Condition Monitoring of Flexible Pipe Connectors (REPA) Through Vibration Analysis

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Motivation and Objective

Flexible pipe connectors, also called rotation and expansion performing assemblies (REPA), are among the most stressed and critical components of Parabolic Trough Collector (PTC) plants. As no explicit REPA wear signs can be observed externally, the usual operational approach is reactive maintenance, i.e. when a malfunction occurs, the REPA is replaced.

As an alternative, condition based maintenance measures parameters continuously to determine the component status, and the part is exchanged or repaired before rupture. Vibration measurement, as a non-intrusive and easily dispatchable technology is widely used for wear monitoring. This work describes the implementation of vibration measurements and first investigation of two swivel joints as part of flexible hose connectors at the REPA test rig at the Plataforma Solar de Almeria [1].

Figure 1. REPA test rig at PSA

Experimental Setup

The tests are executed with the common Biphenyl-Diphenyloxide heat transfer fluid (HTF) flowing at 393ºC and at 35 bar. Under these conditions, 3650 mechanical cycles of rotation and translation respectively from -23.5º to 187º and from -4.74º to 14.24º were performed, the equivalent of 8 years of operation.

Four IDS Innomic KS95B.100 accelerometers were screwed the closest possible to the swivel joint for a sensor temperature below 120ºC.

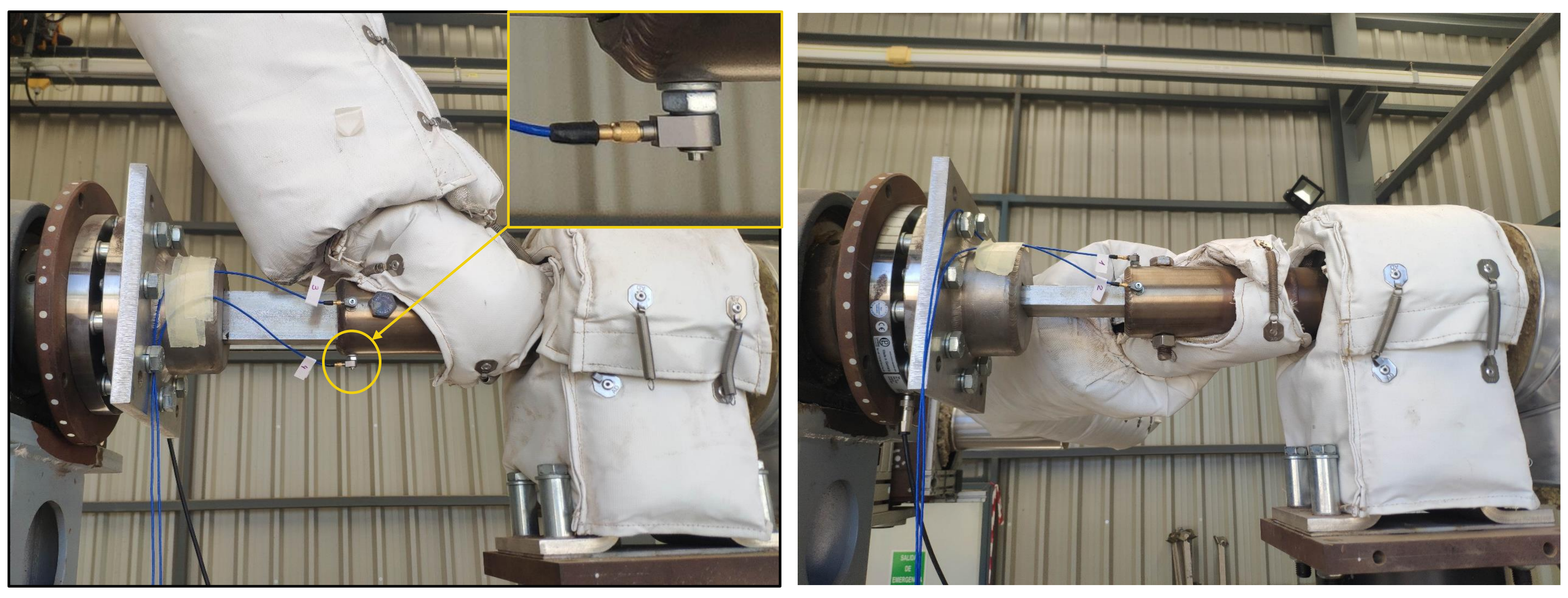

Figure 2. Left: sensor 2 and 3 on the western swivel, traverse at 90º,
Right: Sensor 1 and 4 on the eastern swivel, traverse at 180º

Methodology

In previous work [2], pressure has been shown as major influence on forces applied on the swivel joint. Therefore the influence of system pressure and mechanical cycling were considered independently.

Spectrograms are used extensively in vibration analyses. They represents a full spectrum of frequencies over time (or over a rotation angle in the present case).

They are obtained summing up window functions of one second plus half second overlap of Fourier Transform (FT) from the original accelerometer data set. The applied method is Short Time Fourier Transform (STFT, Figure 3).

From the spectrograms, the acceleration values per frequency are averaged over a cycle or over time. It allows comparison with different operation conditions (different pressure, wear). Also, specific rotation angles of interest can be compared, such as 20º, 90º and 160º.

