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Yin Zhu
Gree Electric Appliances

Sihai Xia
Gree Electric Appliances

Zhengliang Shi
Gree Electric Appliances

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Yin Zhu, Siha Xia, Zhengliang Shi

Compressor and Motor Institute of Gree Electric Appliance, Inc. of Zhuhai,
Jinji West RD., Zhuhai, 519070, P. R. China
Phone: 86-756-8669033, Fax: 86-756-8668386
E-mail: xiasihai2008@126.com

ABSTRACT

The development on study of Nano-ST on tribology, and lubrication characteristic of nano-particles are presented in this Paper. One kind of nano-materials was applied in rotary air conditioner compressor, whose application effect was verified by performance test and 1000 hours accelerated life experiment. The result of experiment was analyzed and compared with normal compressor. The result showed that the nano-materials could improve friction and wear and COP.

1. INTRODUCTION

Nano Science and Technology (NANO-ST) appeared in the late 1980s, which is a new rising science and technology. Its basic meaning is learning and changing nature in nanophase size, to create new substances through direct operations and arrangements of atoms and molecules. With peculiar properties and wide application prospects, nano-materials are renewed as trans-century materials, which capture high attention of scientist, business groups and the government.

Nano particles generally refer to particles between 1nm to 100nm in size, which are atoms or molecules composed a tiny number of atoms or molecules. It plays an important role in nano-materials science and is a precursor in nano-structure materials. With volume effect, surface effect, quantum size effect and macroscopic quantum tunneling effect, it has the physical, chemical properties which traditional materials do not have（Zhang,2000）.

At present, nano-materials have been widely used in catalysis, luminescent materials, magnetic materials, semiconductor materials and fine ceramics(Zhai,1998). It was reported much in the use of lubricant additive, but reports about application and research in air-conditioner, refrigeration and heat pump are few.

It's well known that compressor is the heart of air conditioner. The pump in the rotary refrigeration compressor runs with thousands of turns per minute, which results in abrasion inevitably. This kind of abrasion enlarges the leak of compressor, reduces the cooling capacity, thus affecting the refrigeration effect of the entire air-conditional system. To improve the wear resistance of pump parts, extend the compressor life and improve the efficiency and reliability of the air conditioner, the application of nano-materials will be an important means of innovation. This paper describes the application of a kind of nano-materials in the rotary refrigeration compressor.

2. FUNCTIONS of NANA-MATERIALS

2.1 Improvement of nano-materials on friction

The work of revealing the lubrication mechanism and nature in nano, atomic and molecular scale began in the 80s of 20th century. The appearance of some modern micro-control means, such as atomic force microscope (AFM), friction force microscope (FFM) and scanning tunneling microscopy (STM) together with the continuous improvement of the performance, making people could reveal the lubrication mechanism and nature in nano, atomic and molecular scale. The main works were concentrated on the lubrication process control in micro scale and simulation of molecular dynamics in computer(Zhang,1992).

The report about the research on nano materials used in oil additives began in the early 90s of 20th century in china. The main work was synthesizing MoS_2 and TiO_2 nano-particles with organic group modified on surface. And through surface modification, these inorganic nano-particles had good dispersity in the organic solvents, which could be used as lubricant additives. And the tribological behavior of these particles was also investigated.

Nano-particles which used as lubricating oil additives can greatly reduce the friction between friction parts. Melendres C.A (1989) used MoS_2 nano-particles with the average particle diameter of 10 ~ 15nm and TiO_2 nano-particles with the average particle diameter of 6~8nm as lubricant additives, and conducted a high-speed reciprocating plane mechanical friction performance test. The results showed that antifriction properties of n-MoS_2 and n-TiO_2 are better than ZDDP (zinc disulfide, a common anti-wear lubricants and anti-oxidants), especially the n-MoS_2 is better in the low-load performance, while the n-TiO_2 is better in high-load performance. National experts studied the effects of the nano-nickel hydroxide on abrasion resistance of the oil, the largest non-locked biting of load and friction coefficient. The results show that base oil, in which a certain amount of 30~80nm of nickel hydroxide and dispersants are added, can effectively improve the wear resistance and extreme pressure load performance, significantly reduce the friction coefficient.

