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ON THE INTERPRETATION OF MEASUREMENTS OF TOOTH PROFILE DEVIATIONS

Radu Florin MIRICĂ, George DOBRE, Marcel DĂSCALIUC

Abstract: *The paper analysis several problems appearing at the interpretation of measurement of the profile form. Measurements were carried out on spur gear wheels. Measured tooth profile form emphasized deviations having specific variations from a tooth at another one. As a result, a first problem analyzed in the paper is the extrapolation of the existent measurements on a little number of teeth, to find the maximal profile deviation value. On the other part, the determination of the causes producing these different deviations means is discussed.*

Key words: *toothed wheel, profile deviation, diagnose, FFT.*

1. INTRODUCTION

The problems of the interpretation of the profile deviation diagram are very important for different aims in research and design of the analysed gear wheels. The present paper is starting from the existence of several measuring diagrams traced on spur gear wheels that are manufactured by grinding as final process. A first appearing problem is the impossibility to make measurements on the full number of teeth of the wheel. From here, the need to extrapolate the existent profile deviation measurements to the entire wheel, to establish correctly the gear quality class, is solved.

On the other hand, the measurements emphasized typical profile deviations that are similar as shape at all teeth of the gear wheel. The shape of the profile diagram is suggesting the existence of vibration process during the manufacturing. As a result, the problem of determination of the causes of these vibrations is approached and solved.

It is mentioned that these subjects are resolved using own considerations.

2. ON THE PROFILE DEVIATION

The profile deviation, $f_{f\alpha}$, is the maximal difference measured on the normal to involute profile, between the effective profile and the ideal one of the tooth profile. It is a macro-geometric deviation. The measuring methods and the reference values of $f_{f\alpha}$ are standardized, see for example [4–8] etc. The standardization ensures uniform conditions for:

- carrying-out the measure;
- evaluating the measurement results;
- comparing the results with other ones indicated in literature.

Conforming to [4, 7, 8], it is obtained a total profile deviation, F_α, in relation to the ideal theoretical profile (Fig. 1), by measuring the tooth profile in a frontal plane, using a specialized measuring machine.

Some diagram ranges are considered in the Fig. 1, for measuring interpretation and evaluation:

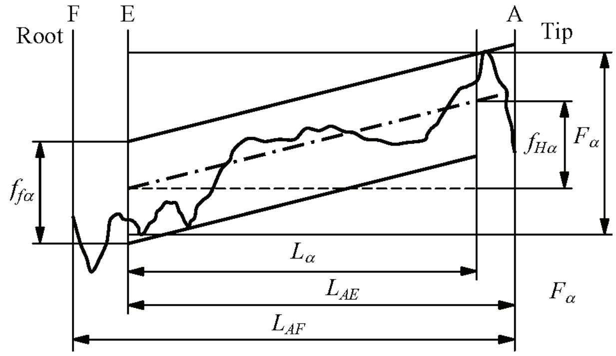

Fig. 1. Determination of the profile characteristics (after [4]).

- the profile evaluation range, L_α, *i.e.* the effective measuring range on that the results are processed;
- the profile evaluation range, L_{AE}, corresponding to length of the path of contact;
- the usable length in which measured values are taken, L_{AF}.

The total profile deviation, F_α, contain two basic deviations:

- the profile deviation, $f_{f\alpha}$;
- the profile slope deviation, $f_{H\alpha}$.

If the data acquisition is made automatically, the results can be processed on computer using the methods presented in the guideline [7]. Here is described in detail the procedure for computer-controlled evaluation of profile and helix deviations. This method was applied partially in the chapter 4 of the present paper.

3. ON THE EXTRAPOLATION METHOD GIVEN BY GUIDELINE VDI/VDE 2607 [7]

The usual measuring methods are applied only for few teeth (typically 4–5 teeth). Because the profile deviation can differ from a tooth to another, the result must be extrapolated for the teeth non-measured. This extrapolation method is given in VDI/VDE 2607 [7]. The method is adequate for least three measured teeth. This method was applied in our paper a particular mode.

