A New Mechanical Oil Sensor Technology

Weihua Guo
warner.guo@emerson.com

Qiang Liu

Ruiqiang Wang

Hongshan Li

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Guo, Weihua; Liu, Qiang; Wang, Ruiqiang; Li, Hongshan

Research & Development Center, Emerson Climate Technologies (Suzhou) Co., Ltd. ,
International Science Park 1355 Jinjihu Avenue, Suzhou, Jiangsu, China
Tel: (86)512-62883688 Fax: (86)512-62883788
Email: warner.guo@emerson.com
qiang.liu@emerson.com
ruiqang.wang@emerson.com
hosun.li@emerson.com

ABSTRACT

In view of disadvantages of commercially available oil level sensing products, this paper introduces a new mechanical type of oil sensor for refrigeration compressor's oil level protection, which is used to avoid failure due to lack of oil in the compressor, especially when multi-compressors were connected in parallel. The paper analyzed this new mechanical oil senor in terms of superiority comparing with other type oil sensor, theoretical working principle, design concept, functional test and typical application on multi-compressors system. The method of installation and the system control logic are also discussed.

Key words: Mechanical-Oil sensor, Oil level, Multiple Compressor Application

1. INTRODUCTION

The air conditioning unit with multi-compressors connected in parallel is widely used in the commercial refrigeration and air-conditioning field due to its high seasonal EER, improved convenience on maintenance. As to such multi-compressors unit, the oil balance between different compressors is a key point to ensure every compressor with good oil lubrication therefore the system maintains superior reliability. A lot of efforts have been done to retain enough oil in each compressor when the compressor is running. The popular method is to use the oil level sensor, including magnetic reed switch oil level sensor, optical oil level sensor, as well as hall effective oil level sensor. These types of sensor function are well in normal conditions, but with the running of compressor, some debris happened and oil physical parameter slightly changed due to moisture and miscibility with refrigerant these types of sensor signal according to sense oil physical parameter could have big signal variation. In addition, the cost is high because of the complexity of the sensor design. This paper mainly discusses the new mechanical oil level sensor technology and its operation principles, through comparing to these commercially available oil sensor, in terms of cost, signal stability and reliability. The functional test results and typical applications on the system have also been presented.

2. DESIGN CONCEPT

This new mechanical oil sensor is a mechanism which is used to judge whether the oil level in compressor is safe by directly detecting oil in shaft by sensing oil pressure, normally the oil pressure in shaft is very low. The key technology of mechanical oil sensor is how to set up a relation between oil pressure and oil level, and design simple mechanism to build enough oil pressure to trigger signal to system control board

2.1 Theoretical Analysis

Figure 1 illustrates the origin of pressure difference. When compressor shaft rotates at angular velocity ω, oil droplet will produce radial velocity v_n due to the centrifugal force as shown in figure 1(a).

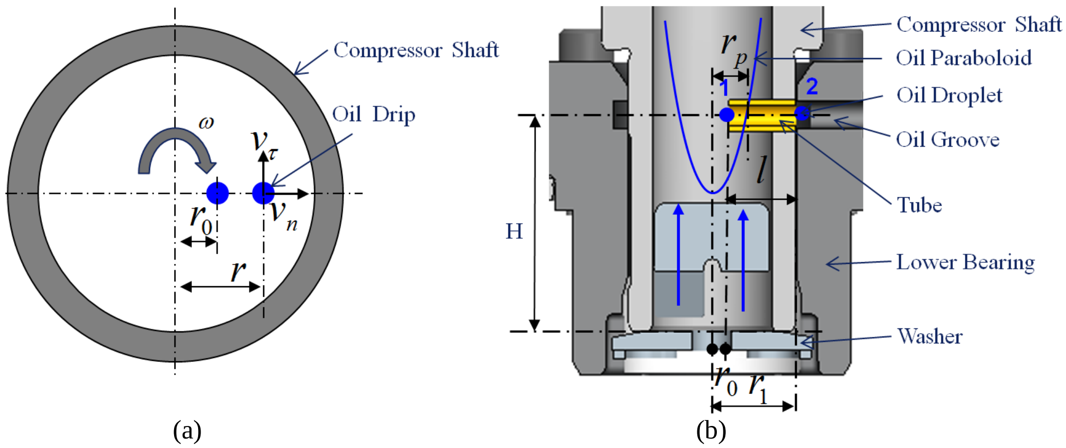


Figure 1: The Diagram Of How Liquid Droplets Speed Up Due To Centrifugal Force

v_n can be deduced from the following equation.

