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VIRTUAL ROLLING GEAR TESTING MACHINE

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ABSTRACT

Measurement of geometric errors is required to evaluate the grade of the manufactured gears. Errors such as the composite error, tooth thickness error, profile errors requires special measuring machines such as the rolling testing machine and involutes testers which are not available to all gear users. In many cases the measurement need a master gear for each tested gear which is economically unfeasible. Again, master gears are required for producing templates and special form tools for manufacturing of gears. The present paper faces this problem by proposing a methodology for producing virtual master gears and to use this methodology for computer utilization for indirect assessment based on the virtual gears model (VGM) so that composite and run out errors can be assessed without the need of actual master gears or the need of special gear measuring machines. The methodology of developing a virtual master gear is generated. The model has been tested by measuring various gears and their measured values were analyzed and compared with the virtual gear through special developed software. The model, also, is capable of producing the profile of any addendum modified gear (perfect involutes profile) for the purpose of designing gears.

KEY WORDS

Virtual master gear, composite gear errors, rolling tester machine, gear measurement and addendum modifications.

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INTRODUCTION

The inaccuracies of manufacturing process result in deviation between the ideal shape of the gear and the actually produced one. Gear errors are classified into individual errors and composite error. Determination of either of them depends on the method of inspection, namely, analytical (all the individual elements of the gear teeth are checked) and functional (tangential composite and radial composite inspection). All the traditional techniques involve the use of special measuring equipment for both techniques. This method is basically hardware- based, relying on the motion of specially designed mechanisms. Thus, for different sizes and types of gears, different measuring machines should be used, imposing economical burden for the industry. Besides, measuring some errors require the presence of a master gear. The manufacturing of such gear with high precision is very difficult and expensive especially when different sizes and types of gears are required to be inspected.

Those are beyond the capability of great region of the gear users, either for cost or time consumed. Researcher tried to apply non-traditional means to achieve the errors.

Tamura and Liu [1] used coordinate measuring machine (CMM) and developed an algorithm for the inspection of manufactured helical gears. They determined the error analytically through measuring the location of different points on the tooth surface of the gear at random and applied the least square technique.

S.H. Suh [2] presented a general and comprehensive method for measuring errors of spiral bevel gear with a three-axis CMM interfaced with an indexing table. The method is purely software-based and capable of measuring various errors including tooth profile error and tooth trace error, which cannot be measured by the conventional methods. The developed algorithms were experimentally validated with gear manufactured by CNC milling operation.

Maria Pia Sammartini [3] developed a new type of master gear, the Gauge Block Gear, for verifying CMMs measurement of pitch and tooth thickness. Its main characteristic is the replacement of the teeth with gauge blocks to achieve direct traceability of the tooth thickness. A mathematical model for the geometrical definitions was formulated and the data was evaluated.

G.Goch [4] used optical technique for gear measurement after reviewing the state of the art of gear metrology.

M. Pueo, et. Al [5] developed a rolling testing machine for checking composite error for a pair of worm and worm gears. They used the double flank method. They compared the results obtained on three different roll testers and detected great differences in quality assessed. They claimed that the lack of standards may be the reason.

Therefore, there is a need to find an alternative way to check the gear errors which does not depend on hardware way and master gears. Thus an algorithm for indirect measurement based on the virtual gears model (VGM) is required so that error measurement can be carried out in computers. The present study proceeded in three phases; the development of the master gear, the development of the perfect gear with any addendum modification and the use of the model in processing of the out of run and the composite errors.

THEORETICAL APPROACH

Generating the Master and the Perfect Gear

Several approaches were used in literature for generating gears on computers. In the present work the parametric equations with matrix transformation, fig 1, are used [6, 7, 8, 9 and 10]. From fig 1, the following relationships stand:

X_i offset in x of point "i" = $((R_p * \sin(\theta_i)) - (((R_p * \theta_i) - B) * \cos(\alpha) * \cos(\theta_i - \alpha)))$ (1)

Y_i offset in y of point "i" = $((R_p * \cos(\theta_i)) + (((R_p * \theta_i) - B) * \cos(\alpha) * \sin(\theta_i - \alpha)))$ (2)

where i is any point on the profile with coordinates (X_i, Y_i)

α pressure angle

R_p radius of pitch circle = $(m * Z) / 2$ (3)

B half the tooth thickness at pitch circle = $(\pi * m / 4) + m * k * \tan(\alpha)$ (4)

θ_i rotation angle for matrix transformation = $(B/R_p) + \tan(\alpha) - \sqrt{(R_i^2 / R_b^2) - 1}$ (5)

R_b radius of base circle = $R_p * \cos(\alpha)$ (6)

R_o tip radius = $R_p + m(1 \pm k)$ (7)

R_r root radius = $R_p - m(1.25 \pm k)$ (8)

In case of generating master gear, k is taken to be zero.

