Improving Efficiency of Gear Shaping of Wheels with Internal Non-involute Gears

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Abstract. In the article questions of improving efficiency of gear shaping of wheels with internal non-involute profile gears. The technique of the analysis of kinematics parameters of gear shaping process is presented. Researches devoted to the influence of root profile form of processed wheel with interna. In the article questions of improving efficiency of gear shaping of wheels with internal non-involute profile gears. The technique of the analysis of kinematics parameters of gear shaping process is presented. Researches devoted to the influence of root profile form of processed wheel with internal non-involute gears on the thickness of the cutting-off metal layer, size of components of cutting forces and a roughness of the processed surface are given.

Introduction

In designs of modern cars and mechanisms details with internal periodic non-involute profiles are actively applied. These details are components of different gears and connections, such as cycloidal drives, epicyclic gearings, gear pumps, ratchet mechanisms, splines, etc., which are used in construction and mining machinery, agricultural machinery, an aircraft industry, the hoisting-and-transport equipment, railway transport and etc [1, 2].

One of the main problems of receiving internal gears of items is the operation determining the accuracy of gear wheel. More or less the only one operation allowing to receive internal gear in a mass production and providing the necessary productivity and accuracy at the minimum prime cost is gear shaping [3]. Modern designs of gear shaping machines include a large number of the axes operated from CNC for ensuring efficient work, reducing the time for readjustment, and solutions of various technological problems of a gear treatment, for example, cutting of two and more mutually oriented wheels. The similar equipment is created by the principles of modular configuration on the basis of one basic model, and in a modification design the concept of the main and support functions automation is realized. Advanced technologies of gear wheels production use machines with the CNC and the tool with high resistance that provides considerable speeds of processing (up to 320 m/min at gear shaping).

It should be noted that the technology of non-involute gear processing and tool profiling are developed insufficiently. In scientific and technical literature data on parameters and the processing modes is not provided.

Launching of gear wheels with internal non-involute profile gears, emergence of the new tool and processed materials forces to make new labor-consuming and expensive experimental investigations

on the definition of the cutting modes and the extent on its influence on surface accuracy. As a result of it, it is necessary to conduct theoretical researches of the impact of method, processing mode, and a gear shape on a kinematic, power characteristics of process, accuracy and a roughness [4] of the received surface, tool wear [5] and process productivity.

Receiving the desired quality indicators and the maximum process productivity at a stage of preliminary design makes actual a problem of technique development of the complex analysis of a tooth profile parameters, physicomechanical properties of tool material and material of preparation, parameters of tool and preparation geometry, kinematic and dynamic characteristics of processing of gear wheel with internal gears.

1. The Complex Analysis of Shaping Process

The analysis of gear shaping processing parameters is based on mathematical display of the cutting scheme. Processing of wheel with internal non-involute gear profiles is characterized by a mutual generating cutting process of the cutting tool edges (figure 1) [3], which remain within hypocycloidal trajectory (extended and truncated) relative to the processing billet [6]. While developing this representation the following assumptions were accepted:

-    the technological system is accepted as absolutely rigid;
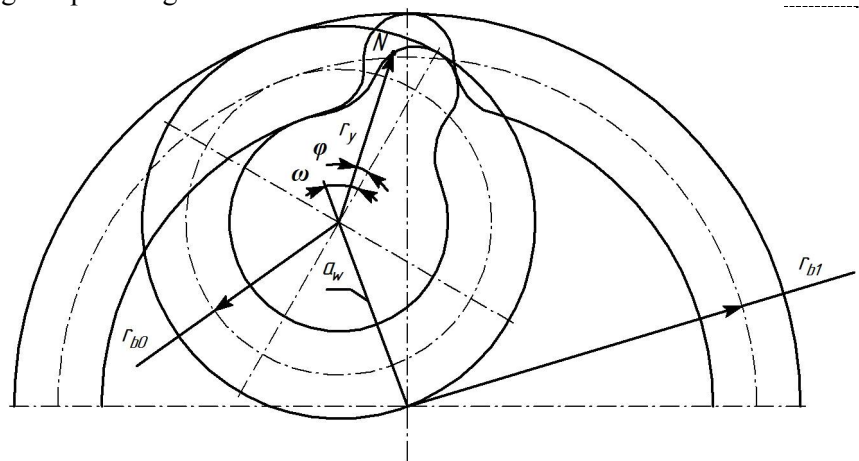-   tool edges represent geometrical lines.