$$\begin{cases} \dfrac{dr}{dt} = v_n \\ \dfrac{dv_n}{dt} = r\omega^2 \end{cases} \Leftrightarrow \int_{v_0}^{v_n} v_n dv_n = \int_{r_0}^{r} r\omega^2 dr$$

$$v_n{}^2 - v_0{}^2 = r^2\omega^2 - r_0{}^2\omega^2$$

$$v_n = \sqrt{r^2\omega^2 - r_0{}^2\omega^2} \quad (v_0 = 0) \tag{1-1}$$

The oil droplets speeds up from point 1 to point 2 due to centrifugal force as shown in figure 1(b). Its kinetic energy will be changed as ΔE

$$\Delta E = E_2 - E_1 = \left(mv_2{}^2 - mv_1{}^2\right)/2 \tag{1-2}$$

The oil droplet's kinetic energy can be converted into oil pressure, the differential pressure between point1 and point 2 is as below:

$$\Delta P = \rho \Delta E / m = \rho\left(v_2{}^2 - v_1{}^2\right)/2 \tag{1-3}$$

Assuming that point 1 is on the center axial of compressor shaft and it has no radial velocity. The value of pressure diffidence can be gained from equation (1-1) and (1-3)

$$\Delta P = \rho \Delta E / m = \rho\left(r_2\omega\right)^2/2 \tag{1-4}$$

From equation (1-4), it can be seen that the value of pressure difference depended on r_2, ρ and ω. These are the original and dominating parameters for delta pressure.

The oil paraboloid will be generated in the shaft due to the rotation of shaft, as shown in the figure1 (b).The shape of oil paraboloid depends on the angular velocity of shaft ω, and the position of oil paraboloid depends on the oil level in compressor. There are no oil droplets entering into Tube, When $r_p > (r_1 - l)$, and it mean there is no differential pressure between point1 and piont2, vice verse, because there will be no oil left inside the tube.

If the compressor design is fixed, its radius of rotation r_2, angular velocity ω and density of lubrication ρ are fixed, pressure difference between point 1 and point 2 depends on the length of tube and oil level inside the compressor.

When the tube length is fixed and the oil level is sufficient, the value of pressure diffidence is more or less constant. If the tube length is determined, the jump point depends on the oil level in the compressor as shown in the figure 3.

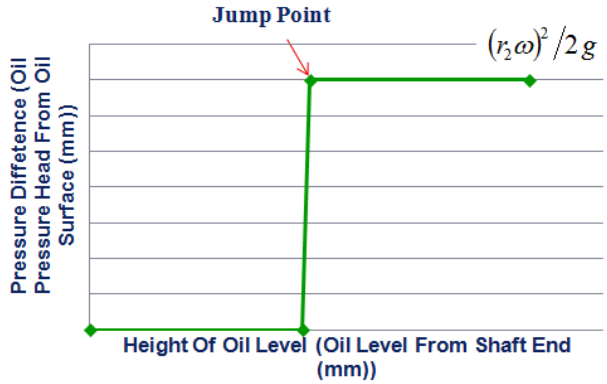


Figure 2: Relationship Between Height Of Oil Level And Pressure Difference

Figure 3 illustrates the relationship between the height of oil level inside the oil sump and the length of tube. When higher oil pressure is needed in the oil groove, the longer of the length of tube, the higher of the height of oil level we need in the compressor, it means that there is a certain relationship between the length of tube and the height of oil level in the compressor.

