USABILITY OF ANALYTICAL METHODS IN DESIGN OF INSTRUMENT PROFILE OF SCREW TYPE COMPRESSORS

Gatis Muiznieks, Eriks Gerins
Riga Technical University, Faculty of Transport and Mechanical Engeeneering,
Institute of Mechanical Engeneering
arai@acad.latnet.lv; 626gacho@inbox.lv

Abstract. A very important catch, not only in the engineering, but also in any industry of production of national economy in general, takes the use of compressed air. Enlargening of industrial production volumes, parallel asks for larger demand of compressed air, for getting them more frequently use technologically most fashionable, economic and the safest of compressors machines - including screw types compressors. Geometry of screw type compressor shaft isn't evolvent type, whereof is dependent compressor action productivity. For creating screw type shaft profile there is necessity to make special designed instrument with which assistance are available reach right forms of profile contours. In the beginning of this article is provided instrument designing possibilities examination, what operates with knock dawn method. In foundation there are examined three possible of calculation methods of instrument profile type: graphical, analytical and graphical analytical method. Also provide analysis of these methods usability in modern production. At the second part of work is given an analytical calculation of disevolvent instrument profile type, conformable the type of rotors of screw type compressors. At the end of article conclusion is done usability analysis of profile designing methods.

Key words: profile, rolling, worm mills, methods, analytical modeling.

Introduction

A very important catch, not only in the engineer, but also in any industry of production of national economy in general takes the use of compressed air. Enlarge for industrial production volumes, parallel it is necessity for compressed air demand, for getting them more frequently use technologically most fashionable, economic and the safest compressor machines – including screw type compressors.

The effective action of screw compressor mainly depends on adjusted or correct constructions of rotors, it is necessary to create type of rotor, which has a large flow through cross section area, a short sealing line and a small blow-hole area.

Higher flow and smaller leakage rates both increase the compressor volumetric efficiency, which is the rate of flow delivered as a fraction of the sum of the flow plus leakages.

A rotor is inferior to influencing of variable forces, which the compressed gases create, and also for forces of inertia and moments of rotation.

To improve efficiency of action of compressor, it is necessary to create the more complicated type of rotor of screw type compressor, which can be attained using more complicated instruments of construction. Certainly, it is possible to make the type of screw using a few methods in which a few from them are even simpler than other. The type of screw can be made using instruments, which operate with rolling, method of copying, using the specially formed tools, using powder metallurgy and other wide using modern technologies.

In details we will examine instruments, which operate with methods of rolling.

Research object and methods

Instruments, which operate under method of rolling, are used not only for formation of disevolvent profile, but also in formation of various cogwheels. Generally this method is used to process:

- cylindrical type details with direct, seldom with spiral profiles;
- types of fashion of the internal opening;
- details with the types of various kind placed on conical or end of the surfaces;
- details are revolved with rectilinear and fashion forming ring and for spiral surfaces;
- prismatic rack-rails and details of prismatic kind.

Treatment can be executed with the specially formed worm mill cutters, plane cogwheels and tools on the special milling machine-tools, planning and turning machine. To create the type of detail, in principle these instruments need to be rolled up round a detail. The profile of detail appears, when a cutting instrument rounds detail round the cutting instrument. Treatment of foundation takes place in forming of type of detail that the type of detail adjoins with the type of cutting instrument. During processing, process profiling points move for the type of detail and accordingly on the edge of cutting instrument. The centers of the processed detail, and also instrument, are only imaginary and their vibrations are compensated by the table of work, which the treated detail reaches on.

Without motion of rolling, to treatment motion of cutting is needed yet. It is created as motion of relative instrument-applying for the worm mill, cuts there back for motion or relative motion of detail to treatment.

Making of detail uses an instrument, which operates after the method of rolling, depends on the form of detail and sizes of his profile, from the processing circumference position, construction of cutting instrument, after their form and circumference state.

Making of details with the method of rolling is related to the theory of forming of profile.

Not all profiles can be made with the method of rolling. Reasons can be following:

- it is not possible to create the linked profiles in the edge of cutting instrument;
- to sharpen of teeth profile of instrument;
- transitory curves obtained in processing time of detail, and which exceed assumed.

