# PC-AIDED DESIGN OF GEAR MOLD DIES FOR CYLINDRICAL AND BEVEL PLASTIC GEARS

## КОМПЬЮТЕРНОЕ ПРОЕКТИРОВАНИЕ ФОРМООБРАЗУЮЩИХ МАТРИЦ ДЛЯ ЦИЛИНДРИЧЕСКИХ И КОНИЧЕСКИХ ЗУБЧАТЫХ КОЛЕС ИЗ ПЛАСТМАСС

Prof., Dr. Sc. Starzhinsky V.E.[1], Dr. Ph. Ossipenko S.A.[1], Ing. Starominsky V.B.[2], Ing. Slepov Yu.A.[2]

V.A. Belyi Metal-Polymer Research Institute of National Academy of Sciences of Belarus, Gomel, Belarus. E-mail: mpri@tut.by[1].
Public Joint-Stock Company "RATEP", Serpukhov, Russia. E-mail: ratep@online.stack.net[2].

The problem of CAD/CAM/CAE for toothed tooling mold dies intended for injection molding of cylindrical and bevel gears is considered. A software for computation of spur, helical and bevel gear pairs, gears, gear tooling dies and EDM- electrodes is suggested. For construction of 3-D gear models for spur and helical gears the transverse gear section is used. For the straight bevel gear model two sections at different distance from the cone apex and perpendicular to the bevel gear axis are employed. Gear models are built with the help of *Solid Works* software. The software algorithm provides for determination of nominal dimensions and geometrical parameters, selection of tolerances, calculation of guaranteed quality ratios and measured parameters, computation of tooth ring profile coordinates for construction of 3-D gear models and manufacture of gear tooling dies on EDM-wire cutting machines or ED-sinking ones.

GEARPAIR-SOFTVARE, HELICAL GEAR, STRAIGHT BEVEL GEAR, MOLD DIE, EDM-ELECTRODE

### 1. INTRODUCTION

Production of plastic gears, including the whole cycle of designing, tooling-up and distribution of the product has been adopted by a number of companies specialized in manufacture of precision plastic parts. As e.g., *ABA-PGT, Inc*. (Manchester, GB) designs and manufactures molds for plastic gears and is engaged in their injection molding [1]. *Crown Gear B.V.* (Enshede, Germany) specializes in production of gears for transmissions with crossed axes having a patented type of involute system Cylkro (cylindrical pinion meshing with a spur bevel or crown wheel) [2]. *Seo Woo Mold Tool Co., Ltd*. (Inchon, Korea) produces dies and distributes precision fine-pitch gears. *SMPI* (Kruset, France) suggests services in designing, optimization, production and assembling of drives with plastic gears. *JUKEN Kogyo Co., Ltd* (Aichi, Japan) offers the complete set of services on injection molding technology of middle-sized and ultra-miniature moldings, including a large range of plastic gears [3].

Special requirements are imposed on design and manufacture of intended for gear forming dies. The main problem of design methods is the correct allowance for mold shrinkage. The latter is considered in forming tools by the purpose of the nonstandard module, nonstandard profile angle and increased shift ratio. Number of taken into account components of mold shrinkage depends on available information on material properties, part structure, presence of prototypes and experience in material processing into articles.

### 2. STATE OF THE ART

Later, in [4] a scientifically grounded concept was proposed based on a generalized geometrical theory of gearings by A.B. Vulgakov. The concept discloses the question of corrected calculation of the main dimensions and accuracy indices of mold dies and gears with account of the differential value of mold shrinkage by three parameters: tip diameter, base diameter and tooth thickness on base diameter.

Both calculation procedures and software intended for different variants of design of toothed mold dies for spur cylindrical gears using various initial data have been developed based on this approach [5-7].

In work [8] the problem of tolerances for molded and formed plastic gears is studied while measurement methods to calculate three components of mold shrinkage and to estimate accuracy of named methods are proposed in [9].

