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Improvement Of Abnormal Wear Between The Vane-slot And Vane In Rotary Compressor

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ABSTRACT

The reason for the abnormal wear between the vane-slot and the vane in the rotary compressor is analyzed in this paper. Firstly, the influence of lubrication at the clearance, the machining equipment accuracy and oil circulation (oil flow rate) is analyzed. Then the material characteristics including the hardness of the vane and vane-slot, the surface treatment of the vane and the deformation of the vane-slot after welding are discussed. After we find the main correlating factors, we will examine the results from the experiments. Eventually, problem of the abnormal wear is solved by inducing an innovative oil circulation.

1. INTRODUCTION

On March 8, 2011, Hefei Gree stopped using one of our compressor models because of the high rate of the lower limit of this model. Until December 2010, At Hefei Gree two compressors stopped running (locked) and 5 compressors having the problem of suction and discharge. After disassembly it was found that it was the abnormal wear that leads to the vane being stalled (Fig.1&2)

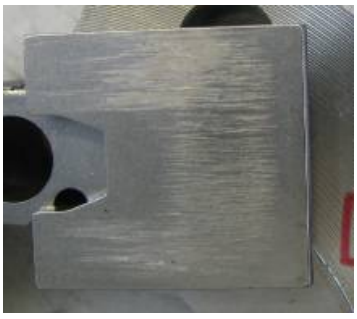


Fig.1 Heavy wear

Fig.2 Localized wear

2. ANALYSIS OF THE CAUSE

The main reasons for the abnormal wear at the vane-slot are as follows: - Load, lubrication, presence of foreign particle, material, precision and clearance matching between the vane and vane slot.

2.1 Load

1）High differential pressure

As the compressor uses R410A as a refrigerant, it can bear much more pressure difference than R22 model，This is the reason why vane-slot abnormal wear often happens in R410A compressors.

R410A:Ps/Pd=1.095/4.268{10.14/42.50}Mpa；Differential pressure:3.173{32.36}Mpa
R22 ：Ps/Pd=0.690/2.700{6/26.5} Mpa；Differential pressure：2.01 {20.5} Mpa

2）Structure（Vane stretch out rate）

Table 1

	type1	type 2	type 3	type 4	Type 5
Eccentricity	5.205	6.191	6.254	5.291	6.188
length	22.1	27	30	30	30
ratio	0.471	0.459	0.417	0.352	0.425

From the stretch out ratio as compared to the above models, our model does not have the highest value. From the 90days reliability test and the stop-up test, there is little wear at the vane slot

Analyzing from the model there has been abnormal wear at the vane-slot. Abnormal wear is independent of the displacement because even the compressor with the lower displacement has abnormal wear at the vane. So this reason can be neglected.

2.2、Lubrication

1）Inadequate supply of oil

（1）Oil level design

From the calculations the oil surface reaches to the edge of the upper bearing，By the observation, the oil level surface is up to six point welding done at the upper bearing and the shell 。To this compressor model, the actual oil amount has reached the upper limit of the volume，The amount of refrigerant allowed is 2300 g，So the oil dilution rate: 0.213（Generally oil dilution rate should be greater than 0.2）。From the design perspective there is no problem with oil dilution rate. As discussed with the customers, it cannot be confirmed that the amount of refrigerant into the compressor has exceeded 2300g or abnormally high. But the amount of refrigerant input into the air-conditioning system is designed to be 2100g and is less than the value we allow.

