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Development of Outer-Envelope Trochoidal Compressors

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DEVELOPMENT OF OUTER-ENVELOPE TROCHOIDAL COMPRESSORS

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ABSTRACT

This paper discusses the configuration of various types of compressors with epitrochoidal geometry. Two types using an epitrochoidal rotor and a stationary outer envelope were selected for development. Proof-of-concept models have been built and tested.

Proven advantages of these compressors are presented, including pressure time curves, torque curves, and test results showing efficiencies.

SYMBOLS

a the radius of the rolling circle used to generate trochoids

b the radius of the base circle used in generating trochoids

c the distance from the center of the rolling circle to the point that is generating the trochoid

k is equal to $\frac{R}{e}$ dimensionless constant

e is equal to c, the eccentricity of a trochoid

R equals a+b, the generating radius of a trochoid

Z is equal to $\frac{b}{a}$ - 1, the number of apexes in a trochoids's envelope

θ an angle (see Figure 2)

ϕ an angle (see Figure 2)

INTRODUCTION

Today there is a trend towards quieter, less expensive, higher efficiency, higher speed compressors. Development of rotary compressors has been successful in meeting these needs. Until now, most rotaries have been either large dynamic type compressors or smaller positive-displacement vane or rolling piston compressors.

This paper shows the progression of work done in developing an efficient rotary variable-speed positive-displacement compressor. Choosing specific types and configurations of epitrochoidal geometries followed a study of the advantages and disadvantages of several combinations of trochoids and housings. Next, the geometry was modified to allow for sealing and running clearances. Finally, proof-of-concept models were built and tested.

EPITROCHOID GENERATION

An epitrochoid is the locus of a point located on a circle other than its center, which is rolled without slipping on a base circle. One of the two methods of generating epitrochoids is illustrated in Figure 1.

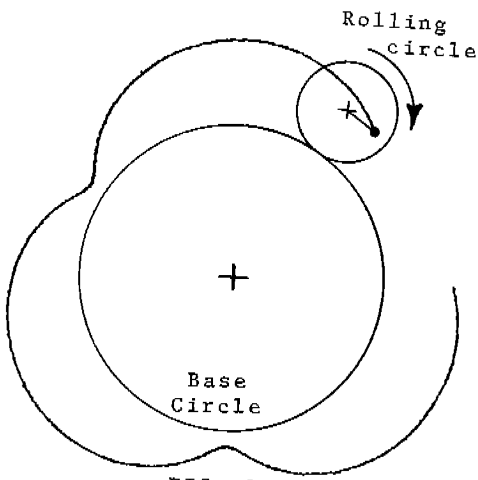

FIG. 1
Generation of an epitrochoid.

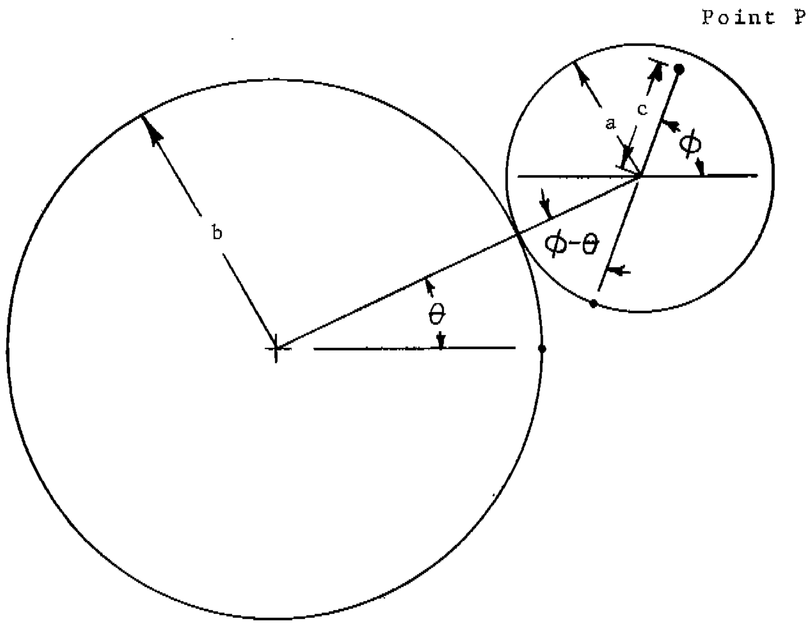

Fig. 2
Model used for developing the equations of an epitrochoid.