To better understand this application, a short description of VDI/VDE 2607 method is done below. It is considered the hypothesis that the variation of the maximal value of each tooth profile deviation has a sinusoidal form. The angular position of the tooth, *i*, is given by:

$$\varphi_i = (i-1)\cdot\frac{360°}{z}, \qquad (1)$$

where *z* is the total teeth number. The deviation considered as a function of φ_i is:

$$f(\varphi_i) = E + A\cdot\sin(\varphi_i - \varphi_0) = \\ = E + K\cdot\sin\varphi_i + L\cdot\cos\varphi_i, \qquad (2)$$

where: *E* is the median value of the deviation, *A* – the amplitude and φ_0 – the phase shift. A facile fitting of the maximal profile deviation values is given by [7], using the modified expression form (2). By this fitting, the following equivalent set of parameters is obtained: *E*, *K* and *L*.

4. APPLICATION OF THE EXTRAPOLATION METHOD

4.1. Initial analysis of measured profile deviations on each tooth

Profile diagrams have been obtained using a specialized measuring machine Zeiss VG 450.

The initial analysis of the profile deviation values on the right flanks at all teeth of a cylindrical wheel (having following characteristics: number of teeth, $z = 25$; module, $m = 4$ mm; addendum of basic rack, $h_{aP} = 1$; normal pressure angle, $\alpha = 20°$; addendum modification coefficient, $x = 0$; helix angle, $\beta = 0°$) is considered (Fig. 2). This task is required:

- to have data for extrapolation;
- to establish the form of the variation of maximal values of profile deviations for all teeth;
- to compare the results of the extrapolation with the real measured values.

On the Fig. 2 it is visible an error in the vicinity of tooth roots. This error varies cyclically from a tooth to another, but its position is the same to all teeth. Possibly, it is caused by a vibration with a very low frequency. This characteristic deviation with the same variation manner is visible on measuring of other profiles of grinded wheels. The maximal values of measured profile deviation – established on each tooth by the indications given in [3] – are given in the Table 1.

4.2. Extrapolation of the maximal profile deviation values measured for few teeth

Now, the analysis of measures on only few teeth is considered. If a form error has a cyclical variation (Fig. 2), it is possible that the maximum error to be on a tooth non-measured.

To apply the extrapolation method in this case, it is evaluated a main condition: the variation of the maximal value of each tooth profile deviation has a sinusoidal form. Analyzing the Fig. 2 and Table 1, one would see that this variation is cyclical; that is, the extrapolation method could be applied without great errors.

The extrapolation is made for sets of 4 teeth equal distributed on the wheel circumference. For these teeth sets, the Table 2 indicates several sizes:

- the teeth numbers (for finding the $f_{f\alpha}$ values in the Table 1);
- the sizes *E*, *K* and *L*;
- the maximal value of the profile deviation extrapolated for each teeth set.

One would see that estimated values resulting by extrapolation are depending of the chosen set of measured teeth.

The real maximal value of profile deviation given in the Table 1 is of 10 μm. It is different of the estimated values in acceptable limits. But the use of maximal estimated profile deviation could determine the establishing of a quality class different of the one real. A too low value of the estimated profile deviations means the es-

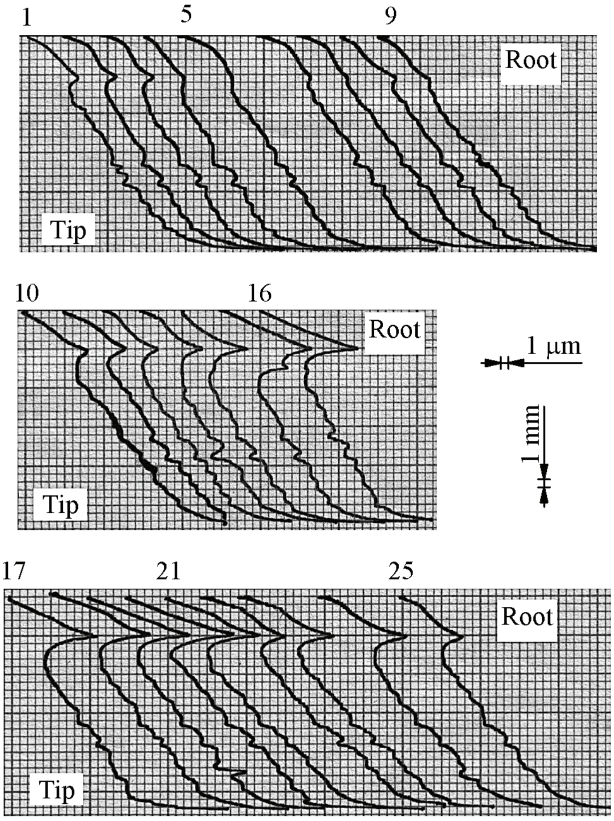

Fig. 2. Measured diagrams of profile deviation. Right flanks were measured.

