PRACTICAL IMPLEMENTATION AND OPTIMIZATION OF EVOLVENT CYLINDRICAL TOOTHED GEARS WITH ASYMMETRIC TOOTH PROFILE

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Abstract: *The paper deals with examples on practical implementation and optimization by different criteria of low-module evolvent cylindrical tooth gears with asymmetric profile in the course of the theorem for direction movement reversing without the presence of parameters summarized. Specific constructive solutions are represented with application in hydraulic gear pumps, differential and planetary mechanisms of type 2K-H, gear clutches and modifying device for one-profile checking.*

Keywords**:** *asymmetric tooth profile*, *practical implementation and optimization*

1. Introduction

The classical theory of tooth gearing takes as initial parameters for design the parameters of tool needed for gear wheels manufacturing. In order to complete a geometrical synthesis of one evolvent cylindrical toothed gear four initial parameters are needed to be known: module of toothed gear - m, profile angle of outgoing contour - α, coefficient of outgoing contour displacement - x, number of gear wheels tooths - z. These four parameters determine axiomatic design of gear mechanisms in case of tool parameters known. When using asymmetric evolvent cylindrical toothed gears the indefiniteness caused by selection of independent parameters disappears and 'free geometric synthesis' can be implemented.

Due to the long 15 years practice and more than 60 scientific papers on asymmetric profile problems the authors found that main problem of its use is reversing of direction movement [1, 2, 3]. For its solving the theorem is worked out by authors [4, 5] in the context of main law of gearing which enables toothed gears implementation with unknown till now quality and strength indices. On the basis of the theorem for direction movement reversing three approaches for geometrical synthesis and implementation of unconditional existence areas in the field of independent variables have been developed.

2. Practical implementation and optimization of toothed gears with asymmetric profile

The free geometrical synthesis of evolvent cylindrical toothed gears with asymmetric tooth profile defined by authors allows implementation of different effects expressive of hydraulic gear pump capacity increase, common and epicycloidal toothed gears carrying capacity increase, implementation of self-stopping gears in case of direction movement reversing.

2.1 Implementation in hydraulic gear pumps

From the industry an assignment has been given to design toothed gear with decreased tooth number by centroidal wrapping method by means of non-standard comb-type tool while saving overall dimensions. When setting requirements to the toothed gear are not met by symmetric tooth profile through outgoing contour displacement then applying of profile asymmetry is possible and implementation of gear with different from known yet quality indices also. A gear pump with increased actual capacity at the expense of operative surface inter-tooth increasing has been implemented by means of this method. The main advantage of such a gear is possibility for direction movement reversing with gear ratio saving but at the same time with considerable change of quality indices [6].

A new construction of hydraulic gear pump has been developed and experimentally tested while the following results are ascertained by means of report № 009/09.05.2002 г., Caproni PLC – Kazanlak stand: The capacity of pumps type ХЗП 00С 0,5Х047 – new construction is higher by 20,2 to 23,3%, in comparison with capacity of pumps being in production.

Figure 1. A model of hydraulic gear pump with asymmetric tooth profile tested

2.2 Carrying capacity increase of tooth gearing in epicycloidal toothed mechanisms

Except for quality indices of gearing the asymmetric tooth profile can increase gearing carrying capacity with or without direction movement reversing. This fact allows possible optimization of gear mechanisms in terms of transmitted driving torque or gearing stiffness which values are different in case of direction movement reversing.

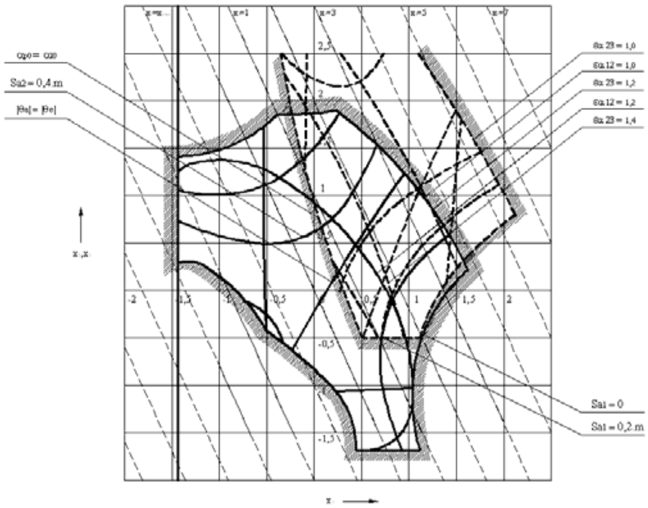

Figure 2. Blocking contour of reversible differential *2K-H mechanism with asymmetric tooth profile*

Use of asymmetric tooth profile in differential anr planetary mechanisms allows increase of their carrying capacity without change of gear ratio. On purpose to carry out this optimization of tooth profile blocking contours have been developed for 2K-H planetary mechanism allowing combining of existence areas in the field of independent tool displacements (Figure 2).

