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Diagnostics practice of heavy duty high speed gear transmissions

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1. Introduction

The gear transmission is a high frequency mechanical vibration system with the gear mesh as the main vibration source. The low rotational speed heavy duty gear power transmission have been modeled and tested in situ to protect unexpected failures [1, 2, 5]. The high rotational speed heavy duty gearing diagnostics is important in modern energy generating machines. In case of complex rotary machines, it is very complicated to trace all sources of vibrations (e.g. internal defects) [6]. The rotor systems with adaptive and sleeve sliding-friction bearings is analyzed in the paper [7]. Due to vibrations of gears, the teeth meshing inaccuracies generate dynamic forces and early wear teeth. So far, the effects on gears loading have been well studied, but an issue that the intensity of vibration acceleration level and teeth meshing shocks – how severe is the problem – has scarcely been studied for practical purposes. The gears vibration acceleration parameter was used to diagnostics and evaluation of teeth meshing problem. This article is dedicated for condition monitoring of the gear power transmissions, protection and failures diagnostics through vibration parameters measured in situ.

2. The objects of research

The modern, high efficiency power generating machines with gas and steam turbines have high rotational speed of rotors (8000 rpm and more). Rotational speeds of the electric generators rotors are 1500 rpm - 3600 rpm. The specificity of these machines design included various types of gear transmissions that reduce the rotational speeds of turbines to electric generators.

The turbo units with power ratings from 700 kW to 10000 kW with gear drivers are experimentally tested in situ using bearing housings absolute vibration parameters measured with seismic transducers – pjezoaccelerometers. The gear power transmissions usually consist of two or more gears meshed for the purpose of transmitting motion (power) from turbine rotor to electric generator rotor. The motion parameters are: P – power, T – rotor torque, n – rotational speed of the rotor or ω – rotor angular velocity.

3. Vibration of the helical gear reducer

Kinematical scheme of turbo unit with steam turbine, ordinary double-helical gear train and electric generator set is shown in Fig. 1.

The two different power generating turbounits have analogous kinematic schemes. The 700 kW power steam turbine (rotor running on four-lobe journal bearings 1 and 2) rotational speed is n_{ST1} = 8000 rpm (133.33 Hz) and the 1250 kW power steam turbine rotational speed is n_{ST2} = 10500 rpm (175 Hz). Rotational speed of the both electric generators rotors (running on antifriction bearings 7 and 8) is low n_{EG} = 1500 rpm (25 Hz). The steam turbine rotor is connected by a coupling 12 to the ordinary double-helical gear train with the speed ratio 1:5.3448 (pinion z_1 = 29, gear z_2 = 155) and the second unit gear transmission speed ratio is 1:6.857 (pinion z_1 = 21, gear z_2 = 144) that reduces turbine rotor high rotational speed to 1500 rpm of the generator rotor 11. The motion parameters of the gear train driven rotors: of the 700 kW power machine – T_1 = 4460 Nm, ω_1 = 157 rad/s and of the 1250 kW power machine – T_2 = 7960 Nm, ω_2 = 157 rad/s.