Diagrams of mold shrinkage dependence on gear diameter approximated by logarithmic curves are shown in [10], and regression equations are given in confirmation of independent variables effect, i.e. geometrical parameters (module and tooth number), on shrinkage components. It is proposed in [11] to consider difference of shrinkage in various directions by four components, including tooth thickness across tips and spaces. Investigation results are cited in [12-14].

In review [15] it was shown how accuracy rose when three shrinkage components were used as compared to a simple scheme of radial shrinkage calculation. In [16] the formalized techniques of tooth ring profile coordinates computation were suggested. In [17] variants of fillet curve formation of tooth profile are shown. In [5] variants of computation are given when different complexes of initial data are available.

All described calculation methods and computer programs were intended for the spur cylindrical gears, whose mold dies are manufactured by the EDM-wire cutting method.

The report is dedicated specially to designing mold dies for helical and bevel gears made by the EDM-tool electrodes. **GearPair**-Software for realization of the method is being considered.

### 3. SOFTWARE CONCEPT AND CONTENTS FOR PLASTIC GEARS DESIGN

**GearPair**-Software is intended to design geometrical parameters of involute external cylindrical spur and helical gear pairs and orthogonal Straight bevel gear pairs with injection molded plastic gears. Tooth dimensions and proportions correspond to the basic rack tooth profile of the State Standard GOST 13755-81 (for cylindrical gears) at module $m \geq 1$ mm, GOST 13754-81 (bevel gears) at $m \geq 1$ mm and GOST 9587-81 (cylindrical and bevel gears) at $m < 1$ mm.

Limiting values of geometrical parameters are the following:

– module – $m$ – from 0,1 to 10 mm;
– reference diameter (mean reference diameter for bevel gears) – $d \leq 400$ mm;
– center distance – $a_w \leq 250$ mm at $m \geq 1$ mm and $a_w \leq 180$ mm at $m < 1$ mm;
– mean cone distance $R_m \leq 200$ mm.

Design of geometrical parameters and nominal dimensions of cylindrical gear pairs and gears is made in accordance with GOST 16532-83; those of bevel gear pairs and gears – in accordance with GOST 19624-74, standard tooth coning – in accordance with GOST 19325-73, providing the constant radial clearance along the whole tooth length.

At designing cylindrical or bevel gear pairs the following positions are realized:

– tolerances in accordance with accepted quality degree, kinds of conjugations and kinds of backlash tolerances $T_{jn}$ are selected;

- conditions providing correctness of measurement are checked;
- control of meshing quality of geometrical indices (absence of tooth undercut, check of the contact ratio and tooth thickness on the tip surface) is made;
- change of gear dimensions under the influence of operating temperature and environment humidity are taken into consideration.

The final data obtained at the gear pair design are the base for designing toothed mold dies and EDM-electrodes. In the process of computation with **GearPair**-Software the following parameters are determined:

- mean value and confidence interval of mold shrinkage at a given reliability ratio;
- geometrical parameters of the mold die and EDM-electrode, their controlled sizes and tolerances;
- coordinates of mean, upper and lower tooth profiles of the mold die;
- coordinates of gear nominal, upper and lower tooth profiles, corresponding the tooth ring nominal dimensions, upper and lower allowance of tooth ring sizes, accordingly;
- coordinates of EDM-electrode for manufacture of the mold die with inter-electrode shift (clearance) given by operator;

**Solver**-software is a supplement to **SolidWorks** (**SW**) software. It is intended to transmit dxf-files, containing information about geometry of the gear, mold die and EDM-electrode tooth ring profile to **SW**-software. With the help of **SW**-software 3D-models of the gears, mold die and EDM-electrodes are constructed.

