Layout and variables of air-powered drive of small-size pneumatic winch

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Abstract. The paper describes three layouts of a winch with a harmonic drive and a flexible gear in the form of a set of spindles: classical layout with the remote motor and barrel; layout with the harmonic drive and remote motor; layout with the barrel with the in-built drive members. The analytical models are developed to determine acting faces and lateral dimension of rigid gear teeth depending on the layout and on the design and kinematic variables of the winch and the drive.

It is preferred to lay service lines in towns using trenchless methods—piercing or puncturing when holes are made with partial or full compaction of soil. These methods are implemented with the help of Russian and foreign pneumatic percussion machines, for instance, pneumatically driven hammers M200, SO166, Typhoon, Grundomat [1].

In hole-making by puncturing, it is possible to drive steel pipes-casings with the shut front end in soil, or to make hole first with a pneumatically driven hammer and then to insert ceramic, plastic, asbestos or steel pipes in the hole.

Puncturing process has two stages: at the first stage a pipe–casing is driven in soil with the open front end, at the second stage soil core is removed from the pipe. Core removal is possible using different tools, including self-propelled suction heads with pneumatic percussion machines employed as impact impulse generators. Pulling-out of the suction head with soil core is executed by an auxiliary take-off assembly.

A feature of these technologies is the backblow of the pneumatic percussion machines, which is required to balance when in the course of hole-making. At early stages of hole-making, friction is low, and a force-feed gear is required to balance the backblow of a pneumatic percussion machine. To this effect, it is possible to use startings in the form of a rod power-units or a leverage mechanism; the force is generated by an operator in this case [4]. Since startings are not in serial production, usually leverage mechanisms or winches are chosen.

Winches are used to pull suction heads with soil core from pipes. As experience shows a winch can balance the backblow of a pneumatic percussion machine at early stages of pipe driving. The current winches have hydraulic, pneumatic, electric and manual drives [6]. Dimension and weight of drives grow in proportion to the value of the pulling force or carrying capacity of a drum (and number of drums). For the confined environment of hole-making with pneumatic percussion machines, it is preferable to chose winches with pneumatic and manual drives.

Inasmuch as the current winches are big and heavy, while manual winches provide low pulling force, it is required to design small-size winches. The aim of this study is designing a winch with a pneumatic drive, of small size and low weight, to balance the backblow of the pneumatic percussion machine at early stages of hole-making or to work in a confined area.

The main components of a winch are motor, reducing gear and rum. This study focuses on the design of a small-size winch with a gear system based on a harmonic gear in the form of a set of spindles, of small size and with a wide-range transmission ratio.

The harmonic gear with spindles consists of generator 1, internal rigid gear 2, disc guide 3 and spindle 4 (Figure 1).

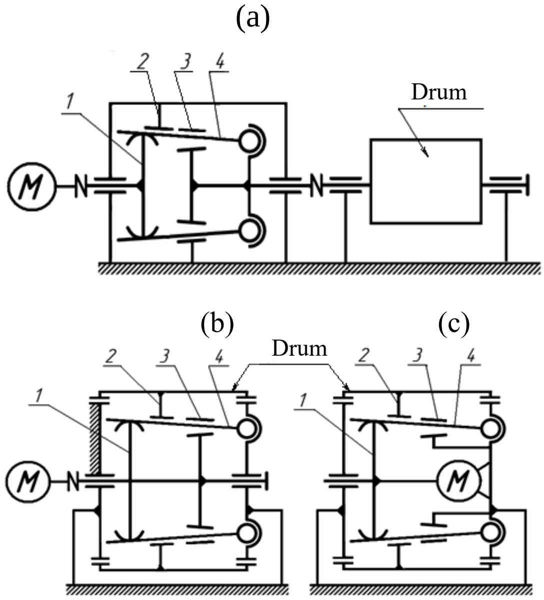

Figure 1. Variants of layout of a winch with a chain harmonic gear. Explanation is in the text.

There may be three variants of layout of a winch with a harmonic gear: outboard motor and drum—classical layout (Figure 1a), which allows collapsible winch to facilitate the winch transport to a work site; outboard motor and harmonic gear integrally mounted in a drum (Figure 1b); all elements of drive, including motor, are embedded in a drum (Figure 1c). Variants (a) and (b) in Figure 1 allow the smallest vertical and horizontal dimensions of a winch.

Capabilities of a small-size winch with a harmonic gear with spindles and geometric and kinematic parameters of the gear depend on dimension of the rigid gear. The most important stage of the rigid gear design is shaping of acting faces of the gear teeth. There are many methods of gear tooth shaping: Gokhman, Olivier, kinematic method. The most popular method is based on the classical apparatus of differential geometry [5–8].

To define acting faces of rigid gear teeth, it is necessary to know trajectory of spindle axes in the coordinate system XYZ connected with the rigid gear.

Let spindle axes move along a trajectory described by a parametric equation [9]

$$\begin{cases} x_M = f_x(t, L_m), \\ y_M = f_y(t, L_m), \\ z_M = f_z(t, L_m), \end{cases} \qquad (1)$$

where x_M, y_M, z_M are the coordinates of the point *M* belonging to the surface (1) and concurrently to a spindle axis; t is the time of travel of the axis along the chain; L_m is the distance between the point M and the center of the spherical base of a spindle.