Table 1

Maximal measured profile deviations on each tooth, using the diagrams given in Fig. 2

z	1	2	3	4	5
$f_{f\alpha}$ [μm]	2.8	3.8	3.5	2.8	2.3
z	6	7	8	9	10
$f_{f\alpha}$ [μm]	2	1.5	2	2.3	4
z	11	12	13	14	15
$f_{f\alpha}$ [μm]	4	4.8	5.3	6.8	9.2
z	16	17	18	19	20
$f_{f\alpha}$ [μm]	9.2	9.5	9	10	10
z	21	22	23	24	25
$f_{f\alpha}$ [μm]	9.8	6	7.5	8	6.8

Table 2

Example of estimation of profile deviation using sets of 4 teeth

Teeth set	*E*	*K*	*L*	Estimated max($f_{f\alpha}$)
		[µm]		for the teeth set
1; 7, 13, 19	5.0005	−4.1366	−1.5558	9.4154
2, 8, 14, 20	5.73375	−4.1457	−0.7505	9.91841
3, 9, 15, 21	6.23015	−4.4338	−1.0471	10.7706
4, 10, 16, 22	5.4263	−2.6118	3.26115	8.67791
5, 11, 17, 23	5.76303	−3.7988	3.90049	9.64933
6, 12, 18, 24	5.88635	−3.7933	0.00632	9.67175

tablishing an unreal too accuracy quality class. As a result, a safety factor is adequate to add at the previous estimation method, to cover the incertitude. If the estimated profile deviation is close of the one standardized specific for a quality class, it is need to measure and interpret profile deviations for a great number of teeth.

5. ON THE CAUSES OF PROFILE DEVIATION BY GRINDED TOOTHED WHEELS

Another important aspect based on measurements of the profile deviations is the diagnosis of causes determining them. The problem is analyzed in the case of the flank grinding.

Conforming to Dudley [2], following causes can produce errors of the form of tooth flank:

- the tool profile deviations that are integrally transmitted to gear wheel teeth;
- the cinematic and dynamic errors of the machine tool;
- the incorrect setting up of machining parameters that can produce forced vibrations.

With end in view to diagnosis these causes, spur gear wheels having 20 teeth and grinded on the same machine are measured. In the Fig. 3, the measured profile deviations for 4 or 5 teeth (noted in figure by their numbers) that are equal distributed on wheel circumference are presented. Wheel data: number of teeth, $z = 20$; module, $m = 5$ mm; addendum modification coefficient, $x = 0$; addendum of basic rack, $h_{aP} = 1$; dedendum of basic rack, $h_{fP} = 1.25$; normal pressure angle, $\alpha = 20°$; helix angle, $\beta = 0°$.

Analyzing the diagrams, one could note the following observations that are used further:

- the profile irregularities are nearly similar;
- on each diagram, the same number of dominant picks (*i.e.* 4 picks) are observable;
- the pick positions on different profile diagrams are the same at all studied gear wheels;
- over the great picks are superposed picks of littler amplitude.

The following observations are given below, to promote the diagnosis method:

- The tip cylinder was grinded and the usual tip chamfer was not executed. So, the tip position in profile deviation diagram is visible as inflexion point (the Fig. 3 notes this point only on the wheel a, tooth 10).
- Considering a set of points equal distanced on the profile diagram, their homologue points on the tooth profile are not equal distanced [7, 9].