Figure 3. Scheme of shaping cutter position definition concerning a gear wheel in the complex analysis of shaping process on the example of a cycloidal profile.

The equations of points movement of the shaping cutter cutting edges and its center relative to the detail is presented in a parametrical form:

$$X = a_w \sin\left[U_0\left(\omega + \frac{S}{r_0}\left(1 + \frac{l}{2L}\right)\right)\right] + \sqrt{x_{0i}^2 + y_{0i}^2}\,\sin\left[(1 - U_0)\left(\omega + \frac{S}{r_0}\left(1 + \frac{l}{2L}\right)\right) + \arcsin\frac{x_{0i}}{\sqrt{x_{0i}^2 + y_{0i}^2}}\right],$$

$$X = a_w \cos\left[U_0\left(\omega + \frac{S}{r_0}\left(1 + \frac{l}{2L}\right)\right)\right] + \sqrt{x_{0i}^2 + y_{0i}^2}\,\cos\left[(1 - U_0)\left(\omega + \frac{S}{r_0}\left(1 + \frac{l}{2L}\right)\right) + \arcsin\frac{x_{0i}}{\sqrt{x_{0i}^2 + y_{0i}^2}}\right], \qquad (1)$$

$$Z = l.$$

where a_w − is interaxal distance of a shaping cutter and the processed wheel, U_0 − is the relation of number of shaping cutter gear to the number of wheel gear, ω − is the corner defining position of shaping cutter tooth relative to the interaxal distance, S − is district giving, r_0 − is the radius of a dividing circle of a shaping cutter, l − is a width of a gear wheels, L − is stroke of shaping cutter, x_{0i} and y_{0i} are positioning coordinate of shaping cutter gear profile, received after profiling.

The analysis of the received representation of the cutting scheme allows to determine kinematic changes of corners by perimeter of an edge and thickness of the cut-off material layer for any point of a profile and at any time. These data are a basis of forecasting of cutting force components, and subsequently – of roughnesses of a gear wheel surface of non-involute wheels with internals gears and the accuracy of their processing.

Definition of kinematic changes of geometrical parameters of internal non-involute gear wheels processing (thickness of the cut-off layer, kinematic change of a forward corner and kinematic change of a back corner) was carried out with use of differential geometry methods, according to the formulas and the scheme that is presented in figure 2:

$$a = \frac{a_X V_{Xs} + a_Y V_{Ys} + a_Z V_{Zs}}{\sqrt{a_X^2 + a_Y^2 + a_Z^2}},$$

$$\Delta\gamma = \arctan\frac{a}{\sqrt{V_{Xv}^2 + V_{Yv}^2 + V_{Zv}^2}}, \tag{2}$$

$$\Delta\alpha = \arctan\frac{\sqrt{V_{Xs}^2 + V_{Ys}^2 + V_{Zs}^2}}{\sqrt{V_{Xv}^2 + V_{Yv}^2 + V_{Zv}^2}}.$$

where a_X, a_Y, a_Z – are vector a coordinates, V_{Xs}, V_{Ys}, V_{Zs} – are vector V_S coordinates, V_{Xv}, V_{Yv}, V_{Zv} – are vector V_V coordinates.

