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ABSTRACT

The paper presents a general algorithm for the specification of a screw machine geometry. The conjugancy condition was solved numerically which thereby enables a variety of primary arc curves to be introduced. In addition, an optional numerical derivation of primary arcs enables any analytical function and even discrete point functions to be used for the primary arc. The approach also simplifies the design procedure since only primary arcs need be given. Secondary arcs are then generated automatically. This procedure is not sensitive to the location of the primary arc, a primary arc can be located either on the main or gate rotor. Any other rotor and also a rack (a rotor of an infinite radius) can be used as a location of the primary arc. All combinations are allowed and the most efficient profiles were obtained by the combined rotor- rack generation procedure.

INTRODUCTION

A twin screw engine is a positive displacement rotary machine consisting of a meshing pair of helical lobed rotors, contained in a casing, which together form a working chamber which volume depends only on the angle of rotation. Rotation leads to a decrease in volume up to a minimum value when compression is complete. The volume ratio of compression is determined by how far the discharge port, through which the fluid is expelled, extends around the circumference of the high pressure end of the casing. At, or near, the angle of rotation corresponding to maximum compression, the discharge port in the casing is exposed. Further rotation causes the trapped volume of fluid to be expelled at approximately constant pressure. Its adiabatic and volumetric efficiencies are highly dependent on both the profile and number of the lobes in each rotor.

The rotor profiles most commonly used are those developed by the Swedish company, Svenska Rotor Maskiner (SRM), the licensors of the original Lysholm patents. The first rotor combination to be developed was based on the circular symmetric profile (Fig 1a) which all the lobe segments are circular. Its use in compressors has been well described in [1]. Its main deficiency is the relatively large gap

formed between the rotors and the casing at the cusp which forms a blow-hole, thereby creating a leakage path for the gas. This was followed by the asymmetric profile, as shown in Fig 1b. It was developed using a system of cycloids to generate the high pressure face of the lobes while the low pressure face was modified by the eccentricity of the gate rotor circle. It has been described fully in [1] and [2]. In Fig. 1c the SRM "D" profile [7] is presented, and "N" profile developed by authors [6] is given in Fig. 1d.

ROTOR PROFILE GENERATION PROCEDURE

Although used for more than 35 years and published 110 years ago [3], a general profiling theory was not widely published in English. We have used this theory to generate our screw compressor profiles presented in [4] and [5]. This paper is an opportunity to advocate the use of this theory to generate practically all kind of helical screw rotors with less then usual effort.

The main and gate rotors, as indicated by numbers 1 and 2 respectively in Fig. 3, roll on their pitch circles about their centres O_1 and O_2 by angles ψ and $\tau = \frac{z_1}{z_2}\psi = \psi/i$, where z_1 and z_2 are number of lobes in the main and gate rotor respectively. If an arc (denoted as "d") is given on either main or gate rotor as an arbitrary function of an angular parameter ϕ:

$$x_d = x_d(\phi) \tag{1}$$

$$y_d = y_d(\phi) \tag{2}$$

a corresponding arc on the another rotor is a function of both, ϕ and ψ.

$$x = x(\phi, \psi) = -a\cos\frac{\psi}{i} + x_d \cos k\psi + y_d \sin k\psi \tag{3}$$

$$y = y(\phi, \psi) = a\sin\frac{\psi}{i} - x_d \sin k\psi + y_d \cos k\psi \tag{4}$$

where $k = 1 + i$ and a i is a rotor centre distance. ψ is a rotation angle of the main rotor for which the primary and secondary arcs have a contact point. This angle must satisfy a conjugancy condition as described [3]

$$\frac{\partial x_d}{\partial \phi}\frac{\partial y_d}{\partial \psi} - \frac{\partial x_d}{\partial \psi}\frac{\partial y_d}{\partial \phi} = 0 \tag{5}$$

which is a differential equation of an envelope of "d" curves. Its expanded form is:

$$\frac{\partial y_d}{\partial x_d}(\frac{a}{i}\sin\psi - ky_d) - (-\frac{a}{i}\cos\psi + kx_d) = 0 \tag{6}$$

Once determined ψ is inserted in (3) and (4) to obtain conjugate curves on the opposite rotor. This procedure requires a definition of a given arc only, other one is always found by a general procedure.

