Vibration assessment of ski lift gearbox

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Abstract. The main goal of this article is to describe a ski cableway gearbox condition assessment process. The cableway is a typical sample of a machine with carefully monitored technical condition for safe operation. The article describes all steps of the process including vibrodiagnostics and optical assessment methods. The gearbox technical parameters are contained. The diagnostics significant frequencies of bearings and gears were computed. The vibration data during real operation of the gearbox were measured. The measured data were processed and graphs were compiled. The teeth flank surface macrophoto were taken and condition was assessed. All results are commented and the cableway gearbox technical condition is summarized.

Keywords: Vibration, Diagnostics, Gearbox, Cableway, Technical Condition, Gear, Teeth,

1 Introduction

The operation of all rotating machines is accompanied by vibration. The analysis of vibration spectra can provide valuable information on the operating condition of machinery. In mechanical engineering, the most important emphasis is placed on the quality, reliability, and service life of the individual components. The components of machines that can be potentially dangerous for man are especially monitored, one of these machines ski ropeway can be.

This paper describes the results associated with the application of vibration diagnostics on a ropeway gearbox, including the measurement and analysis of vibration frequency spectra. Vibrodiagnostic methods and optical damage assessment of available components were used to assess the technical condition of the driveline. This is a modern way of identifying the quality of the operational technical condition, reliability, and durability of the components of the train (e.g. rotors, gears, bearings) and avoiding a possible ski lift accident.

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2 Vibration Spectra Measurement and Analysis

Transmission is made by Leitner, type KSS7/U, production year 1988, with a gear ratio 1:131. The electric motor of the chairlift drive is a three-phase electric motor 1L315L2-4 B3 KEM with an input power of 200 kW, fitted with bearing 6319 at the free rotor end and NU319 at the output of the rotor.

Fig. 1 shows the drive parts of the cableway. A single-channel vibration analyzer equipped with an acceleration sensor for vibration of the cableway gear set measurement was used. The sensor by the magnets was fixed in defined measurement points, horizontal and vertical direction always.

Frequency analysis, envelope analysis (ENV), and Spectral Emission Energy (SEE) method were used for vibration evaluation for each measuring bowl. Fig. 2 shows the measurement locations of the vibration spectra of the cableway gear set. An overview of the gear setup with each type of rolling element bearing and the number of gear teeth are shown in Fig. 3. Table 1 shows the results of the calculations of the frequencies of the main excitation sources of the gear train of the Leitner cableway.

Fig. 1. Part of the cableway drive

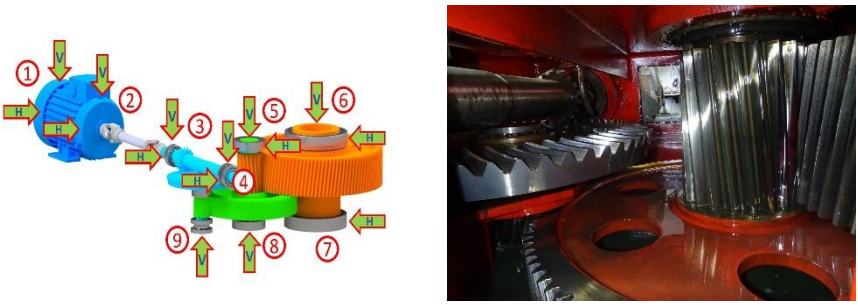

Fig. 2. The cableway gearbox vibration measurement locations and the gearbox internal parts general view.

Fig. 3. Rolling bearings types and a gear teeth number of Leitner gearbox.

Table 1 The calculation of main frequencies excited by cableway transmission system components.

Rotor frequency		Teeth frequency		RPM
f_{R1} [Hz]	20	f_{R1} [Hz]	340	1202
f_{R2} [Hz]	5,67	f_{R1} [Hz]	96,4	1202
f_{R3} [Hz]	0,89	f_{R1} [Hz]	16,9	1202
f_{R4} [Hz]	0,15			1202

Bearing type	f_i [Hz]	f_o [Hz]	f_{vt} [Hz]	f_k [Hz]
6319C3	98,25	62,02	84,1	7,75
23226	215,8	164,7	142,7	8,7
32228	227,4	172,6	137,6	8,6
32244	9	6,8	6,1	0,4
239/560	2,7	3,1	2,2	0,07
31324	52,5	38,1	30,5	2,4

The real cableway part condition is identified by the method based on the measured vibration spectra and calculated frequencies of the main vibration sources of the cableway transmission system (Tab. 1). Some selected measured spectra in next figures are shown.