A three-dimensional model of differential gear which is served as a base for finite element analysis and general view of threading head 'TARMATIK' madnufactured by BALKAN PLC – Lovech are presented on Figure 3 [7].

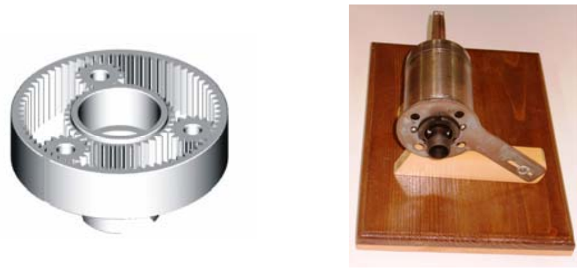

Figure 3. Model and general view of threading head 'TARMATIK'

By analogy a planetary 2K-H tooth gear with asymmetric profile has been developed with application in electro-mechanical screw driver manufactured by ZGPU PLC-Gabrovo (Figure 4).

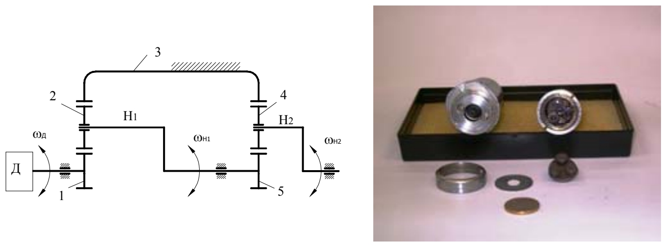

Figure 4. Kinematics scheme and general view of electro-mechanical screw driver manufactured by ZGPU PLC-Gabrovo

Both epicycloidal mechanisms (Figure 3 and Figure 4) with asymmetric tooth profile attain to effect of gear carrying capacity increase with saving of tooth number and mechanism degrees of freedom. Therefore this effect has to be used for mechanical devices with vastly loading in one of movement directions.

2.3 Implementation of tooth gears with minimum tooth number

The evolvent cylindrical tooth gears with minimum tooth number allow creation of special tooth mechanisms with decreased overall dimensions and maximum gear ratio.

In the context of theorem for direction movement reversing an unconditional existence area and model of tooth gear with gear ratio u=1 and tooth number $z_1=z_2=5$ have been developed (Figure 5).

Using asymmetric tooth profile it is possible to decrease by 40% minimum tooth number compared to minimum possible one in case of symmetric profile with symmetric contour $z_1=z_2=7$ toward $z_1=z_2=5$ [8].

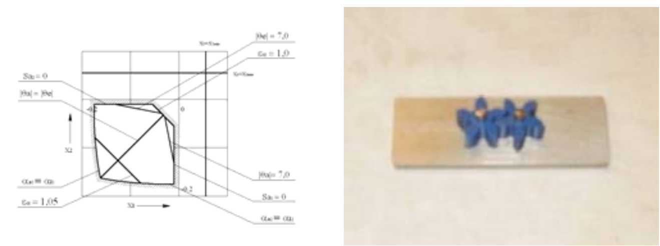

Figure 5. Tooth gear with asymmetric profile and minimum tooth number

On the basis of area represented (Figure 5) such reversible gear with asymmetric tooth profile has been implemented with outgoing contour displacement $x_1=x_2= -0,15$, and front coefficient of overlaping $\varepsilon_\alpha = 1,06$ and $\varepsilon^*_\alpha = 1,01$.

2.4 Implementation of self-stopping tooth gears

Research on unconditional existence areas in case of asymmetric profile and external toothing gets in touch with following general regularity: *when value of one of the toothing angles increases then value of another one increases also independently from its initial value.* Therefore the asymmetric tooth profile features: with lower coefficients of front overlapping in case of one of the toothing angles increase and higher ones in case of one of te toothing angles desrease (outgoing contour respectively) compared to outgoing symmetric tooth profile. That involves the presence of additional occurrences into the toothing which determine its specific character and practical unlimitedness, for example the presence of self-stopping effect.