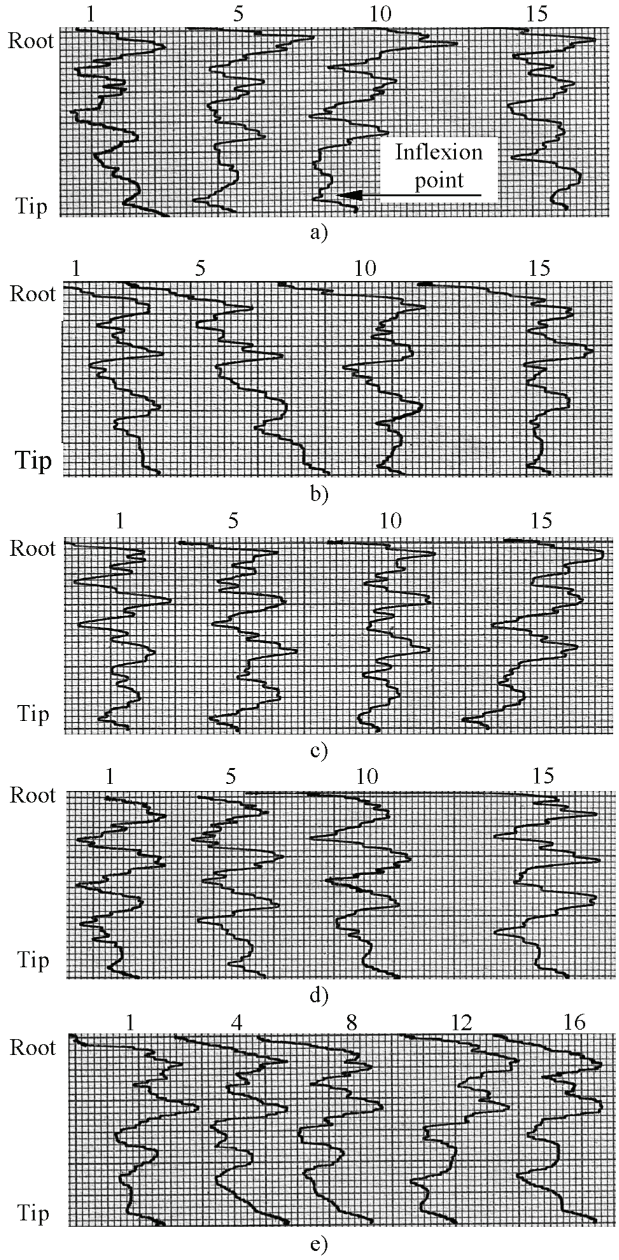

Fig. 3. Profile deviation diagrams measured by 4–5 teeth of five toothed wheels carburized and grinded (a…e – different gear wheels).

- The profile diagram of the tooth 1 (Fig. 2. b) was digitized. The result has been plotted in the Fig. 5.

The dimension on abscissa corresponding to total involute profile is equal with the length of the path of contact, *AE*, between the measured wheel and the theoretic rack simulated [9] by the measuring machine (Fig. 4).

One would see that this profile deviation diagram is similar to the one theoretical given by the Fig. 1; that is, the interpretation procedure is well applied. The dashed line represents the median line of diagram determined by linear regression conforming to [7]. This regression could be evaluated by computer or manual computation. In the figure are marked the points corresponding to begin and end of profile corresponding to the length of path of contact, *AE*.

For determining the vibration frequency producing the profile deviations, the Fourier analysis has been used.

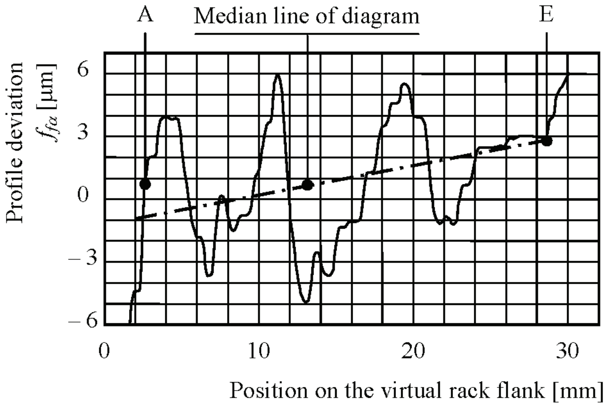

Fig. 4. The studied profile deviation reported to the virtual rack flank. The beginning (A) and ending (E) points of profile used for calculus with FFT are marked.

In this goal, the Fourier spectrum has been obtained (Fig. 5), using the algorithm FFT [1]. The frequencies determining great deviations (given in spectral amplitude picks) are visible in the Fig. 6, having the abscissa measured in multiples of basic frequency. This one has the wave length equal to the length of path of contact:

$$f_b = \frac{1}{T} = \frac{v_{AE}}{AE} = \frac{d_b}{2 \cdot AE} \cdot \omega_1, \qquad (3)$$

in which: T is the period; v_{AE} – the velocity in the direction of the line of action; d_b – the base diameter; ω_1 – the driving speed of wheel in the manufacturing process (grinding in the study case). That is, the positions of the picks on the FFT diagram and the values of vibration frequency are in dependence on driving speed, these being univocally determined.