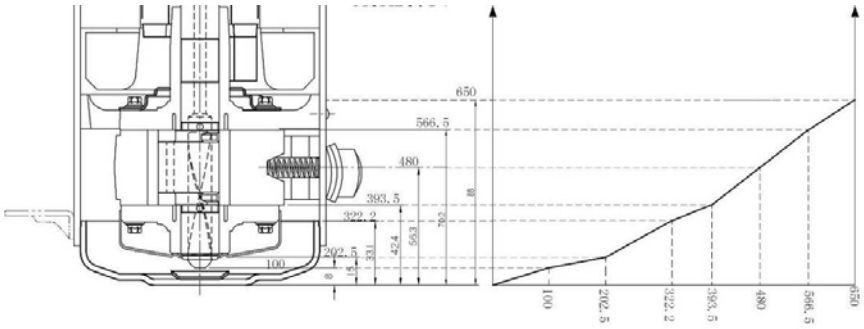


Fig.3 The location of Oil surface

（2）Oil-Flow rate

Another factor which influences lubrication is the high flow rate of the oil. In the process of discharge of the gas from the compressor, part of the oil goes into the air conditioning system with the gas. Due to inadequate amount of oil, vane –slot cannot be lubricated effectively so oil-flow rate test have been done here。Results of the oil flow rate are shown in the table1

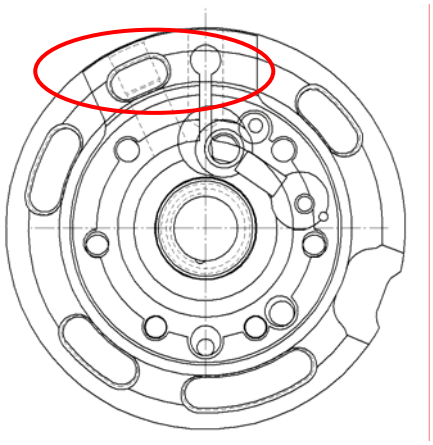
Table 1

Oil-extracting rate of compressor	
Number	Oil-Flow rate
1#	0.99%
2#	0.73%

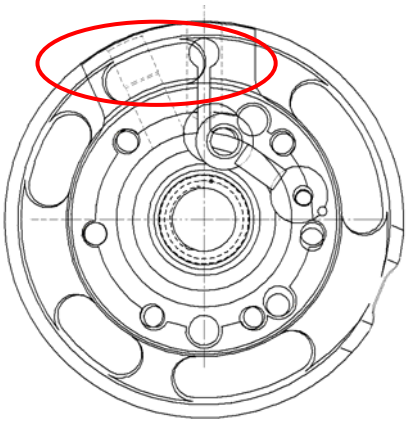
From test results，The oil-flow rate is not so high，So oil-flow rate is not the main reason that affects vane-slot abnormal wear。Backflow of oil will be discuss later in the air-conditioning test observations。

2）Oil flow passage

The kidney shaped hole at the upper-bearing which we are using now is not in contact with the vane-slot (UE-BEAR①)and this would affect the lubrication of the vane-slot. Otherwise if the hole is in contact with the vane-slot(UE-BEAR②), It will increase the lubrication at the vane-slot. Later we will make efforts to improve the lubrication structure.



UE-BEAR①



UE-BEAR②

Disassembly state

（1）Lack of oil in 2 sets of compressors returned from the survey of the compressor disassembly.

Compressor 1 #: locked, the weight is 20.21kg, Both the sides of the vane and vane-slot have abnormal wear; Apparently lack of oil, oil poured out during disassembly about 100 ml.

Compressor2#: No suction and discharge of the gas, the weight is 20.37kg, low pressure side of the vane has abnormal wear and corresponding place of the vane-slot has evident wear, oil poured out during disassembly of about 200 ml.

Note: the oil standard of this compressor is 650 ml; Normal model should be able to pour out more than half the oil.

Possibility of lack of oil

A Compressor with lesser oil

B High oil-flow rate, poor back flow of oil into the compressor when the customers do the inspection

（2）From the location of the wear, there is something common, if it is the local abrasion then the location of the wear is close to the upper-bearing side.

