Design of Machines and Structures, Vol. 2, No. 2 (2012), pp. 93–100.
https://doi.org/10.32972/dms.2012.017

ENSURING OF THE CLAMPING FORCE IN EPICYCLIC TRACTION DRIVE BY A NEW SUN WHEEL DESIGN

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Abstract. The paper tries to introduce different designs of helical torsion springs to install them in epicyclic traction drives as basic elements. The goal of the authors is to show some clamping devices collecting ideas among the traction drives, at the areas of free-running clutches and conventional epicyclic traction drives. Helical torsion springs were developed, derived from a split hollow cylinder. A novel traction wheel design was obtained by merging the functions of rolling and clamping. In order to earn a good quality radial clamping force and load symmetry, and an economical design, some innovative technology were joined to the spring production.

Keywords: axial clamping device, free-running clutch, helical torsion spring, epicyclic traction drive, split hollow cylinder

1. INTRODUCTION

The preliminary constraint of the operation of epicyclic traction drives is the proper clamping of the elements which are in force transmitting relation. There are a numerous well known solutions of which one part assures constant clamping force and another part assures a force that proportional to the load. Both the efficiency and the life rating are more favourable in the latter case [1]. *Figure 1* shows three of them, namely wedge ball type, screw-nut type and roller cam type. The case of clamping force proportional to the load is a feature of some clutches e.g. the axial and radial force closing free-running clutches [2]. The slippage of the traction elements during the starting and load changing process should be avoided to save them. A certain degree of preload must be assured by spring, by gravity or by other force.

Both the constant preload and the clamping force which is proportional to the load, depending on the design and location of the drive, and the clamping mechanisms can be axial or radial. The possible sense of rotation and power flow can be unidirectional or bidirectional. The literature of traction drives [1] publishes axial clamping devices and most of them are able to operate undependently of the sense of rotation, and that of the clutches [2] shows free-running clutches with radial force closing which are able to transmit power in one sense of rotation. *Table 1* summarizes the types of free-running clutches.

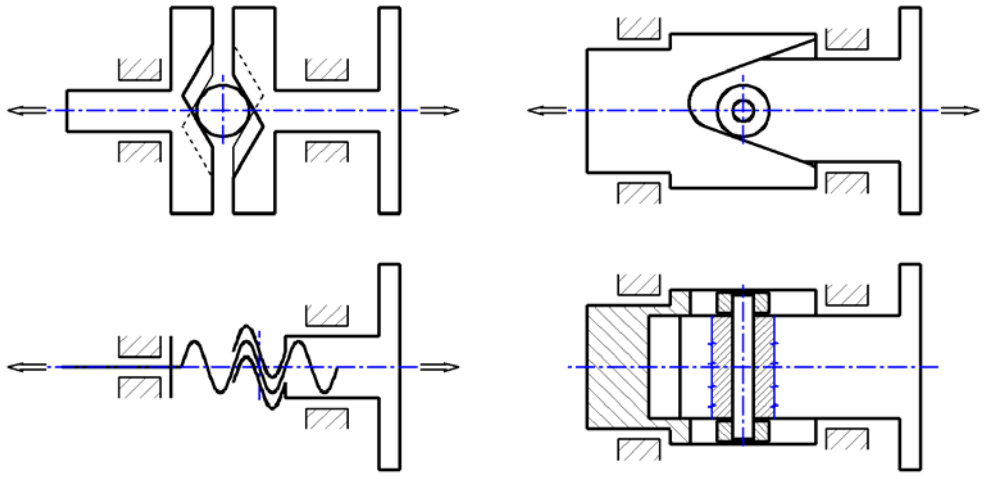


Figure 1. Axial clamping devices [1]

Table 1

Classification of free-running clutches [2]

Shape closing		**Shape and force closing**	**Force closing**
Radial	Axial		
ratchet mechanisms	jaw type coupling driven through screw-nut join		
Axial	Radial		
disk or cone type frictional coupling driven through screw-nut join	wedge roller type	locking body type	Other type

The clamping devices but the radial ones are discussed in the literatures in detail. Only a few of the radial types are available which transmit the axial displacement proportional to the load into radial displacement or radial force by a relatively complicated mechanism shown in *Figure 2*. Let's find solutions in the literature of free-running clutches to generate radial force for the clamping devices.