In Figure 2, the coordinates of point P are

$$X = (a+b) \cos \theta + c \cos \phi$$

$$Y = (a+b) \sin \theta + c \sin \phi$$

Since the two circles have rolling contact, the contacted arc lengths are equal.

$$b\theta = a(\phi - \theta)$$

$$\phi = \frac{b+a}{a} \theta$$

The coordinates of point P become

$$X = (a+b) \cos \theta + c \cos \left(\frac{b+a}{a} \theta \right)$$

$$Y = (a+b) \sin \theta + c \sin \left(\frac{b+a}{a} \theta \right)$$

These equations are usually in the form

$$X = R \cos \theta + e \cos (Z\theta)$$

$$Y = R \sin \theta + e \sin (Z\theta)$$

The trochoids of interest are those that smoothly close after the rolling circle has circumscribed the base circle in one pass. This is true when

$$\frac{b}{a} = \text{integer}$$

When an epitrochoid is simultaneously rotated and planetated, two boundaries are formed. These boundaries, which are never invaded by the epitrochoid, are called envelopes shown in Figure 3.

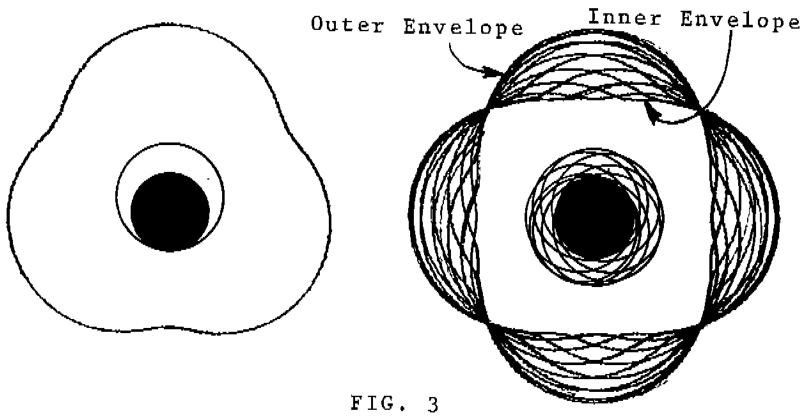

FIG. 3

When the trochoid on the left is rotated and planetated, the boundaries formed are called envelopes.

Hypertrochoids are another family of curves similar to epitrochoids. Hypertrochoids are developed like epitrochoids except the rolling circle rolls on the inside of the base circle.

There are an infinte number of trochoids that can be produced. Some are shown in Figure 4, along with seals in their envelope apexes.

