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The Theoretical Analysis and Experimental Research for a Refrigerating Scroll Compressor

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THE THEORETICAL ANALYSIS AND EXPERIMENTAL RESEARCH FOR A REFRIGERATING SCROLL COMPRESSOR

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ABSTRACT

This paper is a sum-up in experience by which authors developed a first prototype scroll compressor for air condition in China. Taking one pair of sealed fluid pockets which are composed of the orbiting and fixed scrolls as control volumes, the working process's thermodynamics simulation is made. It was founded on the first law of thermodynamics and the law of mass flow conservation, and non-ideal gas behavior of refrigerant. The calculated results are not only in agreement with the measured results obtained with the prototype scroll compressor, but also indicate the advanced quantity of this scroll compressor. A new point of view is that the discharge starting angle can be machined in the completed scroll walls in this paper.The acting force and its balance is discussed. Make use of a new structure of sealing circle, the force balance is realized easily.

INTRODUCTION

Comparing the other types of compressors,the inherent advantages of the scroll compressor are, the fixed built-in volume ratio making it valveless and more reliable, adaptable to variable speed, the large inhaling hole and nearly continuous inhaling making it have the less pressure drop,high volumetric efficiency, and the lower noise.

However, designing and manufacturing this machine is very difficult. In this paper, the basic relation describing the compression process is derived and it is founded on the first law of thermodynamics, at the same time, the differences between scroll and other compressors were indicated. Because of the feature of the fixed volume ratio, the calculated pressure ratio should be agreement with the ratios under the experimental conditions so that useless power is low, which influnces the chioce of structure parameters.A new point of view about pressure ratio, in other word, about the starting discharge angle is put forward. The axial force and its balance is discussed in this paper. Finally, the calculated and experimental results are plotted and show good agreement. The dominant influnce of axial clerance to the volumetric efficiency is pointed out.

THE BASIC RELATION DESCRIBING THE WORKING PROCESS OF SCROLL COMPRESSOR

Working chambers of a scroll compressor are shown in Fig.1. These chambers are three pairs of sealed fluid pockets which are composed of the orbiting and fixed scroll wraps when the involute angle of scroll wrap is 1170°. If roll angle of shaft θ is zero, the outermost pair of sealed pockets, symbol (I), represents the suction volume i.e.the displacement volume of compressor.The intermediate sealed pockets, symbol (II), is being compressed. The (III) is discharge pressure chamber. When the θ increses up to the starting discharge angle θ^*, (II) and (III) become one chamber - discharge pressure chamber. It should be taken into account that the sealed fluid pockets are only two then. When θ continues to get large and is equal to 360°, crank shaft rolls one circle and fixed and orbiting scrolls back to the initial positions. Above is the case of every pair of pocket's volume changing as shaft rolls during 360°. If controlled volume varies from suction to discharge, the shaft's orbiting angle will be (360°+ 0*).

According to the above analysis, the modeling range of compression process will be:

$$
\begin{aligned}
&0^\circ \leq \theta \leq \theta^* \\
&\theta^* \leq \theta \leq 360^\circ
\end{aligned}
\qquad (1)
$$

Taking a pair of sealed fluid pockets as contoll volumes, and neglecting the gravitational and kinematic energies of working fluid, the following equation can be written:

$$
\frac{dp}{d\theta} = \left\{-\left[\frac{1}{v}\left(\frac{\partial h}{\partial v}\right)_t - \left(\frac{\partial h}{\partial t}\right)_v \left(\frac{dp}{dv}\right)_t \Big/ \left(\frac{\partial p}{\partial t}\right)_v\right]\frac{dv}{d\theta} - \frac{1}{V_c}\left\{\left[\frac{dm_i}{d\theta}(h_i - h)\right] + \frac{dQ}{d\theta}\right\}\right\} \Big/ \left[1 - \left(\frac{\partial h}{\partial t}\right)_v \Big/ \left(v\left(\frac{\partial p}{\partial t}\right)_v\right)\right] \qquad (2)
$$

The equation (2) was founded on the first law of thermodynamics and the law of mass conservation, and non- ideal gas behavior of the refrigerant,the relation includes not only energy, mass, and heat transfer in compression process, but also the mass flow rate of the leakage from the control volumes.

Directly perceived through the senses of the relation (2), the difference between scroll and other displacement compressors can not be found, but their implications are not consistent. scroll compressor has the continuous compression chamber which differences with others's.To solve the equation (2) appling only R-K method with initial value is efficient. It must be solved with another limitted condition, this is:

$$
\begin{aligned}
&\text{i:} \quad |M1(360^\circ) - M2(0^\circ)| < E1 \\
&\text{ii:} \quad |T1(360^\circ) - T2(0^\circ)| < E2
\end{aligned}
\qquad (3)
$$

As long as the condition is meeted, the end state of gas in the first compression chamber is just the initial state of gas in the second compression chamber.