### 3.1. Cylindrical plastic gears: design of the mold dies and EDM-electrodes

When the parameters of cylindrical gear pair and mating gears are determined, geometrical parameters and coordinates of toothed profiles of the tooling mold dies and EDM-electrodes are computed by **GearPair**-Software. The **GearPair**-Software permits to compute the forming mold dies, using 1) the limiting mould shrinkage $\varepsilon_{min}$ and $\varepsilon_{max}$ are available in reference books on plastics and 2) the results of simulator or gear measurements. In the second case the first statistical characteristics of mould shrinkage are determined, namely mean value $\bar{\varepsilon}$, root-mean-square deviation $\sigma_{\varepsilon a}$ and confidence interval $\Delta\varepsilon_a$ of mold shrinkage. Computation is performed according to mean shrinkage value and average parameters of plastic gear, corresponding to the tolerance field middle. Parameters $d^m_b$ and $d^m_a$ are determined by the following formula:

$$d^m_b = (d^g_b - d_h * \bar{\varepsilon})/(1-\bar{\varepsilon})\,;$$

$$d^m_a = (d^g_a - d_h * \bar{\varepsilon})/(1-\bar{\varepsilon})\,,$$

whence, profile angle $\alpha^m = \alpha^g$, $m^m$ is found. Then the value of tolerance for shifting coefficient of the mold die are computed by the formula:

$$T^m_H = T^g_H + m^m \cdot z \cdot \cos\alpha \cdot (InvB2 - InvB1)/(2 \cdot \sin\alpha)\,, \quad (1)$$

where $B1$ and $B2$ – auxiliary angles determined by the formula:

$$\cos B1, B2 = (1 \pm \bar{\varepsilon}/2) \cdot \cos\alpha \big/ \left[1 \mp 0.5 \cdot \bar{\varepsilon} \cdot d_h \big/ \left(m^m \cdot z\right)\right].$$

$T^m_H \le 0$ means that deviation of shrinkage from its mean value does not permit to fabricate the plastic gear with the given accuracy of tooth thickness.

By equating the overage shifting coefficients of female die and gear $\bar{x}^m = \bar{x}^g$, the limits of female die shifting coefficient variation are found within which production of gears with a given accuracy is possible:

$$x^m_{\max,\min} = \bar{x}^m \pm T^m_H \big/ \left(2 * m^m\right).$$

The tolerance for female die tip circle diameter is determined from the formula:

$$T^m_{d_a} = T^g_{d_a}/(1-\bar{\varepsilon}) - \Delta\varepsilon * (\bar{d}^g_a - d_h)/(1-\bar{\varepsilon})^2\,. \quad (2)$$

Further computation of sizes to control female die tooth thickness (pin measurement, span measurement), as well as computation of typical coordinates of tooth profile are performed. Using these points the profile graphic image is obtained. The involute portion restricted by points of involute conjugation with the fillet curve and tip round arc, is approximated by the minimal circle arcs, where from approximation error is not higher the value, given in computation.

The fillet curve geometry is determined by the parameters and shifting of the base rack, design module and tooth number.

Coordinates of typical points may be transmitted into the exchange file DXF for using in graphic editor. In addition, these coordinates help to calculate NC-codes in relative displacements, serving as initial data for recording control program for the wire cutting machine.

EDM-electrode is manufactured based on the design mold die profile parameters, and it is different from the mold die profile by the value of inter-electrode clearance given by the operator. Similarly to the mold die profile EDM-electrode profile represents a system of conjugate circle arcs constructed with the same centers as the mold die ones but with radiuses less than those of the mold die of the involute profile part and more than those of the mold die of the fillet curve to a value of the inter-electrode clearance.

Data received for the coordinates of transverse tooth profile of the gear, mold die and EDM-electrode by the **GearPair**-Software are transmitted into the exchange dxf-file with the help of which 3D-models of gears, mold dies and EDM-electrodes in **SW** Software are constructed.

### 3.2. Straight bevel plastic gears: Design of mold dies and EDM-electrodes

Geometrical parameters of the mold die and EDM-electrode for bevel gears are determined by a similar method by which cylindrical gear parameters are calculated.

Accepted in the first approach equality of molding shrinkage ε to the gear outer and inner diameters and the tooth ring face-width mean value of the outer mold die module $m^m_e$ and cone distance $R^m_e$ are determined as shown below

$$m^m_e = m^g/(1-\varepsilon);$$

$$R^m_e = R^g_e/(1-\varepsilon).$$

By the same way as with cylindrical gears mean mold shrinkage and its deviation are taken into account.

