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Methods to Reduce Friction, Increase Efficiency in various Mechanical Components

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Abstract: This Review Paper is concerned with rolling piston type rotary compressors for air conditioners (reduction in friction losses at vane tip, vane sides, journal bearings, piston surface, cylinder), centrifugal compressor (frictional contact problem at the fixed interference of the mating parts i.e. wheel hub and shaft), development of a new scroll type air motor with mounted permanent magnetic spirals (reduce friction and leakages in order to improve efficiency and reduction in torque lost due to friction), development of a new 'Revolving Vane (RV) compressor' (frictional losses are considerably reduced through radial use of rotating cylinder).
Keywords: Compressor, Friction, Efficiency.

I. INTRODUCTION

1) *Rolling Piston type Rotary Compressor:* Friction losses in the rolling piston type rotary compressor taking account of changes of loading force and sliding velocity induced by the planetary motion of the piston, during one revolution of the compressor along with influence of compressor design parameter is analysed. [1]
2) *Centrifugal Compressor:* In a centrifugal compressor, the impeller is located onto the compressor shaft assembly via interference fit. When the rotational speed is high, a complicated friction problem arises at the interface of the mating parts. The radial deformation of axle hole of impeller is larger, which greatly increases the possibility of loosening, slip and slap. It is very important to deal with this fixed interference problem. [3]
3) *(PROTOTYPE) Scroll type air Motor:* The review is focussed on one particular type the scroll type air motor (also called scroll expander), which shows an improvement in performance efficiency. The study of unsteady flow losses with vortexes in the suction process is reviewed. The effect of leakage on volumetric efficiency is also reviewed. The Organic Rankine Cycle (ORC) system is one of the most important application area of scroll compressor. The insertion of permanent magnet materials into the original fixed and moving scrolls to change the distribution of the acting forces or torques. This magnetic air scroll motor is estimated to reduce leakages and increase efficiency. [5]
4) *(PROTOTYPE) Revolving Vane Compressor:* Mechanical losses deteriorate the overall efficiency of the compressor due to wear and tear caused by the friction. In rotary compressors, as parts in sliding contact usually possess high relative velocities, frictional losses are predominant which have limit their performance despite their advantages. Even in rolling piston type rotary compressor frictional losses are predominant. Thus, a new compressor namely Revolving Vane (RV) is employed to effectively reduce sliding velocities within the compressor mechanism. [6]

II. DESIGN, WORKING PRINCIPLE

A. *Rolling piston type Rotary Compressor*

The roller is mounted on a shaft having an eccentric. The shaft rotates about the centre of the cylinder and the roller rolls over the inside surface of the cylinder, thereby rotating about the eccentric. If tolerances were perfect roller would have perfect rolling motion. However, in actual there is a combined motion consisting of rolling coupled with the slipping motion relative to the cylinder. [2]

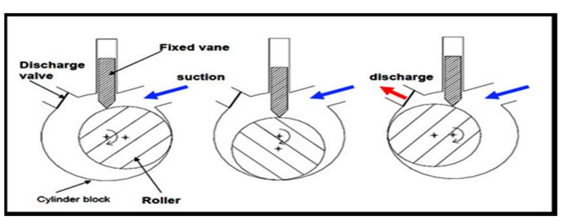

Fig.1 Typical Rolling Piston Rotary Compressor

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Major friction losses are at- Piston bearing, Vane sides, vane tip.