Theoretical researches of processing by a wheels gear shaping with internal triangular, cycloidal gears and gears of ratchet gearing were carried out at the following general parameters: height h of gears is 5 mm, wheel number z_1 is 19, gear number of shaping cutter z_0 is 14, thickness of gear wheel b is 90 mm, gear wheel material is steel 45 (1045, C 45), district giving S is 0.44 mm/double stroke, cutting speed V is 20 m/min.
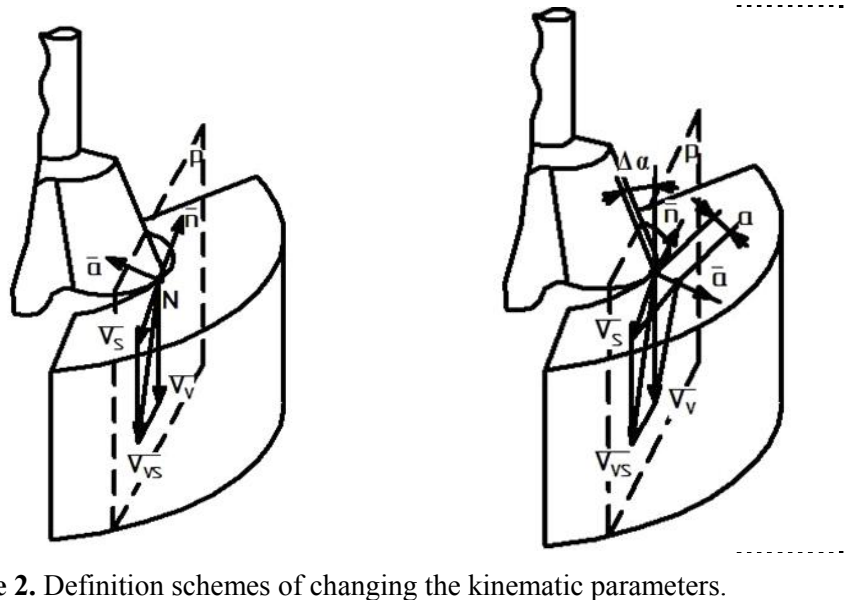

Figure 2. Definition schemes of changing the kinematic parameters.

It is established that at gear shaping the instrument gear has essential impact on change of thickness of the cut-off layers. S_o, at the identical modes of processing and heights of a profile the ratio between loading of an input and output edge is 1.2 for an evolvent root; 1.3 for a triangular and ratchet root; 2 for the cycloidal root.

Cutting forces are the key parameter of gear surface processing which defines quality of the cutting gear wheels and firmness of the cutting tool. Knowing cutting forces it is possible to calculate or

reasonably choose the cutting tool, devices, and also the power spent for cutting and a rational operating machine mode.

Optimization of operational opportunities of gear shaping machines on its productivity and quality of the cut wheels with internal gears is, first of all, connected with determination of the maximum amplitude of cutting forces and their change during gear processing. Calculation of components of cutting force of wheels gear shaping process with internal gears consists in determination of specific forces per unit of length of the shaping edge cutting edge and their subsequent summation on all cutting an edge, participating in cutting. For determination of specific cutting force ΔP experimentally receiving dependences of cutting force for the range of thickness of the cut-off layer from 0.01 to 0.5 mm, from -0.0175 to 0.0349 radians for forward corners and from 0.87 310- 2 to 0. 0524 radian for back corners and also the range of the cut-off thickness from 0 to 0.01 mm. Such division is necessary for the accounting of cutting process and a for metal layer crushing that is deleted by various sites of the cutting edge. Values of components of cutting force for all cutting edges are received by summation of the specific forces arising on an elementary part of the cutting edge:

$$
\begin{aligned}
P_Y &= \sum \Delta P_y \Delta b \cos(\Phi + \psi_{y0})K, \\
P_X &= \sum \Delta P_y \Delta b \sin(\Phi + \psi_{y0})K, \\
P_Z &= \sum \Delta P_Z \Delta b K.
\end{aligned}
\tag{3}
$$

where ΔP_Y, ΔP_Z are specific cutting forces, Δb – an elementary part of the cutting edge, F is a corner defining the wheel root positioning regard to interaxial distance, Δy_0 – is a corner between the point radius vector of the cutting edge and the line of gear symmetry, K is complexity coefficient of shaving formation.