A、 Lack of oil between the vane and vane slot

B、 Because of the welding of the upper bearing with the shell, there is deformation at the vane slot

2.3 Foreign material entry

No foreign particle was found during the disassembly. So this cause can be ruled out

2.4 Materials Cylinder materials：FCE250-A

Vane materials：SKH51 and 11Cr17

Vane used with two different Heat treatment processes. During the disassembly it was found that vane and vane-slot has abnormal wear. The same vane is used in the other series (different models) has no abnormal wear

Matching of the hardness of the cylinder and the hardness of the vane will lead to wear. During the disassembly, adhesive wear was found. With the rubbing of the two parts, temperature also increases. The

small particles (from the adhesive wear) of the lower hardness move to the high hardness part. Investigating into the hardness of the cylinder and oil lubrication

3. Data survey

3.1 Cylinder, Vane hardness

1）Surface hardness of Cylinder

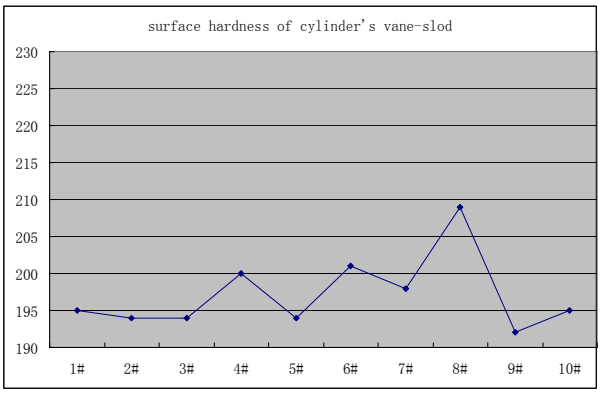


Fig.6 Surface hardness of the cylinder's vane-slot

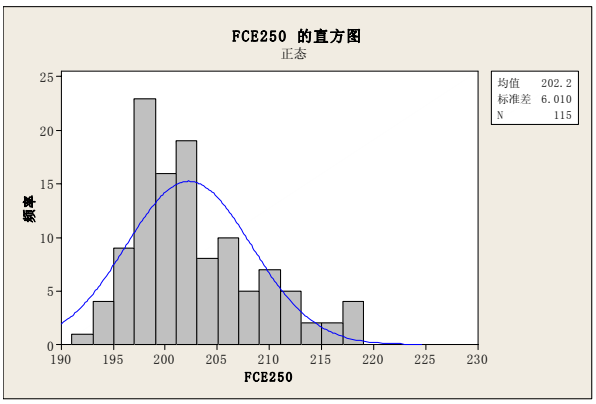


Fig.7 Bulk cylinder hardness distribution

From the hardness distribution Graph, The surface hardness of the vane-slot is closed to the lower limit (Requirement value 190 ~ 230).

The hardness survey data, Cylinder hardness distribution of FCE250 material, the middle value is close to the lower limit. According to the data, during mass production process, there must be some cylinders having hardness value less than the lower limit.

1） Cylinder vane slot hardness

Table 3 Hardness measurement of the Vane slot

Hardness measurement of the vane-slot			Generally the surface hardness difference between the vane-slot and the cylinder is 10-15，The hardness at the low pressure side is slightly lower than the high pressure side
	Low pressure side	High pressure side	
AVG	184	186	
MAX	191	192	
MIN	175	178	

2） Vane surface Hardness

Table 4 Vane surface Hardness

Vane surface Hardness				Vane hardness values are in the specification.
Number	Materials	Hardness	Standard	
1#	Stainless steel + Surface treatment	HV1000	HV900 above	
2#		HV1000		
3#		HV986		
4#	Tool steel + Surface treatment	HV1000	HV800 above	
5#		HV1000		
6#		HV1000		
7#	Tool steel	HRC62	HRC61~65	
8#		HRC64		

3.2 Vane electron microscopy

To make sure what material has adhered to the vane, we do the electron microscope energy spectrum analysis

1) The friction at the high pressure side is more evident than at the low pressure side. And the friction on the both sides is relatively even, no apparent scratch caused by the foreign particles.