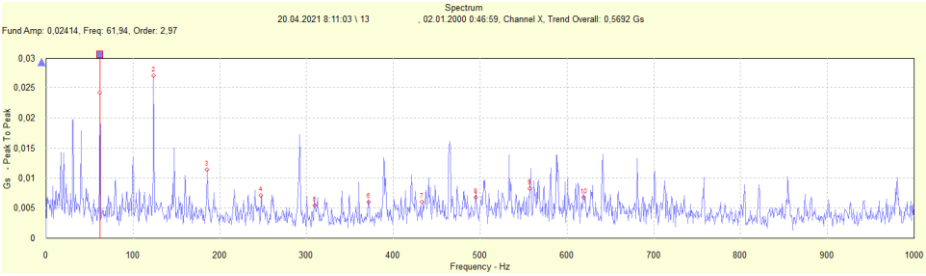

Fig. 4 ENV (envelope analysis) spectrum of the gearbox at the 1V point without load. Start of bearing 6319C3 outer ring damage. Recommended to repeat the measurements before the season.

3 Optical Evaluation of The Components Condition

The gearing condition and available components were documented and assessed. Real-scale and macroscopic photographs show the surface condition. The next teeth flank photos with vibration spectra graphs are compared.

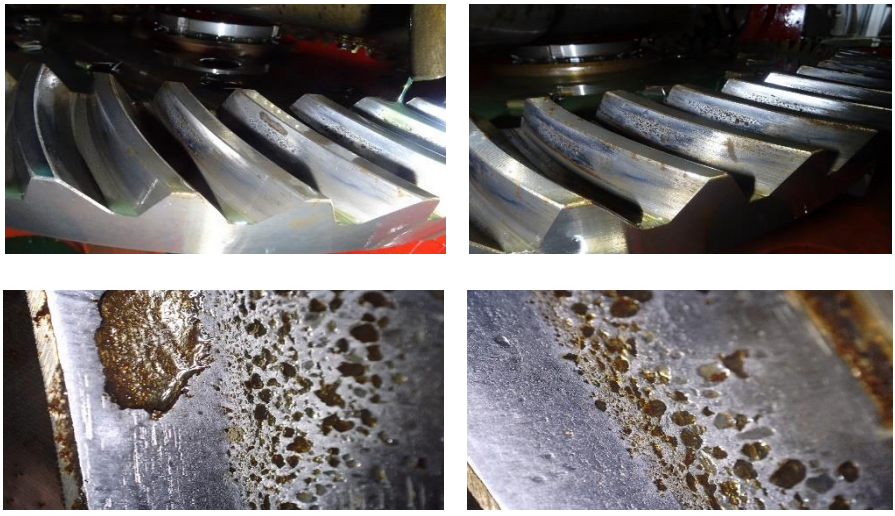

Fig. 5 The spiral bevel gear damage – macro photo.

The pinion and wheel of the bevel gear on Fig. 5 - the gearbox input **K1(z_1)-K2(z_2)**. A bevel gear general view is shown. The gearing of the bevel gear shows considerable wear due to fatigue cyclic loading of the surface, which results the top layers peeling of the tooth flank material and pitting. The condition of the bevel gear teeth sides is shown, the damage is very good visible even without picture zoom. The notches are

formed as a result of pitting and uneven surface and teeth body cracks can nucleate. The cracks may continue to propagate into the tooth material until it breaks off. The tooth surface fatigue wear macro photos are shown in Fig. 5 too and a typical fracture after the material surface layer torn off is clearly visible.