Run Out and Composite Errors

The composite error and the run out error were deduced based on readings r_i (op in fig 2) and φ_j (angle xop in fig 2) stored in a data source file. The readings "r_i" represent the radii at the contact points between the ball end of the probe of the measuring device and the gear tooth at the pitch circle diameter. Hence [11],

Composite errors $(e_i) = r_i - (\Sigma r_j / Z) - c * \cos(\varphi_j - \beta)$ (9)

β (angle xoc) = $\tan^{-1}(\Sigma(r_i * \cos(\varphi_j)) / \Sigma(r_i * \sin(\varphi_j)))$ (10)

Eccentricity (c) = $2 * \mathrm{sqrt}\,(\Sigma (r_j * \cos(\varphi_j) / Z)^2 + (\Sigma (r_j * \sin(\varphi_j) / Z)^2)$ (11)

Proposed Software

The software developed for solving the gear equations are written in Visual Microsoft C# - version 2010. The block diagram representing its flow chart is presented in fig 3. The software is designed such that choosing option “1”, the virtual master gear profile and the perfect profile (if addendum correction is given) are shown as image forms or discrete tabulated points. If option “2” is chosen, it is branched to other two options “3” and “4”. The 1st is analyzing the saved triggered data for the run out, eccentricity of the pitch circle and the composite errors. The 2nd is for expanding the software for future applications. As an example, one extra error is introduced which is the tooth thickness error.

EXPERIMENTAL PROCEDURE

Several gears were tested to validate the applicability of the proposed software. The results, here, are given, only, for gears of module 7, 18 teeth, 20º pressure angle and with addendum modification of – 0.4, -0.2, 0, 0.2, 0.4.

Although, the readings may be taken by any suitable measuring machine as long as the measured radii “r_i” and the angle “φ_j “ are later on saved in the source data file which in this software is Microsoft Excel file. In the present paper the readings were taken on a cam shaft tester, fig 4, with a spherical probe touches the pitch circle at both flanks. The readings were triggered and saved in the source file.

For verifying the possibility of expanding the software for other individual error, similar procedure is used to check the tooth thickness by measuring the tooth thickness at different depths on tool room microscope and triggering the data to the Microsoft Excel source file.

RESULTS

As the main objective of the present paper is to establish a system to develop the profile of the master gear, to develop the profile of any spur gear with any addendum modification and to use them as the standard gear for the virtual rolling tester and for other measured parameters such as the tooth thickness error, it was not necessary to perform the experimental tests on high quality manufactured gears. In fact, gears dismantled from running engines were used to prove the capability of the developed software in retrieving the measured data, analyzing them, comparing with the perfect profile and determining the error values. So the error values found in the results, in it, is not the criteria. The main screen of the software is shown in fig 5.

Generating the Master Profile and Perfect Profile

Figure 6 shows the generated master profile and perfect profiles for the different addendum modifications.

Composite errors
The output of the software for the run out error is shown in fig 7. The eccentricity was found to be 0.4531 mm at an angle of – 81.75º. Filtering out the run out effect, the composite errors were determined, fig 8.

Tooth thickness error
To determine the error in any measured data, the perfect gear data were used as the standard to the measurement of the tested gear; e.g. to test the profile tooth thickness were taken on a tool room microscope and was saved in Microsoft Excel Source file. The software imported the saved data, processed it and compared the outputs with the data of the perfect gear. The profile shape is shown in fig 9. Tooth thickness errors were determined and presented on the main screen of the software.

CONCLUSION

The software which can be expanded to cover several individual spur gear errors is capable of:

- developing the profile of any master spur gear for the use in manufacturing purposes and producing templates,
- developing the profile of perfect spur gear with any addendum modification for the design purposes and determining the error of the measured gears,
- replacing the rolling testing machine with a corresponding virtual machine for duel flank determination of run out , eccentricity and composite errors,
- Assessing the quality of measured spur gear.