For the details of linked profiles and instruments, in the points of their contiguity is necessity for shared general tangent and normal. Normal needs to cross the point in profiling poles circumference touching. For normal in all points of profile it is necessary crossing circumference.

If normal in some point of profile not crossing circumference, then these normal can not appear rotation of detail in time through the pole of profiling, and together with it profile in that part it is not possible to create with the points linked in the edge of cutting instrument.

Standing for more sharp cutting edge of tooth profile of instrument and shown for transitory curves to treatment, related to the various phenomena. In connection with that in two profile parts of cutting edge one is crossed with the second, the height of edge cutting with a tooth does not achieve the necessary height of work, a tooth sharpen and can not process deep into, necessary by details.

Determination of profile. Using instruments with the method of rolling, determination of type in time for planning of instruments it is necessary to take into account admittances on their manufacturing and specific processing terms.

Taking into account processing in time of possibilities to change the type of detail and I can change the type of instrument in connection with his sharpening, noticing the calculated sizes of diameter of circumference at opening and change of groove connection widths, accepts, that they would be making of details of border of admittance, accepts usually ¼ anymore from the value of admittance.

Calculation methods of instrument profile. The profile of part cutting with an instrument can calculate at one of the followings methods:

- graphic;
- graphical analytical;
- analytical.

For each of these methods there are advantages and disadvantages. A necessary profile is found in a few ways, for example, instrument apply the search of part points is concerted with the type of detail or calculation of points of type of rolling in the various consisting processing process of scopes.

By using of graphical method, the necessary profile of worm milling cutter in normal transversal cut is adopted, that it is identical with the profile of detail. This approximate method of profiling gives a smaller error for us as compared to possible admittances of exactness of making of detail. It is possible found so, that in beginning we will find the points of type for an edge cutting with an instrument. Inaccuracy of close profiling is multiplied and increased for the corner of levitating the coils of milling cutter τ, and then to planning corners τ accept no more as 6°. That is why that more frequently we define the points of profile, which is why that in a result obtain more exact instrument.

Most demonstrative, but less exactly rely graphic methods. A graphical method of determination of more frequently used type is determination of profile with the help of profiling lines.

A little more exact method of determination of instrument profile, which use for making of disevolvent profile there is a graphical analytical method. In foundation of this method, we stipulate the profile parts of instrument by graphical and partly by analytical methods. With certain expressions we calculate the certain points of profile or help points for constructing of profile.

Far more precisely and what more frequent in all use in the engineering there is an analytical method in which with the help of various expressions depending on the obtained profile, we can calculate the main points of profile. With the help of this method we are able to design an exact instrument. Before planning of instrument to us it is necessary to know information of output of disevolvent profile, to know which kind of profile it is necessary to create an instrument.

The rotors profiles of screw type compressors are very exact. Clearance between the surfaces of profiles is minimal, exactness of processing is ever-higher what requires using exact calculations methods is analytical method. Graphic methods can not provide asking exactness. An analytical method theory of hitch in scopes is related to differential geometry and kinematics laws of mutual influence. The theories of analytical hitch a kinematics densely interlinked with the mobile systems of co-ordinates. For determination of rotor profiles of screw compressor we use the system of mobile and immobile coordinates in foundation. From the theory of hitch is known, that one of the rounded profile we can choose free, but we find the second type with the help of interface laws. The classic method of the differential geometry allows to us it is consistently and comparing simple to find and to explore the main tasks of theory of hitch.

For determination of the strained profile it is necessary to execute the followings terms:

- to create equation, what allows to us to convert coordinates set by one moved link into other system of coordinates of moving, in which the strained profile is searched;
- to find the group of rounding curved line.

To our knowledge, that the aggregate of tangent points of the strained type on an immobile plane is adopted for the line of catch.

With a cycloid profile we understand types is what is described as epicycloid, gipocycloid, grow down and extended epicycloid which is incorporated under the name are epi and gipotrohoid.

In the screw machines part of main tooth cycloid profile is marked on a trohoid line, created producible on a circumference with such even radius as beginning.