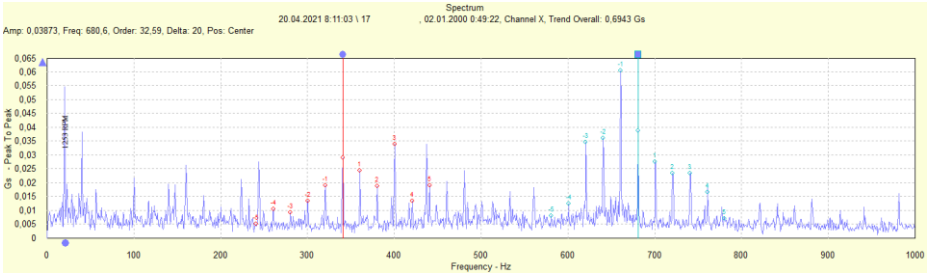

Fig. 6 ENV (envelope analysis) spectrum of the gearbox at 3V, no load. Confirmation of modulation around the first and second harmonic components of the tooth frequency f_{z1} = 340 Hz with multistep modulation with a difference of f_{R1} = 20 Hz. Significant wear of gears K1(z_1)-K2(z_2). Lateral frequencies around the main teeth frequency as a result of varying load or speed.

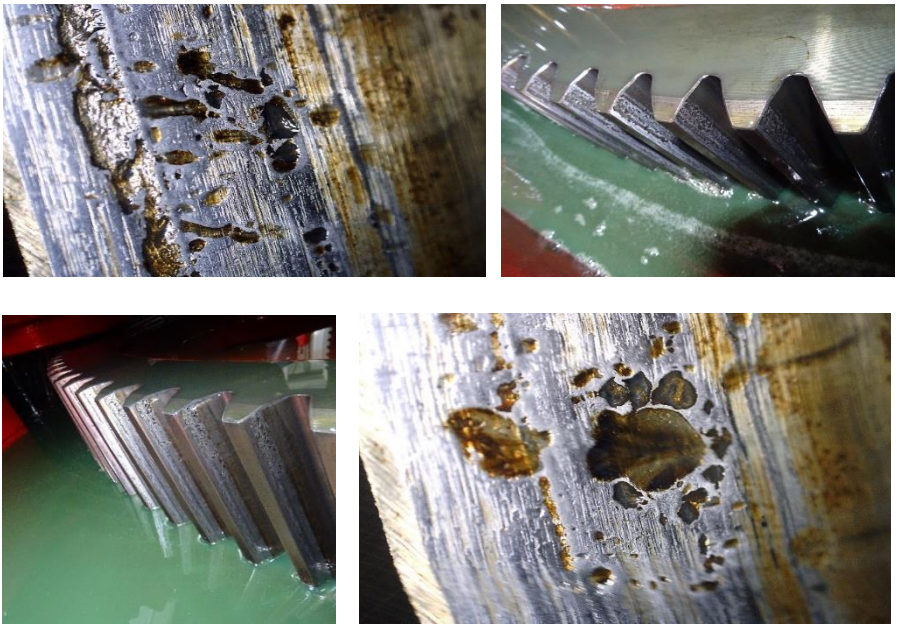

Fig. 7 Damage of the wheel K4 teeth sides of – macro photo.

The condition of gears **K3(z_3)-K4(z_4)** (in Fig. 7) is similar as the previous one. The surface of the K4 gear teeth shows wear due to fatigue and a surface is covered with

pits arrise by material dropped parts. The damage by the naked eye is visible and it is shown in Fig. 7 as a macro photo.

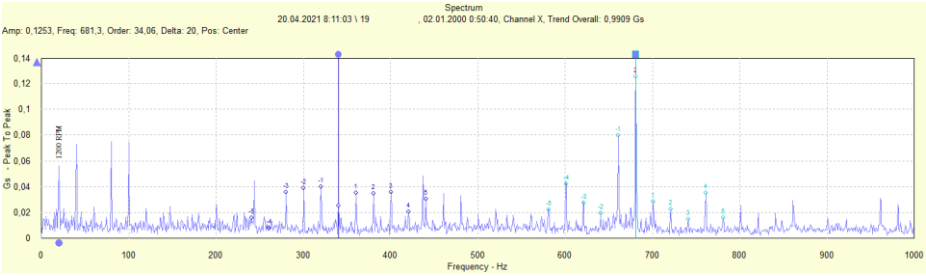

Fig. 8 ENV (envelope analysis) spectrum of the gearbox at the 4V point, no-load.

In Fig. 8 confirmation of modulation around the first and second harmonic components of the tooth frequency f_{z1} = 340 Hz with multistep modulation with a difference of f_{R1} = 20 Hz. The second harmonic component of the tooth frequency is very high which indicates another fault related to gear axis misalignment. The harmonic components of the gear tooth frequency were increased what is a sign of a tooth flank wear. Gearing wear and higher stages of material fatigue of gears K3-K4 were confirmed by ENV envelope analysis. Lateral components of the teeth frequencies are the result of variable load or speed.