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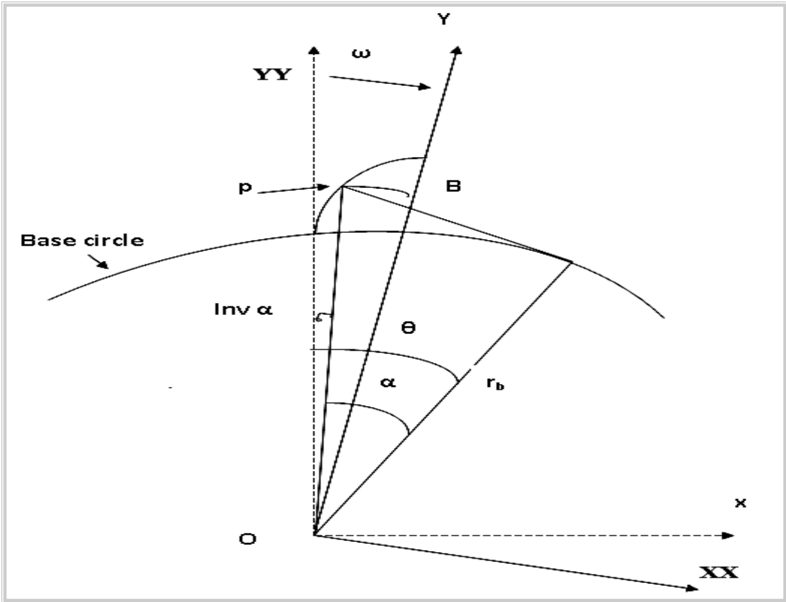

Fig 1. Parametric Equations.

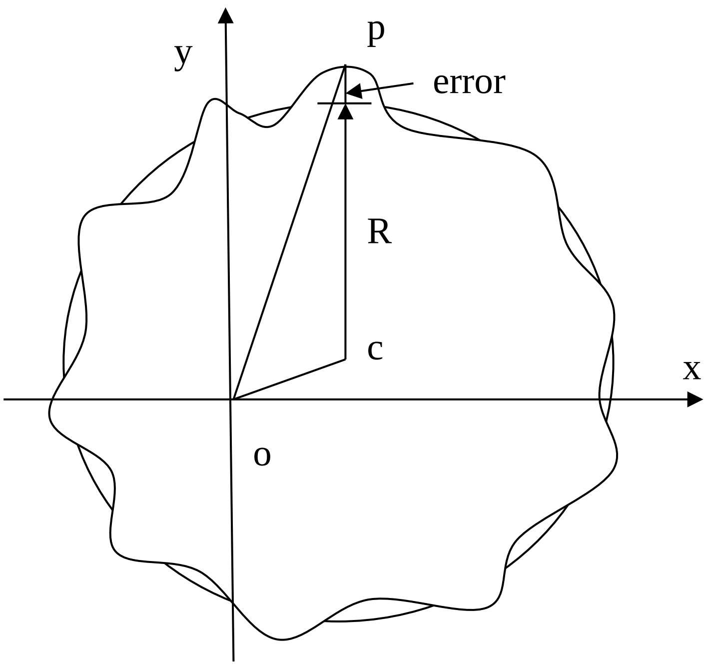

Fig 2. Eccentricity error.