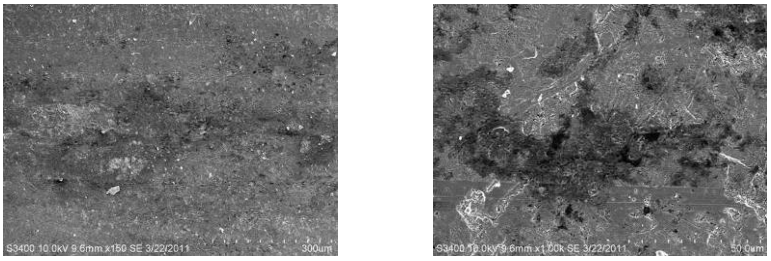
2) The black material content shown in the figure has a relatively high ratio of carbide and some other alloy elements but has no nitrogen elements

3) The grey and the white area contains nitrogen element and should be nitriding vane surface immersed in the sulphur

4) From the linear component analysis, black area has the high ratio of carbon, high ratio of alloy elements, less content of iron and nitrogen

5) From the conclusion above temporarily whether the friction caused by the expansion or the material transfer of cast iron cylinder happened at the vane surface. Because no matter the martensite or the remaining austenite leads to the expansion .Vane surface overheated and decarbonizes or the material transfer both will cause the high ratio of carbon and less ratio of iron at the surface

High pressure side friction marks morphology



Low pressure surface friction marks morphology

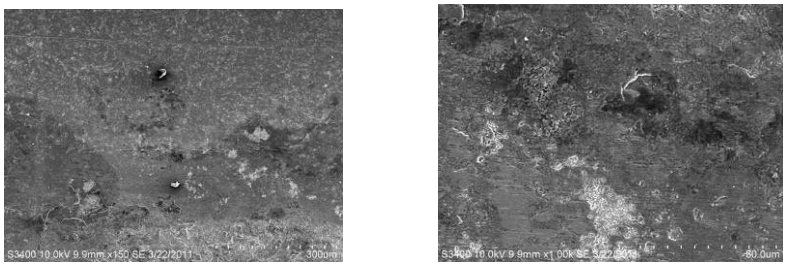


Fig.8 electron microscopy analysis 1

The second electron microscopic analysis:

Vane heat treatment process consists of mainly quenching and tempering many times. Metallographic analysis found that carbide grain boundary along the separation, At high magnification, we can observe the needle shaped and hidden needle shaped martensite, but cannot see the remaining austenite,

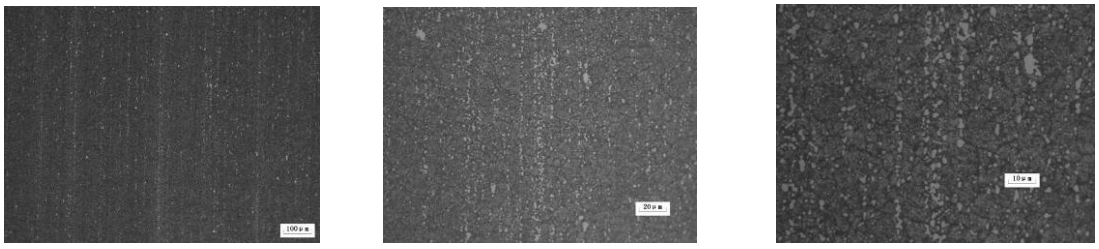


Fig.9 electron microscopy analysis 2

To see the remaining austenite, will cut the vane into small rectangular pieces, analyzing the surface centre of two pieces. The results are as follows:

1 # sample remaining austenite content: 2.5%, 1.9%

2 sample remaining austenite content: 2.1%, 3.2%

3.3 Friction test

1）First test

The test uses different hardness blocks with dry grinding and oil grinding

A）With the increase of Hardness, friction coefficient also increases

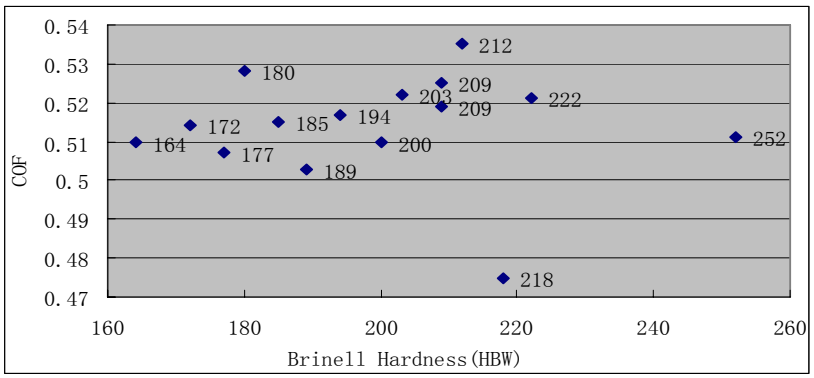
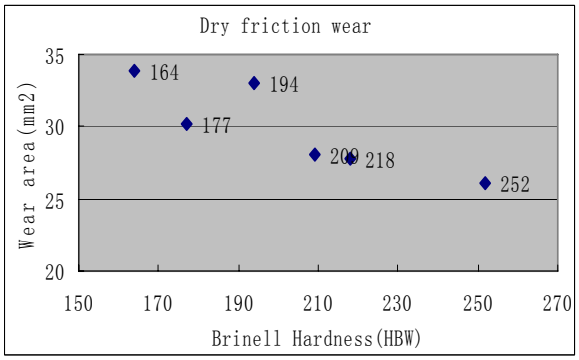


Fig.10 Relation between coefficient of friction and Hardness

B）With the increase in hardness , cylinder wear tends to be slightly lower.



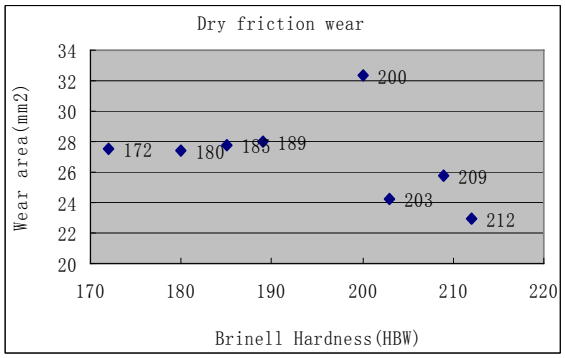


Fig13 Relation between Wear size and hardness

2) The second test

（1）Cylinder and vane samples with different hardness are selected under three different conditions HAF68,4GSI Oil and dry(no oil). Hardness is divided into four grades: are 180HV, 208HV, 160HV and 220HV

Experiment conditions: Back and forth motion, friction stroke 6.84mm, cylinder and vane are immersed into the oil before carrying the experiment. Rotational speed 800RPM, load change, time 30min (if severe adhesive wear is severe then stop)

Severe adhesive wear done to determine the conditions.

From the results, with the increase of hardness grades of the cylinder, the initial load that can lead to adhesive wear will be higher

Table 5 Friction test

No.	Hardness Grade（HV）	Adhesive wear at the starting load （N）
1	160	(290~) 300
2	180	300 (~320)
3	208	330
4	220	(340~)360

HARDNESS	No.	Load（N）	Result	COF AVG	COF	HARDNESS	No.	Load（N）	Result	COFAVG	COF
160HV	1	280	OK	0.045	0.033-0.073	208HV	1	300	OK	0.03	0.027-0.042
	2	290	NG	0.079	0.048-0.154		2	320	OK	0.046	0.036-0.163
	4	300	NG	0.095	0.049-0.142		3	330	NG	0.14	0.112-0.292
	5	320	NG	0.178	0.117-0.213		4	340	NG	0.122	0.057-0.282
180HV	1	260	OK	0.046	0.037-0.117		6	350	NG	0.138	0.046-0.229
	3	280	OK	0.062	0.044-0.135		7	400	NG	0.115	0.103-0.152
	4	300	OK	0.07	0.022-0.149	220HV	1	300	OK	0.069	0.056-0.097
	5	300	NG	0.135	0.087-0.235		3	320	OK	0.068	0.032-0.149
	6	320	NG	0.106	0.068-0.193		4	340	NG	0.082	0.040-0.131
	7	350	NG	0.112	0.082-0.188		5	350	NG	0.119	0.047-0.143
	9	400	NG	0.144	0.122-0.283		7	360	NG	0.113	0.067-0.174

Remarks: - OK (No adhesive wear) NG (Adhesive wear)
Conclusion: With the increase of hardness grades of the cylinder, the initial load that can lead to adhesive wear will be higher ,with the increase of the coefficient of friction, adhesive wear more likely to occur.

