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DESIGN OF AN INDEXING GEARBOX WITH RADIAL CAMS

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Abstract: *Indexing gearboxes are used to convert the uniform rotary motion of the input camshaft into a required non-uniform rotary motion with clearly defined dwell portions of an output shaft. The indexing gearbox with conjugate cams consists of a pair of radial cams and an indexing turret follower fitted with rollers that are mounted on both sides and rolled. The favourable properties of polygon joints are advantageously used in the design of the indexing gearbox with radial cams. The joint profile formed by the polygon has very low, if not negligible, notch effects. For this reason, the fatigue strength of the respective connection is significantly increased. The geometric shape of the follower roller crown in cam mechanisms has also a significant effect on the contact stress due to the load and inertial effects in the surface layers of the general kinematic pair. Together with the design changes of the existing design of indexing gearboxes, modern coating methods can be used, which have become an integral part of industrial practices. Coatings extend the lifetime of sliding and rolling surfaces.*

Keywords: Indexing gearbox, cam mechanism, radial cam, polygon connection, indexing turret follower.

1. Introduction

The company VÚTS, a.s. (VÚTS, a.s., 2024) is a research organization with long-time experience in the design and calculation of cams and cam mechanisms among other things. For this purpose, computational programs and procedures for the analysis and synthesis of combined cam mechanisms were developed here, see (Koloc and Václavík, 1993; Norton, 2009; Ondrášek, 2019). As part of its research and development activities, VÚTS, a.s. ensures the production of cams and cam mechanisms for domestic and foreign customers.

2. Indexing gearboxes with conjugate cams

The company VÚTS, a.s. is also a producer of indexing gearboxes with conjugate cams of the KP series, which consists of a pair of radial cams with an axial disc star fitted with double-sided mounted rollers, see Fig. 1. In these types of the indexing gearboxes, the input and output shafts are arranged parallel to each other. The indexing gearboxes are used to convert the uniform rotary motion of the input camshaft to the unidirectional rotary motion with clearly defined dwell portions of the mechanism output shaft (intermittent rotary motion). We can denote the gearbox output member with the term indexing turret follower.

2.1. Displacement law

Indexing cam mechanisms belong to the mechanisms with non-periodic displacement laws. The shape of the cam contour is determined by the synthesis which goes on the basis of the knowledge of a displacement law $w = f(\tau)$ of the given indexing gearbox and its dimensional parameters. The movement of the driving member – camshaft is described by the independent motion function $\tau(t)$ and the movement of the indexing turret follower by the dependent motion function $w(t)$. The displacement law $w(\tau)$ of an indexing gearbox with a rotating cam increase the functions with dwell portions, with individual rises (indexes) following each other with a period of 2π. Displacements on each motion interval may be

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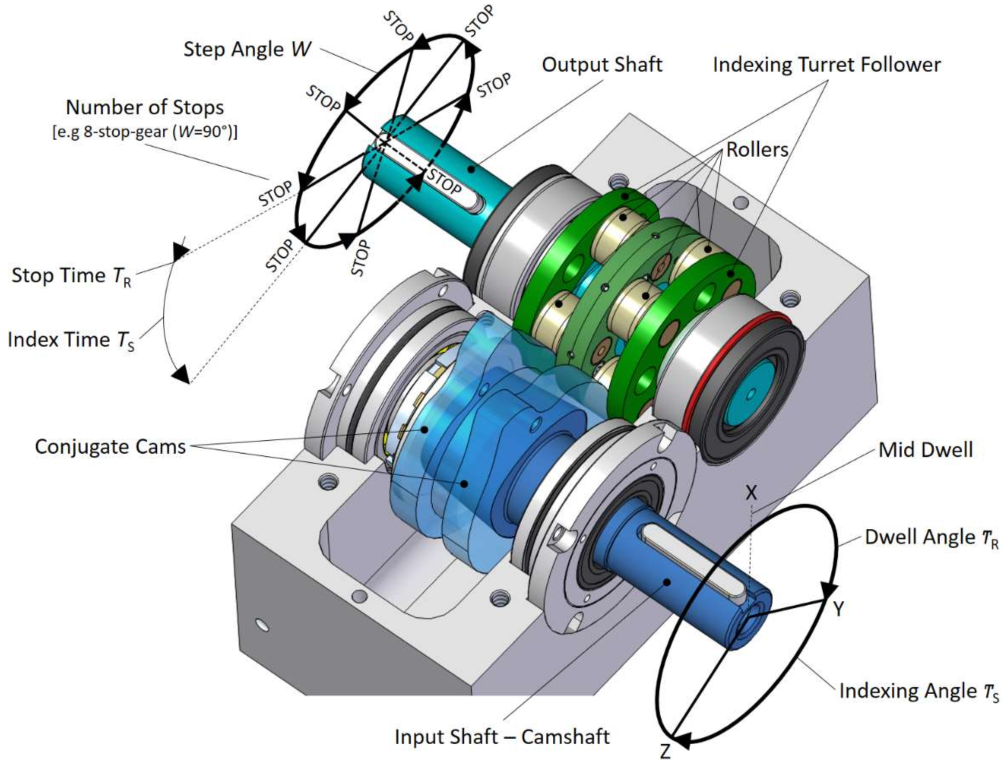