If other than a rotor related coordinate system is used for the definition of given curve arcs, same equations are still valid. A coordinate system independent of both rotors can be used for a definition of "d" curves. Some curves may have a simpler form then if defined on some of rotors. Also, all curves can be defined in one coordinate system, which additionally simplifies the procedure. Fig. 3 presents a template rotor (dashed line) given in a rotor independent coordinate system.

A special one is a rack (rotor of infinite radius) coordinate system, indicated with indices "r" on Fig 2. An arc on the rack is then defined as an arbitrary function of a parameter ϕ:

$$x_d = x_d(\phi) \tag{7}$$

$$y_d = y_d(\phi) \tag{8}$$

From it a secondary arc on some of the rotors is derived as a function of both, ϕ and ψ.

$$x = x(\phi, \psi) = x_d \cos\psi - (y_d - r_w\psi)\sin\psi \tag{9}$$

$$y = y(\phi, \psi) = x_d \sin\psi + (y_d - r_w\psi)\cos\psi \tag{10}$$

where r_w is a pitch radius and ψ represents a rotation angle of the rotor where a given arc is projected, defining a contact point. This angle satisfies the condition (5) which is:

$$\frac{\partial y_d}{\partial x_d}(r_w\psi - y_d) - (r_w - x_d) = 0 \tag{11}$$

A solution ψ is then inserted into (9) and (10) to find conjugate arcs on rotors. Fig. 3 gives the rack (dotted line) and rotors generated by the rack.

Wherever curves are given, their convenient form may be: $ax_d^p + by_d^q = 1$, which is a "general circle" curve. For $p = q = 2$ and $a = b = 1/r$ it is a circle, unequal a and b will give ellipse, a and b of opposite sign, hyperbola, $p = 1$ and q different to p will give parabola.

In addition to the convenience of a comfortable introduction of given curves into one coordinate system, a rack generation offers some advantages compared with rotor coordinate systems: a) a rack profile represents the shortest contact in comparison with other rotors, which means that points from the rack will be projected to rotors without any overlaps or other imperfections, b) a straight lines from the rack will be projected on rotors as involutes enabling almost a pure rotation contact, c) manufacture of rack generated rotors is usually convenient, d) exchangeable rotors.

There exists an inconvenience of a rack generation if compared with rotor based profiling methods. In order to minimize a blow hole area at the high pressure side of rotors, the profile is usually produced by a conjugate action of both rotors, which undercuts a high pressure side of rotors. This practice is widely used and patented: singular points on main and gate rotors were used, or circles, ellipses parabolas were used instead of single points. An appropriate undercut is not possible directly from a rack. On the rack there exists only one analytical curve which can replace a conjugate action of rotors. This is a cycloid, which undercuts the epicycloid and hypocycloid on the main and gate rotor respectively. This exactly corresponds to a singular point undercut. If other curves were used on the rack, a blow-hole area would be usually minimized by a considerable reduction of the outer diameter of the gate rotor below its pitch diameter, which would reduce a blow-hole area, but it also would reduce a rotor throughput [8].

This can be fully overcome by introducing a generation of a high pressure part of a rack by means of a rotor conjugate action which undercuts an appropriate curve on the rack. This rack is later used for profiling of both main and gate rotors by usual rack generation procedure. The same effect is achieved as if a high pressure (flat) side of rotor profile is generated by a rotor procedure.

RACK GENERATION OF "N" PROFILE

The following is a brief description of a rack generated representative of "N" profile family designed for the efficient compression of air, common refrigerants and a number of process gases obtained by the combined procedure. This profile contains almost all elements of modern screw rotor profiles given in the open literature. The profile described here is derived for the presentation and it is not used for any commercial application. But its features offer a sound basis for additional refinements and optimization if it is required for any specific application. An extensive study of use of "N" profile for dry and flooded air an refrigerant compression was presented in [6].