Factors affecting total friction losses-

1) Changing the density of piston- The vane tip loss decreases with decrease in density of piston whereas the others are a little affected. The reduction in clearance at piston bearing slightly reduces the total frictional losses.
2) The vane tip loss decreases gradually with increase of lubricating oil viscosity but the piston bearing loss also increases strongly.
3) The vane tip as well as vane side loss slightly change with cylinder ratio (l/r). Therefore, the total loss changes in same manner as that of piston bearing loss (l- length of cylinder, r- radius of piston).
4) As the radius ratio (r/R), decreases and swept volume increases, the vane side loss increases remarkably because the friction force at the contact point increases. However, the change in vane tip loss is small. This is because of increase of eccentricity of eccentric and decrease of piston moment of inertia simultaneously. Piston bearing loss decreases with decrease of radius ratio mainly because bearing load decreases in proportion to piston radius. Therefore, the total loss increases quickly with decrease of radius ratio (r- radius of piston, R- radius of cylinder).
5) By making the cylinder shape flat and making cylinder bulk large total frictional losses can be minimised. [1]

B. Effect of Irreversible Compression on Efficiency

Nomenclature in the below figure,

Wc- reversible work consumed by the compressor.

Wc'- Irreversible work consumed by the compressor.

Ic- Irreversibility of compressor.

S2- Entropy at the end of reversible compression.

S2'- Entropy at the end of irreversible compression.

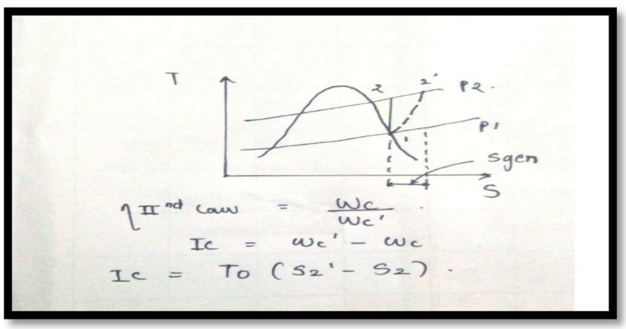

Fig. 2 T-S diagram showing effect of irreversible compression

It can be seen that, the efficiency of the compressor decreases because of irreversible compression. Irreversibility mainly includes frictional losses.

Also, due to this the unavailable energy increases thereby increasing the maximum work consumption. This affects the adiabatic efficiency because the indicated power ($n > 1.4$) increases drastically.

C. Centrifugal Compressor

Impeller of centrifugal compressor is a wheel or rotor having series of backward curved vanes or blades. It is mounted on a shaft which is usually coupled to a motor. The friction in the shaft assembly contributes to most of the mechanical losses due to sliding contact. [3]

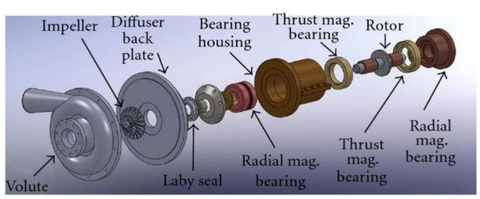

Fig. 3 Shaft assembly of centrifugal compresso

Factors affecting contact friction-

1) The influence of rotational speed- The contact stress distribution on the external surface of the shaft sleeve and on the internal surface of the shaft sleeve was studied. For same amount of interference contact stress of mating surface decreases with the increase of rotational speed due to the increase of centrifugal forces. Variation of the contact stress of mating surface edge is small and the change trend of the contact stress of internal and external surface is uniform. Variation of the contact stress of the external surface edge of shaft sleeve is small owing to the small blade mass at the external surface edge of shaft sleeve. With the increase of the amount of interference between impeller and shaft sleeve, the slippage of sliding point increases linearly.
2) The influence of friction coefficient- With the increase of friction coefficient between impeller and shaft sleeve, the contact stress of mating surface keeps unchanged. Lubricating oil smeared on mating surface has effect on decreasing contact stress by press-fitting, but mating surface can prevent from block and abrasion by using lubricating oil. Therefore, pure vegetable oil is used as lubricant during press-fitting.