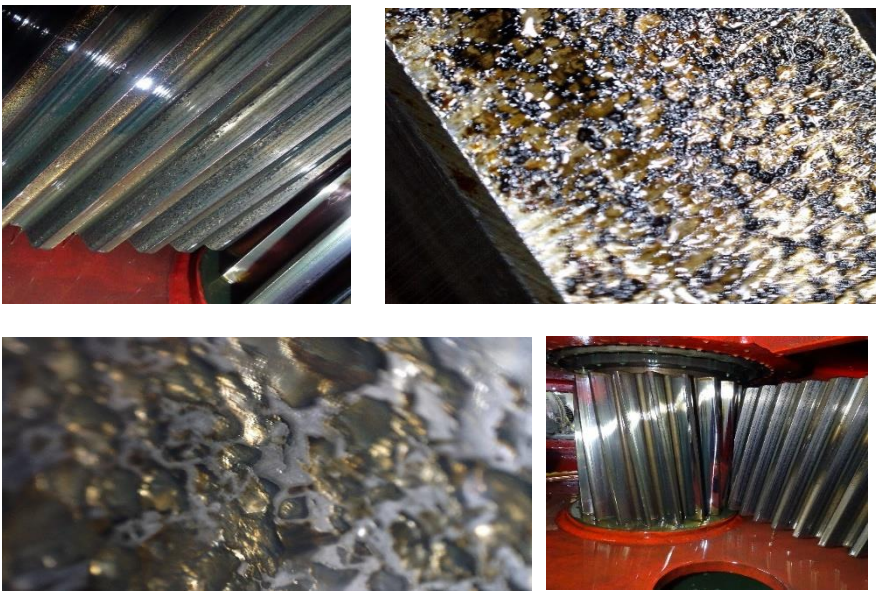

Fig. 9 Spur gears K5-K6. Corrosion and pitting of K6 wheel, macro photo of K6 wheel corrosion and pitting of K6 wheel (macro photo).

On the **K5(z5)-K6(z$_6$)** wheel teeth sides surface fatigue damage and its pieces flaking is very good visible again. The damage is more marked and more extensive due to the engagement unevenness on some teeth flank areas (along the tooth width towards the frontal plane). The damage and its macro photo are in Fig. 9. Wheel K6 tooth top land corrosion damage in Fig. 9 is visible too.

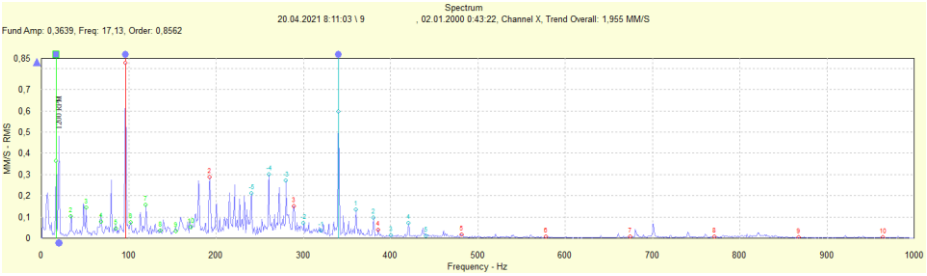

Fig. 10 Gearbox vibration spectrum at the 5V, no-load.

In Fig. 10 tooth frequency fz1 = 340 Hz (multirate modulation with difference f_{R1} = 20 Hz), f_{z2} = 96.4 Hz (harmonic components) and f_{z3} = 16.9 Hz (harmonic components). Significant gear wear and higher stages of gear **K5(z$_5$)-K6(z$_6$)** material fatigue. Lateral components of teeth frequencies as a result of varying load or speed.