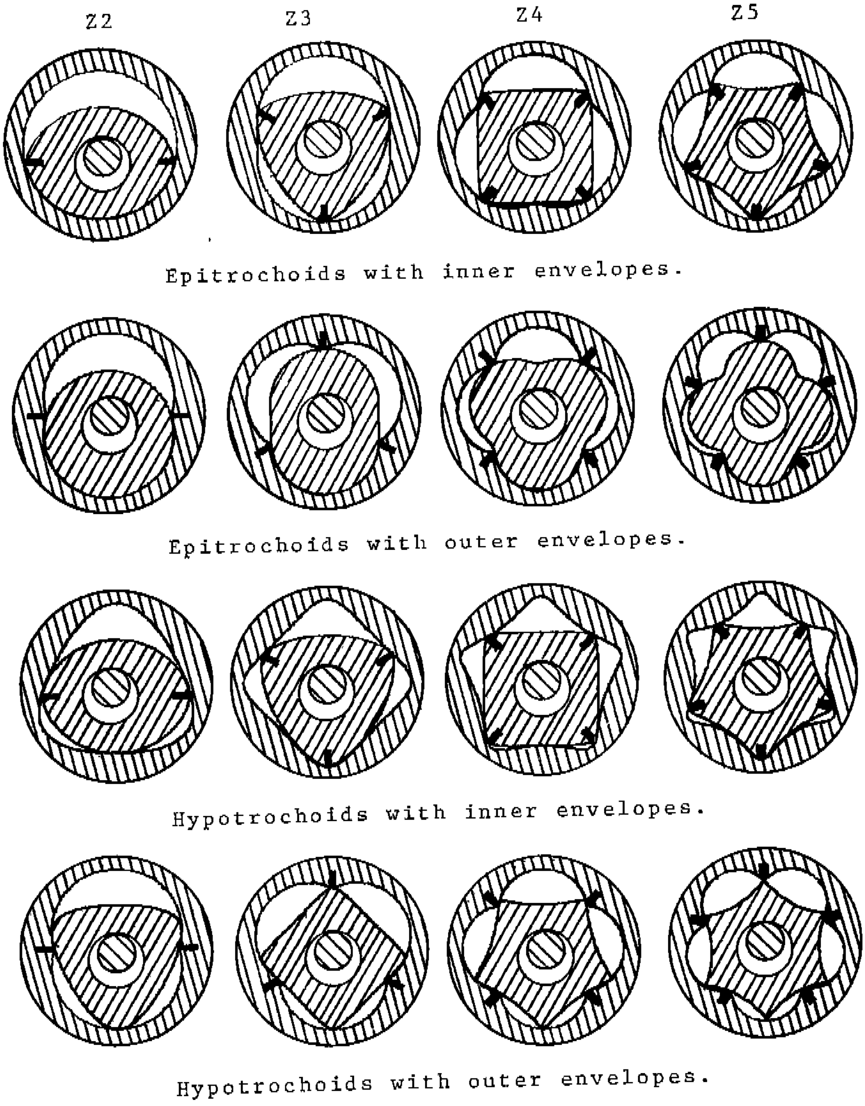

Fig. 4
These are a few of the many possible trochoids.

COMPRESSOR DEVELOPMENT

After surveying the characteristics of many trochoids, two types of epitrochoids were selected. They were three- and four-lobed epitrochoids with outer envelopes as shown in Figure 5 below.

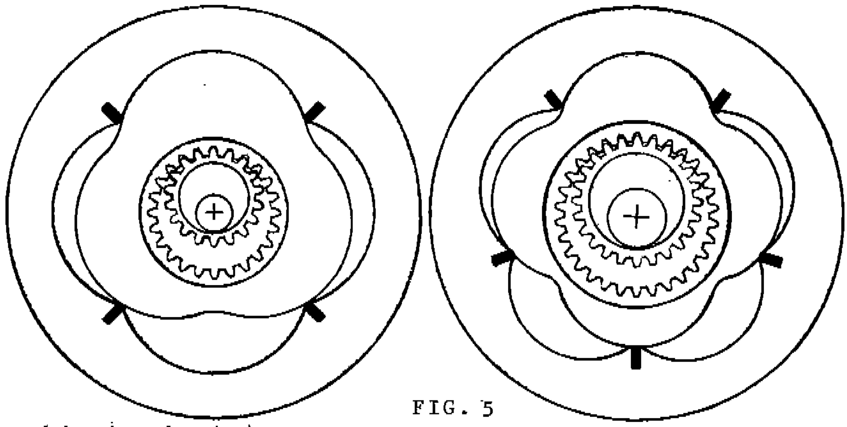

FIG. 5

This is the type of geometry used in building the four- and five-chambered proof-of-concept models.

These two were selected in preference to all others for several reasons. They are both theoretically capable of compression ratios greater than 1000:1. The apex seals are in an exterior housing making it possible, if designed properly, to replace the seals without a major teardown. Since the seals are stationary, there are no centrifugal forces acting on them. The four-chambered design with one rotor is easily used as a two-stage or a single-stage. Additionally, a large diameter straight-thru cam shaft can be used.

For the proof-of-concept models, single-stage compressors were developed. They have stationary housings with valves on both the inlet and exhaust ports. The four-chambered model has a swept volume of 28 in.^{3} (459cc) and is designed for R22 refrigerant. The five-chambered model has a swept volume of 237 in.^{3} (3880cc) and is designed for compressing steam. In both styles, stationary envelopes were used with rotating epitrochoidal rotors. A proprietary method was developed to precisely machine a large modified epitrochoid, thus miminizing seal movement caused by machining imperfections.

VALVING

Since epitrochoidal compressors have a unique motion, their volume changes at a different rate than reciprocating compressors. A study was made of the compression ratio versus the shaft angle of a five-chambered epitrochoidal compressor and a reciprocating compressor having the same swept volume, dead volume, and shaft speed. The pressure ratio initially increases faster in epitrochoidal compressors reaching discharge pressures nearly twice as fast as reciprocating compressors. During the part of the exhaust stroke where most of the gas is being exhausted, the change of volume is less in a trochoid. This means the exhaust valves and ports can be smaller in a trochoidal compressor than in a similar reciprocating compressor, reducing the dead volume. Since the curve is symmetrical, the same holds true for the inlet valves and ports. This is shown in Figure 6.