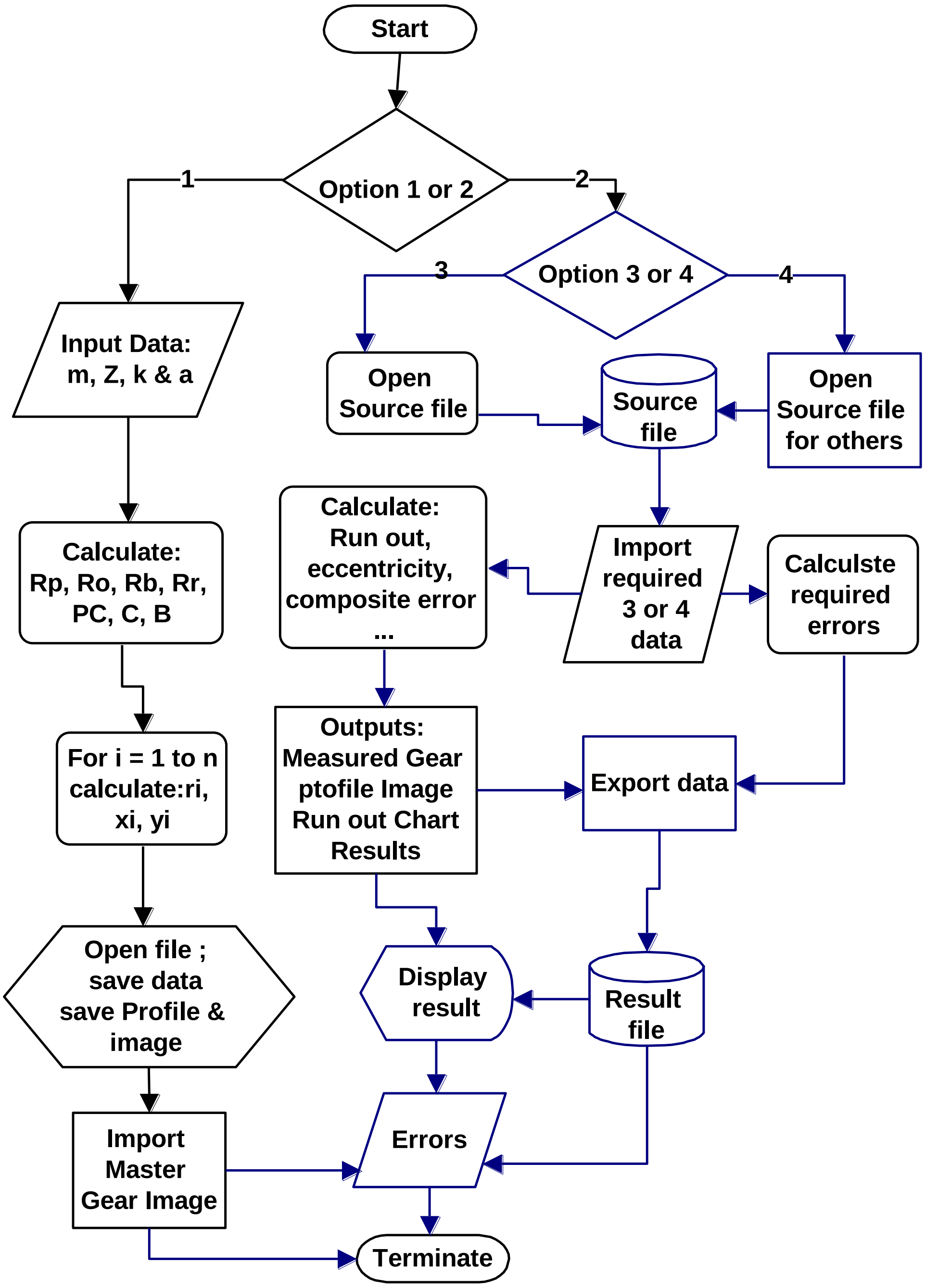

Fig 3. Block diagram for the proposed software.

Fig 4. Cam Shaft tester.

