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SPIN TEST RIG – MOST IMPORTANT STAGE OF TUNNEL THRUSTER'S OVERHAUL

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Abstract

Tunnel thrusters during overhaul pass through several quality tests. After disassembly any clearance, shrink or subassembly are noticed. Measurements taken at verification stage determined which parts should be replaced. Definitely, the most important of tunnel thruster operation is bearings condition. Despite many years of experience, it is hard to find micro damages in the bearings without special devices. After assembly of tunnel thruster, the final stage is spin test. The spin test rig is equipped with bearings condition monitoring system including vibration, temperature and pressure inside the tunnel thruster live monitoring. During 4 hours of spin test, it is possible to check vibrations on the thruster and if any damage occurs it can be easily found, on which part of bearing appeared. Spin test rig gives possibility to check misalignments, gear condition, temperatures during 4 hours of operation and check oil quality (oil particle content acc. to ISO 4407 and water content). Spin test guarantees proper operation of tunnel thrusters after overhaul. If any damage appears during the spin test it can be easily eliminated. Without the spin test after overhaul, damage will be found after assembly on the vessel – on the sea trials. When damage is found too late, there is an additional cost for company to dock the vessel again and disassembly tunnel thruster for inspection. From economical point of view, the spin test rig gives possibility to avoid extra costs. Every passed spin test gives certificate of proper vibration level and proper assembly of thruster's elements.

Keywords: *new generation vehicles, vibration, diagnostics, tunnel thrusters, spin test*

1. Introduction

Spin Test Rig (Fig. 1) creates possibility to diagnose faults in tunnel thrusters just before the overhaul and after final assembly in environment as similar as possible to nominal work parameters. Performing the test before overhaul is important for diagnosis of existing faults. If several thrusters have the same faults, it is the information to producer that directly this part should be modified to improve the quality and reliability of delivered device. Spin test gives possibility to check which parts of bearings, gears are damaged and what misalignments, clearances exists. Rig is equipped with several devices helpful in diagnostics:

- piezoelectric accelerometers are powerful tool to perform vibration analysis,
- electric motor allows to set correct rotation speed depends of thruster's size,
- hydraulic installation is responsible for oil distribution, thruster flushing and propeller blades pitch test,
- manometers shows actual system pressure, pitch working pressure, overflow pressure etc.,

- temperature sensors helps with collecting change of temperature during 4 hours of Factory Acceptance Test,
- oil main and header tanks,
- control cabinet.

Fig. 1. Spin Test Rig at Rolls-Royce MSC Gdynia

2. Construction

The Spin test rig construction was designed to test tunnel thrusters with maximum capacity 6.2 tons. Using special adapters, it is easy to assembly and disassembly the thrusters from rig, to minimize working time and difficulty of process. One of the most important things that the construction needs to face is to create safety environment to work for operators and visitors. In fact that there are many rotating elements during test, additional covers were assembled to create a safety workplace. A supporting structure is also a frame for hydraulic installation, electric motor and cage around restricted test area.

3. Hydraulic installation

Hydraulic system contains severe circuits:

Flushing circuit is responsible for filling, flushing, draining and filtration. Filling the thruster with oil, lubricates all parts and cools the system. Oil is transported by pump to the thruster and also flows through the thruster to header tank. Flushing the thruster during rotation test helps with cooling and enables to perform oil particle content analysis. The oil is forced by inlet valve and is drained back to the main tank by a draining valve. A drain mode is dedicated to drain oil from the thruster by an outlet valve back to the main tank after the spin test. Filtration is used to filtrate the oil to get correct quality according to ISO4406.

Pitch circuit responsible for propeller blades manoeuvring delivered adjustable pressure to the thruster's pitch system. The oil is pressing by the system to high-pressure chambers and propeller blades moves through the crosshead and crank discs. Depending the thruster overflow pitch pressure increases from 75 to 150 bar at the extreme positions of propeller blades – full ahead and full astern position.