②4GSI +220HV Cylinder +Vane

With the increase of load up to 400N the coefficient of friction is relatively stable and remains at lower level .Under HAF-68 condition, load of 340N; wear at the vane and vane-slot increases and load up to 360N the apparent adhesive wear happens (clear adhesive wear)

Table 6

No.	Load（N）	Result	COF（AVG）	COF(region)
1	320	OK	0.045	0.041-0.055
2	360	OK	0.046	0.042-0.062
3	400	OK	0.045	0.039-0.064

. Thus that 4GSI has better lubricating properties than HAF68.

Speculation from these results:

（1）Adhesive wear happens to be occasionally

（2）This type of wear is more prone to happen with the cylinder of lower hardness

（3）Once the adhesive wear happens in the specific load, the wear will get severe as the load increases and then the wear tends to be stable if the load is in the specific range.

Conclusion:- Adhesive wear can be reduced by increasing the hardness of the cylinder and reducing the friction coefficient.

3.4Measurement of Assembly and CAE computing

1）Assembly measurement

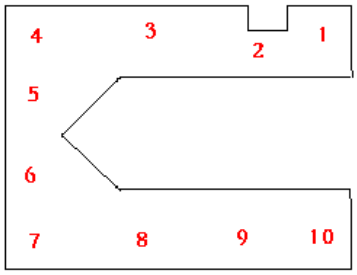


Fig.14 Points selected to measure the deformation

Table 7 Actual deformation measured

Points	1	2	3	4	5	6	7	8	9	10
1＃	-9	-10	-10	-11	-13	-13	-13	-10	-9	-8
1＃-2(Pump)	-12	-12	-12	-13	-13	-13	-13	-10	-8	-8
1＃-3(Welding)	-9	-9	-8	-9	-9	-12	-11	-9	-7	-7
2-1(Deformation)	-3	-2	-2	-2	0	0	0	0	1	0
3-1(Deformation)	0	1	2	2	4	1	2	1	2	1
2＃	-4	-3	-2	-2	-2	-3	-2	-3	-4	-4
2＃-2(Pump)	-6	-5	-5	-5	-5	-6	-6	-7	-7	-8
2＃-3(Welding)	-8	-7	-7	-8	-8	-7	-6	-7	-7	-8
2-1(Deformation)	-2	-2	-3	-3	-3	-3	-4	-4	-3	-4
3-1(Deformation)	-4	-4	-5	-6	-6	-4	-4	-4	-3	-4
3＃	-7	-8	-6	-8	-9	-10	-10	-8	-7	-7
3＃-2(Pump)	-10	-10	-9	-11	-10	-11	-10	-8	-6	-6
3＃-3(Welding)	-13	-13	-13	-13	-15	-11	-9	-7	-5	-4
2-1(Deformation)	-3	-2	-3	-3	-1	-1	0	0	1	1
3-1(Deformation)	-6	-5	-7	-5	-6	-1	1	1	2	3

From the statistical data , After assembly of the pump and welding, the part of the vane-slot near upper bearing has larger deformation .Due to which the clearance between the vane and the vane slot decreases

2）CAE computing:-

Analyzing the deformation of the vane-slot during pump assembly and during the process of running .CAE Calculations are as follows:-

A) Reducing the clearance by tighten of bolt is shown in fig 1, the largest is not more than 0.4mm and contributes less to the vane-slot deformation. The clearance contribution to the deformation more in R410A than in R22

B) R22 refrigerant, A / T conditions, Because of the gas pressure, the maximum clearance reduction of R410A compressor is 1.88um.Its almost the same as with R22 compressor(1.87um).But In A/T condition of r410A compressor, the gap deformation caused by gas pressure reached to 2.95um

4. Countermeasure:-

From the above analysis, we can find the strategies to solve the problems by changing the hardness and improving oil lubrication.

