PLANETARY REDUCTION GEARMOTOR VIBRATION DIAGNOSTICS

Dmitrijs Ļitvinovs
Riga Technical University, Faculty of Transport and Mechanical Engineering,
Institute of Engineering Technology
arminius@inbox.lv

Abstract. The methods of planetary reduction gearmotor vibration diagnostics are described in this article. The most frequent defects and methods of their estimation using vibration diagnostics are described. The analysis of satellite gear bearings duration work depending on different factors is also resulted. In the end of the paper conclusions are done about appropriateness of planetary reduction gearmotor vibration diagnostics works conducting.

Keywords: frequency, envelope spectra, torsion and transversal oscillations, sensor.

Introduction

A planetary reduction gearmotor (Fig. 1) has obvious preferences as compared to an ordinary cylindrical reduction gearbox. It is a small specific material consumption at large enough loading ability that is explained of the high-capacity gearing presence; compactness, noiselessness, less mass and sizes, possibility of large reduction rates obtaining.

Fig. 1. **Planetary reduction gearmotor**

Due to the specific structural constructions, planetary reduction gearmotors were and remain the most progressive types of reduction gearboxes of industrial application. Compactness, small specific gravity and, simultaneously, possibility to pass the promoted loadings – here what planetary reduction gearmotors are attractive for developers and users. Also application of planetary reduction gearmotors instead of cylindrical reduction gearboxes allows considerably reducing weight of transmission. Thus, the more power or moment, passed by reduction gearmotor, the greater winning in mass and sizes of transmission will get a user.

However in spite of all improvements in the construction of planetary reduction gearmotors, it is necessary to practice the permanent monitoring and vibration diagnostics of these reduction gearmotors. On Fig. 2 the scheme of the simplest planetary gearing is resulted.

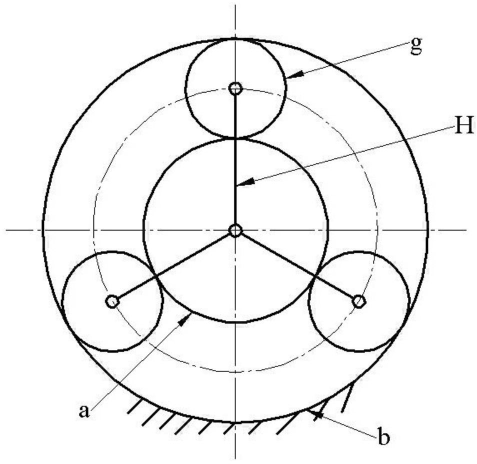

Fig. 2. **The scheme of the simplest planetary gearing:**
a – a leading gear (a sun); g – satellite; H – rein; b - epicycle (crown), fastened on a case

One stage of planetary reduction gearbox Fig. 2 consist of leading gear (a sun) – a, three intermediate gears (satellites) – g, revolving on the rein – H, and big gear, called by epicycle (crown) – b. Sometimes for the reduction rate increasing the double satellites (two planes) are utilized, each of which are two parallel gears on a shaft, which bearings of satellite are set into.

Nature of vibration origin in planetary reduction gearmotor

There are general regularities to the law of acoustic signal change character at violations in work of gearing mechanism, caused the defects of making, assembling and maintenance, being information sources at the estimation of the planetary reduction gearmotors technical state. Thus the changes of vibroacoustic processes develop on a background of the perturbing forces action, accompanying normal functioning of gearing and determining interferences level at diagnostics.

Noise and vibration of gearing arise up as a result of variable forces influence, conditioned a change in time of toothing parameters. It means that even the ideal gearing can not work noiselessly [1].

