Proceedings of the 11th World Congress in Mechanism and Machine Science
August 18–21, 2003, Tianjin, China
China Machinery Press, edited by Tian Huang

Kinematic Criteria of Smoothness of Work of Cylindrical Gear Wheels

Alexander V. Dragan
Brest state technical university, Moskovskaya St. 267, 224023 Brest, Belarus,
E-mail: draganav@mail.ru

Andrew S. Scorohodov, Vera S. Alexandrova
Institute of Machine Reliability of National Academy of Sciences Republic Belarus,
Academicheskaya St. 12, 220072 Minsk, Belarus

Abstract: The results of theoretical and experimental researches are given in the work, which purpose is the development of techniques and means of diagnostics of gear wheels, and also criteria determining smoothness of work of gearing on the basis of the information about kinematic errors.

Keywords: Gear, Kinematics, Composite Error, Smoothness Of Work, Diagnostics, Dynamic Loads, Vibroactivity

1 Introduction

Defects of gear wheels, including technological, equally with process features of gear remating, variable rigidity of gears along a total length of transmission are one of the main factors resulting in a lowering of reliability, long life, rise of gear vibroactivity, also a variation of a theoretical law of rotary movement transformation of a driving member into a driven member rotary movement. The latter is reflected in composite error $\Delta\varphi(\varphi_1)$ that is a difference between a real and rated angle of rotation of a driven member transmission and is shown in the following formula:

$$\Delta\varphi(\varphi_1) = \varphi_2(\varphi_1) - \varphi_1 i \quad (1)$$

φ_1 - a rotation angle of a driving member;

$\varphi_2(\varphi_1)$ - a rotation angle of a driven member as a function of a driving member rotation angle;

i – a transmission ratio taken as constant.

2 Statement of a problem

Lately a quality estimation of gear transmission based on a composite error evaluation has found more importance as meeting practice requirements among leading manufacturers of machinery. A composite error is highly sensitive to the slightest changes of gear transmission conditions as a literature analysis has revealed. It makes the information about a composite error more important in solving problems of diagnostics in gear transmission and mechanism sphere.

An unquestionable advantage of a composite error signal is also a possibility of receiving some information about meshing character on all sections of gearing phase, but not in separate points. As practice shows such data are very useful for carrying out some possible profile correction, for example, by means of a profile modification.

The research work shows that not only a standardized value of a cyclic component of composite error f_{zzor}, but also the character duration of its changes are characterized with smooth work and have influence on dynamic loads and vibroacoustic features of transmissions. Functional indices practiced nowadays don't define smooth work of transmission completely. At the same time a composite error has enough necessary information for formation of new, more absolute estimate criteria of smoothness that became one of the directions in tests and research work.

Effective use of the shown parameters is often held in by functional potentialities of the used means. Realization of the complex approach makes it necessary to expand a list of their functions and to fill them with completely new qualitative contents. Qualitative receipt of a composite error signal is not the only thing of practical importance, but a possibility to pick out more important and informative components out of whole information, depending on the problems under the study, by means of applying new algorithms of signal treatment. The described principles are realized in creation of a new control diagnostic complex (CDC), which is a totality of modern apparatus means of high capacity, directly connected with computer and controlled by means of a program system.

3 Means and methods of experimental research work

CDC permits to carry out a receipt and treatment of vibration mechanism data by means of original algorithms and by three independent channels at once, and also of a composite error using impulse data units of angular travels. Creating CDC, most attention was paid to a maximum transmission of function of apparatus means of the complex to a computer in order to carry out a rearrangement in the complex program system for concrete tasks of any user as soon as possible. Profundity of the received signals analysis is determined by a complexity of the solved problems and is carried out by computer by means of special program supply. Apparatus means carry out a taking down of measuring data of the examined object and its initial processing. In this case the complex ensures a quick receipt of large amounts of information, its study and storage and also its presentation in a form convenient for a user by saving his time that makes the estimation of technical conditions of units and parts of drives.

Stabilization of movement speed of the drive under the study is not necessary for CDC function, that gives an opportunity to use it both for stand and exploitation tests.

Using specially worked-out algorithm program means lets us pick out the components of the whole signal created by separate elements of the drive. It makes it possible to get information about vibration and composite error both for the studied object in the whole and for separate toothed gears and drives.

Combined analysis of a composite error and a vibration load of a mechanism permits to ground more precisely reason and nature of dynamic phenomena, appearing in toothed gears work, to define places of defects and also to establish connections between a composite error and a vibroacoustic load of the object.

As tests show not the whole spectrum of frequency has the same informative value in gear transmission study. That's why it often becomes necessary to carry out analysis of definite frequency fields and also of some frequency components of the studied processes. Worked-out program means of CDC give an opportunity to get synthesized diagrams of "vibration" processes and "composite" error and its amplitude-frequency characteristics using any set of frequency (Figure 1-4).