In figure 3 schedules of components change of cutting force at processing by one gear of shaping cutter with internal gears of an evolvent, triangular, cycloidal profile and a profile of ratchet gearing from steel 45 (1045, C 45) are submitted with a height of tooth of h=5 of mm, S is 0.44 mm / double stroke, at the standard modes of cutting. Figures shows that the profile of the processed root has direct impact on the making cutting forces that is connected with change of length of the active cutting edge of an edge of shaping cutter gear and the total area of the cut-off material layer during processing.


a

b
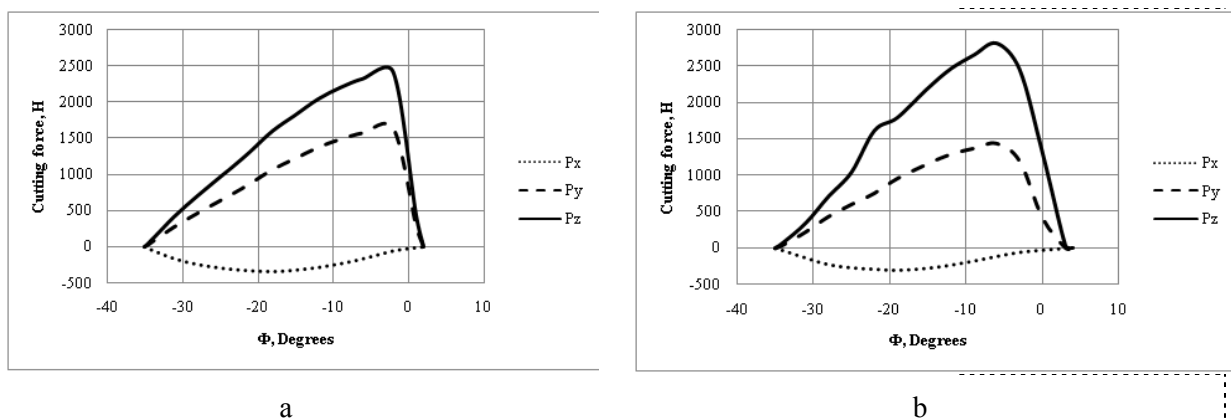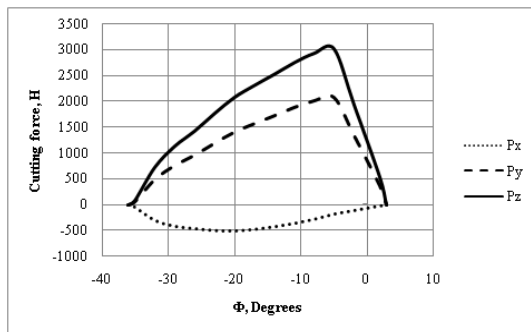
c
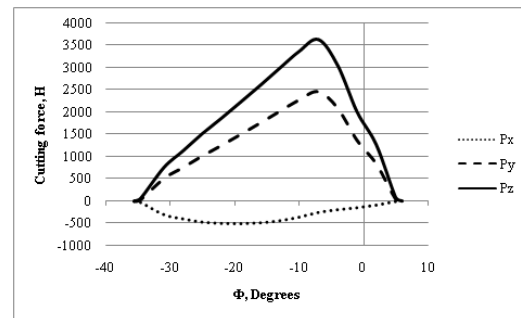
d

Figure 3. Cutting force during the work of one gear of shaping cutter at a gear shaping of wheels with internal gears: a – for evolvent profile, b – for triangular profile, c – for cycloidal profile, d – for a profile of ratchet gearing.