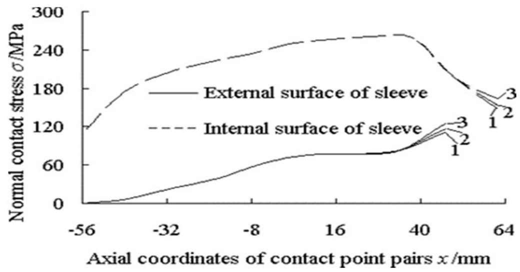

Fig. 4 Influence of wall thickness of shaft sleeve

3) Influence of wall thickness of shaft sleeve- With the increase of the rotational speed, the contact stresses of both the external and internal surface of shaft sleeve descend. At the same rotational speed, the contact stress of the external surface of shaft sleeve decreases with increase of the wall thickness of shaft sleeve, but the contact stress of internal surface increases instead. It is the reason that the wall thickness of shaft sleeve varies by changing radius of the external surface of shaft sleeve. The wall thickness of shaft sleeve increases means when the internal diameter of impeller increases, the rotational mass of impeller decreases, when the amount of interference between the shaft sleeve and shaft remains unchanged. Consequently, the contact stress of the external surface of the shaft sleeve decreases. [4]

D. (PROTOTYPE) Magnetic Scroll Type air Motor

The main components of a scroll air motor consist of a moving scroll connected with a crank shaft via a bearing and a fixed scroll mounted inside a motor shell. The compressed air flowing through the scroll air motor experiences three phases: 1) charging; 2) expansion; and 3) discharging, which associate with three types of chambers: a) central; b) side; and c) exhaust chambers, respectively. When the compressed air goes through the three phases in the air motor, its pressure decreases and its energy is released and converted into the shaft kinetic energy in terms of the air motor driving torque output. The volumes of all chambers discontinuously vary in cycle-to- cycle operation. In an ordinary scroll-type air motor, the material of both the fixed scroll and the moving scroll is a type of nonmagnetic alloy. For implementing the proposed design, two or more magnetic spiral segments are designed to be inserted into the two nonmagnetic alloy scrolls. Each magnetic spiral segment should be magnetized in a specific direction to enhance the air motor’s useful torque output. In addition to the driving torque generated from the compressed air (which is the same as for ordinary scroll air motors), the magnetic field resulting from the magnetized spiral segments will generate extra workable torque at some angular positions and this extra torque can potentially benefit the air motor’s operation and performance. [5]

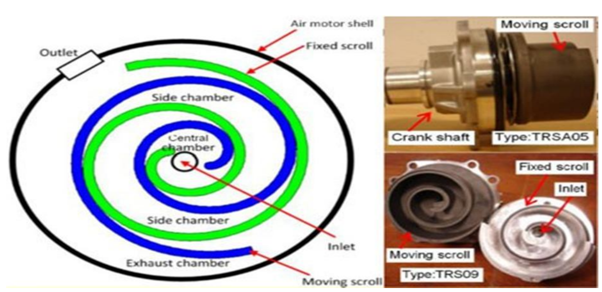

Fig. 5 Scroll motor with magnetic spirals

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The selection of permanent magnetic materials is very important. The selection needs to consider the following important factors.

1) The selected materials must be able to produce a strong magnetic field to generate useful magnetic torque, which involves the consideration of key properties of magnetic materials, e.g., coercivity, the remanence of the permanent magnet, and energy density.
2) The magnetic materials should be able to operate and to provide a stable magnetic field within a wide temperature range, considering the various applications of the air motor, e.g., exhaust (heat) recovery. [5]

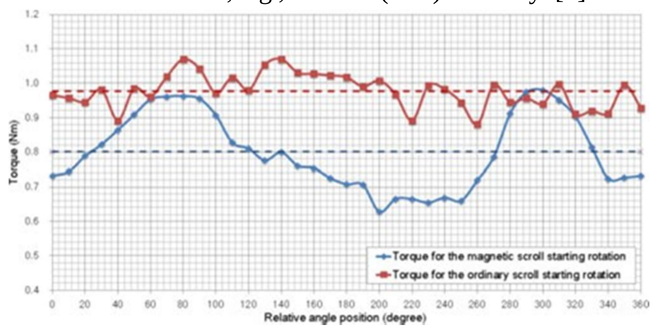

Fig. 6 Torque Comparison between ordinary and magnetic scroll

Improvement in efficiency- For the prototype magnetic scroll air motor, the variation range of the corresponding torque is within 0.801, (+,-)22.9% N m (the blue solid line) and its average value is 0.801 N m (the blue dotted line). It is proved that the variation range of the measured torque of the prototype magnetic scroll air motor is wider than that of the ordinary scroll air motor. [5]