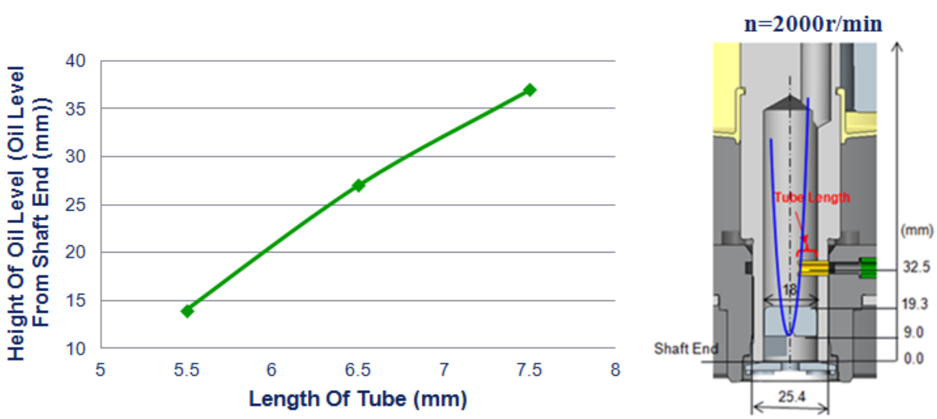
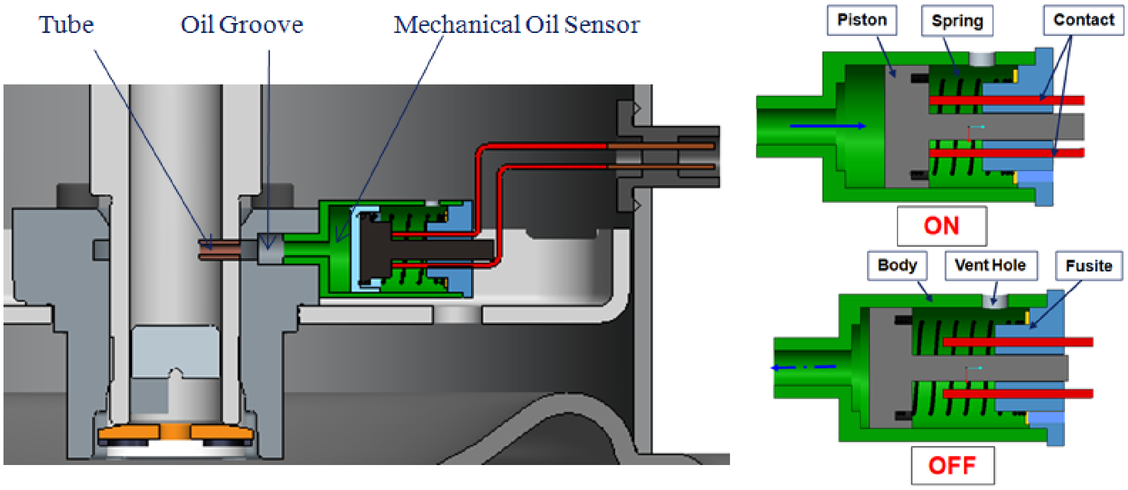


Figure 3: Relationship Between The Height Of Oil Level And The Length Of Tube

2.2 Oil Pressure Switch Mechanical Design

Theoretical analysis gives the relation between oil level and oil pressure jump point, and enough oil pressure difference. Oil mechanical sensor structure design focus on how to use this oil pressure difference to trigger the signal and send the signal to system control board as figure 3, the pressure switch mechanism structure will be used as Figure 4, and Figure 5 .

When pumping oil, oil flows through the tube and gets into low bearing groove, oil sensing pressure will be built up by centrifugal force. Oil sensing pressure pushes piston to close contact electrodes to send out an oil presence signal , spring force pushes piston back to open contact electrodes to send out lack of oil signal.