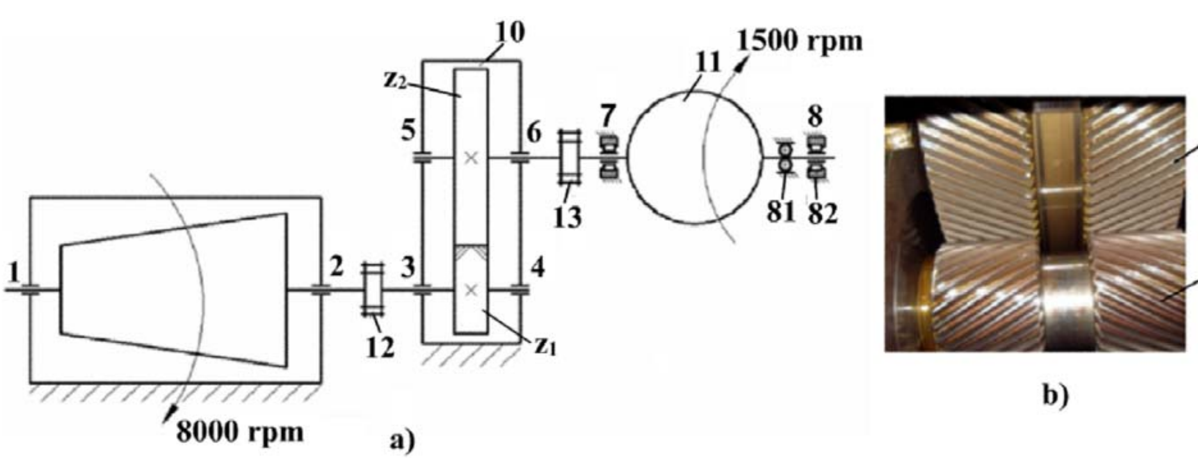


Fig. 1 Scheme of the high speed turbounit rotating system (a) and ordinary double-helical gear train; z_1 - driving gear, z_2 - driven gear (b)

Vibration acceleration spectrum of the 700 kW power gear transmission bearing housing is shown in Fig. 2. The gears $z_1 = 29$, $z_2 = 155$ mesh generate high frequency (29·133.33 Hz = 3880 Hz) shocks with severe vibration acceleration amplitudes (143 m/s^2) of 4th bearing, Fig. 2. The measured vibration intensity is too severe for long term safe operation mode of the turbounit. The increased radial gaps in journal bearings 3-6 or damages of white metal in bearings (rubbing) generated transmission error in gear mesh.

Frequency of the 1250 kW power turbounit gear mesh is (21·175 Hz = 3600 Hz) with high level vibration acceleration amplitude of 4th bearing measured in vertical direction. The plots of root mean square vibration acceleration value a_{rms} = 113.8 m/s^2 (161 dB) and maximum peak value a_{max_peak} = 227.3 m/s^2 (167 dB) are shown in Fig. 3. The high vibration intensity is too high for safe continuous operation of the turbounit. The damaged journal bearing generates transmission error in gear mesh and generates high vibration amplitude of gear mesh frequency and sidebands.

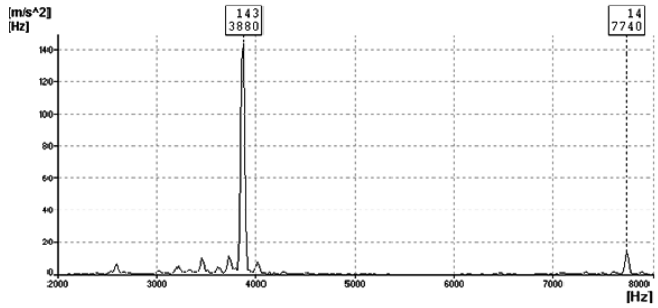


Fig. 2 Axial vibration acceleration spectrum of the 700 kW power turbounit ordinary helical gear train 4th bearing housing: driving gear $z_1 = 29$ rotational speed 8000 rpm, teeth meshing frequency 3880 Hz vibration acceleration amplitude 143 m/s^2 (163 dB) is dominated