In dependence of the rounded profile of screw type compressors rotors it is certain in some system of coordinates, we obtain equations:

$$\left.\begin{aligned} x_1 &= x_1(\varphi_1;\phi) \\ y_1 &= y_1(\varphi_1;\phi) \end{aligned}\right\} . \tag{1}$$

To define a cycloid profile on a driving rotor, it is necessary to find profile strain and its line of hitch. The epicycloid equations in the moved system of co-ordinates $x_1 0_1 y_1$, we can define as:

$$\left.\begin{aligned} x_1 &= a\cos\varphi_1 - b\cos c\varphi_1 \\ y_1 &= a\sin\varphi_1 - b\sin c\varphi_1 \end{aligned}\right\} . \tag{2}$$

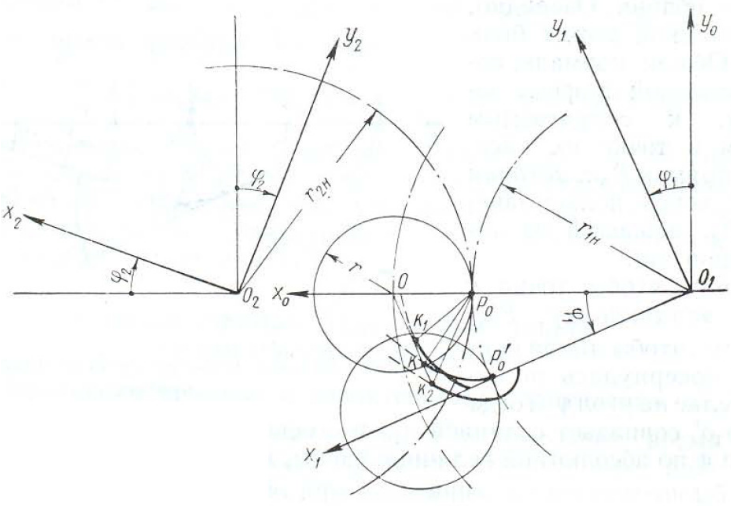

Fig. 1. **Chart of determination of the epicycloid equations**

We find strained equations of profile. To define disevolvent rotor type we need the beforehand examined equation which is given in the mobile leading link of the system of coordinates on the link of the system of other mobile coordinates on which we search the strained type, in this case in the $x_2 0_2 y_2$ system.

$$\left.\begin{aligned} x_1 &= -(A-a)\cos\varphi_2 - b\cos k\varphi_1 \\ y_1 &= (A-a)\sin\varphi_2 - b\sin k\varphi_1 \end{aligned}\right\}, \tag{3}$$

where $k = r_{1H}\dfrac{r_{2H} - r}{r_{2H}\, r}$.

Equation (3) is description of gipotrohoid. This is equation of epitrohoid set for a rotor conducting by the strained type. Equations descriptive by this profile are propped up on the proved connections of equality after absolute values, line of wheel rotation corner and line of center $|\varphi_1|=|\psi|$. It takes to for the zero of equality of identity of functional determinant.

$$\begin{vmatrix} \dfrac{\partial x_2}{\partial \varphi_1} & \dfrac{\partial x_2}{\partial \psi} \\ \dfrac{\partial y_2}{\partial \varphi_1} & \dfrac{\partial y_2}{\partial \psi} \end{vmatrix} \equiv 0$$

When we know information of profile output, then we can start to design an instrument. An instrument making of disevolvent profile in time is rolled on the surface of type so forming the necessary form of profile. Now we should make an instrument, which will satisfy the requirements of profile. For making the profile of screw type compressor rotors we design the worm milling cutter.

In calculations of instrument profile, we execute use a few systems of co-ordinates, where instrument is designed in the immobile system of coordinates, but rotor disevolvent profiles in the mobile coordinates system. Designing the profile of instrument we knock down a detail by the profile of instrument or other way. Execute the calculation of profile of tooth of milling cutter coordinate in the rectangular system „*xOy*", what is related to the tooth of milling cutter. We adopt abscises axis on the straight line of beginning of milling cutter, but we will place beginning coordinate point, what crosses in the straight line beginnings of profile of tooth of milling cutter. The axis of ordinate is the straight line of the perpendicular beginning and directed on the center of detail. For beginning adopt the state to which the type of details and instrument touches for somebody in the pole *P* of profiling.