Fig. 1: Indexing gearbox with conjugate cams.

different in a maximum total rise W and an expression of the normalized form where the displacement $\eta = \eta(\xi)$ and the range are in unity. The variables ξ_k ,η_k of k^{th} motion interval are in linear correlation with the original variables τ, w and are expressed as:

$$\xi_k = \frac{\tau-\tau_{0k}}{T},\ \eta_k(\xi_k) = \frac{w(\tau)-w_{0k}}{W},\ \xi_k \in \langle -\tfrac{1}{2};\ \tfrac{1}{2}\rangle,\ \eta_k \in \langle -\tfrac{1}{2};\ \tfrac{1}{2}\rangle. \tag{1}$$

The coordinates τ_{0k}, w_{0k} determine the position of the origin O_k of the motion interval coordinate system $O_k\xi_k\eta_k$, while in the following step it is given by the coordinates:

$$\tau_{0(k+1)} = \tau_{0k} + 2\pi,\ w_{0(k+1)} = w_{0k} + W. \tag{2}$$

The derivatives in the original variables τ, w and normalized variables ξ_k, η_k are related by the relations:

$$w' = \frac{dw}{d\tau} = \frac{W}{T}\cdot\frac{d\eta_k}{d\xi_k} = \frac{W}{T}\eta_k'(\xi_k),\ w'' = \frac{d^2w}{d\tau^2} = \frac{W}{T^2}\cdot\frac{d^2\eta_k}{d\xi_k^2} = \frac{W}{T^2}\eta_k''(\xi_k). \tag{3}$$

If the variable $\tau = f(t)$ is a function of time t, then the following relations are valid:

$$\dot{w} = \frac{W}{T}\eta_k'(\xi_k)\dot{\tau},\ \ddot{w} = \frac{W}{T}\left(\frac{1}{T}\eta_k''(\xi_k)\dot{\tau}^2 + \eta_k'(\xi_k)\ddot{\tau}\right). \tag{4}$$

VÚTS, a.s. produces indexing gearboxes with radial cams, whose displacement law of the motion interval is mathematically defined by a standardized form that expresses a 5 ° polynomial function:

$$\eta(\xi) = \frac{1}{8}\xi[15 - 10(2\xi)^2 + 3(2\xi)^4],\ \eta'(\xi) = \frac{15}{8}[1-(2\xi)^2]^2,\ \eta''(\xi) = -30\xi[1-(2\xi)^2]. \tag{5}$$

The numerical parameters of the motion interval and dwell intervals are contained in Tab. 1. An example of the course of such the displacement law of a indexing cam gearbox is shown in Fig. 2.

Boundary Points	**1**	**2**	**3**	**4**
$\tau - (k-1)\cdot 360$ [°]	0	220	320	360
W [°]	0	0	90	90

Tab. 1: Numerical parameters of the displacement law intervals.