Yuping Zhang(1996) added diamond particles (NMD) of the average particle size of less than 10nm into Cu-Sn alloy matrix uniformly, examined the performance of its dry friction through experiments, and considered that a continuous solid lubrication film can be formed on the friction pair surface. Yi YE prepared boric acid lanthanum ions of 10~70nm using supercritical drying method of CO_2, which can significantly improve their abrasion resistance if added into the lubricating oil. It is because lanthanum borate particles can form the physical deposition film and chemical reaction films on the friction surface.

Lubricating oil additive can empower or improve the using performance of base oil, additives which have good performance are an indispensable part of high-grade lubricating oil. Due to fine grain, atoms within the grain defect center and grain boundary, and its own quantum size effect, small size effect, surface effect and macroscopic quantum tunneling effect, nano-materials have high load capacity and special lower-friction capacity in aspects of Lubrication and tribology. Nano-materials in the friction surface existing in the form of nano-particles or nano-film have good lubrication properties and antifriction properties. Lubricant made with nano-materials can observably improve its lubrication performance, load capacity and product quality, especially suitable for harsh conditions of lubricating occasion.

2.2 Lubrication Mechanism of Nano-materials

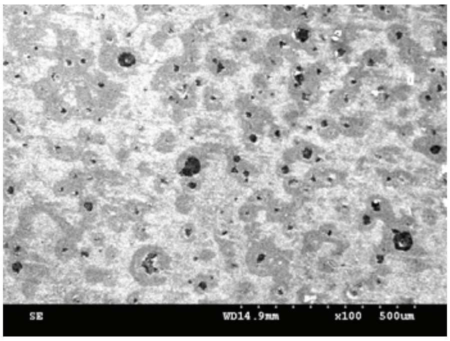
For lubrication mechanism of the cooling system, generally,

(1) Add the so-called "active element" to base oil, such as Cl, S, P, etc. The mechanism is forming the physical, chemical adsorption film on friction surface or producing inorganic protective film with low melting and low shear strength in the chemical reaction, such as $FeCl_3$, FeS, $FePO_4$, etc. But corrosive wear problems inevitably accompany this process at the same time.

(2) Through method of surface modification. Cover the metal substrate with a protective layer or change the surface atomic components through various physical or chemical methods, such as carburization or surface coating, to change the crystal and the stress state of the surface, thereby enhancing the extreme pressure and anti-wear ability of the material.

Mechanism of nano-particle additive is different with the above two. Due to nano effect such as small size effect and surface effect, it is different from the above materials. So it may have new tribology properties. Different from the traditional additive, lubrication in high-load conditions is no longer depending on whether the additive elements is the chemical activity of substrate, but rather depending on whether they can form penetrate layer or solid solution with the matrix components.

Tribological aspects of metal studies have shown that there are pits and crevice in the metal surface, even after the special processing. In fact, no matter how sophisticated the processing, surface of the parts is impossible absolutely smooth, and you can see both ups and downs, rugged by microscope. Traditional mechanical processing tools can only achieve micron-level, while the size of these pits and cracks are mostly micron-level, so mechanical processing techniques can not break through this limitation.



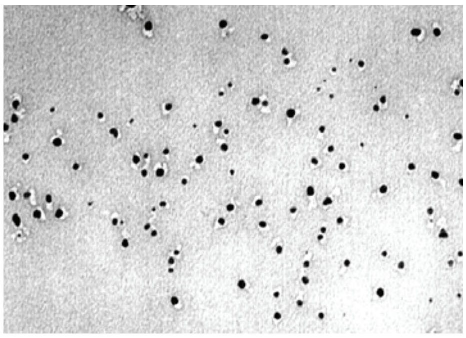


Fig.1 Surface microscope of shaft Fig.2 TEM Morphology of nano-material by 180000 times

Figure 1 is the SEM photograph of the crankshaft surface. A large number of pores whose size is range from few microns to tens of microns, can be seen on the surface of the crankshaft by 100 times. Since the surface of the compressor pump parts also have these small pits and cracks, Researchers in Electrical and Mechanical institute decide to choose nano-technology which is advanced presently, to solve the problem. Namely, using nano-materials (code X) to lubricate and self-repair the friction parts, thus improve the wear resistance, hardness and life span of the compressor pump parts.