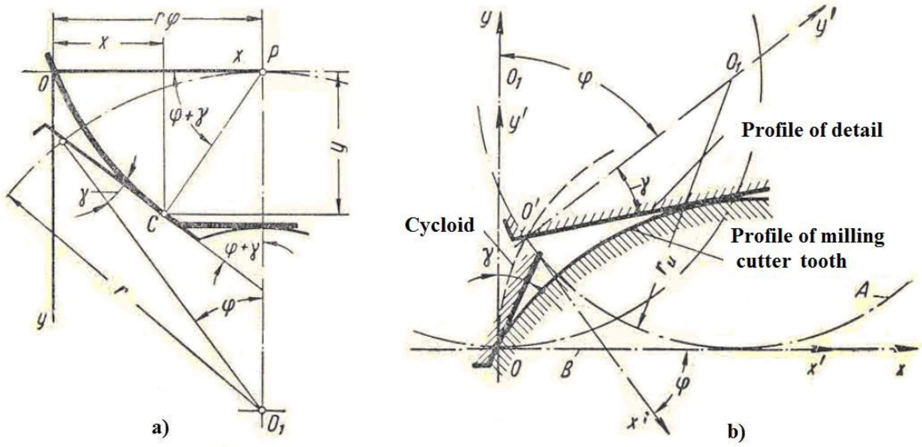

Fig. 2. **Analytical determination method of profile of worming milling cutter**

Taking into account that in the straight line of beginning the teeth of milling cutter move without sliding on the circumference of beginning of detail, then turning the profile of detail for a corner φ, the profile of teeth of milling cutter and system of co-ordinates moves from pole P by the straight line of beginning for distances $r\varphi$.

To reduce expressions of evolvent profile we obtain expressions of not evolvent profile. Points of tooth profile of milling cutter coordinates (Fig. 2. a) we offer with the followings equations:

$$x = r\varphi - PC\cos(\varphi + \gamma) \tag{4}$$

$$y = PC\sin(\varphi + \gamma) \tag{5}$$

For the coordinates x and y calculation is needed size φ and α for border of changes suitable extreme profile points.

The profile of tooth of milling cutter can be certain also in the way of finding stipulating for the next states of profile of detail of general circumferences to direction of circumference of beginning on the straight line of beginning of milling cutter (Fig. 2. b).

The profile of teeth of milling cutter can be calculated, using the system of immobile coordinates „$x0y$”. Axle x coincides with the straight line of beginning of milling cutter, beginning of coordinates is in a point in which a type is crossed with the straight line of beginning. The type of details is formed in the mobile system of coordinates $x'O'y'$ which is related to detail circumference. Axle $O'x'$ in that system behaves to the circumference of beginning of detail, beginning of coordinates is placed in the point of crisscrossing of type with the circumference of beginning. Consisting of beginning of both systems mobile $x'O'y'$ and immobile xOy coincides. The type of the straight line detail, in the system moving by coordinates, is outspoken with equations:

$$x' = y'\operatorname{tg}\gamma \tag{6}$$

By the detail turn the vibrations of circumference of their beginning coincide directly with a milling cutter - moving of the beginning coordinates mobile system after a cycloid. Going out from it we can define beginning of instrument coordinates:

$$x_0 = r(\varphi - \sin\varphi) \tag{7}$$

$$y_0 = r(1 - \cos\varphi) \tag{8}$$

That it was possible farther to design the type of instrument to us, there is necessity to convert it from one system of co-ordinates to the other system of co-ordinates, a conformable type is found in which. We will use transition formulas, that from one system of co-ordinates $x'O'y'$ are the mobile would pass on systems of other coordinates xOy immobile.

$$x' = (x - x_0)\cos\varphi - (y - y_0)\sin\varphi \tag{9}$$

$$y' = (y - y_0)\sin\varphi + (y - y_0)\cos\varphi \tag{10}$$

In theory tooth apply for making facilitation of part types use a one circumference arc or use contiguous arcs with two or rarer for not many circumferences, what changes the theoretical arc knee of type.