If the allowance for the tooth thickness is given as the minimal constant chord deviation $E_{s\bar{cs}}$ and its tolerance $T_{s\bar{c}}$ then the average value of additional addendum modification coefficient for the gear $x^g_{mid}$ and its tolerance $x^g_{\overline{Tsc}}$ are determined by the following equations:

$$x^g_{mid} = (x_{Es\overline{cs}} + x_{Es\overline{cs}Ts\bar{e}})/2;$$

$$x^g_{\overline{Tsc}} = (x_{Es\overline{cs}} - x_{Es\overline{cs}Ts\bar{e}}).$$

Additional mean addendum modification coefficient for the mold die is accepted equal to one of the gear. Design tolerance on additional addendum modification coefficient is determined in accordance with the formula (1).

Limiting values of mold die addendum modification coefficient are determined by the formula:

$$x^m_{\min,\max} = x^m \pm T^m_{sc}(2m^m_e).$$

Tolerance for the model tip diameter (mold die root diameter) is calculated by the formula, similar to (2).

If to accept that for the bevel plastic gear the mold shrinkage in a general case is different from the outer diameter ($\varepsilon_{de}$), inner diameter ($\varepsilon_{di}$) and facewidth of the gear tooth ring ($\varepsilon_{bw}$), then the corrected value of the mold die cone angle $\delta^m$ should be determined by the formula:

$$tg\delta^m = \frac{d^g_e(1-\varepsilon_{de}) - d^g_i(1-\varepsilon_{di})}{(1-\varepsilon_{de})(1-\varepsilon_{di})} \cdot \frac{1-\varepsilon_{bw}}{2b^g_w}.$$

EDM-electrode geometrical parameters are found analogously with consideration of the inter-electrode clearance value.

To receive the initial data for construction of a 3D-model of the bevel gear, mold die and EDM-electrode it is necessary to compute coordinates of tooth ring profiles in planes, perpendicular to the gear axis. Construction of the profiles for the bevel gear, mold die and EDM-electrode is analogous and contains the following steps.

1. The coordinates of equivalent gear involute profile approximated by circle arcs and coordinates of other typical points including the fillet curve profile are designed.
2. Profile of equivalent gear tooth ring is projected on the surface of the back cone with determination of the profile point coordinates X, Y and Z relatively to the reference cone apex.
3. Obtained point coordinates are projected on the design plane DD (Fig. 1) corresponding to the outer tooth ring design section, through the tooth top land, and perpendicular to the gear (mold die, EDM-electrode) axis.

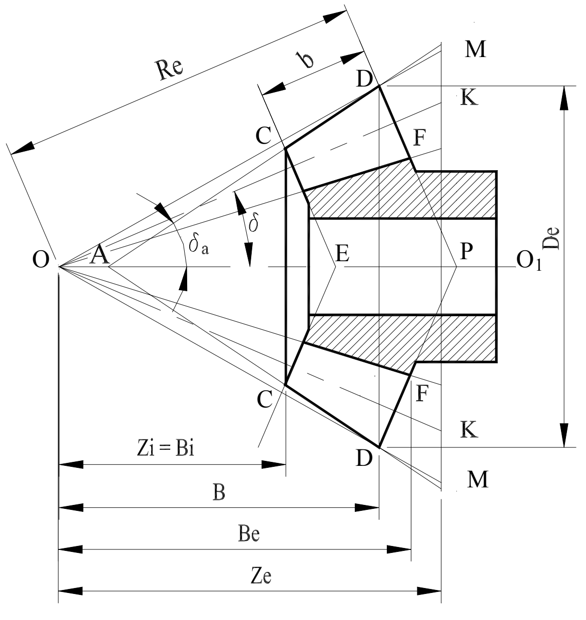


Fig. 1. Scheme to the construction of auxiliary planes of bevel gear model

4. Obtained point coordinates are projected on the inner and outer auxiliary planes FF or MM (Fig. 1) perpendicular to the gear axis the planes are located from the reference cone apex on the distances (along the gear axis) $Z_i = B_{ai}$ and $B_{fe} \leq Z_e$ accordingly, where $B_{ai}$ and $B_{fe}$ are distances from the reference cone apex to the inner tooth top land section ($B_{ai}$) and outer tooth root section ($B_{fl}$) (Fig. 1).