The design of force closing radial free-running clutches may be locking roller type, locking block type or others with elastomer inserts [4], and there are solutions where the shafts are connected to each other by helical torsion springs [5]. The conditions of traction connections are fulfilled only at one of the driving directions in the following ways. The equally rigid driving and driven parts are connected by wedging rigid rollers, closure body, or moulded elastomer disk having wedging elements shown in *Figure 3*. The shafts can be connected by helical torsion spring which coils are tightened rope – like to the cylindrical surfaces shown in *Figure 4*.

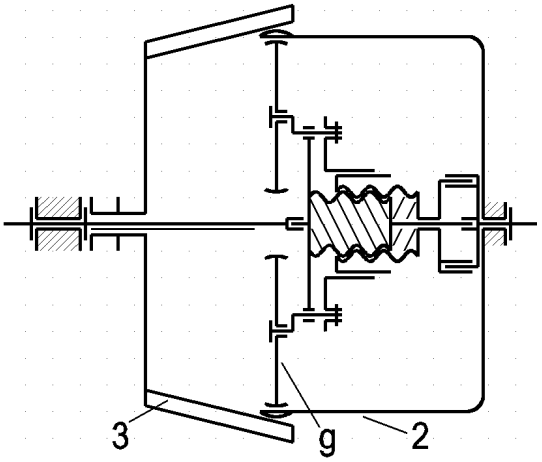


Figure 2. Providing the radial force by pinion-sector gear driven eccentric rollers [3]

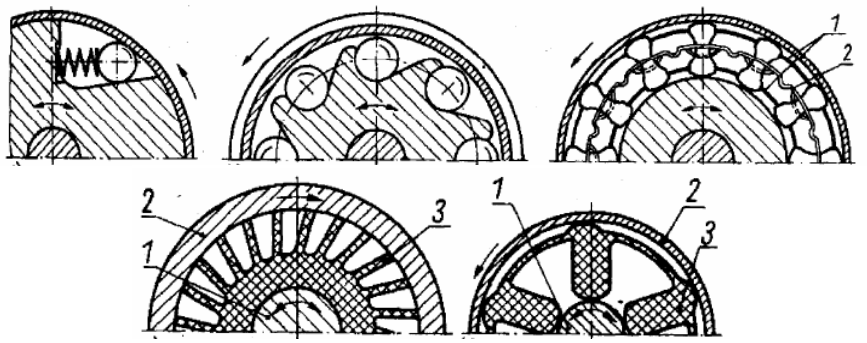


Figure 3. Free-running clutches – wedging rigid roller type, closure body type and elastomer disk type [4]



Figure 4. Free-running clutch – the torque is transmitted by helical torsion spring [5]

2. THE GENERATION OF THE RADIAL FORCE

The free-running clutches of *Figure 3* are force closing types. The degree of wedging of the locking elements between the driving hub and the driven drum depends on the stiffness of the drum. The rigid shape of drum causes large normal clamping force but a more elastic design results less. The elastic design is associated with the greater radial deflection. There are more possible chances to enlarge the flexibility of the drum. The wall thickness of the drum, made of spring steel can be decreased. The original cylindrical shape due to radial force will be changed, formed in polygonal shape. The thin walled cylinder can be split,

too, where the degree of polygonal formation is less and the increase in diameter is greater. The drum can be made of elastomer which can be elongated tangentially, both the large radial increment and the polygonal formation occurs.

In an epicyclic traction drive, in all the rolling relations, a proper clamping force possibly proportional to the load should be made. Let's consider the possible sun wheel designs of an io type epicyclic drive (having one inner and one outer connection) to make the required radial clamping force.