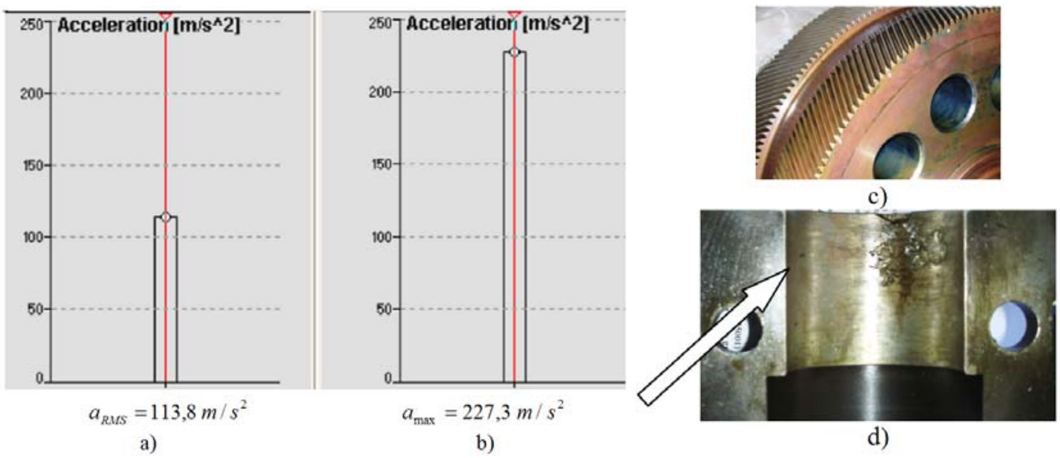


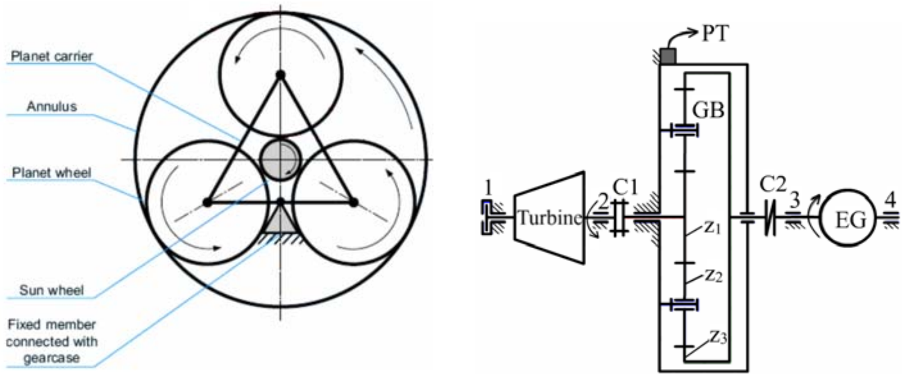
Fig. 3 The 4th bearing housing vertical vibration acceleration a_{rms} (a) and a_{max} (b) values of 1250 kW turbounit ordinary helical gear train: gear z_2 (c) and damaged journal bearing (d) caused transmission error in the gear mesh and generates high frequency vibration acceleration amplitude

4. Vibration of the high rotational speed epicyclical gear train

Planetary gear trains, also referred as epicyclic gear trains, are those in which one or more gears orbit about the central axis of the train. Thus, they differ from an ordinary parallel shaft gear trains by having a moving axis or axes: sun pinion gear, planet gear, planet carrier, internal toothed ring gear – annulus, Fig. 4. The most significant advantage of epicyclic gears is that the input torque is distributed to all of the planets gears with optimum utilization of space and minimum weight due to effective load distribution. The torque is balancing equally between the planets gears. The radial forces of each gear teeth mesh offset each other that allow achieve compact design with the best load equalization at tooth contact points. The double helical epicyclic gears are especially suitable for high powers and speeds (power range 1-37 MW, high speed shafts 3000-19000 rpm, low speed shaft 1500 or 1800 rpm), e.g. gas or steam turbine driven el. generators. They eliminate axial thrust, prevent tilting moments and ensure silent running owing to the larger contact ratio of meshing teeth, improved distribution of heat in the tooth area. Usually all shafts run in plain bearings or multilobe bearings.

Epicyclic gear units can operate at up to 1% higher efficiency than a parallel shaft gear unit, and are inherently quieter than parallel shaft gear units, with lower noise and vibration [6].

