From design to manufacturing of asymmetric teeth gears using computer application

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Abstract. The asymmetric cylindrical gears, with involutes teeth profiles having different base circle diameters, are nonstandard gears, used with the aim to obtain better function parameters for the active profile. We will expect that the manufacturing of these gears became possible only after the design and realization of some specific tools. The paper present how the computer aided design and applications developed in MATLAB, for obtain the geometrical parameters, in the same time for calculation some functional parameters like stress and displacements, transmission error, efficiency of the gears and the 2D models, generated with AUTOLISP applications, are used for computer aided manufacturing of asymmetric gears with standard tools. So the specific tools considered one of the disadvantages of these gears are not necessary and implicitly the expected supplementary costs are reduced. The calculus algorithm established for the asymmetric gear design application use the „direct design“ of the spur gears. This method offers the possibility of determining first the parameters of the gears, followed by the determination of the asymmetric gear rack’s parameters, based on those of the gears. Using original design method and computer applications have been determined the geometrical parameters, the 2D and 3D models of the asymmetric gears and on the base of these models have been manufacturing on CNC machine tool asymmetric gears.

1. Introduction

The asymmetric teeth gears are cylindrical gears with different base circle involute teeth profiles.

Designing asymmetric teeth gears contain also the design for symmetric teeth gears because the last one can be considered a particular case of the first one. So the classical gears with symmetric teeth can be considered asymmetric teeth gears, having equal values for the design parameters in relation with the two profiles. In that way it can be considered that it is not necessary to mention like different the asymmetric and symmetric teeth gears. The design algorithm developed is valid and can be used for both.

Designing asymmetric teeth gears offer the possibility to choose the geometrical parameters from many values, not only those corresponding to the standard gears, in order to obtain better or optimal, for one specified objective, functional parameters.

Many results of the paper author’s research on this subject have been published as step of the work considering the partial result as objective of the stage, part of the final objective.

The aim of this paper is to present, as a whole considering full research, how the calculus algorithm and the computer applications developed make possible to realize all the step necessary for obtain one optimized asymmetric gears, from the geometrical design, through carrying out the functional
parameters, to manufacturing of the gears with standard tools. The calculus algorithm used for obtain the geometrical parameters of the involute asymmetric profiles of the gears have been developed on the base of “direct gear design” [1], [2].

For obtaining the functional parameters have been created calculus algorithms and then for obtain all the results in short time and for comparing different cases have been created and developed a system of computer applications that give for any user many answers to the questions put on the asymmetric gears.

2. The stages of application development

Final application, that offer all the geometrical and functional parameters studied on the steps of the research, uses as subroutines gradually made applications [3], in the same time with establishing the calculation algorithms and the results that can be carry out will be presented using for example one asymmetric gear transmission.

2.1. Setting initial parameters

The initial dates are: the axial distance (a) and the number of teeth (z₁, z₂).

The pressure angles for the direct profile and for the inverted profile (α₁d, α₁i) are considered designing parameters. The pressure angles can be modified and, the computer calculation being very efficiency, it is very easy comparing the functional parameters for asymmetric gear transmission with different values of the asymmetry coefficient.

The geometrical parameters can be also modified by the coefficient of the gear rack angle, noted with “f”, and by using one or two gear rack for generating the pinion ad the gear, for emphasize that it has been used the parameter noted with “cr” with two values 1 or 2.

The functional parameters are different if the gear transmission it is used with the pressure angle with greater value on the active profile, called “direct asymmetric gear” or with the pressure angle with smaller value in the active profile, called “inverted asymmetric gear”. The variable used for indicate one of the two possibilities noted with “var” can also have values 1, for the first case, or 2 for the second case. So the designing parameters are: [α₁d, α₁i, f, cr, var].

It has been chosen for the case studies the following initial dates and design parameters:

[a, z₁, z₂, α₁d, α₁i, f, cr, var] = [190, 25, 38, 40, 20, 5, 2, 1].  (1)

2.2. Asymmetric gears encoding

For a better systematization of the results have been established that every asymmetric gear transmission will be notated with eight values, all used in design applications. Three of them are the initial date followed of the five designing parameters.

For example if it is used the notation A_as_25_38_190_40_20_0_1_1 that can be read like “Asymmetric gears transmission with the number of teeth 25/48, the axial distance 190, the pressure angles on the involute profile 40/20, with the gear rack angle equal with the pressure angle of the gear, pinion and gear generated with the same gear rack and the ending 1 show that will be used as direct asymmetric gear.