4 Diagnostics of elementary errors of gear transmissions

Moreover it is also necessary to have a theoretical background of new ideas about potentialities of a kinematic control and methods of its realization in practice for a successful solution of problems.

The mechanism of a composite error origin in a gearing can be studied on the base of this or that error influence on profile parameters. Profile parameters of involute gear transmission are involute radius – the base circle r_0 – and an involute tangle turn which is a tangle turn φ for a toothed wheel.

A normal in every point of exact involute profile is a tangent of a theoretical base circle with radius r_0. If a toothed wheel has any error so as a rule some changes in a theoretical radius of the base circle take place. In such cases a profile normal in every point of a gear working part is a tangent of the base circle with radius r_{01r} different from nominal r_{o1} on some quantity Δr_{01} caused be an error in gearing. There is a composite error in gearing with a precise wheel with radius r_{02} of the base circle and this error can be defined in every point with the help of the following formula:

$$\Delta\varphi(\varphi_1) = \int_0^{\varphi_1} \frac{\Delta r_{o1}(\varphi_1)d\varphi_1}{r_{02}} \qquad (2)$$

Special samples of toothed wheels with module m=2mm and toothed wheel rim width of b=20mm, HRC=50-54 were used as experimental objects. These or those production or exploitation errors of such samples (except for two taken as pair standards) were modulated. Experimental wheels conformed to the sixth accuracy grade of state standards according to all controlled parameters (except for the modulated error). The modulated errors conformed to the eight grade and lower. The study of this or that error was held with the installation of the necessary wheel combination. It was a stand for tests of a composite error of gear transmission used that provided us with the necessary frequency of the driven shaft rotation in 0…3000 min^{-1} range and with brake torque till 2500Nm on an outlet shaft.

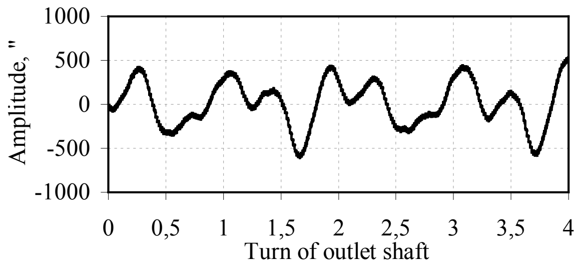


Figure 1 A composite error of a mechanism

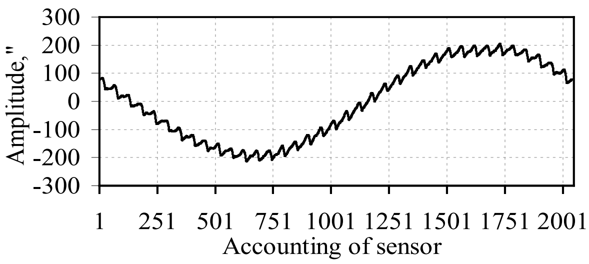


Figure 2 A composite error of the 1st shaft

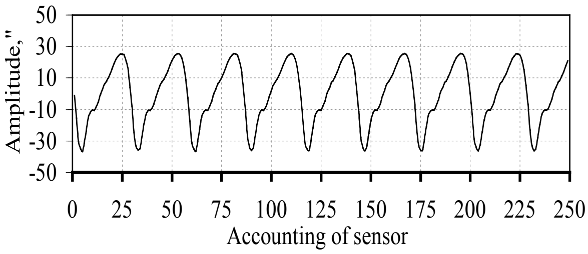


Figure 3 Components of a composite error of the 1st shaft with frequency divisible by the frequency of the first wheel gear remating

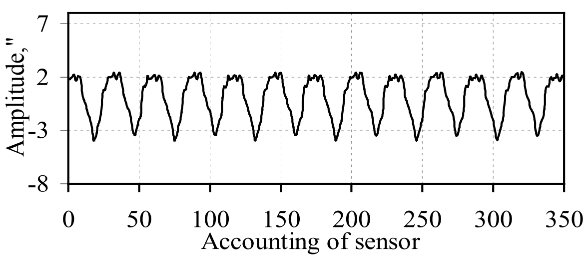


Figure 4 Components of a composite error of the 1st shaft with frequency divisible by the frequency of the second wheel gear remating

An error of gearing pitch f_{pbr}, as it is known, happens when a radius of the base circle r_0 is different from theoretical and unchangeable in every point of working profile.