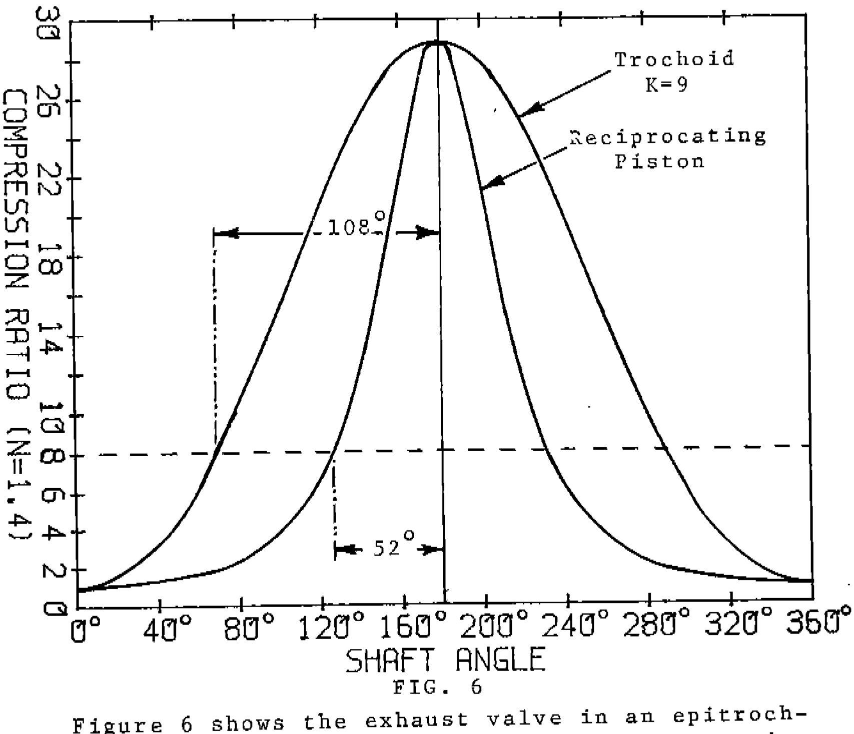

FIG. 6

Figure 6 shows the exhaust valve in an epitrochoidal compressor will be open longer than in a reciprocating piston compressor with the same dead volume at the same speed. A big advantage in high speed compressors.

Although these designs can be ported, valves were selected for the inlet and exhaust of the proof-of-concept models. In the five-chambered model, off-the-shelf circular plate valves were purchased. In the four-chambered model, a flat reed valve was used.

PERFORMANCE

The real-time torque of the five-lobed compressor was recorded at several operating conditions. Figure 7 is typical of the results and shows that both the average minimum and average maximum torque peaks vary by approximately plus or minus 15% of the average torque. This relatively constant torque gives the trochoidal compressor advantages over compressors with large torque pulses. A flywheel is not necessary. Phasing is not critical when coupled to a prime-mover having a fluctuating torque, and electrical motors run more efficiently since they do not have current pulses.

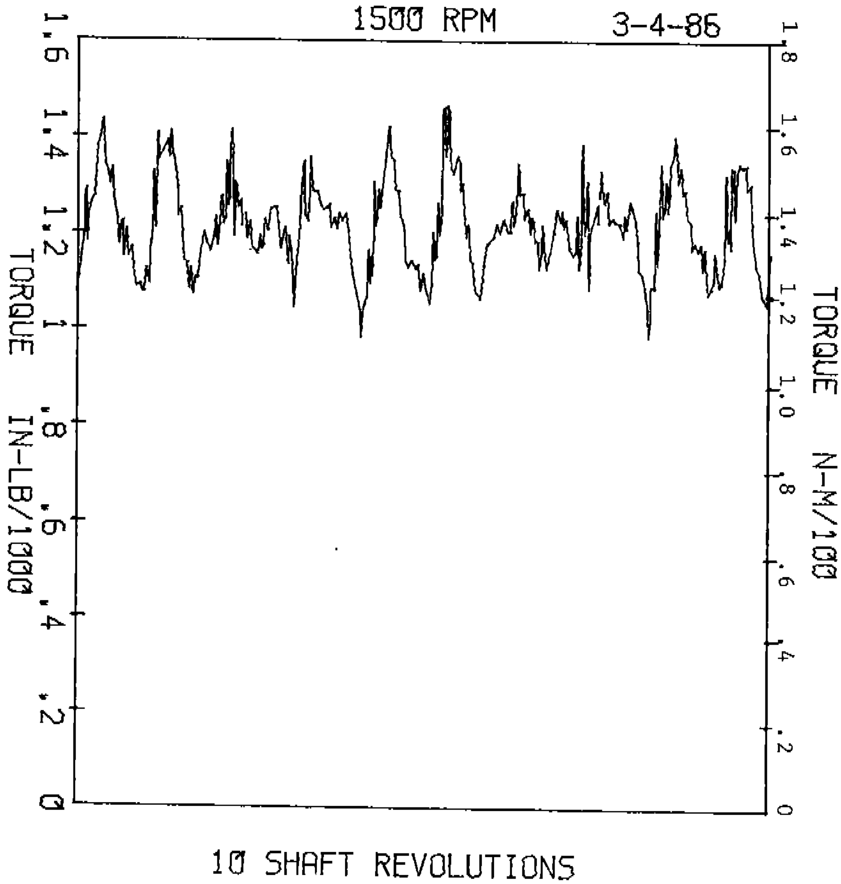

FIG. 7

This plot shows that the torque of a five-lobed compressor is relatively constant.