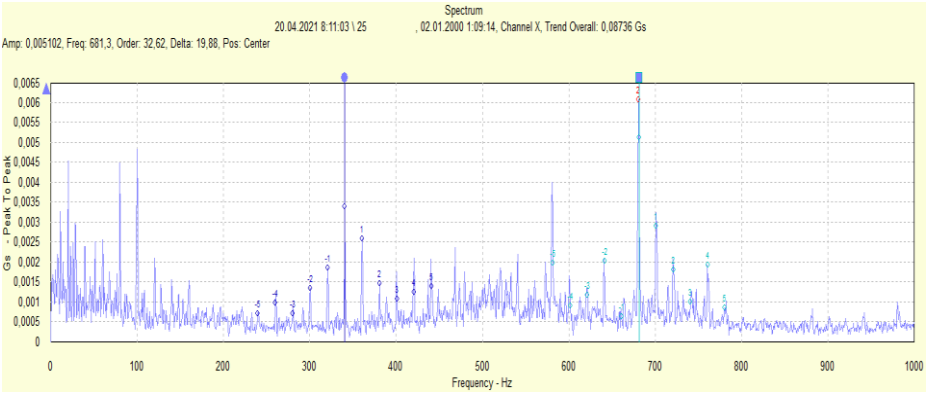

Fig. 11 ENV (envelope analysis) spectrum measured at location 7H, no-load of the gearbox.

There was an increase of the gear tooth frequency harmonic components in the vibration spectrum what is a sign of tooth flank wear. Significant gear wear and higher stages of gear K5-K6 material fatigue. Lateral components of teeth frequencies as a result of variable load or speed in Fig. 11 depicted.

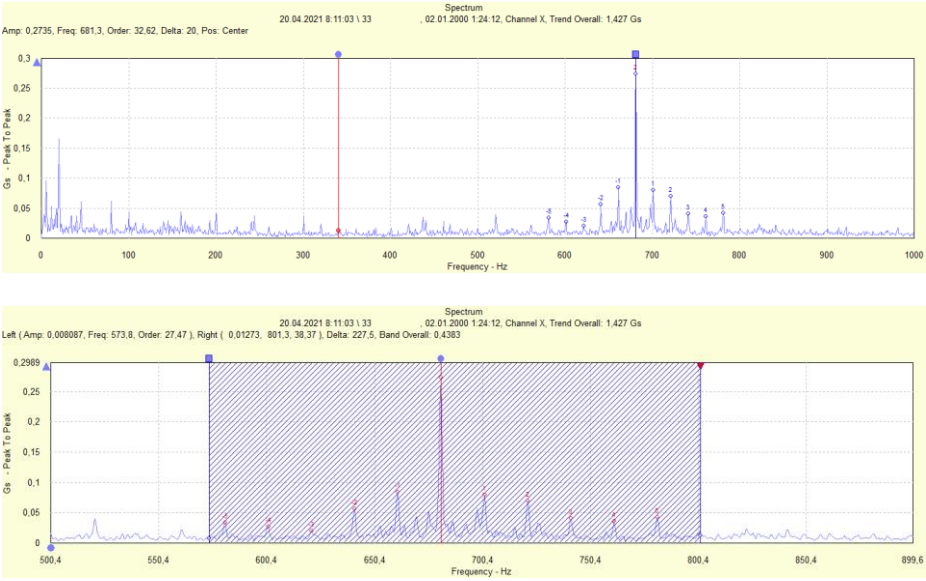

Fig. 12 ENV (envelope analysis) spectrum of the 9H point and its zoom, without load.

In position 9H (Fig. 12) there was the teeth frequency harmonic components increase in vibration spectrum as a sign of tooth flank wear. The high effective acceleration value = 1.427 Gs. Arising of modulation around the second harmonic component of the teeth frequency 681.3 Hz indicates complex teeth flank wear.

4 Conclusion

Preventive maintenance of machinery and equipment has a positive impact on all areas of business risk and efficiency. Preventive maintenance deeply affects safety, efficient use of energy, product quality and meeting customer needs. Maintenance plays one of the most important roles in the life of the entire organization. It ensures the equipment's ability to perform its function, its reliability and ultimately its safety. The model situation of the ropeway gearbox's current technical condition evaluation in this paper is described. The assessment was carried out of using vibrodiagnostic tools and an optical method of component damage assessment.

Vibration spectra measurements in the unloaded gear response mode were realized in order to diagnose pitting and small shape deviations caused by gear surface fatigue damages. The vibration response of these defects would be superimposed by the engagement stiffness fluctuation response during common operational load performance. The engagement stiffness depends on the teeth deformation. The engagement stiffness vibration response is periodically changed according to the gear teeth frequency. The described defects cause an increase of noise and vibration which means an increased

environmental adverse effect. The efficiency of the whole drive train can be deteriorated by damages and higher energy consumption during operation can be expected.

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