1）From the friction test, with the improvement of the hardness of the cylinder under the same load, the adhesive wear happens less frequently. So we improve the cylinder hardness properly

Currently used, Cylinder hardness of HB 190 ~ 230, actually the hardness of the vane slot is about HB 185 .We can improve the cylinder hardness from HB200 to HB240. This can reduce the probability of occurrence of adhesive wear; the drawback is that, with the increase in the cylinder hardness machining process becomes difficult

2）Oil lubrication Improvement:-

Add a oil channel at the cylinder vane slot. As the compressor starts, the back and forth motion of the vane can bring the oil from the oil channel to the gap of the vane and vane slot

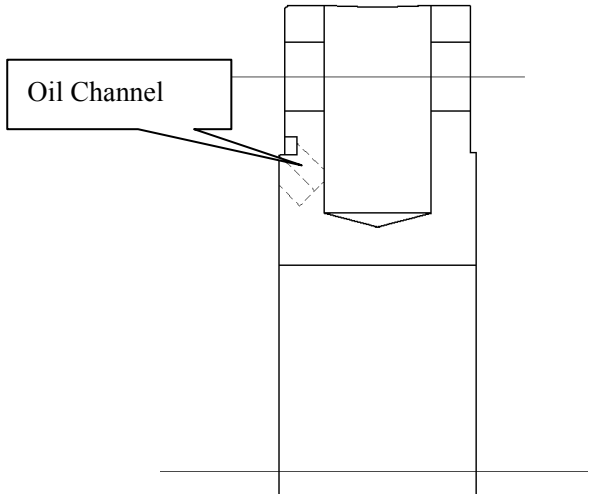


Fig.19 Oil channel

After carrying out the load test. The results are shown in Table 8 as follows:

Table 8 load test

Program	number	Gapμm	A load test situation
Slant-hole 1	4#	8	The test conditions can not be established
	5#	10	Normal
Slant-hole 2	6#	8	Normal
	7#	10	Normal
Straight hole	8#	8	The test conditions can not be established
	9#	10	Normal
Normal (without hole)	1#	14	Normal
	2#	15	Normal
	3#	9	locked

From the test results, In a normal cylinder, the clearance between the vane and the vane-slot decreases to 12um.It is prone to be locked. Sometimes the abnormal wear of the vane-slot happens just as the wear happens in the products returned from the customer.

After adding oil channel to the vane-slot. Even though the clearance is decreased to 10um.It can run normally. But if the clearance is decreased to 8um, the compressor can work but the operating condition

cannot be established. The friction between the vane and vane-slot increases, the vane cannot move properly and vane is not able to make the contact with the outer diameter of the piston during the process. So the operating condition cannot be established. So adding the oil channel at the vane slot can improve the oil lubrication and reduce the probability of the compressor from being locked or having abnormal wear

5. Summary

From the above analysis, following improvements have been proposed:

1 Vane with a low coefficient of friction and with surface treatment such as the DLC , the PEEK coating , etc can improve the self - lubrication (Disadvantage : High cost)

2 Currently using cylinder hardness HB 190 ~ 230 , the hardness of the vane slot is HB 185 , If the cylinder hardness is in the range from HB 200 and 240 . This can reduce the probability of occurrence of adhesive wear(Drawback: cylinder machining process due to increase in the hardness)

3 Some other good lubricating refrigerating oil
(Disadvantages: very difficult to carry the tests with the new refrigerating oil)

4 Adding the oil channel at the vane slot can improve the oil lubrication and reduce the probability of the compressor from being locked or having abnormal wear.
(Disadvantages: machining process will be increased, but can operate)

5 Improvement of the clearance between the vane slot and vane
(Drawback: With the too much increase of the clearance between the vane and vane slot, overall performance of the compressor decreases**)**

6 Can improve deformation caused during the welding process

To sum up: Adding an oil channel at the vane-slot is the most suitable method. It will be the first to be implemented to the production models