The other models for determining the compression process are made:

1. The leak flow from axial clearance was assumpted to be the leakage of oil with refrigerant when the clearance is small.

2. The leak flow from radial(flank) clearance or from the axial clearance when the clearance is large are considered as compressible fluid flowing with friction through a convergent nozzle.

3. Takes freon-22 as refrigerant.

MAKING THE STARTING DISCHARGE ROLL ANGLE IN THE SHAPED SCROLL WALLS

The starting discharge roll angle is the roll angle at the contact point of scroll walls when the discharge process commences. It is determined by the interaction between the involute sprial and cutter, and under the influnce of the starting Involute angle of scroll wrap. But varing the starting involute angle α is varing the structure parameters, becuse:

$$t = 2a\alpha \tag{4}$$

Otherwise, the built-in volume ratio is decided by following relation:

$$\rho = \frac{2N-1}{3-\theta^{*}/\pi} \tag{5}$$

Generally speaking, the sealed fluid pocket number N is a integral chosing in a small range. To meet the needs of the built-in volume ratio, the α is considered to be a known number. In terms of relation (3), the two important structure parameters (wrap thickness t and basic circle's radius a) exist a direct relation, which is not our willingness, especially in the optimizing design.

The method of resolving this question is: when starting involute angle of scroll α is large and structure parameters is ideal, or the scroll wrap is shapped with the cutter whose diameter is less than (p-t), the starting discharge roll angle may be machined with the cutter whose diameter is less than (p-t) after the cutter center position is set again. the results are: ① make starting involute angle of scroll expanded; ② the stating involute angle will be not limitted by the compression ratio.

AXIAL FORCE AND ITS BALANCE

The method taken to prevent the orbiting scroll from being seperated from the fixed scroll under the action of axial force are: utilizing the intermediate chamber or the unity of it and discharge pressure district; appl'ng thrust bearing between the frame and orbit'ng scroll.

In the prototype of scroll compressor developped by authurs, the compressed gas inters the shell first, circles the motor and inhales heat from it, finally, goes out from the small hole in the shell. Fig. 2 shows the structure of axial force balance. The gas in intermediate chamber in which there is a oldham coupling goes in and out the intermediate compression chamber througth a small aperture located in the orbiting scroll. A sealing circle is installed between intermediate pressure chamber and high pressure district..

DISCUSSION OF RESULTS

the curves concering the volumetric efficiency are expressed in Fig.3. The curves show axial clearance's influnce to volumetric efficiency is larger than the radial clearance. The larger the clearance,the faster the volumetric efficiency falls. The reasons for this are as follows: on the one hand, the leakage length of axial clearance is longer than that of radial clearance; on the other hand, as the clearance increases the mixture ratio of oil and refrigerant varies and the mass ratio of refrigerant gets gradually large. The calculated and experimental results are shown in Fig.4, the plot show their coincidence.

CONCLUSIONS

1. The relation describing the working process of scroll compressor is agreement with that of other displacement compressors in shape, but the conditions soliving the relation are different.

2. The leakage through the axial clearance is dominant and influnces the volumetric efficiency to a greater degree.

3. The new point of view that starting discharge roll angle is machined in the shaped scroll wrap makes the starting involute angle of scroll variable, and is useful to the optimizing of structure parameters.

4. The effective sealing circle between high and intermediate pressure districts is important in the calculation of axial force and its balance.

NOMENCLATURE

a --- Radius of basic circle of the involute sprial
EER - Energy efficiency ratio
E1 -- Iterative precision for mass
E2 -- Iterative precision for temperature

h --- Enthalpy of gas in the sealed pocket
h_i -- Enthalpy into the sealed pocket
m_i -- Mass into the sealed pocket
$m1$ -- Mass of the first compression chamber
$m2$ -- Mass of the second compression chamber
N --- Number of sealed fluide pockets
p --- Pressure or wrap pitch
Q --- Heat transferred to compression chamber
t --- Wrap thickness
T --- Temperature
$T1$ -- Temperature of the first compression chamber
$T2$ -- Temperature of the second compression chamber
$T0$ -- Evaporation temperature of refrigerant
Tk -- Condensation temperatuur of refrigerant
V --- Volume of compression chamber
Vc -- Displacement volume of compressor
ρ --- Build-in volume ratio
π --- 3.1415926...
α --- Starting involute angle of scroll
θ --- Roll angle of shaft
θ^* -- Roll angle at the discharge starting position