Such gear tooth with asymmetric profile has been designed by classical approach but because of extremum angles of the comb-type tool a method of the thread erosion for production of gear wheels with thread gauge of 0,2 mm in 'Arsenal' PLC – Kazanlak has been applied [9].

In this gear with external toothing a self-stopping effect at tooth angle $\alpha^*_w=48,23°$ (Figure 6) has been achieved which is impossible with symmetric profile. This limitation was fixed for the first time by Professor V. A. Gavrilenko who advise to determinate the profile angles of outgoing symmetric contours from $\alpha \leq 35°$.

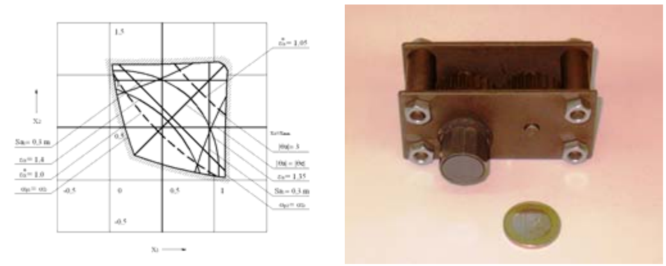

Figure 6. Tooth gear with asymmetric tooth profile and self-stopping effect

2.5 Implementation of tooth gears with internal toothing and minimum tooth number

In case of internal toothing and minimum difference in tooth number of evolvent cylindrical tooth gears with asymmetric tooth profile there is a narrowing of unconditional existence area because of additional interference presence. A boundary cases appear the mechanisms with internal toothing and equal tooth number where invariant sliding velocity in all of the active toothing line points for each of the profiles and different carrying capacity has been observed.

Figure 7 represents an evolvent cylindrical tooth gear with asymmetric profile, internal toothing and equal tooth number [10].

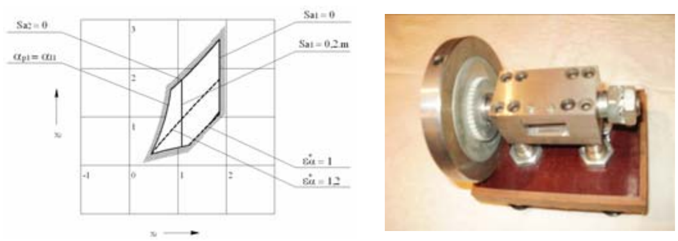

Figure 7. Tooth gear with asymmetric profile and equal tooth number of wheels $z_2=z_1=44$; profile angles of the tool $\alpha=20^\circ$ u $\alpha^*=30^\circ$

In the presence of fixed axes of gear wheels such a gear play a character of clutch which couples two parallel non-coaxial shafts. If given gear is a planetary mechanism so called 'satellite wheel' makes endlong movement while the trajectory of all its points is a circumference with diameter $2.a_w$.

2.6 Tooth gears with asymmetric profile and tooth slope

With a view to obtaining greater coefficients of overlapping it is possible to implement gears with asymmetric profile and tooth slope by means of using the theorem for direction movement reversing.

Figure 8 represents the unconditional existence areas of such a gear and a model of evolvent cylindrical tooth gear with asymmetric profile and tooth slope.

From this area the coefficients of displacement $x_1=x_2=0,5$ have been chosen while at width of the wheels b=5 mm the coefficients of overlapping achieved are $\varepsilon=2,2$ (1,61); $\varepsilon^*=2,0$ (1,46).