Oil particle monitoring (Fig. 2) provided by laser sensor is able to check oil particle content according to ISO4406:99 or SAE AS4059E. The components are a measurement cell through which the fluid flows (1), a laser beam (3) and a photo diode (2). As the particle passes through the laser beam, the light intensity detected by the photo diode is reduced. The larger the particle, the larger decrease of the intensity.

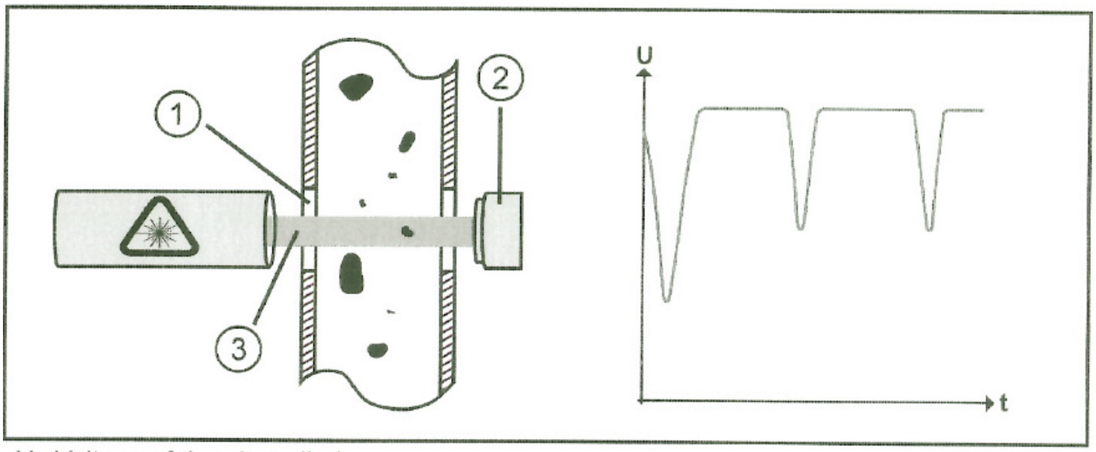

Fig. 2. Oil particle sensor components

The range number (1), according to ISO 4406:99, can be calculated based on the current value, measured on the analogue output to the following formula:

$$OZ = \frac{26}{16mA} * I\ [mA] - \frac{26}{4}, \quad (1)$$

where:
OZ – range number,
I – current on the analogue output.

The current range (Tab. 1), according to ISO 4406:99 covers the range numbers from 0 to 26. A current value of 4 mA corresponds to a range number of 0; a current value of 20 mA corresponds to a range number of 26. The values are on a linear characteristic curve.

Tab. 1. Range number presentation

Range number	0	13	26
I_{out} in mA	4	12	20

According the ISO 4406:99 there are many particles in the oil consist mainly of fibres, silica (dirt) and metals, which are damaging to devices. Cleanliness Rating (Tab. 2) reports on the quantity and size of the particles existed in 1 millilitre of oil.

Tab. 2. Part of ISO4406:99 Cleanliness Rating

ISO 4406:99 Cleanliness Level Standards		
Range number	Number of Particles per ml	
	More than	Up to and including
24	80 000	160 000
23	40 000	80 000
22	20 000	40 000

By the oil particle counter, it is easy to initially describe oil quality. Moreover, the best is to perform full oil analysis including water content, type of particles material and emulsification. Through the type of material included in oil sample (Fig. 3), it can be easy to describe which part of the thruster is worn out.