In Fig. 4 change of cutting force components in operating time of all gears which are in cutting when processing wheels with internal evolvent, triangular, cycloidal gears and gears of ratchet gearing is presented. Researches of cutting force components showed that the gear shaping of wheels with internal gears of non-involute profile from steel 45 (1045, C 45) with a gear height is h=5 mm, S is 0.44 mm / double stroke, V = 20 m/min is characterized by the following ratios: processing of a triangular and evolvent profile – P_{YT}/P_{YE} = 0.81, P_{ZT}/P_{ZE} = 1.09, P_{ZT}/P_{ZE} = 1.28, a cycloidal and evolvent profile P_{YC}/P_{YE} = 1.38, P_{ZC}/P_{ZE} = 1.38, a ratchet and evolvent profile – P_{YR}/Y_E = 1.27, P_{ZR}/P_{ZE} = 1.28.
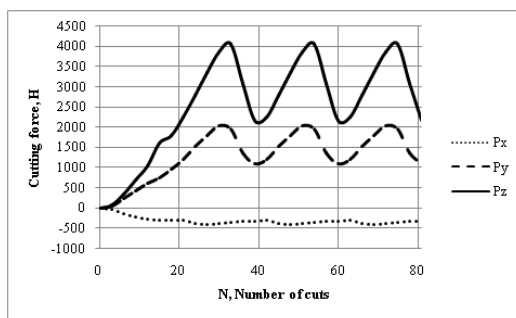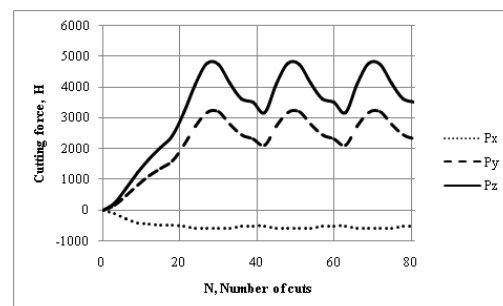

a
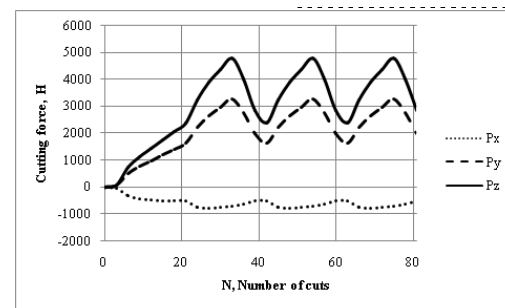
b
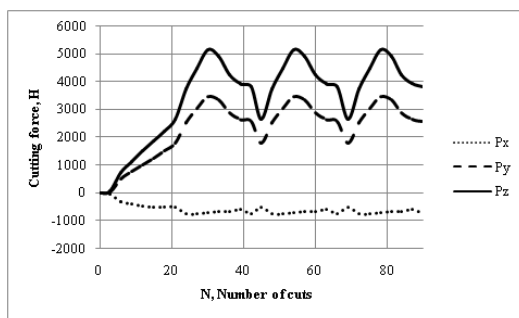
c

d

Figure 4. Cutting forces at a gear shaping of wheels with internal gears: a – of evolvent profile, b – of triangular profile, c – of cycloidal profile, d – for a profile of ratchet gearing.

2. Experimental Research

Experimental research of cutting force components at a gear shaping of wheels with internal non-involute gears was made by means of a universal dynamometer of UDM-600, the personal computer and the LabView environment. Works were performed on the gear shaping machine 5140. The program of pilot studies provided measurement of three mutually perpendicular components of cutting force at processing a wheel with internal gears of a triangular profile. The universal dynamometer UDM-600 was applied to the definition of three components of cutting force.

The system works as follows. Signals from the strain gages pasted on elastic elements of a dynamometer arrive on a payment of balancing resistance, then on amplifiers of signals of SG - 3016 which are working from a voltage of 15V. After that signals from amplifiers are given on a payment of ADC of the personal computer which directly transmits signals to the LabView software. By means of a program application on the monitor of personal computer curves that are equivalent to cutting forces are displayed.

When carrying out experiment specially developed adaptation serving for fixing of billet of a wheel with internal gears of non-involute profile in UDM (figure 5) was used. The adaptation is attached on UDM-600 by means of 6 openings. Fixing of billet is carried out by holding straps on openings. Experiment duration on the developed installation takes few minutes. Before measurement of cutting forces the dynamometer calibration in a static state by loading of cutting (serial) in the direction of force components action is carried out and the indication of a virtual oscillograph in the LabView environment on this component is fixed.