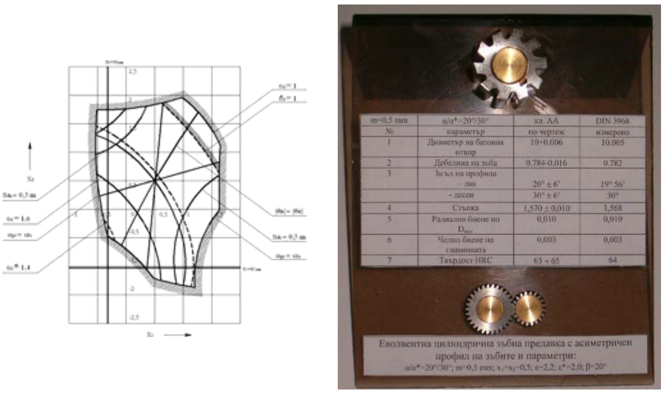

Figure 8. *Tooth gear with asymmetric profile and tooth slope β=20°*

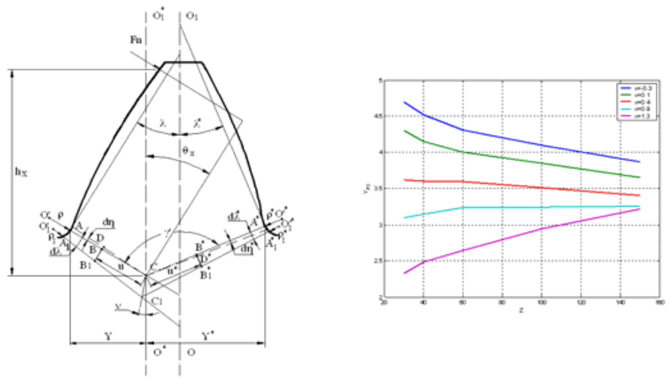

Figure 10. Method of non-plane cross-sections for determination of tooth-shape coefficient

2.7 Precision checking of low-module tooth gear with asymmetric profile

Tooth gears applied in the mechanical device construction are kinematics ones while there in the theory and practice is absence of complex ways for kinematics precision checking without changes and modifications necessary and connected with the asymmetric profile geometry.

The main method for kinematics error F'_{ir} measuring is one-profile complex checking. This method is applied for degrees of precision from 3 to 8. For degrees of precision mentioned group indices can be used also. In capacity of these ones for tooth gears with asymmetric profile it is convenient to use F_{rr} and F_{rc}. The group indices have to be chosen in such a way that one of them to present the radial F_{rr}, and another one F_{rc} – the tangential component of kinematics error.

For practical decision of problem discussed a modified device for one-profile complex checking has been developed. Device type БВ 5033 has been used as a pattern while a set of standard combs have been produced which serve for tangential and radial component of kinematics error determination (Figure 9).

Figure 9. *Modified device for one-profile checking of tooth gears with asymmetric tooth profile*

With a view to check the precision of low-module tooth gears with asymmetric tooth profile a methodology for precision checking has been introduced and tested which covers determination of size by rollers, radial beating and length of asymmetric normal in the firm ZGPU PLC-Gabrovo [11].

2.8 Determination of stressed and strained state of evolvent cylindrical tooth gears with asymmetric profile

The stressed and strained state of evolvent cylindrical tooth gears with asymmetric tooth profile is difficult because of absence of theoretical and experimental researches in this field.

The tooth-shape coefficient in case of asymmetry of tooth profile can be defined on the basis of the non-plate crosses method (Figure 10).

By means of non-plate crosses method it is established a parabolic law of distribution of stresses in the base and dependences have been got for the tooth-shape coefficient which are expalend graphically for different asymmetry [12].

As a comparative method for determination of stressed and stained state the finite element method has been used (Figure 11), while the coincidence of 5% in the base of the tooth has been achieved for equivalent stresses.

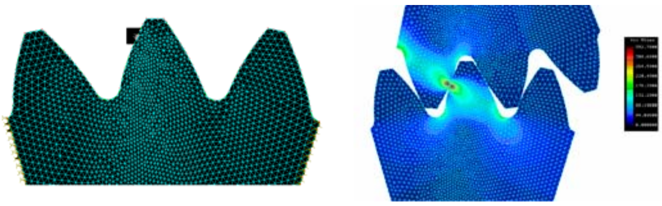

Figure 11. *Finite element method for asymmetric tooth profile*

In order to increase the precision while determine the contact stresses Master-slave surfaces have been used. In this case the loading is assigned as invariant driving torque which is uniformly distributed over finite elements area for driving gear wheel in cylindrical co-ordinates (Figure 12).

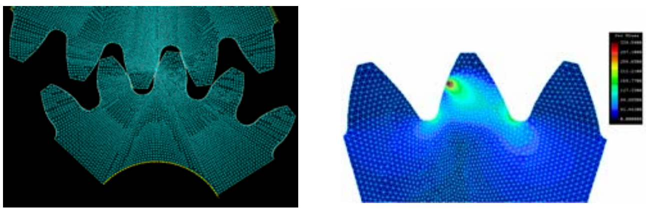

Figure 12. *Finite element method forasymmetric tooth profile*

For determination of deformation in evolvent cylindrical tooth gears with asymmetric tooth profile an approach by means of theory of elasticity methods has been developed by the authors. The main feature is determination of constants in the 'theory of endless cotter' in case of non-symmetric elastic semi-space which allows the determination of tooth profile moving along the toothing line (Figure 13).