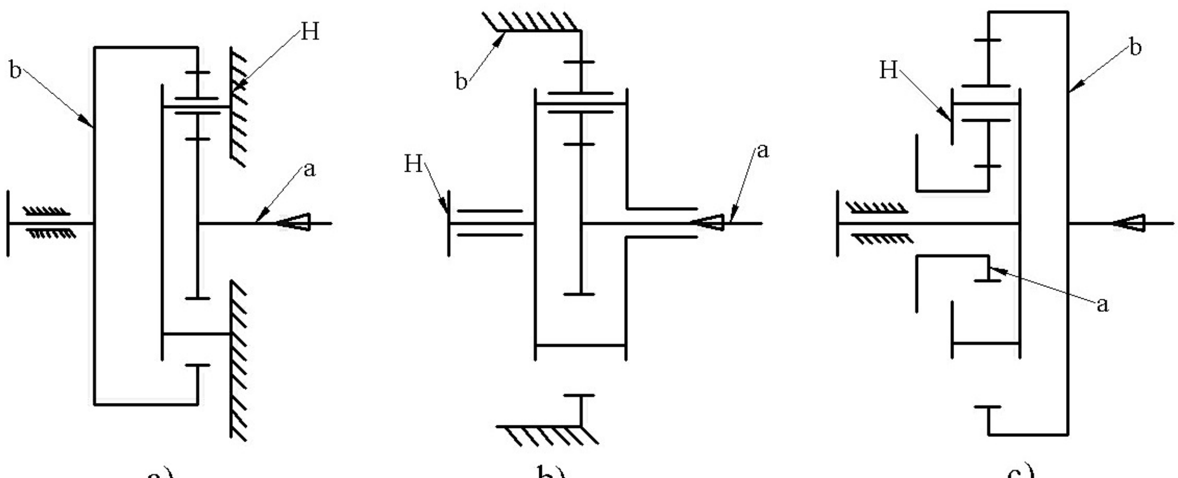

Fig. 3. **Kinematics of planetary reduction gearboxes on the basis of one stage planetary gearing:**
a – with immobile rein H; b – with immobile epicycle (a crown) b;
c – with an immobile leading gear a (a sun)

The harmonic constituents of oscillation forces in planetary reduction gearboxes have a kinematics and parametritic origins. Frequencies of oscillation forces are determined by schemes of reduction gearboxes Fig. 3 which are very various, especially in the cases, when multi-stage reduction gearboxes and gearboxes with all rotating units (a sun, crown, rein) are utilized. Gearboxes with single satellites can have immobile either crown either rein or a sun.

Rotation frequencies of gearbox gears with immobile rein $f_H = 0$ Fig. 3, a and, accordingly, vibration frequencies of basic components accounts also, as well as in usual double stage reduction gearbox, that is, rotation frequency of satellites f_g is related to rotation frequency of a sun [2]:

$$f_g = f_a \frac{Z_1}{Z_2}, \tag{1}$$

where $Z_1; Z_2$ – amount of teeth on a sun and satellite.

Rotation frequency of crown is equal accordingly:

$$f_b = f_a \frac{Z_1}{Z_3} = f_g \frac{Z_2}{Z_3}, \tag{2}$$

where Z_3 – amount of teeth on a crown.

Toothed frequency, identical for "sun-satellite" and "satellite-crown" gearings, is determined by expression:

$$f_z = f_a \cdot Z_1 = f_g \cdot Z_2 = f_b \cdot Z_3 . \tag{3}$$

Rotation frequencies rein and satellites in an ideal reduction gearbox with an immobile crown Fig. 3 b, in which the number of crown teeth is equal to the sum of a sun teeth number and satellite teeth doubled number, determined as follows:

$$f_H = \frac{1}{2} f_a \frac{Z_1}{Z_1 + Z_2}, \tag{4}$$

$$f_g = (f_a - f_H) \frac{Z_1}{Z_2} . \tag{5}$$

Toothed frequency is determined by expressions:

$$f_z = (f_a - f_H) Z_1 = f_g Z_2 = f_H Z_3 . \tag{6}$$

In the real gearboxes through technological reasons at the teeth angular correction the amount of crown teeth is increased on one – two, that results in rotation frequency of rein small increasing, toothed frequencies and satellite rotation frequencies. More exactly these frequencies can be defined:

$$f_H = \frac{f_a \cdot Z^*}{Z^* + 2Z_3}, \tag{7}$$

$$f_g = \frac{f_H Z_3}{Z_2}, \tag{8}$$

$$f_z = f_H Z_3 , \tag{9}$$

where $Z^* = Z_1 + 2Z_2 + Z_3$.

Planetary reduction gearboxes with an immobile sun gear Fig. 3 **c** are utilized much rarer. Rein and crown rotation frequencies in such gearboxes are determined by correlation:

$$f_H = \frac{2 f_b \cdot Z^*}{Z^* + 2Z_3} . \tag{10}$$

Toothed frequency and satellite rotation frequency is equal:

$$f_z = \frac{2f_b \cdot Z_1 \cdot Z_3}{Z^* + 2Z_3}, \tag{11}$$

$$f_g = \frac{f_z}{Z_2} = \frac{2 \cdot f_b \cdot Z_1 \cdot Z_3}{Z_2\left(Z^* + 2Z_3\right)}. \tag{12}$$

From planetary reduction gearboxes with double satellite gears are more frequent than other utilized gearboxes with one immobile crown, having either internal or external gearing. In first case a reduction rate comes to the value 15, in the second can exceed 100.