Information on the profile coordinates in the inner and outer planes is recorded in the form of **dxf**-file and transmitted to **SW**-Software for construction of 3D-models of bevel gear, mold die and EDM-electrode. When necessary the inner CEC and outer DPD back cones could be constructed (Fig. 1)

By that method the nominal, upper and lower tooth ring profiles of the gear, mold die and EDM-electrode could be designed and constructed.

### 3.3. Scheme of the Software interaction. File structure, format and purpose

Scheme of input and output files format and interaction between the softwares is shown in the Fig. 2. File names consist of next parts: NAME 1, NAME 2 – file names of mating gears; - _1X – denotes driving gear (pinion), where symbol X – direction of inclination for helical gear: R – right, L – left, absence of the symbol indicates that it is a spur gear; - _2X – denotes a driven gear (gear wheel); - -0…-6 – denote gear ring profiles:

0, 1, 2 – profiles corresponding to the mean, upper and lower allowance for size of the female die toothed profiles, accordingly (mean female die toothed profile is a profile whose coordinates are used for manufacture. Upper and lower allowance for the female die toothed profiles are the profiles whose female die could be manufactured with account of a given or designed shrinkage deviations); 3, 4 – upper and lower allowance for size of gear profiles are accordingly the profiles between which the actual profile size should be found account of a given or designed shrinkage deviations; 5 – EDM-electrode mean toothed profile whose coordinates are designed to take into account the inter-electrode clearance; 6 – nominal (design) gear tooth ring profile.

Numbers are added to the file name automation.

File format of the **GearPair** software and its purpose are the next.

File with expansion **cgp(bgp)** is a gear pair data-file. It is a basic input file, which contains the results of the gear pair (pinion/gear wheel) design in the text format. File could be open by **GearPair** Software for edition.

File with expansion **doc** – report file which represents a copy of the file **cgp(bgp)** in WORD format.

File with expansion **rtf** contains data included in the tables of the gear tooth ring parameters for gear drawings.

File with expansion **dxf** contains gear tooth ring design (nominal) profile coordinates. The file is used to obtain drawings of gear tooth ring design (nominal) profiles in any CAD-system, for example AutoCAD.

File with expansion **imm** is an exchange file aimed at translation of **GearPair** Software design results in **Solver**-Software as the initial data.

File format of the **Solver-**Software and its purpose are the following.

File with expansion **imm** is the basic file of **Solver**-Software containing design results of the **GearPair**-Software. The file could be open by **Solver-**Software for edition. According to selection of the operator from a single file **imm** in turn, it is created and automatically saved and contains data on different toothed ring profiles of the gear, female die and EDM-electrode in the next formats:

File with expansion **dxf** contains tooth ring profile coordinates.

File with expansion **txt** is a report file containing initial data, inspection data, coordinates of typical points of tooth ring profiles.

File with expansion **sldprt** is a 3D - toothed ring model in format **SW**.

In addition, the **Solver**-Software provides the creation of an assembly from a pair of the gears in which their rotation is simulated. It provides the detection of the possible profile interference at different values of tolerances, radial and axial run-out, axes scew asked by the operator.

Assembly file is preserved in the **SW** assembly format **- *.sldasm**. When simulation of rotation in the assembly takes place the report file is created automatically (ASCII-file with expansion log). The file contains information about performed actions and defected problems.