Because the grinding abrasive wheel shape has been frequently adjusted, the errors of this one have been eliminated from the causes of producing of the errors with great amplitude of the profile deviation.

As a main conclusion, the driving velocity has to be chosen, so that the critical frequencies to be avoided. So, the level of vibrations in the grinding process are diminished and, as consequence, the determined amplitude of profile errors. The establishment of the critical frequencies in the technological process is a subject of another research. The solution of this aim permits the obtaining noiseless gears, using the same technological machine tool and corresponding devices.

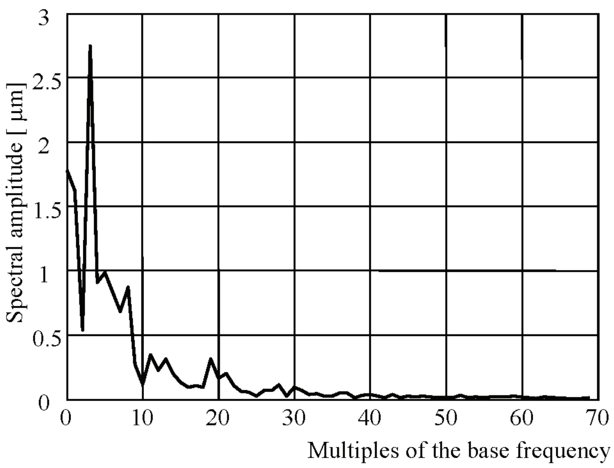

Fig. 5. FFT diagram of the profile deviation in Fig. 3.

6. CONCLUSIONS

The profile deviation diagrams of gear wheel tooth could be interpreted/used in two modes: the extrapolation of results done by the existent few diagrams to establish with good precision the toothing quality class; the diagnosis of the causes of apparition of the profile deviations.

The extrapolation of the results carried out for few teeth is given after VDI/VDE 2607 (2000) [7]; though a safety factor is need to be supplementary introduced.

The diagnosis of the causes of the profile deviations is carried out by FFT analysis and own experience in diagram interpretation.

REFERENCES

[1] Bakhvalov, N. (1976). *Méthodes numériques. Analyse, algèbre, équations différentielles ordinaires*, Edit. Mir, Moscou.
[2] Dudley, D. (1994). *Handbook of practical gear design*, Technomic Publishing Company, ISBN 1-56676-218-9, Lancaster, Pennsylvania.
[3] Niemann, G., Winter, H. (1985). *Maschinenelemente. Band II. Getriebe allgemein, Zahnradgetriebe-Grundlagen, Stirnradgetriebe*, Springer-Verlag, ISBN 3-540-11149-2, Berlin.
[4] *** (1987). *Begriffe und Bestimmungsgrößen für Zylinderräder und Zylinderradpaare mit Evolventen-verzahnung*, DIN 3960.
[5] *** (1992). *Cylindrical gears; Code of inspection practice: Inspection of corresponding flanks of gear teeth*, ISO TR 10064-1 Part 1.
[6] *** (1981). *Angrenaje cilindrice: Toleranţe*, STAS 6273-81.
[7] *** (2000). *Rechnerunterstützte Auswertung von Profil- und Flankenlinienmessungen an Zylinder-rädern mit Evolventenprofil*, VDI/VDE 2607.
[8] *** (2000). *Profil- und Flanken-linienprüfung an Zylinderrädern mit Evolentenprofil*, VDI/VDE 2612.
[9] *** *Documentation "Evolventenprüfgerät VG 450"*, Carl Zeiss, Jena.

Authors:

Assist. Prof. Dr. Eng. Radu Florin MIRICĂ, Department of Machine Elements and Tribology, "Politehnica" University of Bucharest, 313 Splaiul Independenţei, 060042, Bucharest 6, Romania, E-mail: mirica@meca.omtr.pub.ro
Prof. Dr. Eng. George DOBRE, Department of Machine Elements and Tribology, "Politehnica" University of Bucharest, 313 Splaiul Independenţei, 060042, Bucharest, 6, Romania, E-mail: geo@meca.omtr.pub.ro
Dipl. Eng. Marcel DĂSCALIUC, WPC, 250 Basarabia, 030352 Bucharest 3, Romania,
E-mail: marceldascaliuc@yahoo.com