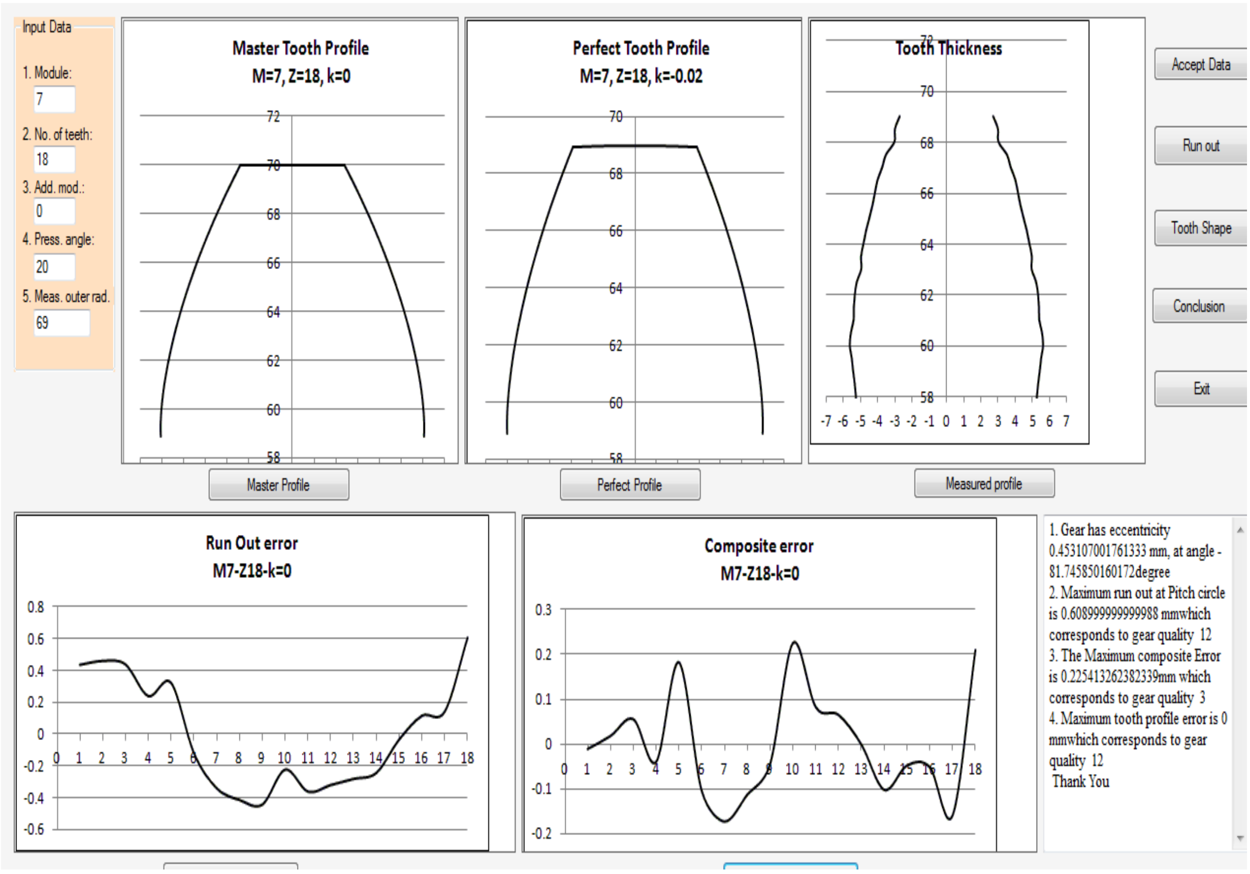

Fig 5. Main screen of the proposed software.