(a) (b)

Figure 4: Mechanical Oil Sensor Structure And Working Process Diagram

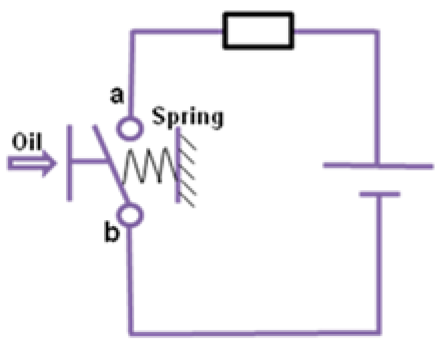


Figure 5: Mechanical Oil Sensor Working Principle Diagram

3. FUNCTIONAL TEST

One compressor with the mechanical oil sensor is built for testing. The sensor signal was recorded when the compressor starts/stops, to determine whether or not the compressor lacks of oil. As show in figure 6, when the compressor starts-up with normal oil level, point "a" and point "b" of mechanical oil sensor connects, and the sensor sends out normal oil level signal. When the oil level decrease below the protected oil level, point "a" and point "b" of mechanical oil sensor disconnects, sends out lack of oil signal.

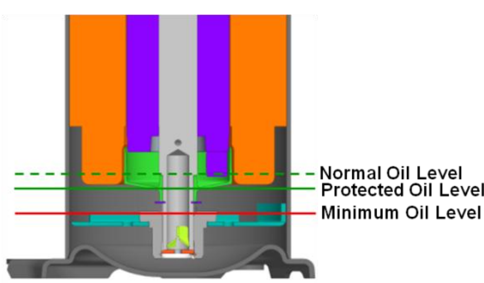


Figure 6: Mechanical Oil Sensor Protected Oil Level

3.1 Functional Test Setup

Use scroll compressor which is built with the mechanical oil sensor. Two valves are used to change the oil level when the compressor is running. As shown in Figure 7, use valve 1 to add oil into the compressor to increase the oil level and valve 2 to remove oil from oil sump in compressor to decrease oil level. The mechanical oil sensor signal detecting circuit is shown as figure 5, which is used for catching the sensor's signal when compressor is running

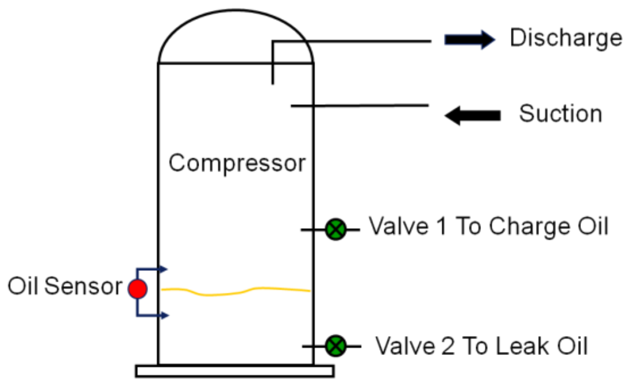


Figure 7: The Functional Test Method and Sensor Signal Detecting Circuit

3.2 Test Results

When the compressor starts-up with normal oil level, point "a" and point "b" of the mechanical oil sensor closes, the sensor signal is shown in figure 8, about 0.1s delay after compressor start up. This response time is acceptable for application on compressor oil protection

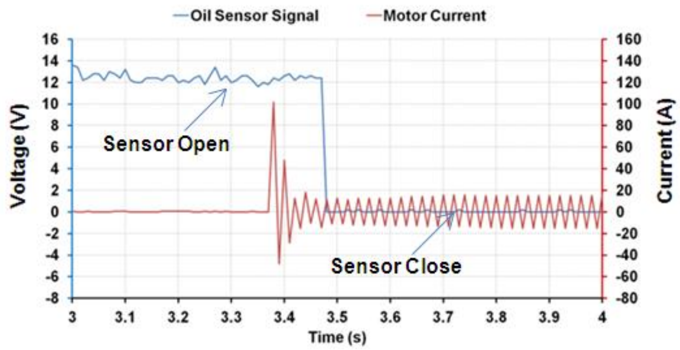


Figure 8: Mechanical Oil Sensor Signal When Compressor Starts-up

When the oil level inside the compressor is lower than protected oil level, point "a" and point "b" of mechanical oil sensor opens, sends out lack of oil signal, as shown in figure 9. This signal is very steady and is friendly to use for system logical control