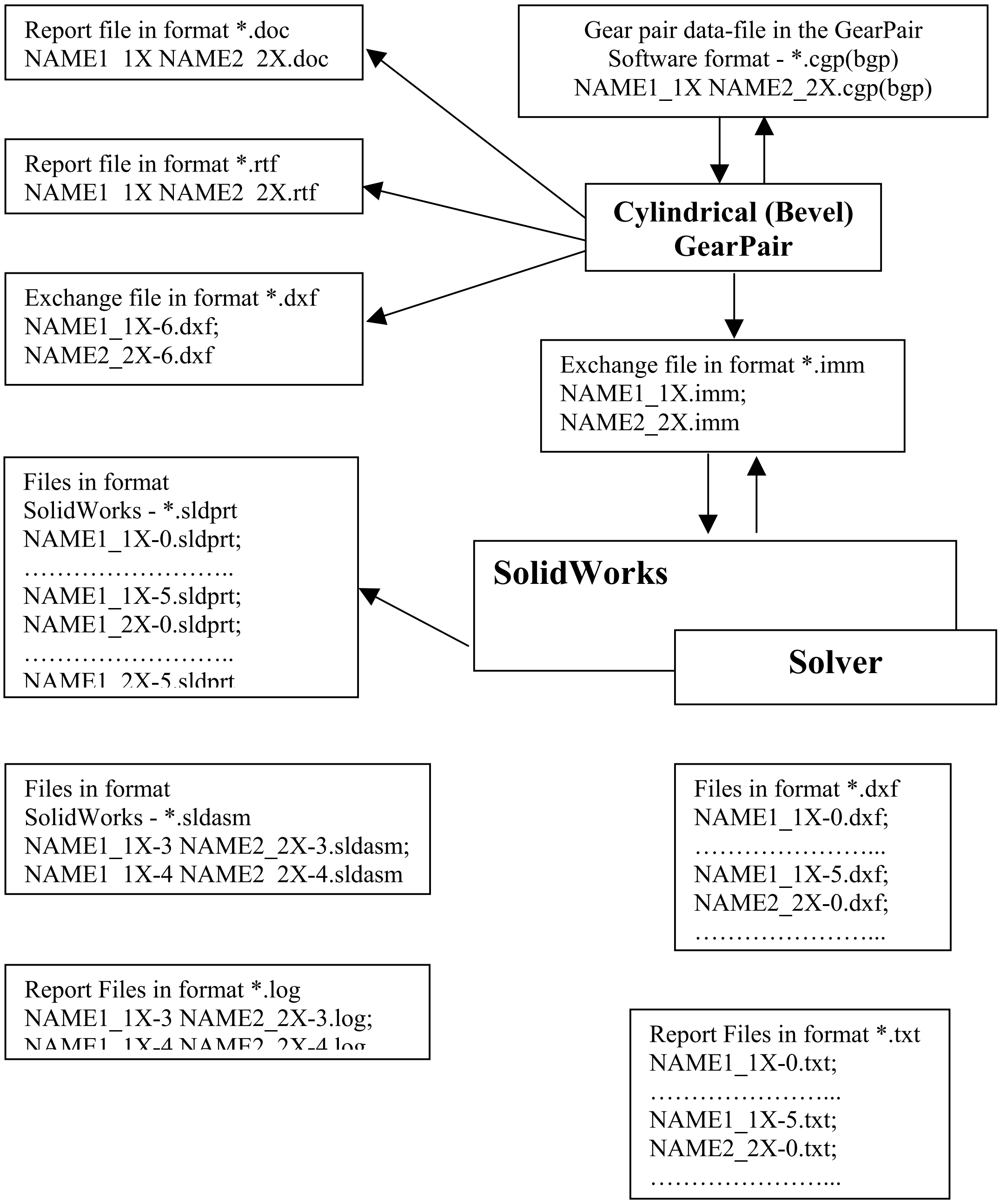


Fig. 2 – Scheme of file format and interaction between **GearPair**- Software and **Solver**-Software.

Rules of using the results of the **Solver**-Software are determined by plant design documentation.

For the building 3D-tooth ring profile models in other CAD/CAM-Systems, it is necessary to use files of corresponding profiles in dxf-format.