E. (PROTOTYPE) Revolving Vane (RV) Compressor

The RV compressor comprises of three main components, namely a rotor, a vane and a cylinder. The vane is assembled with the rotor such that it slides within a slot in the latter. Both the vane and the rotor are housed in the cylinder, where the tip of the vane is connected via a hinge joint to the cylinder. The rotor and cylinder are supported individually and concentrically on bearing pairs, where their respective axes of rotation are separated by a distance such that a virtual line contact always exists between the two components. During operation, the rotation of the rotor revolves the vane which in turn rotates the cylinder. The motion causes the volumes trapped within the rotor, vane and cylinder to vary, resulting in suction, compression and discharge of the working fluid. [6]

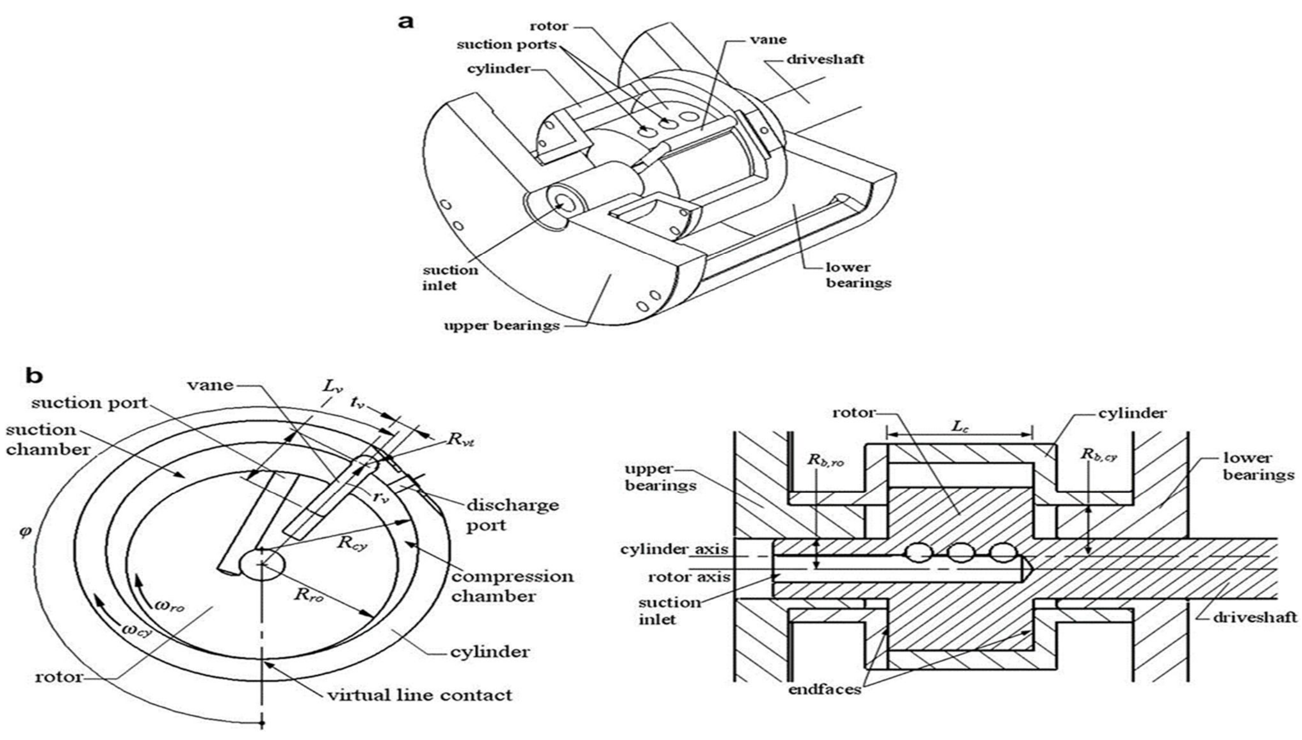

Fig. 7 The RV compressor (a) Cutaway view, (b) front and side sectional views

Rotary sliding vane compressor is similar to revolving vane compressor. Only difference between the former and latter is that, the latter consists of revolving cylinder instead of fixed. Entire cylinder assembly is driven in rotary motion with the help of rotor. Therefore, all the friction that takes place between the contacting surfaces is significantly reduced. Accordingly, modifications are made in the cylinder design in order to obtain rotary output. For suction and compression it uses centrifugal action on the working fluid. Also, the modification in suction and delivery passages is that suction is located at the center of the rotating cylinder whereas the discharge is at the periphery.

A reed valve is used as discharge valve. The valve rotates along with the cylinder and hence inertia forces due to rotation may affect the performance of the valve. [6]

Frictional losses mainly occur at vane sides, journal bearings, vane tip, cylinder end faces.

1) *Vane Sides:* Due to continuous sliding of vanes within the slots in the rotor, there is significant amount of boundary sliding friction at the contact
2) *Journal Bearings:* They should provide full hydrodynamic lubrication at all times yet avoiding excessive friction.
3) *Vane Tip:* Friction at the vane tip occurs due to the swiveling motion of the vane about the hinge joint which connects the vane to the cylinder. As the rotation of the vane relative to the cylinder is oscillatory and at low velocities, boundary friction is most likely to be present at the contact.