The 9.5 MW power steam turbine-electric generator unit is additional power module of the 25 MW power gas turbo unit, Fig. 5. The epicyclic gear train is integral module of this power generating machine. The sun gear $z_1 = 29$ is connected to the steam turbine high speed rotor with rotational speed 11224 rpm (187 Hz). The planet carrier is stationary connected to the gear train case. The annulus has $z_2 = 217$ teeth and connected to the four poles electric generator rotor with 1500 rpm. The motion parameters of the 9500 kW power gear train driven rotor are: $T = 60510$ Nm, $\omega = 157$ rad/s, gear ratio $u = 7.4813$.



a b

Fig. 4 Epicyclic gear unit with fixed planet carrier (a) [6] and the kinematic scheme of turbounit (b)

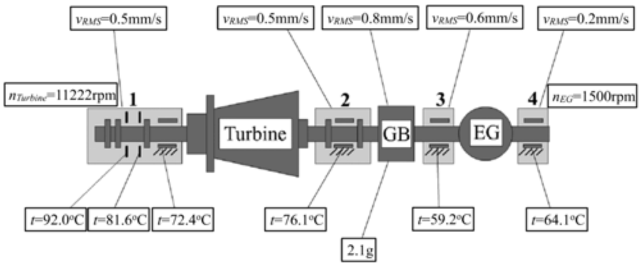


Fig. 5 Turbo unit scheme with steam turbine, epicyclic gear train GB and electric generator EG with monitoring vibration velocities of bearing housings (v_{rms}, mm/s), bearings metal temperatures and rotational speeds (courtesy of SC "Panevėžo energija")

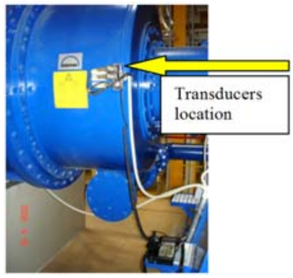


Fig. 6 Vibration measurement transducers stationary fixed to the epyciclic gear transmission case at the planet carrier fixed location

The gear case absolute vibrations were measured in horizontal-radial direction with piezo accelerometers stationary attached at planet carrier fixed location on the gear case point, as shown in Fig. 6.

Root mean square of the steam turbine 2nd bearing housing horizontal vibration velocity value is low 0.5 mm/s, Fig. 5. The vibration velocity spectrum has scarce information about condition of the gearing because the vibration intensity is too low measured up to 1000 Hz interval: el. generator rotor driven by annulus vibration amplitude 0.29 mm/s at synchronous frequency 25 Hz, the sun gear rotation frequency 187 Hz vibration velocity amplitude is low 0.34 mm/s and dominated in the spectrum.

Root mean square of the epicyclic gear train case absolute horizontal vibration velocity value is 0.8 mm/s and has scarce information about vibration of gears, Fig. 5. The vibration velocity comprises the el. generator rotational frequency 25 Hz amplitude 0.38 mm/s, the planet gear rotational frequency is 57.5 Hz amplitude 0.61 mm/s, 373.7 Hz amplitude 0.1 mm/s.

Acceleration spectrum of the epicyclical gear train case horizontal vibration is more informative in diagnostics and shown in Fig. 7. The gear mesh frequency is high ~5420 Hz with acceleration amplitude 52 m/s^2 and dominated in the spectrum (29·187 = 5423 Hz). This difference indicated some inaccuracies of stationary monitoring system, as shown in Fig. 5 (2.1 g vibration acceleration).

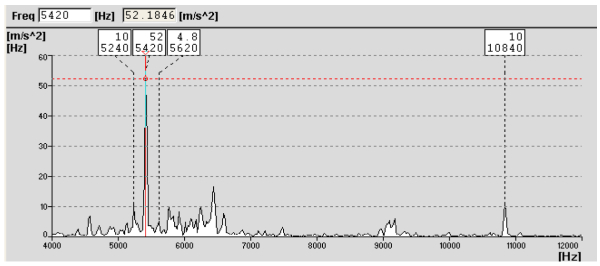


Fig. 7 Epicyclic gear train case horizontal vibration acceleration spectrum: gear mesh frequency 1X = 5420 Hz amplitude 52 m/s^2; sidebands 5240 Hz/10 m/s^2 and 5620 Hz/4.8 m/s^2; 2X = 10840 Hz/10 m/s^2