### 3.4. Method of correcting mold dies based on test results

The developed software complex consists of a correcting software designed for a refined version of female die computation. The initial data should contain measurement results of experimental gear batches according to which mold shrinkage components at the tip circle diameter $\varepsilon_a$, base circle diameter $\varepsilon_b$ and angle tooth thickness on the base circle $\varepsilon_s$ are calculated. The methods are mainly used to correct mold die dimensions in order to rise accuracy of molded polymer gears.

The mentioned mold shrinkage components are calculated according to a chosen measuring complex. Most suitable is the complex with measurements of tip circle diameter $d_a^g$ and root circle diameter $d_f^g$; as well as two meanings of span measurement $W_n$ and $W_{n+1}$ measured from embraced teeth number $z_n$ and $z_n+1$. Proceeding from this, the value of base circle $d_b^g$ and tooth angle thickness $\theta_b^g$ on the base circle, then values of mold shrinkage components $\varepsilon_a$ , $\varepsilon_b$ and $\varepsilon_s$ can be determined.

The analysis of experimental data obtained as a result of measurements was carried out from the viewpoint of two criteria: correlation of confidence interval $\Delta X$ and size tolerance $T_X$ and comparison of $\Delta_X$ (value of displacement of arithmetic mean of measuring parameter $X$) to the average size dependent on position of tolerance field, namely:

$$2 * \Delta X \le T_X \quad \text{and} \quad \Delta_X = \overline{X}^* - \overline{X} .$$

Measurement data are processed by the methods of mathematical statistics. The analysis of dimensional accuracy is based on condition that all random gear samples and, correspondingly, all gears to be manufactured should be within size limits of dimensions given on the drawing:

$$\left(\overline{\Delta}_X + R_X / 2\right) \le T_X / 2 \quad \text{or} \quad \left(\Delta_X + 2\Delta X / 2\right) \le T_X / 2 .$$

In case inequality (10) is not obeyed leads to relationship $2\Delta_X / R_X \ge 0.5$ (or $2\Delta_X / 2\Delta X \ge 0.5$ ), so it is necessary to change the article nominal size by value $\Delta_X$ .

Using the statistical processing results of measurements the probability of gear manufacturing at a given accuracy involving parameters $d_a^g$, $p_b^g$ and $W^g$ and process capability indices $C_p = T_x / 6\sigma$ (where $T_x$ – tolerance , $6\sigma$ – dispersion range of measuring parameter) are calculated. Indices $C_p$ characterize the potential possibility of making gears of a given accuracy at an actual mold shrinkage variance.

The necessity of correcting mold die dimensions is determined by coefficients

$$C_{pL} = \left(\overline{X}^* - X_{\min}\right)/3\sigma ; \qquad C_{pU} = \left(X_{\max} - \overline{X}^*\right)/3\sigma$$

characterizing mean shift of variance field $6\sigma$ relatively to the tolerance field middle $C_{pL} < 1$ or $C_{pU} < 1$ means that it is necessary to correct the corresponding mold die dimension according to the actual mold shrinkage value.

## 4. GEARPAIR SOFTWARE OPERATION

The GearPair Software starts with the title page Window opens where brief information on the Software is given.

"Tuning" menu enables to set the condition to start up the Software in turn with address to the previous operation performance. A part of the General Window serves for the initial data input, which are chosen from the results of strength design or from the experience of designing analogous gear drives.

After start of the Software the operator has a possibility to input and edit the initial data, record initial data in a file and to read out it from the file.

Using the GearPair Software geometrical parameters of the gear pair (cylindrical or bevel), gears, mold die and EDM-electrode, statistical mold shrinkage characteristics, basic parameters of the gear model (mold die), measuring dimensions for mold die and EDM-electrode, coordinates of the tooth ring profiles of the gear, mold die and EDM-electrode (nominal, upper and lower profiles, corresponding to the nominal, upper limiting and lower limiting sizes of the designed dimension) are computed and displayed. Tooth profile coordinates are recorded by the exchange file DXF so that the gear and mold die drawings can be made in the graphical System, for example in AutoCAD and used in the SW projecting system. Both the initial data and the results of the design could be printed out.