2.3. The geometrical parameters that can be carry out with the computer application

Geometrical parameters it have been considered all the diameters and profiles angles of the two gears of the transmission and all the parameters necessary to represent the single gear rack or two gear racks in relation with the pinion and the gear.

The calculus algorithm that was used for writing the application permit to obtain all the significant diameters like: diameter of the pitch circle (d₁d, d₂d), diameters of the base circles (d₁b, d₂b), diameters of the outside circles (d₁a, d₂a), diameters of the dedendum circles (d₁f, d₂f); all profile angles with significant values, from the profile angles corresponding to the points of
beginning of involute profiles \((\alpha_{u1d}, \alpha_{u1i}, \alpha_{u2d}, \alpha_{u2i})\), profile angles for the first contact point from the bottom of the tooth \((\alpha_{p1d}, \alpha_{p1i}, \alpha_{p2d}, \alpha_{p2i})\) to the profile angles on the outside circle \((\alpha_{sld}, \alpha_{ali}, \alpha_{s2d}, \alpha_{s2i})\) and the profile angles on the tip circle \((\alpha_{v1d}, \alpha_{v1i}, \alpha_{v2d}, \alpha_{v2i})\) on the same time for the pinion and for the gear; the contact ratio for the direct and inverted profile \((\varepsilon_{ad}, \varepsilon_{ai})\).

Also can be obtained the geometrical parameters of the generating gear racks like: generating rack profile angles \((\alpha_{dc}, \alpha_{ic})\), generating rack pitch \((p_c)\), diameters of the generating pitch circles \((r_{c1d}, r_{c2d})\), minimum radial clearance \((c_{min})\), tip gear racks radius \((R_1 \neq R_2\) or \(R_1 = R_2\)). The calculation of geometrical parameters can modify the shift rack of the pinion and of the gear \((x_1, x_2)\) for a new set of gears parameters until the achievement of the conditions imposed by the correct meshing. Examples of results are given in table 1.

Table 1. Geometrical parameters

| Parameters | Pinion (1) | Gear (2) |
|------------|------------|----------|
| \(\alpha_{wd}, \alpha_{wi}\) | 0.6981 | 0.3491 | 0.6981 | 0.3491 |
| \(d_{a1}, d_{a2}\) | 162.4495 | | 242.7298 | |
| \(d_{w1}, d_{w2}\) | 150.7937 | | 229.2063 | |
| \(d_{f1}, d_{f2}\) | 135.0152 | | 215.2955 | |
| \(d_{b1d}, d_{b1i}, d_{b2d}, d_{b2i}\) | 115.5146 | 141.6997 | 175.5823 | 215.3835 |
| \(\alpha_{vld}, \alpha_{vli}, \alpha_{v2d}, \alpha_{v2i}\) | 0.7888 | 0.5268 | 0.7701 | 0.4937 |
| \(\alpha_{ald}, \alpha_{ali}, \alpha_{s2d}, \alpha_{s2i}\) | 0.7798 | 0.5110 | 0.7621 | 0.4793 |
| \(\alpha_{pld}, \alpha_{pili}, \alpha_{p2d}, \alpha_{p2i}\) | 0.5859 | 0.1266 | 0.6375 | 0.2304 |
| \(\alpha_{ult}, \alpha_{u2d}, \alpha_{u2i}\) | 0.5633 | 0.0387 | 0.6228 | 0.1722 |
| \(\alpha_{dc}, \alpha_{ic}\) | 0.6881 | 0.3252 | 0.6881 | 0.3252 |
| \(p_c\) | 18.7917 | | 18.7917 | |
| \(r_{c1d}, r_{c2d}\) | 149.5398 | 227.3005 | |
| \(R_1, R_2\) | 0.7421 | 0.5639 | |
| \(x_1, x_2\) | 0.0802 | 1.5230 | |
| contact ratio for: | direct profile | inverted profile |
| \(\varepsilon_{ad}, \varepsilon_{ai}\) | 1.2937 | 1.7241 |
2.4. Generating of the pinion and gear models
All the above mentioned parameters make possible to have the complete profile of the gear and pinion teeth in a graphic representation obtained in MATLAB and also can be used as initial date for write the AUTOLISP application for generating the 2D models of the gears, implicitly the 3D models.