Coordinates of all primary arcs on the rack are summarized here relative to the rack coordinate system. The lobe of this profile is divided into several arcs. The divisions between the profile arcs are denoted by capital letters and each arc is defined separately, as shown in Fig. 4.

Segment E-F is a circular arc on the rack, $p = q = 2$, $a = b$.
Segment F-G is a straight line (upper involute), $p = q = 1$.
Segment G-H on the rack is an undercut of the arc $F_2 - H_2$ which is a general arc of type $ax_d^p + by_d^q = 1, p = 1, q = 0.25$ on the gate rotor.
Segment H-A on the rack is an undercut of the arc $A_1 - H_1$ which is a general arc of type $ax_d^p + by_d^q = 1, p = 1, q = 0.75$ on the main rotor. The rack coordinates $G - H - A$ are obtained through the procedure inverse to (7) - (11)
Segment A-B is a general arc of the type $ax_d^p + by_d^q = 1$ on the rack with $p = 0.43$ and $q = 1$.
Segment B-C is a straight line on the rack (lower involute), $p = q = 1$.
Segment C-D is a circular arc on the rack, $p = q = 2$, $a = b$.
Segment D-E is a straight line on the rack which complete parts of rotor inner/outer circles

A variety of modifications is possible but all of them should be extensively tested before their adoption. Rotor profiling practice has shown that some modern refinements do not always improve screw machine performance.

CONCLUSION

A general method for a screw rotor profile generation used by authors long time ago for generating screw rotor profiles was presented in the paper. The method is convenient for the design of new rotors as well as for the improvement of existing rotors. Also a rack based procedure capable to generate a modern screw rotor profile was presented. The main advantage of both methods is their simplicity enabling a variety of profiles be created at a short time by practically all mechanical engineering designers, a priviledge which was previously shared only by a limited number of exclusive specilaists.

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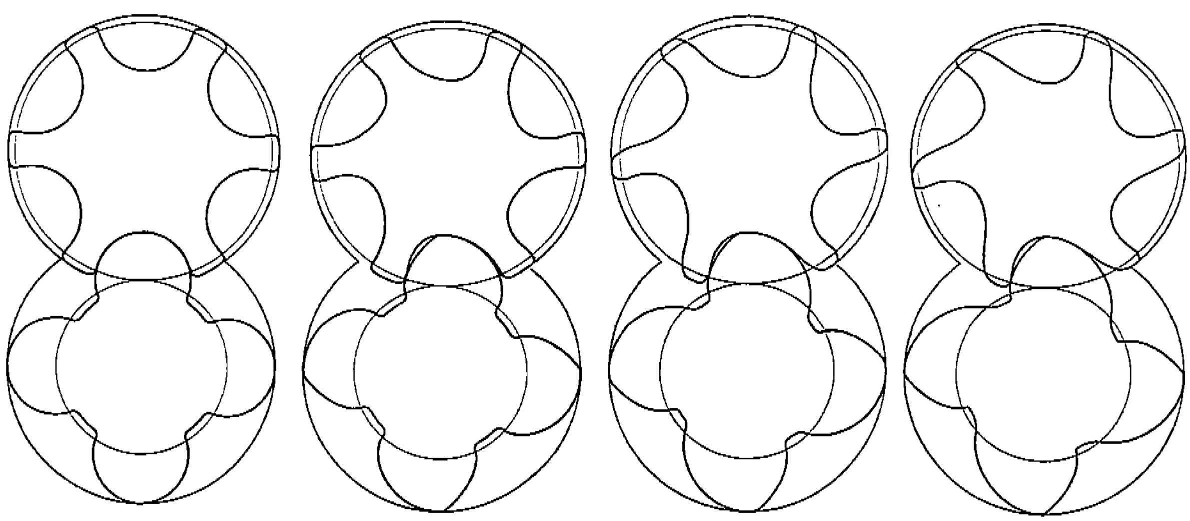