In a gearbox with a crown, having the internal gearing, without the account of teeth correction that is under condition:

$$Z_1 + Z_2 = Z_3 - Z_2', \tag{13}$$

where $Z_1; Z_2; Z_2'; Z_3$ – number of teeth on a sun gear.

Large and small satellite gears and crown, rotation frequency of rein related to rotation frequency of sun gear as follows:

$$f_H = \frac{f_a \cdot Z_1 \cdot Z_2'}{\left(Z_3 + Z_2'\right)\left(Z_2 + Z_2'\right)}. \tag{14}$$

Rotation frequency and toothed frequencies of satellite are determined by expressions:

$$f_g = \frac{f_H\left(Z_1 + Z_2 + Z_2'\right)}{Z_2'}, \tag{15}$$

$$f_z = f_g \cdot Z_2 = \frac{f_H \cdot Z_2\left(Z_1 + Z_2 + Z_2'\right)}{Z_2'}, \tag{16}$$

$$f_{z'} = f_g Z_2' = \frac{f_H Z_2'\left(Z_1 + Z_2 + Z_2'\right)}{Z_2'}. \tag{17}$$

In a reduction gearbox with a crown, having the external gearing, rotation frequency of rein:

$$f_H = \frac{f_a \cdot Z_1 \cdot Z_2'}{Z_3 Z_2 + Z_2'\left(2Z_2 - Z_1\right)}. \tag{18}$$

Peculiarities and methods of planetary reduction gearboxes vibration diagnostics

The vibration of planetary reduction gearmotors is measured on bearings of input and output shafts, and also on a crown (crowns) in radial direction. Most difficult for vibration measuring of appear gearmotors with the rotating crown, especially multi-stage, drum execution, in which a vibration can be measured only on rotation supports with one immobile element.

In gearings with input shaft variable direction of rotation the gearing vibration strongly depends on direction of its rotation. Therefore the vibration of such gearings is measured twice, at each directions of rotation, and the gearing vibration state is determined on the vibration maximal size in any directions of rotation. The toothing of such gearing is diagnosed also twice, but each periodic operation of diagnostics can be conducted at one direction of rotation. Rotating direction of the diagnosed gearing in this case change not on every stage of the diagnostic measuring conducting, but during next operation of diagnostics conducting, through 2-3 month of continuous work. Thus the vibration of gearing comparison at different times must be made only at the same direction of rotation.

The basic feature of planetary gearing is the points of forces attack cyclic spatial moving in gearing in relation to the immobile vibration sensor, setting on a gearbox case, which creates an additional interference as balanced peak modulation [3], showing up in addition two peak-modulated oscillations in opposite phase with complete or partial indemnification of carrier frequency. Thus, actual excitation frequencies of oscillations in planetary gearings do not coincide with frequencies, perceived by vibration sensors, related to the immobile coordinate system.

In a planetary reduction gearbox torsion and transversal oscillations of gears have different frequency descriptions of distribution ways and subject to different mathematical transformations. For torsion oscillations the form of the signal transformation is determined by expression (19):

$$U_{rot.} = A_0 \cos(\omega_Z t + \varphi_0)\left[1 + A_1 \cos(\omega_1 t + \varphi_1)\right] = A_0 \cos(\omega_Z t + \varphi_0) + \\ + \frac{A_0 A_1}{2}\cos\left[(\omega_Z - \omega_1)t + (\varphi_0 - \varphi_1)\right] + \frac{A_0 A_1}{2}\cos\left[(\omega_Z + \omega_1)t + (\varphi_0 + \varphi_1)\right] \quad (19)$$

For transversal oscillation the transformation form of initial information has the view of balanced modulation with frequency ω_2 of perturbation source in space moving in relation to a sensor, set on an immobile case (20):

$$U_{tran.} = \left\{A_0 \cos(\omega_Z t + \varphi_0)\left[1 + A_1 \cos(\omega_1 t + \varphi_1)\right]\right\} A_2 \cos(\omega_2 t + \varphi_2) = \\ = \frac{A_0 A_2}{2}\left\{\cos\left[(\omega_Z - \omega_2)t + (\omega_0 - \varphi_2)\right] + \cos\left[(\omega_Z + \omega_2)t + (\omega_0 + \varphi_2)\right]\right\} + \frac{A_0 A_1 A_2}{4} \cdot \\ \cdot \left\{\cos\left[(\omega_Z - \omega_2 - \omega_1)t + (\varphi_0 - \varphi_2 - \varphi_1)t + (\varphi_0 + \varphi_2 - \varphi_1)\right] + \cos\left[(\omega_Z + \omega_2 + \omega_1)t + (\varphi_0 + \varphi_2 + \varphi_1)\right]\right\} \cdot \\ \cdot \cos\left[(\omega_Z - \omega_2 - \omega_1)t + (\varphi_0 - \varphi_2 - \varphi_1)t + (\varphi_0 + \varphi_2 - \varphi_1)\right] + \cos\left[(\omega_Z + \omega_2 + \omega_1)t + (\varphi_0 + \varphi_2 + \varphi_1)\right] \quad (20)$$