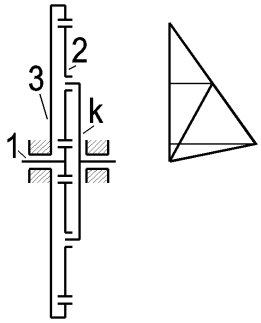


Figure 5. io type epicyclic drive

What kind of drum design of the free-running clutch should be suggested to provide both the function of sun wheel and ensuring the radial clamping force? From the options outlined above the drums made of elastomeric material should be excluded from the scope of studied cases due to its small value of maximum allowable hertzian stress. By similar manner, the very thin walled cylindrical shells, made of steel and tends to large degree of polygonal formation, are also excluded. The split cylinder having greater wall thickness consequently more rigid, retaining the cylindrical shape more accurately, but able to be properly deflected radially, is able to serve the solution which can be refined to find the applicable solution.

3. SUN WHEEL UNIT ENVELOPED BY A SPLIT RING

Let the sun wheel the driving element of the epicyclic drive. The drive receives the driving torque through the hub carrying the locking rollers or locking bodies. The split hollow cylinder increases its diameter due to torque or when the deflection is limited, the radial force is increasing. There are two constraints in relation with the direction of split curve for the proper operation. One of them is the need for the smooth rolling and the other is the unobstructed transmission of the radial clamping force which is proportional to the driving torque.

Considering the symbols of *Figure 6*, when the diameter, d and the with, b of the sun wheel is constant, the smooth rolling can not be assured in case of $\alpha = 0°$ split angle, but the radial clamping force can be transmitted effectively. Increasing the split angle, the roling of the planet wheels on the sun wheel becomes smoother but the efficiency of the transmission of radial clamping force becomes less. To assure the same contact phases in all the sun wheel – planet wheel engagements with smooth rolling, then using the symbols of *Figure 6* an $\alpha = n \arctan \frac{b}{d\pi}$ split angle should be set, where $\mathrm{n} = 1, 2, \ldots$ natural number.

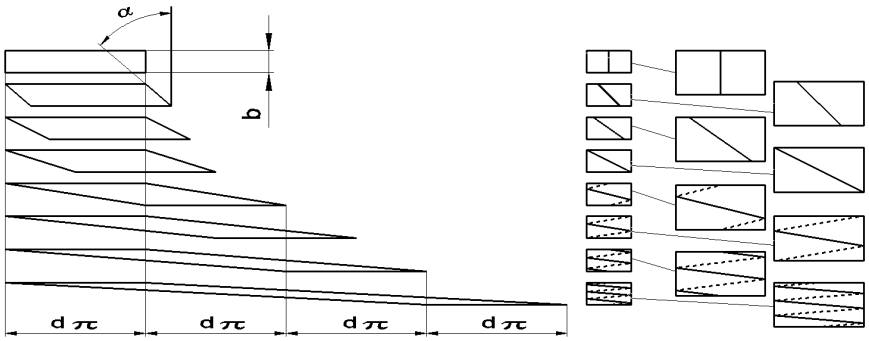


Figure 6. The influence of the split angle, α to the shape of the unfolded split hollow cylinder (d and b are constants)

Choosing $n = 1$, both the smooth rolling and the proper quality driving torque – clamping force transfer can be provided.

From the above mentioned sample it is visible, that a radial clamping force can be generated directly, without any tapered surfaces or axial clamping devices. *Figure 7* shows three example for clamping force application with axial forces, on the area of adjusting drives (io), prosthesis of extremities (io) and the power drives (o+i). The sun wheel and/or the ring wheel is conical. At the (o+i) type epicyclic drive, the inner connection is divided in two parts to make load symmetry.

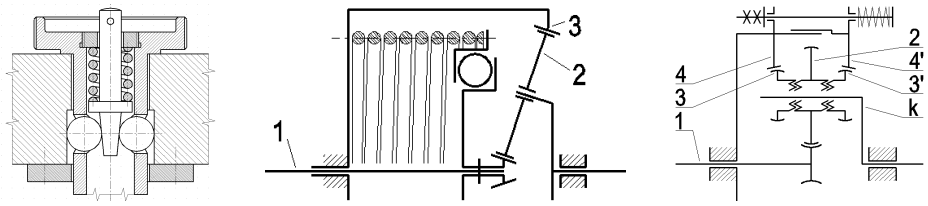


Figure 7. Axial clamping with tapered surfaces [6, 7]

The clamping with radial forces can be made, similarly to the free-running clutches, proportionally to the load. The only difference is in the output element, the thinner ring design and the split ring. The increasing torque at the driving shaft of the epicyclic drive causes the enlargement of the ring, i.e. the increment of the clamping force.