The five-chambered epitrochoidal compressor was tested at several conditions. Figure 8 is a performance plot of the compressor with a 2 psig saturated steam inlet. Other tests not shown indicate that increasing the inlet pressure results in increased efficiencies. Even at low inlet pressures, the greatest efficiency was never reached due to power limitations of the test stand. The tests conducted with high inlet pressures showed efficiencies reaching 80%.

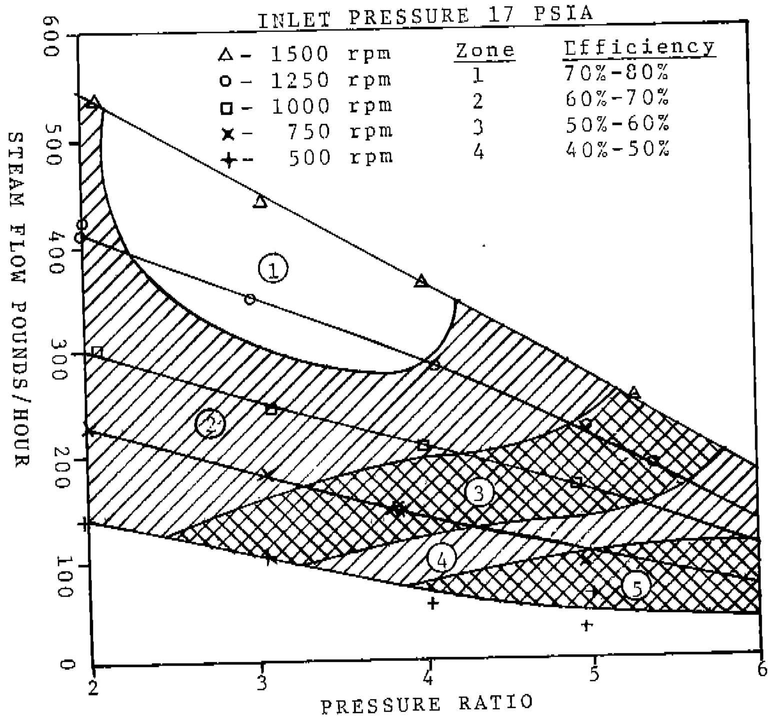

FIG. 8

This plot shows that as a steam compressor efficiencies approached 80% and could go higher.

Assembly of the first four-chambered freon compressor was recently completed and testing has begun. As of this writing, the preliminary performance tests have not been completed and the compressor has not been improved beyond its original design.

Initial testing revealed efficiencies close to 70% and a COP of 8.

CONCLUSIONS

Compressors with epitrochoidal rotors and outer envelopes have great promise because of the simplicity of the design, balanced operation, smooth torque curves, and their competitive efficiencies. Manufacturing costs should be low because of the small number of parts used, and their smaller size and weight.

ACKNOWLEDGEMENTS

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THE STUDY OF DUAL CYLINDER ROTARY COMPRESSOR

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ABSTRACT

Rolling piston type rotary compressor has been widely used nowadays because of the features of high efficiency, compact size and light weight. On the other side rotary compressor with large capacity, for example more than 5 HP, has a tendency to be difficult in the application to an equipment on account of vibration characteristics.
The paper refers to the basic study of dual cylinder rotary compressor which has also the excellent feature of low vibration. Dynamic characteristic analysis, efficiency improvement, and efficiency evaluation were studied theoretically and experimentally as compared with single cylinder rotary compressor of conventional type. The results of this study suggest much applicability of dual cylinder rotary compressor to the refrigerating system with large capacity.

INTRODUCTION

Rolling piston type rotary compressor has been widely used for refigerator, room air conditioner and unitary nowadays, particularly rapidly these several years. Because it has the attractive features which are, as well known, high efficiency, compact size, light weight and so on. And these meet the requirement of the times, that is the saving of energy. But on the other hand of the remarkable features mentioned above, it has a tendency to be difficult in the application to an equipment on account of vibration characteristics as it increases in capacity.