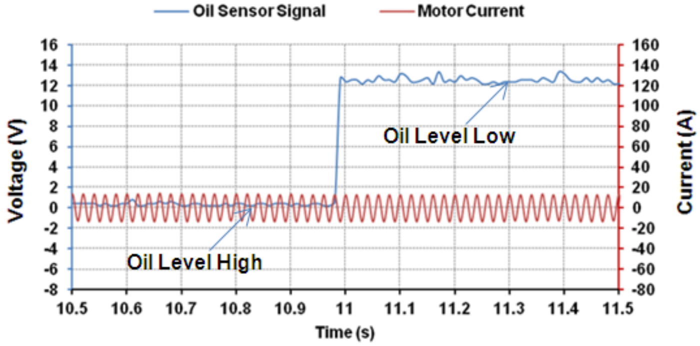


Figure 9: Mechanical Oil Sensor Signal When Compressor Lack Of Oil

When the compressor stops, point “a” and point “b” of mechanical oil sensor opens, the sensor signal is shown as figure 10.

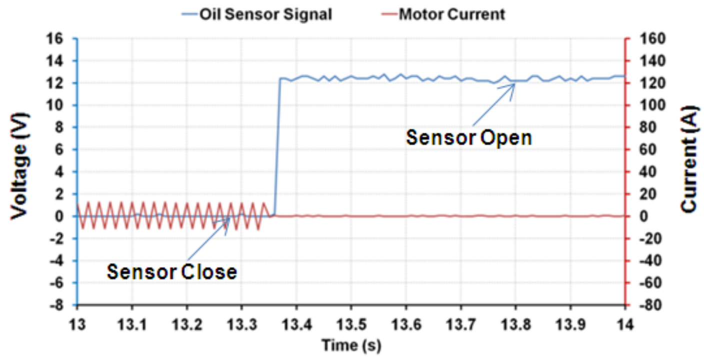
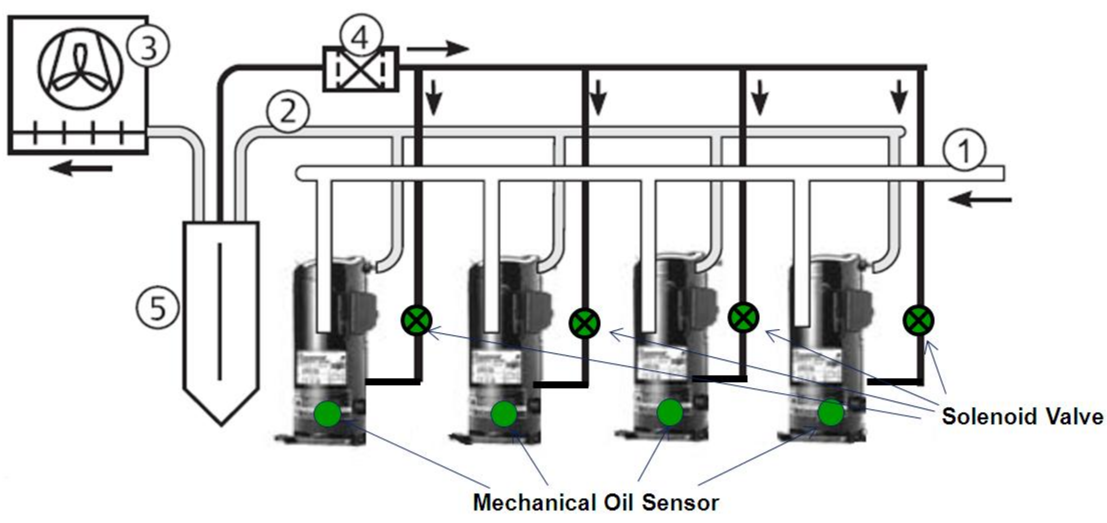


Figure 10: Mechanical Oil Sensor Signal When Compressor Stops

4. TYPICAL APPLICATION

This new mechanical oil sensor is applicable to multi split AC system (as shown in figure 11). The new mechanical oil level sensor is a switch. When an individual compressor starts with normal oil level, the switch will close. When the oil level decreases below the protected oil level, the switch opens, a time delay starts (due to the oil level is dynamic when compressor is running), open the solenoid valve, brings more oil into this compressor. When the oil level returns above the protected oil level, the switch closes, delay some time (in order to charge oil to normal oil level), close the solenoid valve to complete the cycle. Typical application logic in the system is shown in the figure 12. It is worth noting that the mechanical oil sensor only detects liquid level inside the compressor, and it couldn’t identify whether or not the liquid refrigerant mixed with the oil, so the liquid-back control logic is still needed in the system, as it is popular today on these commercial heat pumps and refrigeration systems.