The sun wheel derived in such a way has got a very simple design. It is able by itself to assure the initial tensioning force and then to assure the clamping force proportionally to the load, and furthermore to assure the smooth rolling on the planet wheels that were shown in our previous study [8]. The helical spring can be considered so as a split hollow cylinder with a highly increased split angle. The initial tensioning is assured so as the diameter of the unloaded spring is chosen to be greater than the diameter of the inner tangent circle determined by the planet wheels, and the adjacent coils of the spring during the installation, when the spring diameter is decreased, should not be in contact with each other. There could be other needs in relation with the drive. E.g. let the drive be able to work in both

directions or let the load of the drive be symmetric, or let the manufacturability of the sun wheel be easy.

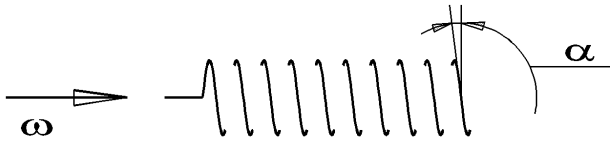


Figure 8. The hollow cylinder having large split angle is a helical spring

4. BIDIRECTIONAL FUNCTIONALITY

The operating principle of the free-running clutches was used to assure the radial clamping force of the epicyclic traction drives, however the free-running function is usually not needed. Installing symmetrical locking bodies which are able to get stuck at any sense of rotation of the hub, causing the radial deflection of the split hollow cylinder, the problem can be solved simply without increasing the space requirement.

When, for example, the helical spring of the *Figure 8* having right hand side inclination, is driven through the middle point of its length, then the torque is transmitted towards the planet wheels through the part of spring between the driving point and the right free end, in case of reverse drive it is done by the left-hand side part of the spring. This solution causes the doubling of the width of the drive.

5. BALANCED HELICAL SPRING SUN WHEEL

When the lead of the symmetric design of helical spring is half left - half right, and it is driven through its middle point then a sun wheel with unidirectional functionality is obtained. The load distribution will be symmetric longitudinally, too as *Figure 9* shows. The situation is even more favorable if the spring is manufactured with double thread. It is easier to drive in the middle and is expected to have a better load distribution.

6. THE PRODUCTION OF HELICAL SPRINGS

Split rings should be developed from spring steel strip. The single thread helical spring of *Figure 9* should be manufactured from tube by cutting (turning, milling), that of the double thread by spark cutting. Recognising that the location of the obtained double, left-right-hand side threads are located on cylindrical surfaces, and knowing the unfoldability of the cylindrical surface, the pre-product of the spring winding can be made from sheet metal, practically without any waste by laser cutting. Prior to the windings of the two V shaped plates the minimum gap between the coils should be adjusted and the nose at the end should be bent.

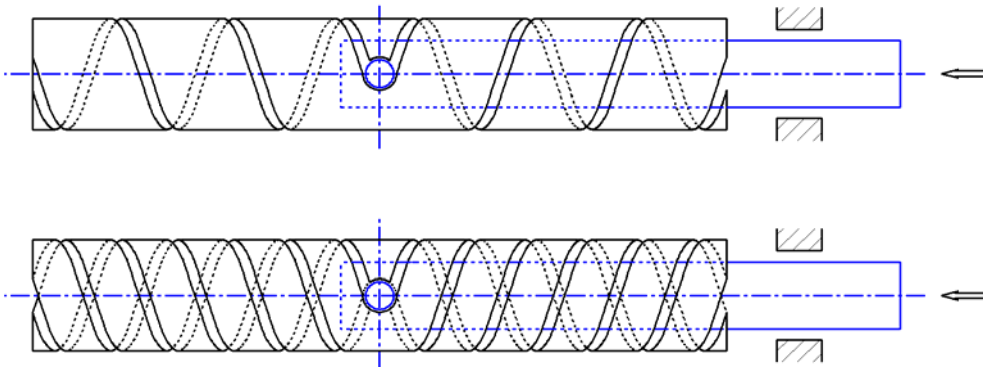


Figure 9. Symmetrical design helical springs (single and double threads)