The coordinates of the point P belonging to the acting face of a tooth of the rigid gear can be presented y the coordinates of a radius-vector

$$\overrightarrow{OP} = \overrightarrow{OM} + \overrightarrow{MP} \quad (2)$$

where the vector $\overrightarrow{MP}$ is given by

$$\overrightarrow{MP} = \pm \ \vec{n} \cdot r , \quad (3)$$

where $\vec{n}$ is the unit normal vector drawn to the surface (1); r is the radius of the acting face of a spindle. The vector $\vec{n}$ is obtained by normalizing of the vector $\vec{N}$ determined by a vector product of two non-collinear vectors tangential at the point M to the trajectory of the spindle axis

$$\vec{N} = \vec{v} \times \overrightarrow{MW} \ . \quad (4)$$

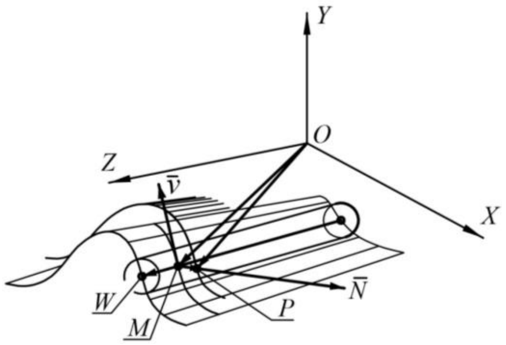

Figure 2. Schematic to determine the acting face of a rigid gear spindle.

In our case, the vector $\bar{v}$ is the velocity vector of the point M

$$\begin{cases} v_x = \dfrac{\partial f_x(t, L_m)}{\partial t} \\ v_y = \dfrac{\partial f_y(t, L_m)}{\partial t}, \\ v_z = \dfrac{\partial f_z(t, L_m)}{\partial t} \end{cases} \quad (5)$$

where f_x, f_y, f_z are the functions of the coordinates of the point M belonging to the spindle axis, in the coordinate system connected with the rigid gear.

Another vector of the product (4) is the vector $\overrightarrow{MW}$ belonging to the surface (1) and coinciding with its generating line

$$\begin{cases} x_{\overrightarrow{MW}} = x_W - x_M , \\ y_{\overrightarrow{MW}} = y_W - y_M , \\ z_{\overrightarrow{MW}} = z_W - z_M . \end{cases} \quad (6)$$

We use the expressions (1)–(6) to derive the equations for the acting faces of the rigid gear teeth in the parametric form

$$\begin{cases} x_P = \psi_x(t, L_m), \\ y_P = \psi_y(t, L_m), \\ z_P = \psi_z(t, L_m), \end{cases} \quad (7)$$

where x_P, y_P, z_P are the coordinates of the point P. The values t and L_m are the curvilinear coordinates of the point. The relations (7) are the closed spatial curves with the fixed parameter L_m and the variable parameter t. The surface described by (7) can be represented as a population of such lines for the variable values of L_m if L_m is constant, for the variable t we obtain a curved line that is the line of contact of a spindle and a rigid gear tooth.

Figure 3 shows the surface of the rigid gear teeth. The equidistant curve for the gear teeth is plotted out of the spindle axis travel trajectory.

The acting faces of the rigid gear teeth are to be limited by the design parameters of the harmonic gear in the direction of its axis coinciding with the coordinate Z of the chosen coordinate system *XYZ*.

The acting faces of the rigid gear teeth are obtained by cutting out the surfaces, described by the relations (6), by the planes Π_1 and Π_2, which are parallel to the plane XY at the distances $L_{\max}$ and $L_{\min}$ (Figure 4).

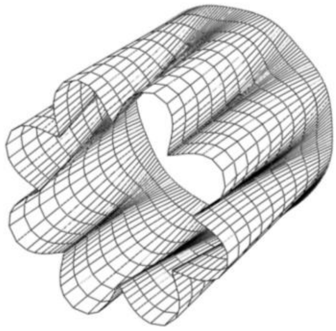

Figure 3. Surface of a rigid gear tooth.

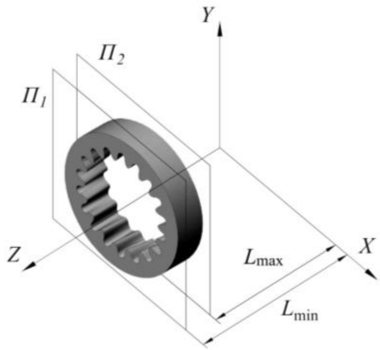

Figure 4. Rigid gear. Explanation is in the text.

Conclusion

The authors have offered three layouts of a winch with a harmonic gear with spindles: outboard motor and drum, outboard motor and harmonic gear integrally mounted in a drum and with a drum with all elements of the gear in-built.

The developed model of toothing of the harmonic gear and the rigid gear enables synthesizing the toothing at the linear contact of spindles.

The limiting conditions for the longitudinal parameters of the rigid gear teeth are determined as function of layout and design of a winch with a harmonic gear with spindles.

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