The operational principle of Nano-materials (code X) is: metal based ion dispersant in the refrigeration oils, which can run along with the oil flow to friction parts, fill the pores of the metal surface automatically and gather to repair the metal surface, refer to Figure 2. Thus the roughness of the zinc surface is reduced from micron-level to nano-level, and the friction coefficient decreases. The friction inevitably reduces since the friction coefficient decreases. According to the law of conservation of energy, input power is equal to the output energy plus the energy loss, the friction energy reduces, the output energy increases simultaneity, thus achieving energy saving purpose.

In addition, there is a function which can not be ignored when using nano-materials in rotary compressors, that is the friction surface modification, improves the sealing performance, reduces the leakage of refrigerant and improves the volumetric efficiency.

3. EXPERIMENT AND RESULTS

Nano-materials (code X) in this article are product of a company, and the product is synthesized of nano-scale particles. Testing method is adding this material in proportion to the frozen oil, stirring in a sealed state, uniform, and then injecting the mixed oil into the compressor. The compressor for test is made by Landa, which is a certain type fixed-frequency rotary compressor. The refrigeration oil is NM 56EP. Testing the compressors under the situation that only the refrigeration oil is changed while the sample compressor keeps the same one.

3.1 Data contrast before and after oil changed

Contrast the data before and after oils changed for the three samples. Firstly, inject the common NM 56EP refrigeration oils into the samples, then testing and record the date, showing in Table 1. Secondly, pour out all the refrigeration oil in the container, add a certain percentage nano-materials into the refrigeration oils. Finally, re-inject the mixed oils into these samples and retest. One important point is that test bench needs cleaning before compressor test. The latter test date shown in Table 2.

Table 1 and Table 2 are compared. In the same sample, by adding nano-materials into the refrigeration oils, the cooling capacity increased by 33W, power decreased by 24w, COP increased by 0.08, the current decreased by 0.09A..It is make out that nano repair particles significantly enhance the compressors average performance, results contrast as shown in Figure 3.

Table 1 Test data of normal mass compressor

No.	Capacity /W	Power /W	COP/ W/W	Current /W
1	3607	1182	3.05	5.46
2	3633	1194	3.04	5.51
3	3644	1190	3.06	5.49
Average	3628	1189	3.05	5.49

Table 2 Test date of samples with nano-materials

No.	Capacity /W	Power /W	COP/ W/W	Current /W
1	3642	1162	3.13	5.38
2	3661	1173	3.11	5.43
3	3679	1160	3.16	5.37
Average	3661	1165	3.13	5.39

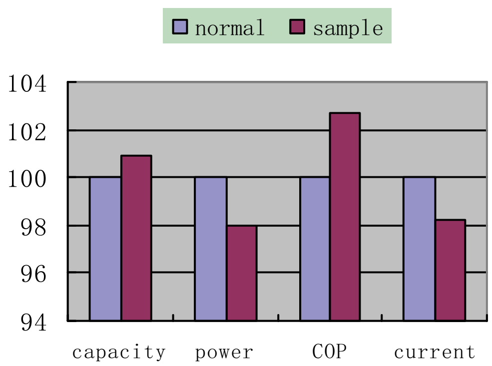


Fig.3 Chart of performance change before and after using nano-materials

3.2 Before and after performance of long-term life test

In order to confirm the long-term reliability of the nano-materials, two samples are carried on the long-term operation and 1000 hours accelerated life test. R22 as refrigerant, refrigeration oil contained nano-materials in the sealed sample machines. After the accelerated life test, compressor performance test result as shown in Table 3.The performance of common compressors and sample compressors are also test before and after long term accelerated life test. Table 4 is the compared result between two different installed programs.