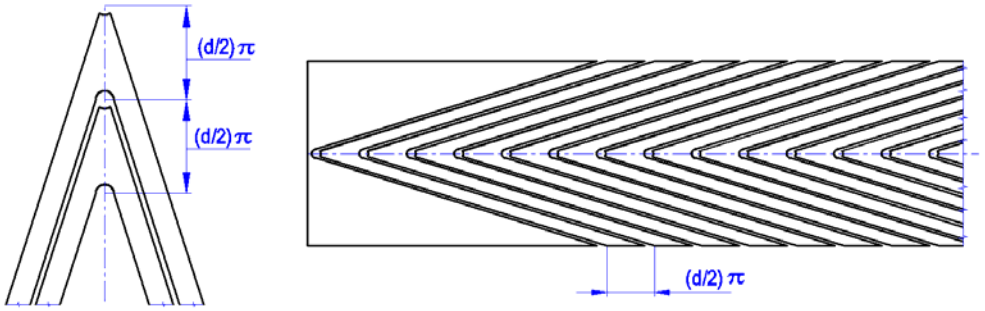


Figure 10. The plate pre-product of the balanced double thread helical spring

7. ASSEMBLY AND WINDING DIRECTION OF THE ELEMENTS IN THE EPICYCLIC TRACTION DRIVE

The principle and formation of flexible shafts is useable for the design of io type epicyclic traction drive. A flexible shaft consists of more layers of helical springs wound alternately and tightly on each other. Driving in the proper direction, the diameter of the outer layer is reduced. Let's consider an epicyclic drive, whose every rolling basic element is made of helical spring. The relationship between the winding direction and the sense of rotation of the springs is chosen to increase the diameter proportionally to the load in the outer connection (sun wheel – planet wheel) and to decrease the diameter at the ring gear. In such a way the generated clamping force between the elements will be proportional to the load. When all the rolling elements that is made of helical spring have symmetrical design, due to *Figure 9* and double thread, driven in at the middle of width, (or in case of ring wheel the middle point is fixed to the housing) then a flexibly operating, highly efficient drive is hoped of the described solution.

8. SUMMARY

One of the necessary constraints of the operation of epicyclic traction drives is the assurance of the proper clamping force. The well known solutions are based on mainly the self tensioning of a wedge roller, the relative axial displacement of the mating element in a drive containing conical element (*Figure 1*) or a mechanism transforming the axial displacement to radial one (*Figure 2*). Directly generated clamping force that proportional to the speed of the shaft is found only where the principle of the clamping device is on the centrifugal force. At the other group of the machine elements, namely at the free running clutches there are a lot of devices working on the principle of radial force closing. This paper investigates the usability of these principles at the area of epicyclic traction drives.

It was detected that the clamping device enveloped by flexible ring which has proper split angle may be suitable to ensure a clamping force proportionally to the load. It was also demonstrated that enlarging the split angle of the split hollow cylinder, a helical torsion spring is obtained. This spring is useable individually, too, and it is able to assure both the preliminary constraints of the high efficiency traction drives and the preliminary clamping force, and also the proportionality of the clamping force relatively to the load.

It was presented that the helical spring with symmetrical design, partly left- and right-hand wound, driven through the middle of its length and is favourable not only in terms of the loads but its material saving manufacturability also foresees the possibility of the economical design.

The join of the above described sun wheel and the driving shaft is easy through bending a nose part at the peak of the V-shaped plate strip (*Figure 10*). The ring wheel and possibly the planet wheels can be similarly formed. The design of bearings of the planet wheels to the planet carrier is not simple. The strength calculation of the helical torsion spring with sun wheel function was introduced in one of our previous papers [8], and the generation of uniformly stressed spring shape requires further analysis.

Acknowledgement

"This research was carried out as part of the TAMOP-4.2.1.B-10/2/KONV-2010-0001 project with support by the European Union, co-financed by the European Social Fund."

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