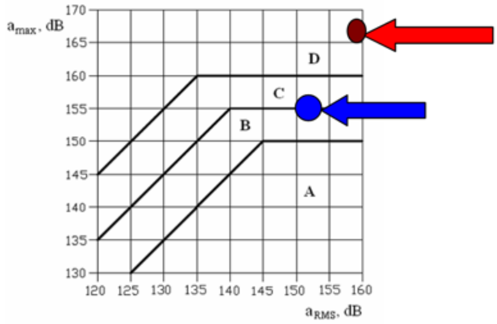


Fig. 8 Evaluation gearing technical condition: double-helical gear with damaged bearing $a_{rms\_1250\ kW} = 114$ m/s^2 = 161 dB; $a_{max\_1250\ kW} = 227$ m/s^2 = 167 dB; epicyclic gear $a_{rms\_9500\ kW} = 42$ m/s^2 = 153 dB; $a_{max\_9500\ kW} = 60$ m/s^2 = 156 dB

Vibration acceleration amplitude of the gear mesh frequency 5420 Hz, measured in vertical direction, is few times less in comparison with horizontal direction, because dynamic stiffness of the gear case in horizontal direction is less in comparison with the vertical direction.

As diagnostics practice showed that not only the antifriction bearings technical condition can be evaluated according plot in Fig. 8, but partially the gearings teeth meshing conditions [7]. The ordinary double-helical gear generates high teeth meshing high shocks in comparison with epicyclical gear and can be evaluated partially using data in Fig. 8.

5. Conclusion

The ordinary helical gear train has few times higher vibration acceleration level in comparison with the epicyclical gear train.

The peculiarity is that each gear box must be evaluated separately using condition monitoring system with vibration acceleration and frequency parameters.

The vibration measurement location is decisive for evaluation of gear mesh technical condition and could be chosen as the most sensitive point on the gearbox for location of the transducers. The measured vibration values as gear mesh frequency f_{mf} vibration acceleration amplitudes a, root mean square values a_{rms} and maximum vibration acceleration values a_{peak} are the most informative in diagnostics and can be evaluated similar as high frequency vibration intensity of antifriction bearings.

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DIDELĖS GALIOS KRUMPLINIŲ PAVARŲ DIAGNOSTIKOS PRAKTIKA

R e z i u m ė

Straipsnyje nagrinėjama didelės galios krumplinių pavarų krumplių susikabinimo žadinamų virpesių intensyvumas ir guolių techninė būklė. Tyrimų rezultatai gauti ilgametės diagnostikos praktikos metu energetikos pramonės įmonėse. Parodyta epiciklinės krumplinės pavaros pranašumai, palyginti su įprasto virpesių intensyvumo cilindrine pavara. Krumplinės pavaros techninei būklei kiekybiškai įvertinti pasiūlyta naudoti aukšto dažnio virpesių pagreičio parametrai, kaip riedėjimo guolių diagnostikoje.

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DIAGNOSTICS PRACTICE OF HEAVY DUTY HIGH SPEED GEAR TRANSMISSIONS

S u m m a r y

Condition monitoring of the gear power transmissions teeth meshing vibrations and bearings vibration evaluation are studied in this article. The research results were acquired in practice during long term diagnostics of energy generating machines in situ. The ordinary helical gear train has few times higher vibration acceleration level in comparison with epicyclical gear train. The gears vibration acceleration parameter was used for diagnostics and evaluation teeth meshing quality as high frequency vibration in antifriction bearing diagnostics.

В. Барздайтис, П. Мажейка

ПРАКТИКА ДИАГНОСТИКИ ЗУБЧАТЫХ ПЕРЕДАЧ БОЛЬШОЙ МОЩНОСТИ

Р е з ю м е

Статья посвящена оценке технического состояния зубчатых передач и подшипников ротора. Результаты исследований получены экспериментальным путем многолетней практикой диагностики энергетических машин. Показано преимущество планетарных передач по отношению к обыкновенным в смысле виброинтенсивности. Предложены параметры виброускорения и использование норм подшипников качения для количественной оценки технического состояния зубчатых передач.

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