	6.84	6.15

Finally, the average value was obtained to obtain the pull-out force under the corresponding dwell time. With displacement parameters. Finally, the experimental and measurement results obtained the relationship between the dwell time and the pull-off force and displacement shown in Figure 2. For the tube-fin heat exchanger, the dwell time is about 10s, which is suitable for too short. The pressing time will cause the pulling force to be insufficient. The excessive holding time will cause the heat exchanger to work less, and the holding time is suitable for 10s-12s.

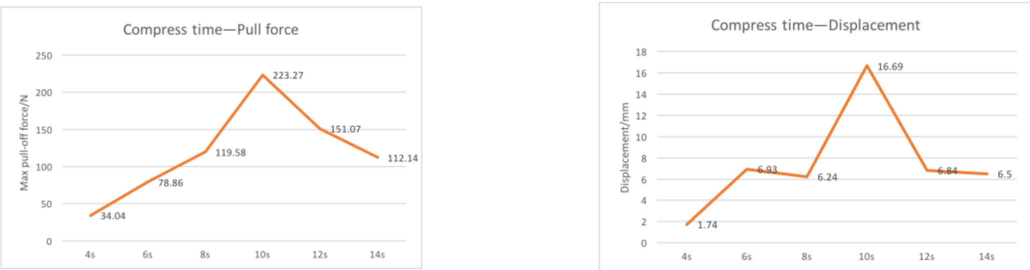

Figure 2. Relationship between packing time and pull-off force and displacement.

4. Analysis of local characteristics of hydraulic expansion process

4.1. Sample contact observation experiment

Through the experimental data obtained in the previous section, under the premise of the holding time of 10s, nine experiments were carried out in three groups of experiments at 9MP, 10MPa and 11MPa respectively, and the anatomy was carried out in the axial direction through the water cutting machine. Eighteen observation experiments were obtained. According to the axial direction of each heat exchange tube, it is divided into six parts, A_U\\$A_D$、$B_U$\\$B_D$、Cu\\$C_D$, for metallographic microscope observation. The observed parts are shown in the figure 3.

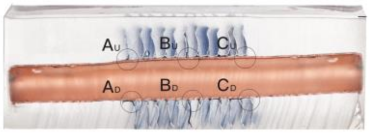

Figure 3. Experimental sample molding and size.

4.2. Experimental research and analysis of results

In the case, it is found that the maximum gap generated in the middle of the flat side of the fin is 0.035 mm and 0.030 mm. To this end, we made nine sets of experimental samples and cut them in half along the axis. Through actual observation, it is found that under the condition of hydraulic expansion joint, the tube-fin heat exchanger has a clear gap between the fin and the heat exchange tube under the condition of 9MPa expansion, and the heat exchange in the case of 10MPa and 11MPa. The gap of the test piece was almost completely eliminated, and a good expansion effect was obtained. According to the results obtained by the experiment, in the case of hydraulic expansion, the results of the B_U part of the 9MP, 10MPa, and 11MPa pipes were observed as shown in the figure. In the case of 9 MPa, a significant gap appeared in the expansion of the heat exchanger, and then complete expansion was achieved under other pressures.

According to these observation phenomena, the contact gap of the tube-fin heat exchanger in the hydraulic expansion joint is proposed. In the case of hydraulic expansion, the effective contact area between the flat portion of the fin and the heat exchange tube is used to express the heat transfer under the hydraulic expansion joint.

Nine sets of heat exchanger samples were subjected to water cutting and dissection under different hydraulic pressures. Eighteen groups of samples were obtained. Observation and measurement were performed by an optical electron microscope at a magnification of 50 times, and finally, statistical data as shown in the table 2 was obtained.

Table 2. Effective contact area of fin contact under different liquid pressures.

Hydraulic pressure	Numbering	Au/mm	Ad/mm	Bu/mm	Bd/mm	Cu/mm	Cd/mm
9MPa	No1	0	0	0.234	0.345	0	0
	No2	0.290	0.243	0.501	0.427	0.256	0.267
	No3	0	0	0.196	0.203	0	0
10MPa	No1	0.934	0.934	0.944	0,986	0,862	0.944
	No2	0.782	0.789	0.904	0.854	0.864	0.853
	No3	0.702	0.718	0.914	0.928	0.853	0.834
11MPa	No1	0.734	0.790	0.843	0.903	0.911	0.958
	No2	0.417	0.419	0.873	0.816	0.951	0.943
	No3	0.288	0.213	0.242	0.246	0.404	0.166

As shown in the table 2, it can be seen that there is a state of incomplete contact at both ends of the A/C of the heat exchange tube. The main reason for this phenomenon is that the entire heat exchanger has a large due to insufficient initial expansion pressure. Contact gap. In the case of 10 MPa, there is no obvious contact gap in the complete expansion of the A/B/C three parts. In the case of 11 MPa, the data in the experimental group showed large fluctuations. The possible reason was that the hydraulic pressure was unstable or the holding time was too long during the expansion, and the over-expansion occurred, resulting in plastic deformation of the fins. The decrease of contact pressure increases the corresponding contact gap.

As shown in Figure 4, the electron expansion lens is observed under the 9MPa expansion pressure. The effective expansion area of the tube-fin heat exchanger is almost 0. The intermediate ratio is 24.5%. There is a significant contact gap. The reason for this is that the insufficient expansion pressure causes the tube and the fin to not fully expand, resulting in a certain contact gap inside.

Due to the processing technology of the fin itself, we can see from the figure that there are two original angles in the flanging process of the whole fin, so we observe the fillet in the actual expansion joint contact angle during the expansion process. The range has an effect on the entire expansion effect. In the previous large number of experiments, we determined the liquid pressure value and the reasonable pressure holding. Finally, different experimental groups were made at 9 MPa, 10 MPa, and 11 MPa, respectively. The best expansion effect of the control was at 10 MPa. The proportion of the entire contact area reached 94.1%.

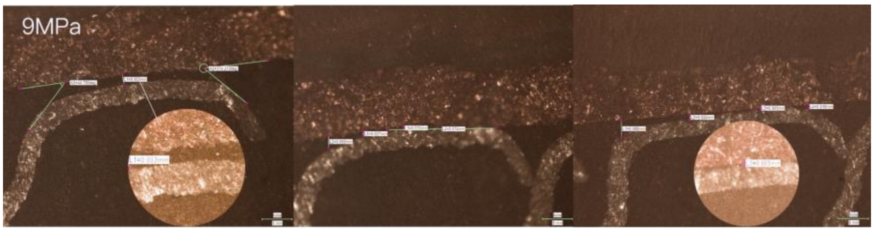

Figure 4. Contact gap of different parts under 9MPa hydraulic pressure.

5. Conclusions

The experimental research shows that the range of hydraulic expansion of the tube-fin heat exchanger is combined with theory and experiment to obtain the best expansion range in the range of 10~11MPa. The reasonable holding time is about 10s. Under this holding time, it can provide the maximum pulling force between the heat exchange tube and the fin to ensure the performance of the whole production, and at the same time ensure the effective expansion of the tube-fin heat exchanger. Forming. Through the experiment, under the condition of 10MPa hydraulic pressure, the contact gap between the tube fins is basically completely eliminated, and the substantially effective expansion joint area is above 91.4%. Since the hydraulic expansion joint can effectively solve the drawbacks caused by the mechanical expansion tube, in the cost control and the specific process, there will be a contact gap between the two ends of the heat exchange tube, how to effectively deal with the contact gap at both ends It is necessary to conduct further research in the future.

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