The appearance of a gearing pitch error is connected with the presence of some parts of involute and edge interaction of profiles on a pitch phase (Figure 3). If the first one is characterized with an inclined line in a signal of composite error in accordance with (2), so the second as test data show described with a curve which is truly enough approximated with a quadratic dependence that is evidently corroborated in literature, for example /1/. A transcendental function for composite error determination on the part of the edge contact and dependence for a determination of angles of edge and involute interaction were theoretically received during the investigations /2/. It made it possible to link quantitatively a magnitude of a gearing pitch and parameters of the composite error upon a quantity of an angle pitch and accordingly it becomes possible to set a magnitude and a sign of the given error from the data of a kinematic control with an acceptable exactness (Table).

Quantities of gearing pitch error of experimental toothed wheels upon kinematic control data

Factual quantity f_{pbr}, , mkm	f_{pbr} upon kinematic control data, mkm	Factual deviation, %
+31	+28	9,7
-13	-11	15,4
+45	+44	2,2

There can't be well-seen parts of edge and involute contacts if teeth have a profile form error in a composite error signal when there is a prominent increase of teeth and multiples of its components. A composite error type is on a gearing part is defined by a character of a profile deviation from involute. For example, the type of a composite error presented on figure 4 permits us to make a conclusion that the experimental toothed wheel has a profile error in a form of an excessive convexity of a tooth profile. And in this case low points of the characteristics, in which the function is broken, correspond to an impact in gear remating. The received test data prove theoretical results and also assume an effective usage of a kinematic control for a treatment of a rational tooth profile that is closely connected with generated noise and vibration in work.

Local tooth defects of exploitation character can be successfully found out during a kinematics control. Their manifestation in a composite error signal is clearly seen in a presence of sharp splashes of characteristics of a chance character during one wheel rotation. Microdefects of teeth cause signal changes which are insignificant in length and quantity that's why their finding out during the analysis of a kinematogram is not always possible and has a subjective character. So for their diagnostics it is suggested to use diagrams of redundant angular velocities and accelerations which are more sensitive to high frequency processes and are received be means of mathematics processing of the initial signal of a composite error with CDC help. As figure 5 shows, it's problematic to establish a tooth defect operating only with a composite error diagram, as the defect is reflected on an acceleration diagram in a form of a characteristics leap.

The above errors include the main errors controlled in spur toothed wheels. The quantities of errors of other gear transmission elements taken for control and standardization are defined in a high degree with the studied parameters which they can be taken to.

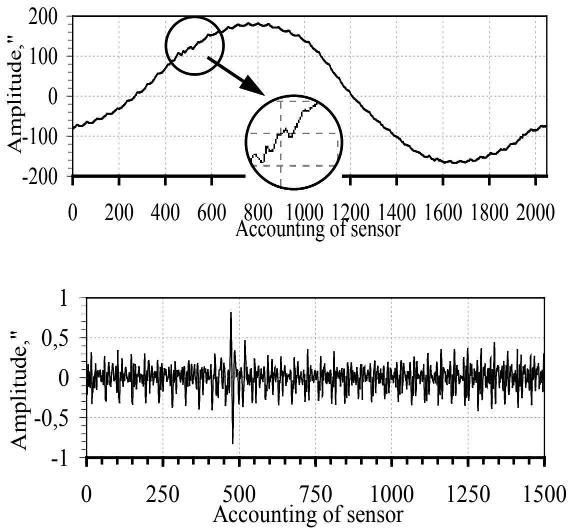
5 Estimation of percussive processes with gear remating

Gear remating with some error and also with tooth deformation is accompanied by appearance of speed differences between teeth getting into a mesh on a line of action v_p. This leads to a smooth percussive process of teeth getting into action and along with outside dynamic interference is a reason of high noise and vibration of transmission /3, 4, 5/. It was determined and theoretically proved that tooth impact when getting into a mesh clearly becomes apparent in a composite error signal in a form of diagram breaks. In these circumstances their quantity characteristic – an impact speed can be determined with the help of kinematic control data by initial signal differentiation:

$$v_p = \omega_1 r_{o2}\left(\frac{d(\Delta\varphi^I)}{d\varphi_1} - \frac{d(\Delta\varphi^{II})}{d\varphi_1}\right) \qquad (3)$$

ω_1 – an angular speed of a driving speed movement;

$\Delta\varphi^I$, $\Delta\varphi^{II}$ – a redundant angle of a driven wheel at the moment of driven and driving wheel teeth throwing into engagement.



a).

б).

Figure 5 A manifestation of a local tooth defect on a composite error diagram (a) and angular accelerations (b)

The parameter got in the results of tests and information processing of a composite error and called as a relative speed of an impact is a more perfect characteristic of smooth work of transmission in comparison with a quantity of a composite error of tooth frequency f_{zzor}, the amplitude of which is not always proportional to a percussive disturbance by gear remating.