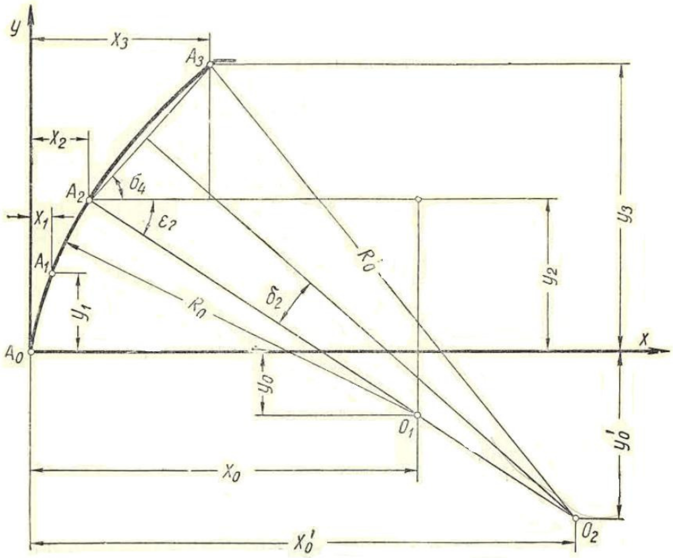

Fig. 3. **Replacement of theoretical profile**

Radius of profile and determination of location of the state of this center takes place following (Fig.3.). On the theoretical profile of milling cutter tooth choose three points and through them analytically drag arcs, in a mark his radiuses and center. Choose one point on the straight line of beginning – beginning of coordinate, second approximately for the middle of profile, but third close by the surface of profile.

Coordinate x_0 and y_0 centers O_1 changes, and then we calculate a circumference with the following equation from analytical geometry:

$$x_0 = \frac{(x_2^2 + y_2^2)y_1 - (x_1^2 + y_1^2)y_2}{2(x_2 y_1 - x_1 y_2)} \tag{11}$$

$$y_0 = \frac{(x_2^2 + y_2^2)x_1 - (x_1^2 + y_1^2)x_2}{2(x_2 y_1 - x_1 y_2)} \tag{12}$$

Radius of arc changes a circumference R_0 identically:

$$R_0 = \sqrt{x_0^2 + y_0^2} \tag{13}$$

A radius and center of replacement of circumference can be calculated also with other method, for example, using trigonometric connections.

To check up exactness of replacement, calculates arc you take ΔR, what changes a circumference – from a theoretical curve in two points of type $A1'$ and $A2'$. Points for the calculation control take between calculations points $A0$, $A1$ and $A2$, their coordinates calculates after the entered formulas of profile of milling cutter tooth. Distance F between these points $A1'$ and $A2'$ and center of arc, what changes a circumference (x_0, y_0) identical

$$F = \sqrt{(x - x_0)^2 + (y - y_0)^2} \tag{14}$$

Controls points can fall short of to the maximal rejection of profile. For determination of points of rejection of maximum the maximal values $\Delta R = F - R_0$ of function stipulate to the condition.

$$\frac{d\Delta R}{d\varphi} = 0$$

$$(x - x_0) + (y - y_0)\frac{dy}{dx} = 0 \qquad (15)$$

The obtained equation is equation of normal of type of milling cutter tooth, which to go through the center of replacing circumference.

Conclusions

The rotors of screw type compressors are one of main components of compressors, which are very exact. The types of these rotors comparatively have difficult structures, which we can describe with various curves-cycloid profile. With a cycloid profile we understand types is what is described as epicycloid, gipocykloid, brief and extended epigipocyloid which is incorporated under the name are epi and gipotrohoid. By analyzing I drew conclusion that more precisely in all of type can be described with analytical expressions, which are related to differential geometry and kinematics laws of mutual influence.

One of methods as we can make the profile of rotor is using instruments which operate with the method of rolling is worm mill cutter. The profile of instrument goes away with the profile of rotor. Profile of instrument we can obtain by various ways, but most exact from those, which give us results of high exactness, there is analytical determination of rotor profile. By using of analytical method we mathematically design the profile of instrument, in which we obtain reduced equations of disevolvent profile.

References

1. И.А. Сакун Винтовые компрессоры, Ленинград, Машиностроение 1970 с.400.
2. И.И. Семенченко, В.М. Матюшин, Г.Н. Сахаров Проектирование металлорежущих инструментов, Москва 1962 с. 952.
3. Loomis A. W. “Compressed air and gas data” – USA: Ingersoll-Rand Company 1980.
4. Stosic N., Smith I. K., Kovacevic A. “Screw compressors” Mathematical modeling and performance calculation – School of Engineering and Mathematical Sciences Northampton Square City University, London EC1V 0HB,U.K. 2005.