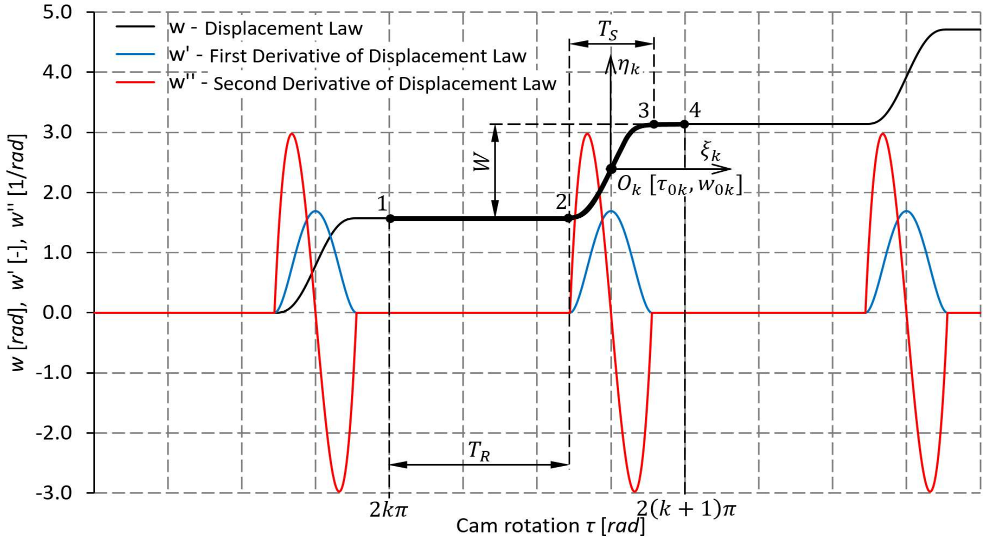

Fig. 2: Displacement law of indexing gearbox.

2.2. Design of a camshaft and an indexing turret follower

In the design process of the input (camshaft) and output member (indexing turret follower) of the indexing gearbox, the favorable properties of conical polygon connections were used, see Fig. 3. In the design process of the camshaft and the indexing turret follower of the indexing gearbox, the favorable properties of the conical polygon connections were used. The joint profile formed by the polygon is characterized by a transmission of large, variable and shock torques, possibility of defining the mutual rotation of the cams of the cam pair and their axial position on the shaft, self-centering, simple backlash elimination between the cams and the camshaft and the discs and the indexing turret follower shaft, simple assembly and disassembly. In the case of indexing turret follower production, there is a saving of material because the indexing turret follower body used to be made from a piece of semi-finished product.

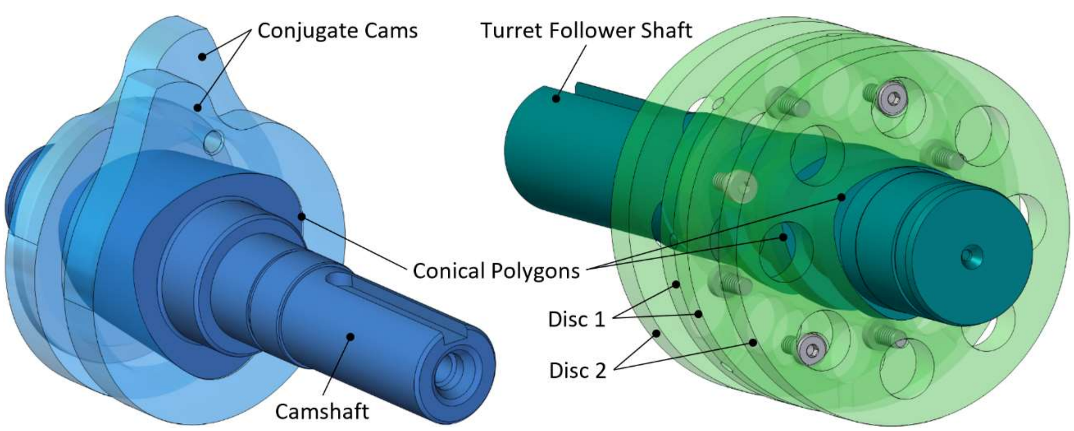

Fig. 3: Camshaft and body of indexing turret follower.