Table3 Contrast result of sample before and after 1000h accelerate life test

Items	sample 2			sample 3		
	Before life test	After life test	Data Contrast	Before life test	After life test	Data Contrast
Capacity/W	3661	3701	+39.8(+1.09%）	3679	3694	+15（0.41%）
Power/W	1173	1162	-10.9（-0.93%）	1160	1156	-4.7（-0.41%）
COP /W/W	3.11	3.18	+0.08（2.54%）	3.16	3.19	+0.03 (0.85%）
Current/A	5.43	5.30	-0.13（-2.36%）	5.37	5.33	-0.04 (-0.74%）

From Table 3 we can find, two sample mixed nano-materials refrigeration oil have the same change trend before accelerated life test in performance. Sample 2 have more significantly improved in performance compared with sample 3. After 1000 hours life test, the cooling capacity increased by 1.09%, the power decreased approximately by 1%, therefore the efficiency (COP) rose by 2.54%. Accordingly, COP of sample 3 increased by 0.85%. It showed that the performance of samples used nano-materials increased after long-term accelerated life test, while the mass production machine decreased.

Can be seen from Table 4, the average date on the performance of sample using nano-materials are better than the normal compressors after 1000 hours accelerated life test, indicating the refrigeration oil by adding nano particles can reduce the friction losses, lower power consumption, reduce pump gap leakage, thereby enhancing the overall performance of the compressor.

Table 4 Contrast between sample and normal mass compressor before and after accelerated life test

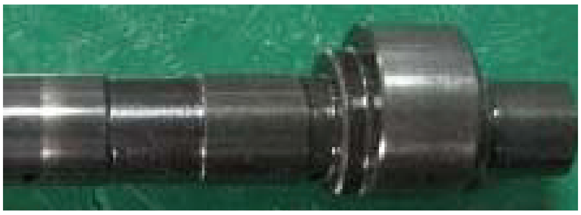
Items	Contrast data before and after life test	
	Sample	Normal mass compressor
Capacity/ W	0.75%	-2.35%
Power /W	-0.67 %	-0.42%
COP /W/W	1.695%	-2.0%
Current /A	-1.55%	0.6 %

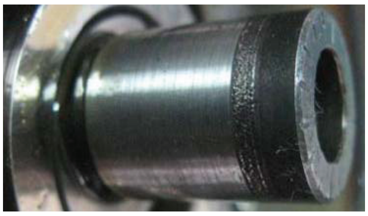
Table 5 Wear volume date of crankshaft after 1000h accelerated life test

Wear volume \µm				
	Lower crank -shaft	Upper crank -shaft	Thrust surface	eccentric
sample 2	0.98	1.02	1.2	0.91
sample 3	1.17	1.03	0.69	1.21
Normal mass compressor	9.94	2.16	0.76	0.31

3.3 wear of the main pump part after life test

Check the internal compressor motor stator, rotor and pump parts by anatomizing two samples after long-term life test. The result showed that the electrical components are normal, as well as the wear of pump components. Generally, severe wear often took place the top and lower bearing and eccentric crankshaft for normal mass production compressors. Especially after long-term life test, the crankshaft with phosphide layer exposing the bright metal matrix color as a result of poor lubrication and severe wear. As shown in Figure.4





(a) upper crankshaft and eccentric (b) lower crankshaft

Fig.4 Frayed parts of normal mass compressor crankshaft after accelerated life test.

However, the wear condition of pump of the sample using nano-materials looks well, especially the crankshaft eccentric wear can negligible. As shown in Figure5.

（a） upper crankshaft and eccentric （b） lower crankshaft

Fig.5 Frayed parts of sample crankshaft after accelerated life test.

After long-term life test, samples were anatomized. Pump parts were sent to measure. Table 5 lists wear volume of the main body of the crankshaft. The date showed that the wear volume of samples below the normal mass compressors between long and crankshaft position after accelerated life test. The maximum wear value of the crankshaft was 1.2μm for sample 3.It also presented that the nano-scale particles in rotary compressor have played a good lubrication and self-repair especially in the typical friction pairs (for example, the upper bearing and long axis ,the lower bearing and short axis), reducing friction and wear under high speed operation. This point can be proofed by contrast between Figure5 and Figure.6.