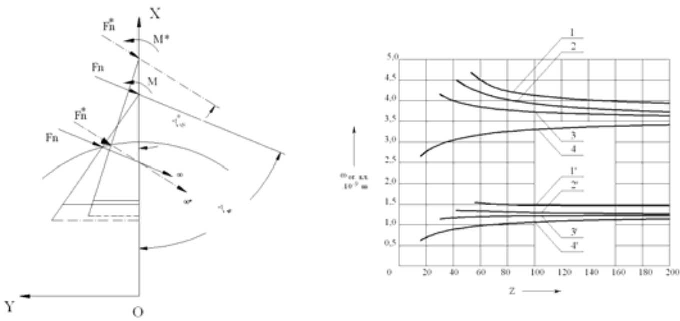

Figure 13. *Elastic displacement of tooth profile determination by toothing lines*

2.9 Optimal geometric synthesis of evolvent cylindrical tooth gears with asymmetric tooth profile

Defined by authors possibility II for forming of asymmetric tooth profile is close connected with the choice of optimal angles of the outgoing contour at preliminary set quality indices (Figure 14).

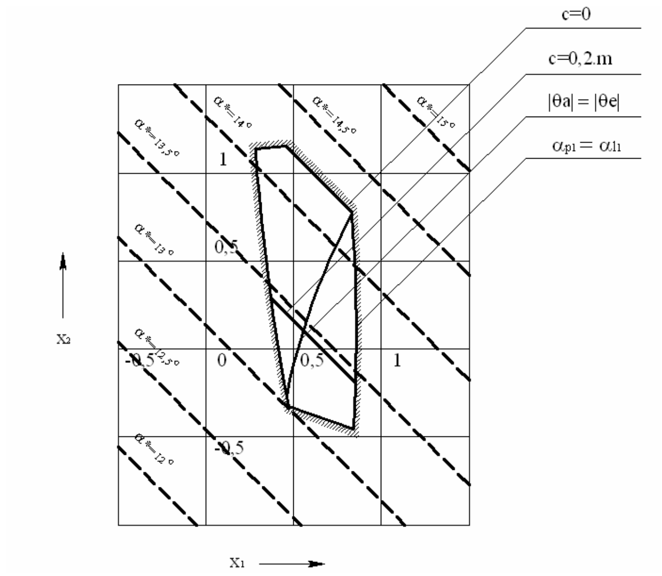

Figure 14. *Unconditional existence area of evolvent cylindrical tooth gear with coefficient of asymmetry 1,0368 and front coefficient of covering* $\varepsilon_\alpha > 1,4$ *guaranteed in all area*

The optimization area in Figure 14 is a new type one and till now it is not implemented for symmetric profile because of structural limitations imposed. This new area has additional isolines of invariant profile angle α^* of the outgoing contour which allows the space area of existing to be represent as a plane. *This way a decrease of the independent variables can be achieved in the axiom of tool toothing applied for asymmetric tooth profile while independent profile angle* α^* *of the outgoing contour is transformed into dependent variable.* Obtaining of such areas of existence is impossible out of the theorem for direction movement reversing in case of evolvent cylindrical tooth gears with asymmetric profile.

3. Conclusions

The authors 15 year practice has been summarized and represented which is in the field of optimal synthesis and practical implementation of evolvent cylindrical tooth gears with asymmetric tooth profile in the context of the theorem for direction movement reversing expressed in: tooth number of toothing decrease while saving quality and strength indices; optimization of epicycloidal gear mechanisms; implementation of tooth gears with self-stopping effect; design of tooth clutches with compensation of non-coaxiality of shafts.

On the basis of the theorem for direction movement reversing the optimal geometric synthesis in the field of independent variables – the coefficients of tool displacements has been expressed, their number is decreased in the axiom for tool toothing and approaches for determination of stressed and deformation state in different possibilities for forming have been expressed.

Methodology and modified device for one-profile checking of evolvent cylindrical tooth gears with asymmetric tooth profile allowing technological dimensions checking during production have been developed and proved.

By means of the theorem for direction movement reversing free geometrical synthesis and conversion of classical tooth gearing have been done through transformation of independent variable into dependent and optimization by quality indices of asymmetric tooth profile excluding geometrical tool parameters.

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