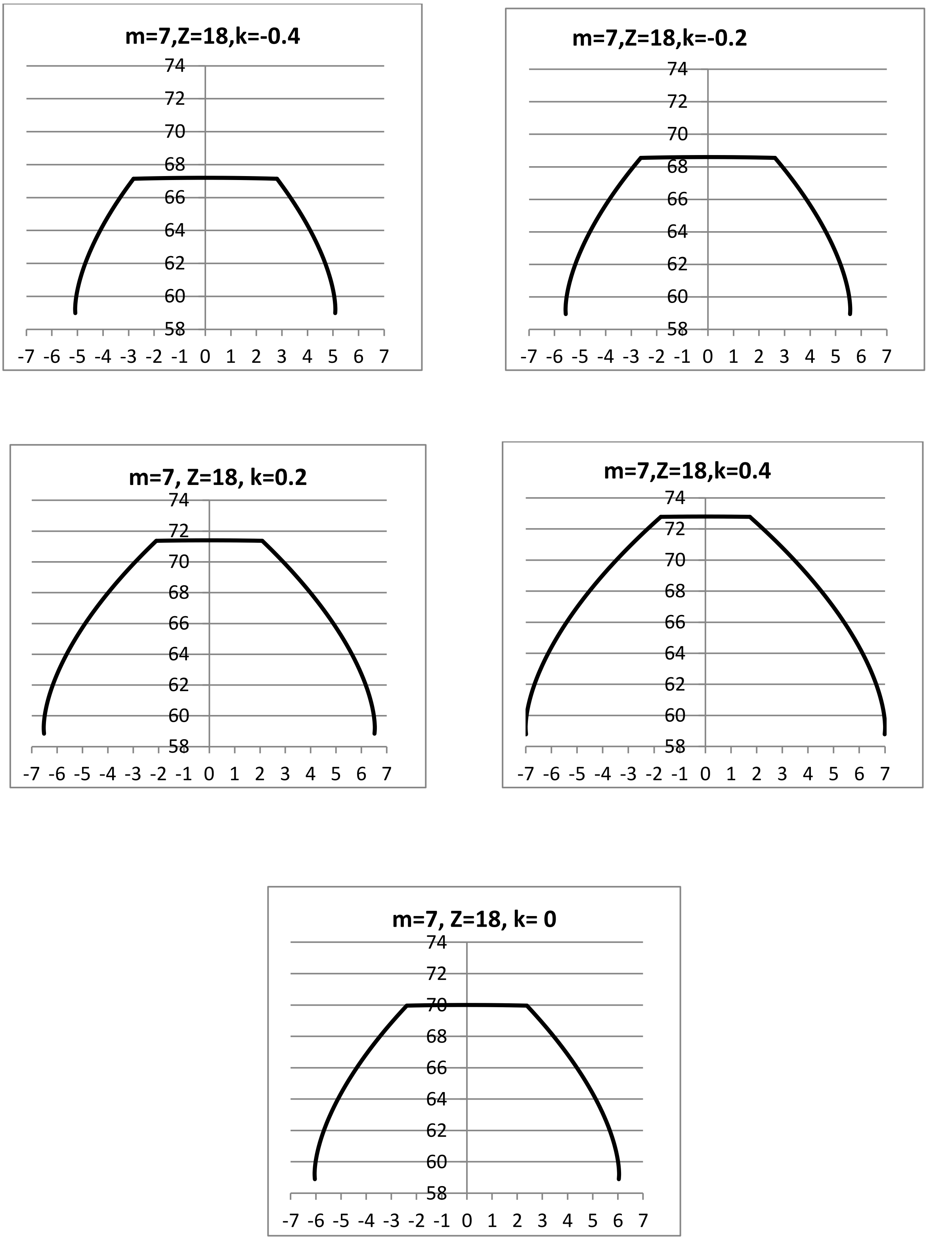

Fig 6. Master & perfect profile gears.

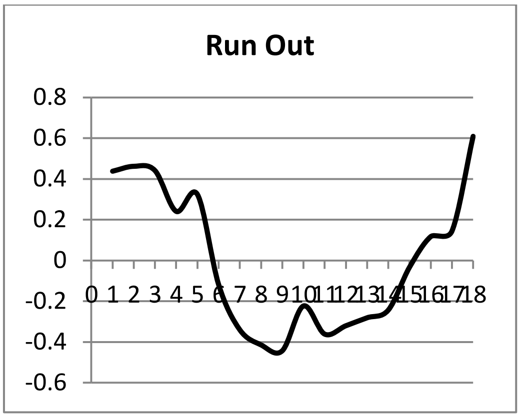

Fig 7. Run-out + composite errors.

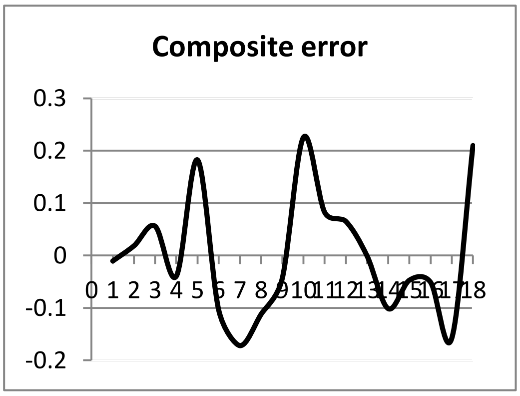

Fig 8. Composite errors.

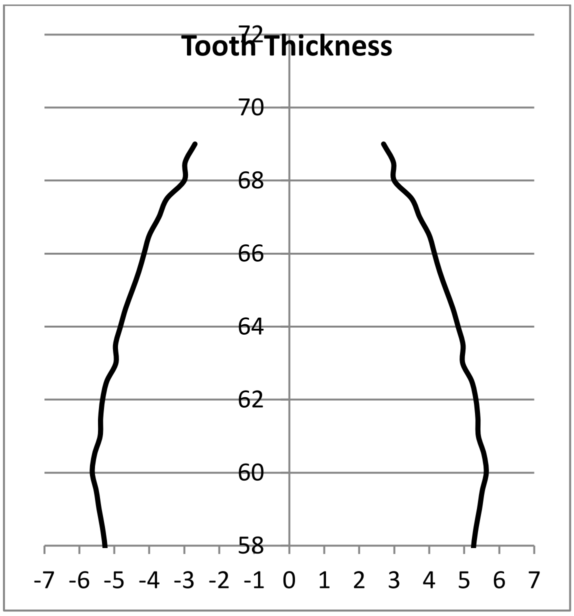

Fig 9. Tooth thickness error.