## 5. CONCLUSION

Proceeding from the above it can be developed that-the Software ensures the design of geometrical parameters and dimensions of the cylindrical and bevel gear pairs with account of actual dimensions of gears in design stages, their manufacture and operation. It gives a possibility to design at a high level of reliability more precise gears, corrected mold dies and EDM-electrodes in order the mean size value corresponds to the tolerance field middle.

There is a possibility to construct 3D-models of gears and gear pairs and check visually the process of interaction gear in a gear pair, investigate and eliminate errors and inaccuracies occurred during designing.

Computation in SW-environment ensures interchangeability of the Software and other Specialized Software, for example, **MoldFlow, Cimatron, Ansys** etc. which substantially enlarges potentialities of the developed software.

## REFERENCES


1. Injection Molding. Small Precision Engineering Plastic Components-Especially Gears. Plastics Gearing Technology, Inc.
2. G. Basstein, Cylkro Gears - a new Challenge, Antriebstechnik, 1994, vol. 33, no. 11.
3. Information and Moulding Catalogue. Juken Kogyo Co., Ltd. – 1993. – 28 pp.
4. V.E. Starzhinsky, A.T. Kydinov // Vestnik Mashinostroyeniya, 1985, no. 10, p. 38-41, (Russian).
5. V.E. Starzhinsky S.A. Ossipenko, A.T. Kudinov // Int. Conf. Gears-96, Manufacturing, Control, Maintenance, Poznan, 1996, p. 350-356.
6. V.E. Starzhinsky, S.C. Lee, S.A. Ossipenko, A.T. Kudinov // Proc. XXXVIII Machine Parts Development Conf., Bratislava, 1997, p. 167-171.
7. V.E. Starzhinsky, S.A. Ossipenko, A.T. Kudinov, E.V. Shalobaev // Proc. 4th Int. Congress on Gearing and Power Transmissions, Paris, 1999, vol. 1/3, p. 813-818.
8. A.T. Kudinov, V.E. Starzhinsky // Design of Parts from Plastic materials, Moscow, MDNTP, 1986, p. 68-73, (Russian).
9. A.T. Kudinov, V.E. Starzhinsky, S.S. Pesetskii, et. al // Plasticheskie Massy, 1988, no. 7, p. 27-30, (Russian).
10. A.T. Kudinov, V.E. Starzhinsky, M.L. Gurevich, L.I. Kosterina // Plasticheskie Massy, 1990, no. 3, p. 61-64, (Russian).
11. S.C. Lee, Study of Design and Manufacturing Technology for Precision Plastic Gears, 1994, 81 p.p.
12. V.E. Starzhinsky, W. Krauze, O.V. Gavrilova, et al., Plastic Gears in Precise Instrument Drives, Minsk, Nauka i Tekhnika, 1993, 360 pp. (Russian).
13. A.T. Kudinov, Technological Accuracy of Molded Plastic Gears and Methods of its Improvement, Ph.D. Thesis, Gomel, 1993, (Russian).
14.] Kudinov A.T. Design of Forming Tools for Plasic gears // Production Technology and Methods of Providig Gear and Gear Pair Quality. Texbook. / Edited by V.E. Starzhinsky and M.M. Kane. Minsk: Technoprint. – 2003. P. 566-603
15. V.E. Starzhinsky, A.T. Kudinov, S.A. Ossipenko // Vestnik Mashinostroyeniya, 1995, no. 6, p. 3-7, (Russian).
16. S.C. Lee, V.E. Starzhinsky, A.T. Kudinov, S.A. Ossipenko // Vestnik Mashinostroyeniya, 1995, no. 10, p. 8-12, (Russian).
17. V.E. Starzhinsky, A.T. Kudinov, S.A. Ossipenko // Int. Congress "Gear Transmissions-95", Sofia, 1995, vol. 3, p. 91-93.