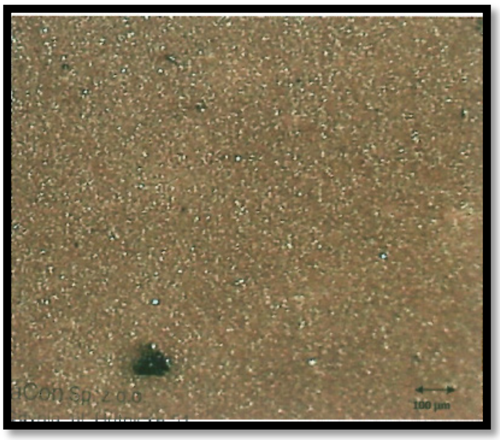

Fig.3a. Oil sample in x40 enlargement

Fig.3b. Oil sample in x100 enlargement

4. Vibration diagnostics

The spin test vibration diagnostics use piezoelectric accelerometers, which by far are the most common types of transducers used in machinery vibration analysis. The sensor is placed at the bearings housings on the thruster and record the charge output, which is proportional to the force, and therefore acceleration (Newton's second law; force is proportional to the acceleration of mass). An amplifier, equipped at the spin test, is required to convert charge output to a voltage output. Accelerometers are most commonly used in diagnostics. In fact of, that it is easy to integrate the data from acceleration to velocity and to displacement. However, it is more expensive and much more difficult to transform from velocity to acceleration, so this kind of vibration sensors systems are not commonly used. The signal from the sensors is converted from analog to digital signal and shown as FFT (Fast Fourier Transform) chart (Fig. 4), FFT Envelope chart (Fig. 5) and the waveform.

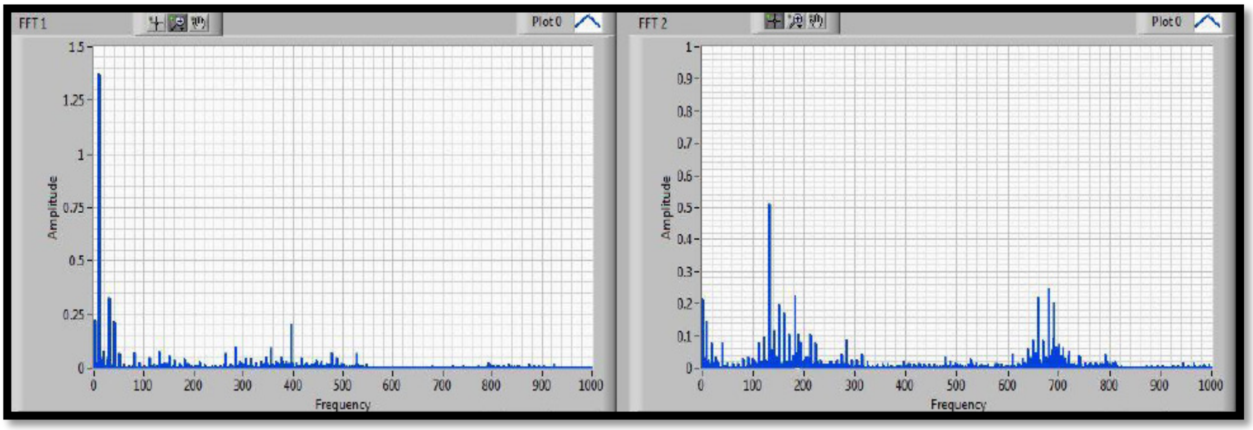

Fig. 4. Fast Fourier Transform chart at Spin Test Rig software readings

The vibration spectrum is the result of a Fourier Transform (2), which turns a complex wave into its harmonics components.

$$f(t) = a_o + \sum_{i=1}^{\infty} a_i * sin * 2\pi f_i + \emptyset_i) * t. \tag{2}$$