The schedule of figure 6 shows interaction between a relative speed of an impact and levels of vibroacceleration appearing in transmission work when a rotation frequency of a pinion is $n=1500min^{-1}$ and a loading torque on an outlet shaft is T=120Nm. Getting into consideration the fact that load causes tooth deformation and this in its turn influences a percussive speed, smoothness of work was estimated upon $n=50min^{-1}$ and T=120Nm. As the drawing shows, the points on the schedule are approximated by line dependence, ensuring a quantity of a correlation coefficient more than 0,9. The presence of close connection between the given parameters permits to suppose that vibroacceleration can be prognosticated with 2-3 dB exactness upon kinematic control data. Similar analysis can form a base for development of requirements to toothed wheel quality upon the suggest parameter.

Except for impact interaction of teeth throwing into a mesh, it is also necessary to take into consideration smoothness of work on a whole part of a gearing phase. The appearance of variable speeds and accelerations can be called as the main reason of inertia loads, leading to vibration increase. The analysis of angular speed and acceleration amplitude on a part of meshing phase of a tooth pair permits to find out places of profile correction of teeth more effectively.

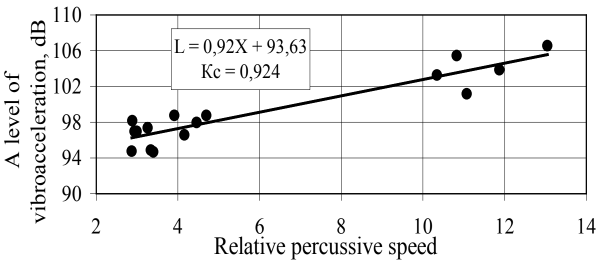


Figure 6 A dependence of common levels of vibroacceleration on a bearing basement of a gear box on a tooth percussive speed.

6 Influence of load and speed conditions

In conditions of high load and speeds of rotation the character of a composite error is determined not only with geometrical parameters of toothed wheels but also with dynamic effects taking place both in toothed wheels of transmission and on similar elements situating on the part of a kinematics chine between outlet and inlet data units of angular shifts /6 , 7/. Some experiments were carried out in this connection and in order to estimate the influence of a speed and load composite error, to state its connection with dynamic phenomena and other exploitation characteristics of transmissions. As a result, it was found out:

- parameter components of errors of wheel teeth appear with load increase geometrical components of errors and compensate them , leading to a correspondent change of amplitudes of tooth components of a composite error and also to speed changes of tooth impact in gear remating.

- the increase of frequency rotation brings to the increase of tooth percussive speed and leads to the growth of dynamic loads. A composite error character is more determined by dynamic phenomena with the increase of rotation speed, than by geometrical tooth parameters. And this helps to use a kinematics control for estimation of some dynamic phenomena in tooth drive work in operation conditions. And for example, a method of exposure of resonance frequencies of tooth drive vibrations on the base of composite error data and also of angular speeds and accelerations was worked out.

7 Conclusion

1. A tooth transmission composite error is not only a characteristic of exactness of rotation transmission from one shaft into another, but also a rather informative parameter, characterizing the main elementary technological and operational toothed wheel errors and also operational transmission characteristics including operational conditions of work.
2. The law of a composite error change permits to reveal for certain the mechanism of impact formation in the conditions of gear remating and it contains necessary information for estimation of its speed which is one of the main factors determining dynamic loads and vibroacoustic phenomena in mesh.
3. The solution of new practical tasks in the sphere of tooth transmission diagnostics, elaboration of new technologies of their production and design using composite errors puts forward principally new demands to kinematic control means within a whole range of directions: the increase of productivity, exactness, expansion of functional possibilities to process measuring information and so on.

References

1. Markov N.N., Guschin V.G. Influence of base pitch on smoothness of work of cylindrical gears //Vestnik mashinostroyeniya. – 1983. - №1. – p.14-17. (in Russian).
2. Dragan A.V. Estimation of smoothness of work of cylindrical gears on kinematic kontrol data // Vestnik BGTU. – 2000. - №4. – p. 2-6. (in Russian).
3. Suchorukov J.N. Modification of evolvent spur gears. – Kiev: Technica, 1992.- 197p. (in Russian).
4. Berestnev O.V., Goman A.M., Ishin N.N. Analytic mechanics methods on drives dynamics. – Minsk.: Navuka i technika, 1992. – 238p. (in Russian).
5. Kosarev O.I. Model of vibroexcitation in spur gears// Problemy mashinostoyeniya i nadeschnosti maschin. – 1996. - №1. – p.22-33. (in Russian).
6. Weck M., Plewnis C. Einflanken-Wälzabweichung und Getriebegeräusche von Kegelradverzahnungen// Antriebstechnik.- 1991. - №11 - S. 70-73.
7. Houser D., Blankenship G. Methods for measuring gear transmission error under load and at operating speeds // SAE Techn. Pap. Ser., 1989.- № 891869.