Two applications have been developed: MDA1 – Asymmetric involute teeth modelling for the first gear and MDA2 – Asymmetric involute teeth modelling for the second gear. The representations of the curves that limit the tooth body have been made on the base of the parametrical equations of asymmetric involute profiles [2] and the parametrical equations of the joint profiles [4]. The two gears are in contact on the active profile on the meshing point (Figure 1).

![Figure 1. The model of the gear transmission – pinion and gear](image)

The models of the gears offer the possibility of verifying the correct meshing by animation of the models, the study of teeth stress and displacements with the finite element method and also the transfer of the dates on the soft of one cutting machine tool. The geometrical parameters that are given in the first line of the programs are: $z_1, z_2, a, \alpha_{wd}, \alpha_{wi}, \alpha_{dc}, \alpha_{ic}, \alpha_{a1d}, \alpha_{a2d}, R_1, R_2, x_1$, all determined in the previous applications.

2.5. Determination of functional parameters
The aim of designing nonstandard gears, in this case asymmetric involute teeth gears, is to obtain better behavior under the load of the gear transmission.

Having this objective there was first necessary to establish and apply in the computer application the calculus algorithms for some significant features on which one can evaluate the performances and compare different possibilities.

The functional parameters that can be calculated with the developed applications are: the elasticity of the pinion tooth ($V_1$), the elasticity of the gear tooth ($V_2$), and the elasticity of the pair of teeth ($V$); the normal force on the active profile ($F_n$); the transmission error due to the displacements of the teeth ($A_e$); the specific sliding ($\eta_1', \eta_2'$); the instantaneous efficiency and the medium efficiency ($\eta$); the equivalent bending stress ($\sigma_{ech}$); the contact stress ($\sigma_H$).

The mentioned parameters are calculated in an established number of meshing points, and studying the variation can be carry out the maximum values on the meshing period – Table 2.
### Table 2. Functional parameters

| Fn [N] | Ae [mm] | η₁' | η₂' | η | σ₁ [N/mm²] | σ₂ [N/mm²] | σ_H [N/mm²] |
|--------|---------|-----|-----|---|-------------|-------------|-------------|
| 2976   | 0.0024  | 0.4383 | 0.3326 | 0.9873 | 11.6587 | 10.1720 | 272.9418 |

#### 2.6. Optimization of functional parameters

The advantages of the computer design is the short time for obtain the dates, the comparison between the results obtained using different design parameters, the optimization by comparing the functional parameters and choosing the designing variable in relation with the requirements imposed by the beneficiary.

For studying and comparing a great number of possible asymmetric gears designed with the same initial date, obtained by changing the designing variable and select those that give the best solution for a specified objective function it have been developed an optimization application based on the genetic algorithms. The objective function can be obtained as a weighted average of partial objectives.

#### 2.7. Computer aided machining of the asymmetric gears

In the classical manufacturing, with standard tools, of the involute teeth gears, the curves of tooth profile result as tangent curve to the successive positions of the standard generation gear rack, with symmetric profile materialized by the edges of the cutting tool.

In this case, of the direct design of the asymmetric gears, the design of the gear rack it is made after establishing the useful profiles of the teeth, than it is used for obtain the equations of the joint profiles and it is not a standard gear rack. So for being materialized it is necessary the design of a nonstandard tool in relation with the gears parameters. That it is not possible because it involves extra costs. For this can be avoided it is necessary, for the nonstandard gears, that a standardized tool to follow a trajectory so as to realize the already designed profile of the gear.

The date necessary for programing the movements of the tool are contained in the model of the gear and could be transferred to the soft of the CNC machine tool (Figure 2, Figure 3). Gears manufacturing have been realized (Figure 4) on MICROCUT Challenger model MCV-2416, the material used being PEHD, with a standard tool coded 514L030Z4.0-SIRON-A.

![Figure 2. Power Mill Interface containing the pinion](image-url)
3. Conclusions

With the original developed computer applications have been realized all the steps necessary for the optimal design of the nonstandard asymmetric gears and those have been obtained on a CNC machine tool with a standard tool. The models of the gears permit to establishing the trajectory of the tool and can be modify, by studying the stress and displacements of the asymmetric teeth, until the best behavior under the load it is attend.

References

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