① common suction ② common discharge ③ condenser ④ oil filter ⑤ oil separator
Figure 11: Mechanical Oil Sensor Typical Application System

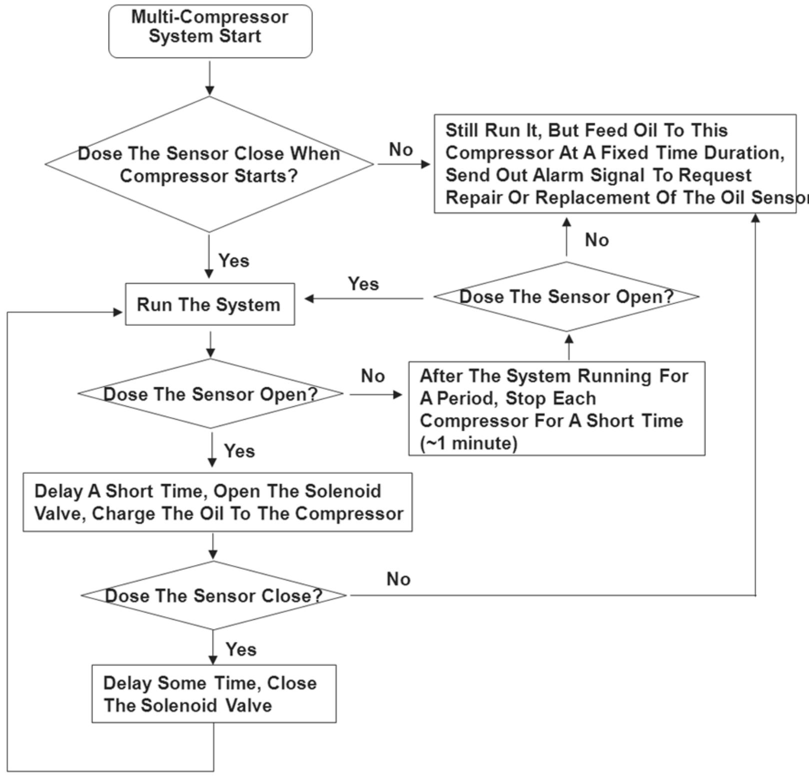


Figure 12: Typical Application Logic In The System

5. SUMMARY

A new mechanical oil sensor is discussed from the theoretical analysis and structure design. The sensor signal during compressor start/stop and lack of oil condition are tested on a sample compressor with the mechanical oil sensor built-in. The mechanical oil sensor technology which is discussed in this paper has obvious advantages, such as simplified structure, lower cost, high signal stability and reliability and simplified control logic. It is a promised solution to make a reliable oil balance on multi-compressor system and therefore the overall system reliability is improved.

6. NOTE OF EQUATION

r - The distance between oil droplet and the center line of compressor shaft
v_n -Radius velocity of oil droplet
ω -Angular velocity of compressor shaft
r_0 -The original distance between oil droplet and the center line of compressor shaft
m -The mass of oil droplet
ΔE -The differential kinetic energy between point 1 and 2
ρ -The density of oil lubrication
ΔP -The differential pressure between point 1 and 2
E_2 -The kinetic energy of point 2
E_1 - The kinetic energy of point 1
v_2 -The radius velocity of point 2
v_1 -The radius velocity of point 1

r_1 -The radius of compressor shaft rotation

l - The length of tube

H -The height from the bottom of compressor shaft to the center of tube

r_p -The distance between center compressor shaft and the point on oil paraboloid at H height