Because of casual errors of separate measurements cannot be excluded completely, for reduction of value of measure of inaccuracy some parallel experiments were made. At measurement of cutting force their number equaled 6, 7 or 8.

In the process of experimental researches establishment of cutting force components dependence on the processing modes (speed of cutting or giving), parameters of the processed billet (a profile of gear or the module) was planned. Preparations for research were selected from one party of delivery and were checked for hardness before researches, for more complete elimination of influence of fluctuations of hardness and a chemical composition of preparations on an error of measurement of cutting force. To exclude influence of scratches of the cutting edge on an error of measurements, before experiences the cutting tool is examining under a microscope. Wear on a back lateral surface of gears is allowed no more than 0.03 mm.
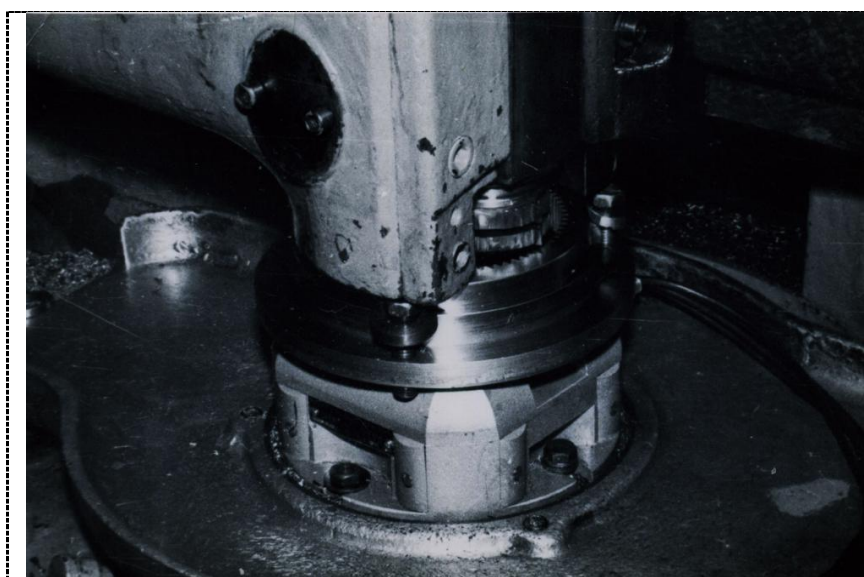

Figure 5. Appearance of experimental installation for measurement cutting forces

The obtained data when carrying out experiment are given in Fig. 6, 7, 8, 9. The difference in values of cutting force between theoretical data and received experimentally makes 4-11%. Besides, P_X differs up to 4%, components P_Y and P_Z – to 11%. Also it was established that at increase in circular giving the making forces of cutting and amplitude of their fluctuation grow not in proportion to giving. This results from the fact that at increase in district giving thickness of the cut-off layer increase and the specific force that contains cutting force growth decreases.
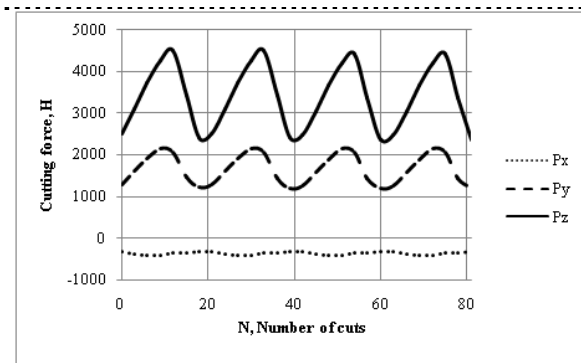

Figure 6. Change of cutting force components at a gear shaping of wheels with internal gears of the triangular profile.
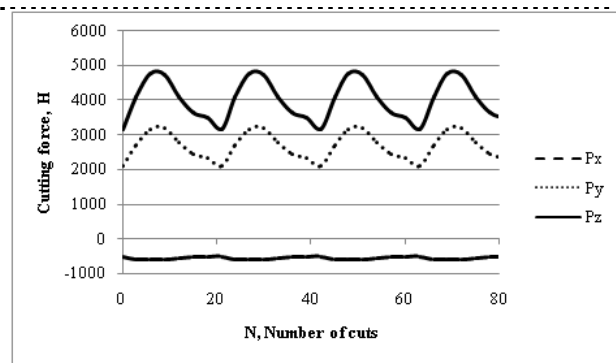