2.3. Optimization of roller shape of a cam follower

The geometric shape of the crown of the follower roller has a significant effect on the contact stress due to the load and inertial effects in the surface layers of the general kinematic pair. In the case of a cylindrical roller, there are discontinuities at the intersections of the cylindrical profile with the cam profile. The mentioned discontinuities cause a very sharp increase in the pressure distribution in the respective contact surfaces of the bodies. These local increases in pressure distribution can exceed the ultimate strength of the material and thus cause plastic deformations, occurrence of residual stresses in material or eventually steel hardening. A possible variant how to ensure a more even distribution of the contact stress is a structural change in the shape of the axial cross-section of the roller crown. This is one of the reasons for the practical application of the roller with convex segments of the crown while the middle section of the crown being cylindrical, see Fig. 4. The characteristic dimensions of such a roller are diameter D, width l_e, radius R of the crown convex part, width w of the convex part and radius r of edge rounding. The optimization parameters of such a crown profile are the radius R of the convex region and its width w. The entire optimization of the crown profile is carried out in order to distribute the contact stress as evenly as possible with the largest possible load generated by the effects of the force N.

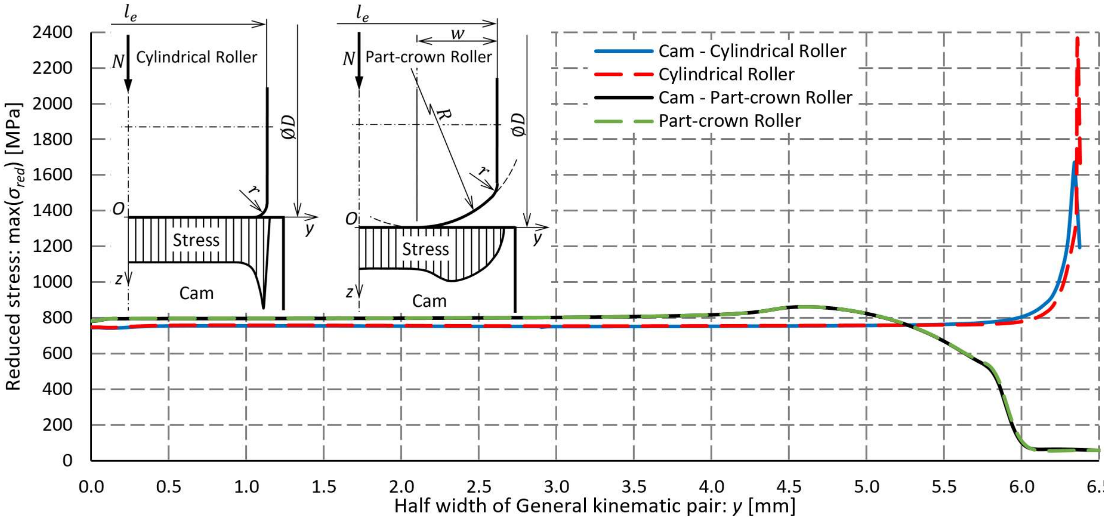

Fig. 4: Stress distribution in general kinematic pair.

3. Conclusions

In the case of an indexing drive of KP series, a conical polygonal connection was used to mount the conjugate cams on the camshaft and the lever discs on the lever shaft. In the case of this type of connection, the exact position of the cams on the camshaft is ensured. The profile of the connection formed by the conical polygon has very low, even negligible notch effects, this means a significant increase in the fatigue strength of the respective connection. These connections are used to transmit large, variable and shock torques. Patent CZ 306709 protects this arrangement of the cams on the camshaft and lever discs on the lever shaft.

The rollers have an optimized shape, thanks to which the service life of the indexing gearbox is extended. This is because there is no increase in the values of the contact stresses in critical regions when the cam and roller are in contact.

Another result of the development is the use of modern technologies from the areas of coating. Parts that form sliding pairs are coated, and another solution would be technologically too demanding, i.e. rollers and pins on which the rollers are sliding seated. In the case of rollers, this is the surface that is in contact with the cams. The coated pins allow clean sliding of the rollers. Coatings extend the lifetime of the sliding and rolling surfaces and help reduce the required power consumption while simultaneously increasing performance. Coatings are generally used to improve hardness, wear resistance and oxidation of contact surfaces.

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