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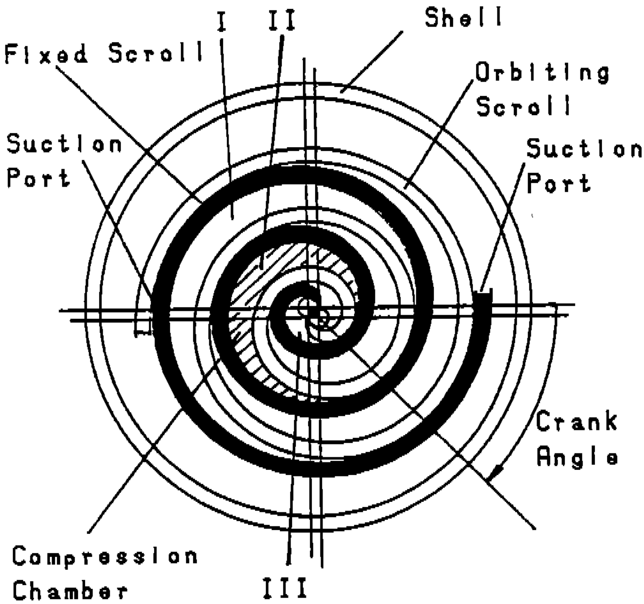

Fig.1 Compression Chambers of
Scroll Compressor

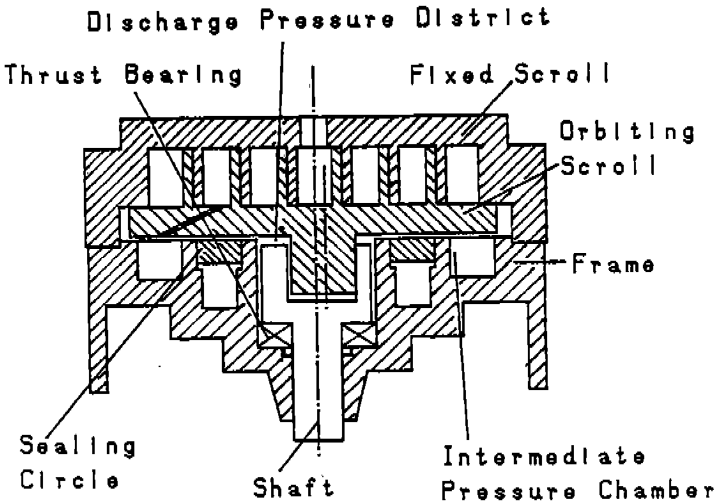

Fig.2 The Basic Structure of The
Prototype Scroll Compressor

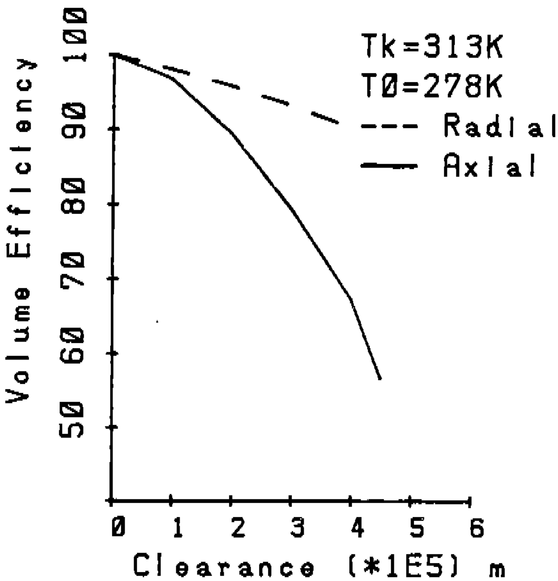

Fig.3 The Influence of Aixal and Radial Clearance on Volumetric Efficiency

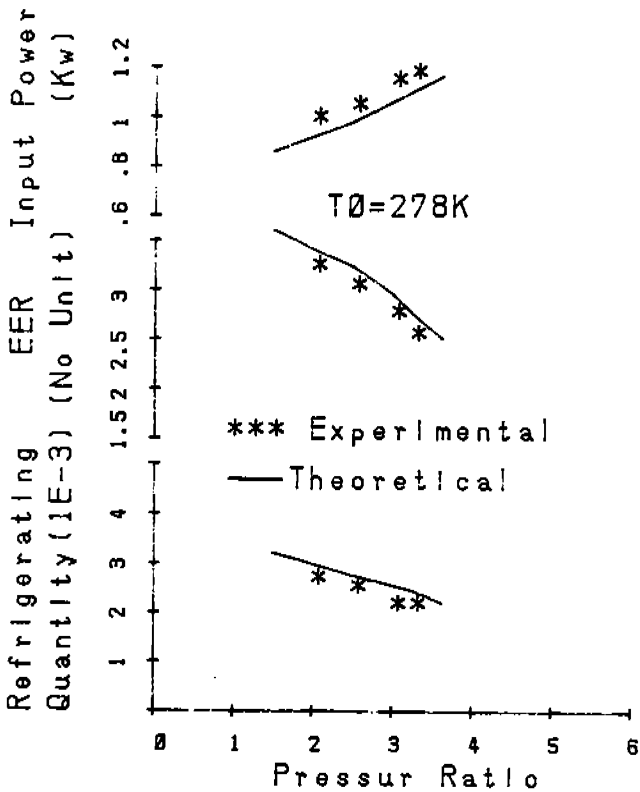

Fig.4 Pressure Ratio Effects on Compressor Performance