Figure 7. Change of cutting force components at a gear shaping of wheels with internal gears of the ratchet profile.
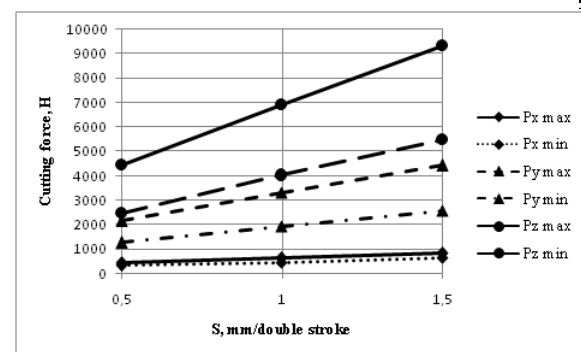

Figure 8. Cutting forces at a gear shaping of wheels with internal gears of the ratchet profile.
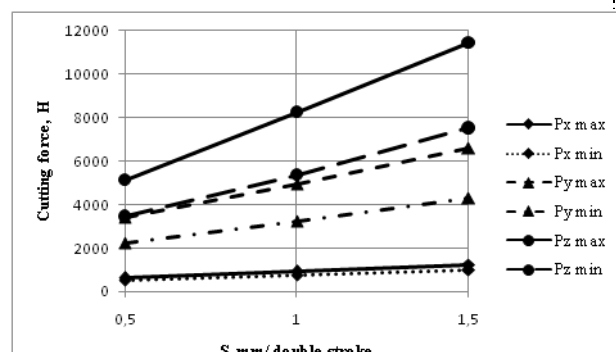

Figure 9. Cutting forces at a gear shaping of wheels with internal gears of the triangular profile.

3. Conclusions
The complex of universal mathematical software of display of the cutting scheme of a gear shaping of wheels with internal non-involute gears including the description of the tool movements and billet which analysis by means of provisions of differential geometry allowed to establish analytical dependences for definition of working corners of the cutting edge, thickness of the cut-off layer on a profile of the cutting edges, is developed. This further allows to define fluctuations of components of cutting force which have solving impacts on values of a roughness and accuracy of a product with internal non-involute gears. Dependences of ratios between loadings entrance and the output cutting edge are established at a gear shaping of wheels with internal gears with an identical height of gear which make: 1.2 for evolvent gears; 1.3 for triangular gears and gears of ratchet gearing; 2 for cycloidal gears. Numerical dependences between sizes of components of cutting force and a gear profile of shaping cutter are established.

References

[1]   K Nagamura, K Ikejo, F G Tutulan Design and performance of gear pumps with a non-involute tooth profile Proceedings of the Institution of Mechanical Engineers, Part B: J of Engineering Manufacture. **218 (**2004) 699-711

[2]   F L Litvin, I Gonzalez-Perez, A Fuentes, K Hayasaka Design and investigation of gear drives with non-circular gears applied for speed variation and generation of functions Computer methods in applied mechanics and engineering **45** (2008) 3783-3802

[3]   K D Bouzakis Manufacturing of cylindrical gears by generating cutting processes: A critical synthesis of analysis methods CIRP Annals-Manufacturing Technology **57** (2008) 676-696

[4]   A Gok new approach to minimization of the surface roughness and cutting force via fuzzy TOPSIS multi-objective grey design and RSA Measurement **70** (2015) 100-109

[5]   J Gerth, On the wear of PVD-coated HSS hobs in dry gear cutting Wear **266** (2009) 444-452

[6]   G Figliolini, P Rea Effects of the design parameters of involute gears generated by rack-cutters International Gear Conference (2014) 294