Fig. 1 a) Symmetric Profile b) Asymmetric Profile c) "D" Profile d) "N" Profile

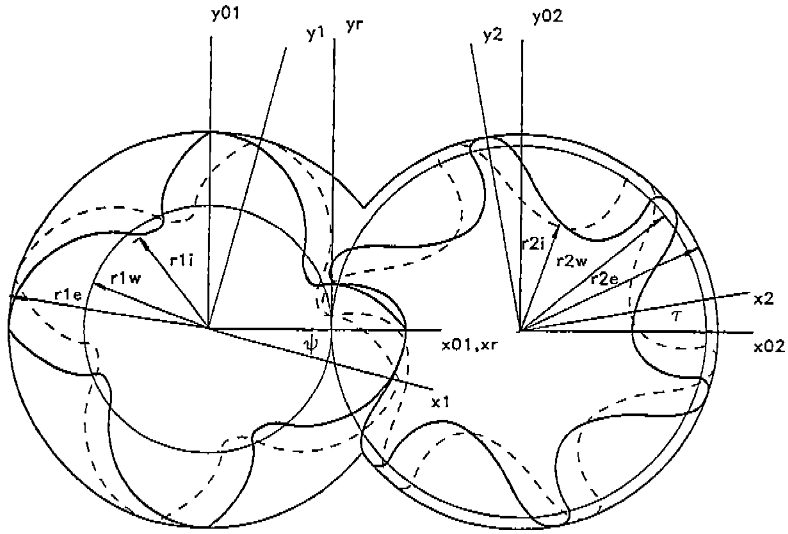

Fig. 2 A screw rotor pair: definition of symbols

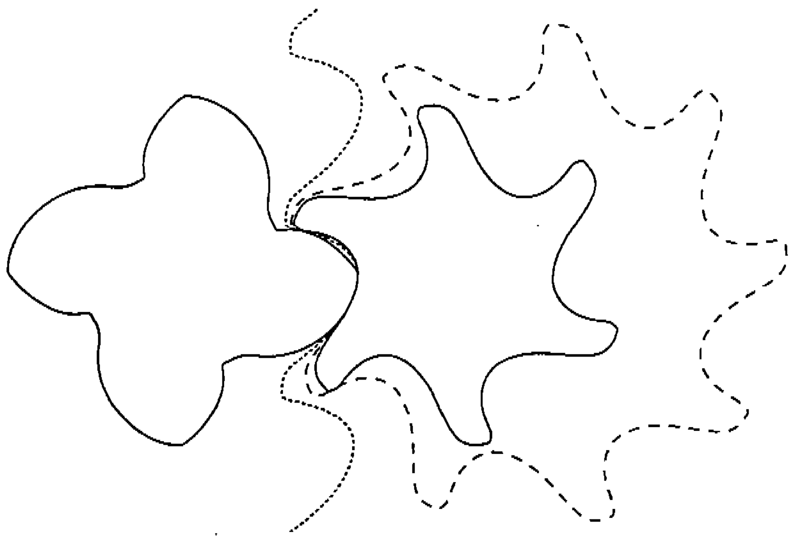

Fig. 3 View of a pair of "N" rotors: solid - actual rotors, dashed - template rotor, dotted - rack

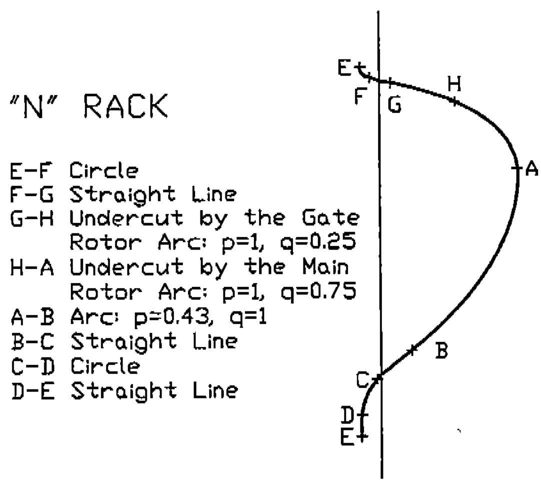

Fig. 4 "N" Rack