4) *Cylinder end Faces:* It occurs due to offset distance between the centers of rotating components and differences in angular velocities. [6]

Factors affecting mechanical efficiency and frictional losses-

a) Effect of cylinder moment of inertia- Varying angular velocities result in inertia forces which gives rise to friction at vane sides and vane tip. When the cylinder has high density vane tip and side losses are increased due to larger contact forces during first half of the revolution. Since vane tip friction loss is small, total friction losses increases in same manner as that of vane side loss. Smaller moment of inertia results in higher mechanical efficiency.
b) Effect of rotor to cylinder radius ratio- When rotor to cylinder ratio is decreased mechanical efficiency is decreased, which may be caused due to increased vane side friction. The losses at vane tip and end faces also increase with decrease in rotor to cylinder radius ratio. Only friction reduced is bearing loss due to decrease in rotor to cylinder radius ratio. [6]

III. CONCLUSION

A. *Rolling Piston Type Rotary Compressor*

1) Total friction losses reduce with change in density of piston.
2) By making the cylinder shape flat and making cylinder bulk large total frictional losses can be minimized.
3) The total friction loss increases with decrease in radius ratio.

B. *Centrifugal Compressor*

1) The amount of sliding friction increases with increase in interference between impeller and shaft sleeve.
2) Change in value of friction coefficient has no effect on contact friction between impeller and shaft sleeve.
3) Lubricating oil decreases contact stresses.
4) The contact stress of the external surface of shaft sleeve decreases with increase of the wall thickness of shaft sleeve.

C. *(PROTOTYPE) Magnetic Scroll Type air Motor*

1) The variation range of the measured torque of the prototype magnetic scroll air motor is wider than that of the ordinary scroll air motor.

D. *(PROTOTYPE) Revolving Vane (RV) Compressor*

1) Vane tip and vane side friction losses are increased due to high piston density.
2) Smaller moment of inertia results in high mechanical efficiency.
3) Mechanical efficiency decreases with reduced rotor to cylinder ratio.
4) Bearing friction losses are reduced due to decrease in rotor to cylinder ratio.

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