The important feature of planetary gearings vibration is the variable loadings transmission from one stage to other. As a size of oscillating forces in the toothing at least quadratic increases with rotation frequency of gears, the slow stages vibration of multi-stage transmissions, mainly, is determined by oscillation forces, passed from the high-speed stages. At the same time torques on all stages have near values, therefore, influencing of identical defects on the different stages of reduction gearbox results in appearance of comparable on a size pulsating moments and comparable on a size modulation consumed electrical current by the drive electric motor. Exactly from the listed features of oscillating forces forming and pulsating moments in defective reduction gearboxes the diagnostics of the high-speed stages of gearing is easy to conduct on their vibration, and the low-speed stages – on electrical current consumed by a drive electric motor.

Analysis of satellite gears rolling bearings operation time depending on different factors

On satellite gears rolling bearings operation time the large influencing is rendered by such factors as:

- Manufacturing precision of satellite gears, rein and also epicycle;
- Reduction gearmotor assembling precision;
- Presence and quality of greasing;
- Over loadings during maintenance.

By basic diagnostic signals at state control of the planetary reduction gearbox rolling bearings, there is its vibration and temperature. The basic problems of gearing bearings diagnostics are determined impossibility to measure a high-frequency vibration and temperature of some inaccessible bearings for measurement, and also part of defects diagnostic signs coincidence in bearings and in other elements of gearing.

For rolling bearings deep diagnostics the vibration spectral analysis of bearings units, and also spectral analysis of envelope its high-frequency component, are utilized. Thus the coincidence of defect signs of bearings and other units of gearing takes a place in those cases, when they are built on vibration harmonic components and random vibration of bearing modulation increasing with frequencies, multiple its rotation frequency. So, the identical are become greater part of beating shaft signs with the gear (pulley, chain-wheel) mounted on it and bearing wear, related to vibration increasing on frequencies $kf_{rot.}$ and vibration modulation by the same frequencies. Part of gears distortion signs and heterogeneous radial tightness of rolling bearing are coincides. The most difficult situation arises up from the coincidence of gear tooth defect signs with the signs of rings slipping in rolling bearing.

How to separate the indicated defects? At first, at gear defects are often enough the electrical current of drive electric motor appears modulated. In the second, practically all defects of gear and gearing result in modulation of gearing vibration toothed constituent, while the bearings defects such influencing do not make practically. In the third, the defects gears and gearing modulate the high-frequency vibration of most bearings of both gearing shafts, while bearing defects, as a rule, show up in the imperfect bearing vibration envelope spectra only.

Conclusions

It is possible to make a conclusion coming from all above-stated that in spite of planetary reduction gearmotor labouriousness of vibration diagnostics process, especially rolling bearings of satellite gears, application of permanent vibration diagnostics and monitoring gives considerable effectiveness of costs due to repairs which are conducted on the equipment actual state. The presence of permanent and operative information about the state of reduction gearmotors base allows also opportunely planning the purchase of repair parts, or new reduction gearmotors. Also the modern methods of diagnostics application allow taking the losses of the finished product and equipment downtime to the minimum, and also allow considerably promoting quality of the finished product.

References

1. Неразрушающий контроль. Справочник в 7 томах под редакцией чл.-корр. РАН В.В. Клюева. Том 7. Машиностроение, Москва, 2005. 830 с.
2. Барков А.В., Баркова Н.А., Азовцев А.Ю. Мониторинг и диагностика роторных машин по вибрации. Санкт-Петербург, Издательство СПбГМТУ, 2000. 162 с.
3. Генкин М.Д., Соколова А.Г., Виброакустическая диагностика машин и механизмов. Москва: Машиностроение, 1987. 288 с.

Acknowledgements

This work has been partly supported by European Social Fund within the National Programme “Support for the carrying out doctoral study program’s and post-doctoral researches” project “Support for the development of doctoral studies at Riga Technical University”.