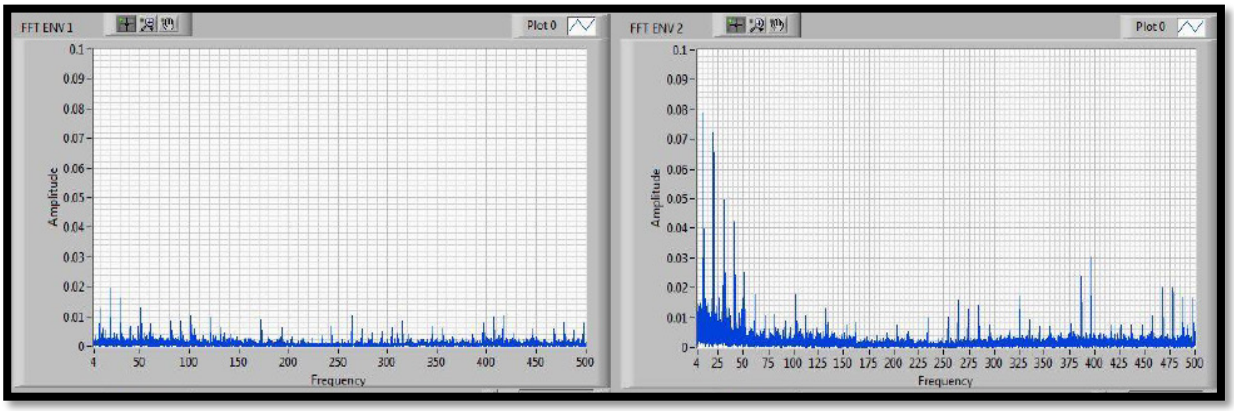

Fig. 5. FFT Envelope chart at Spin Test Rig software readings

FFT works for spectrums consists of periodic components only, by extracting sine waves. Every peak in spectrum refers to a sine wave of amplitude a_i, frequency f_i and the phase Θ_i.

By all vibrations seen at the time waveform, FFT or envelope it is possible to describe even what is the stage of bearing damage or either which part (rolling element, cage, outer or inner raceway) is damaged. Bearing forcing frequencies are generated based on its physical make-up. There are four forcing frequencies on the bearing:

- Ball Pass Inner Race (BPI) or Ball Pass Frequency Inner race (BPFI),
- Ball Pass Outer (BPO) or Ball Pass Frequency Outer race (BPFO),
- Fundamental Train (FT) or Fundamental Train Frequency (FTF),
- Ball Spin (BS) or Ball Spin Frequency (BSF).

The physical characteristics (Fig. 6) are used to calculate the frequencies generated by a defect on the bearing component.

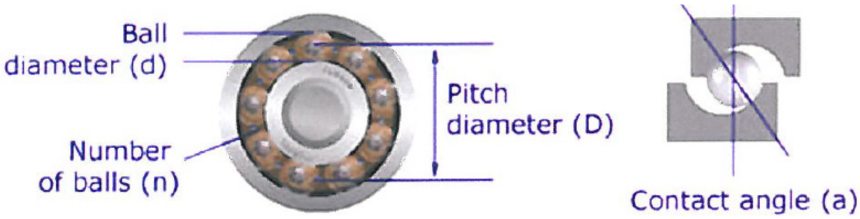

Fig. 6. Physical characteristics of bearings

The formulas are as follows:

$$\text{Defect on Inner Race } (BPI) = \frac{1}{2}n\left(1 + \frac{d}{D}\cos\alpha\right), \quad (3)$$

$$\text{Defect on Outer Race } (BPO) = \frac{1}{2}n\left(1 - \frac{d}{D}\cos\alpha\right), \quad (4)$$

$$\text{Defect on Cage } (FT) = \frac{1}{2}\left(1 - \frac{d}{D}\cos\alpha\right), \quad (5)$$

$$\text{Defect on Balls } (BS) = \frac{1}{2}\frac{D}{d}\left[1 + \left(\frac{d}{D}\right)^2 \cos^2\alpha\right]. \quad (6)$$

5. Factory Acceptance Test

After overhaul of tunnel thruster factory acceptance test is required to accept condition of unit. The test consists of 4 hours rotation of propeller with 620 rpm. During 4 hours of spin vibration, temperatures and pressures are collecting. By trending of vibration and temperature, it is easy to designate growth of these values in time. FAT test consists pitch test and pressure test of unit. By this, the thruster can be accepted as unit without leakages. On portable computer, all vibration charts are live view so it is possible to check vibrations levels at any time of spin test. After rotation test, oil sample is taken and send to analysis to confirm cleanliness of thruster hydraulic system. The test should be summarized and approved by class surveyor.

References

[1] Rolls-Royce Poland sp. z o. o. documentation.
[2] SKF Bearings documentation.
[3] DraCon company oil analysis reports.