The wear volume in the region of crankshaft thrust face and eccentric have only about 1μm, within an acceptable range of the normal wear. Table 5 can be judged the effect of nano-particles in the lubrication and self-repair are not obvious through good friction and wear surface of friction pairs of normal mass compressors in the mentioned region.

The reliability of test results from the above we can see that the use of nano-scale repair materials showed good lubrication after long-term accelerated tests on decreasing power consumption and improving COP. The nano-materials has a significant protective effect on crankshaft that the appearance was almost comparable to pre-installed crankshaft after long-term operation.

4. EXPERIMENT on LARGE VOLUME COMPRESSOR

We can see from the previous test, the application of nano-materials takes out good results on one type compressor. In order to verify that the nano-materials have the universal effect on sealed compressors, large volume compressors are also considered which have a worse operating condition, a greater load for friction pairs.

Similar to the previous experiment method, three mass-produced large volume compressors are commissioned performance test, the test results shown in Table 6

Table 6 Performance date of normal mass large volume compressors

No.	Capacity /W	Power /W	COP /W/W	Current /A
1	5208	1676	3.11	7.72
2	5189	1663	3.12	7.66
3	5211	1661	3.14	7.66
Average	5203	1667	3.12	7.68

Table 7 Performance date of large volume compressors using nano-materials

No.	Capacity /W	Power /W	COP /W/W	Current /A
1	5238	1616	3.24	7.48
2	5248	1623	3.23	7.51
3	5239	1614	3.25	7.47
Average	5242	1618	3.24	7.49

After the performance test, pour out the refrigeration oils, add a certain percentage of nano-materials into the refrigeration oils, and then re-inject the mixed nano-materials refrigeration oils into the large volume compressors.

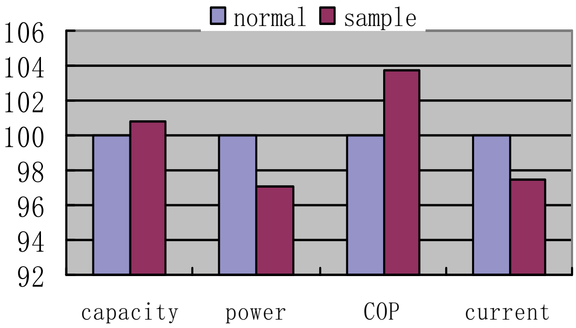


Fig.6 Chart of performance change on large volume compressor using nano-materials

Re-test the Performance of these compressors, test bench to be washed before the test, shown in Table 7. After Table 6 and Table 7 a comparison can be seen in the same compressor, by adding nano-materials into the refrigeration oils, the cooling capacity increased by 39w, power lower 49w, COP increased by 0.12, the current decreased by 0.19A, as shown in Figure 6. Illustrate that the application of nano-materials on the mass-produced large volume compressors also significantly improve performance.

5. CONCLUSIONS

- Only replace the oil for nana-materials in the same compressor, then the cooling capacity increased by an average of 33W, average power decreased by 24W, COP increased by 0.08, the current decreased by 0.09A.
- After 1,000 hours accelerated life test for samples using nana-materials mixed refrigeration oils, the cooling capacity, the cooling capacity increased by an average of 0.75%, power consumption decreased by 0.67%, COP increased by 1.7%. The maximum wear volume was 1.2μm on the severe wear position including upper and lower bearing and eccentric.
- When nano-materials applied in large volume compressors with larger load and worse working condition, similarly,

the cooling capacity increased by 39W, power lower 49W, COP increased by 0.12,and current decreased by 0.19A.

▪ It can be seen that nano-materials performed excellent tribology property through improving friction conditions in the sealed compressor. Not only can improve the key parts of the anti-wear performance and reduce power consumption, but also reduce the pump leakage, increasing the cooling capacity, and significantly improve compressor performance.

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