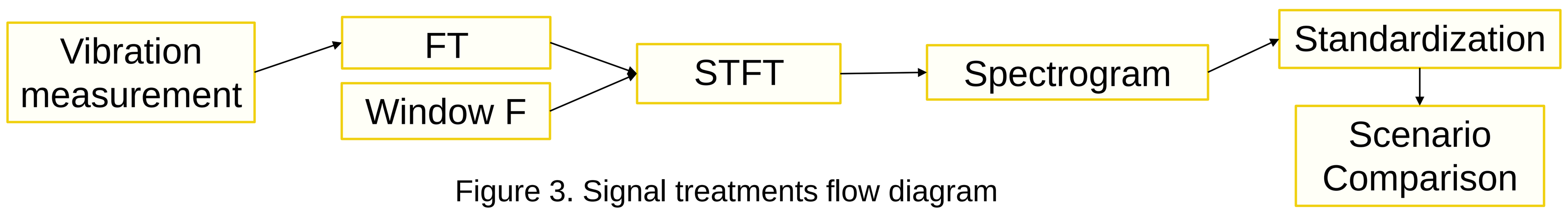

Figure 3. Signal treatments flow diagram

Results

Starting mechanical cycling, the swivel joint presented a "slip-stick" effect, showing higher excitation at specific frequencies and pressure, that progressively disappeared.

HTF temperature is recognized to have a significant impact on the vibration intensity due to HTF viscosity and behavior change. The follow results are shown for sensor 3, transversal to the western swivel at the REPA test rig at Plataforma Solar.

Effect of pressure on vibration measurements

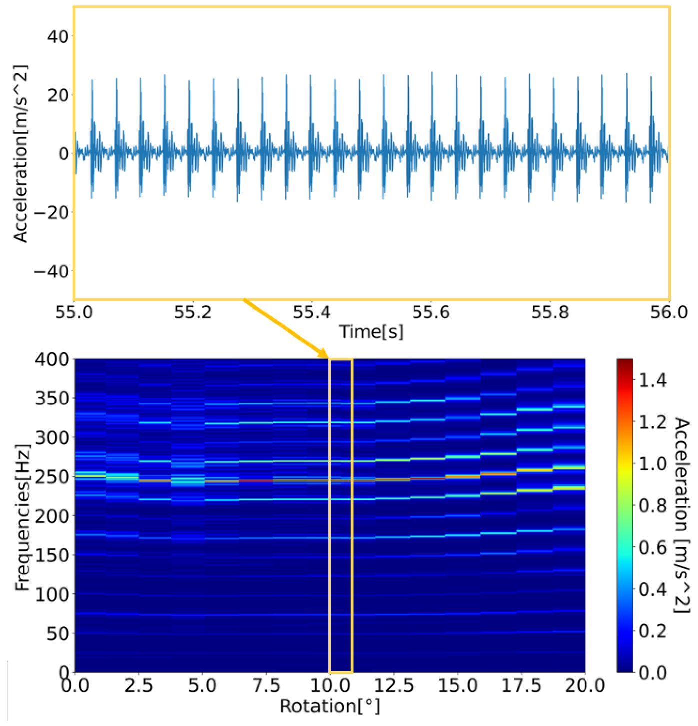

Figure 4. Spectrogram of vibrations
at 0 bar and for 0 to 20º rotation angle,

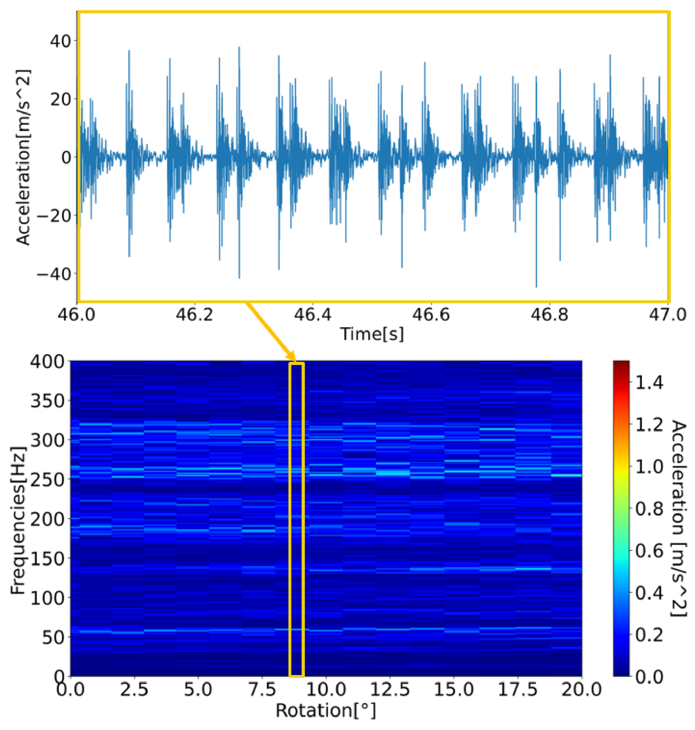

Figure 5. Spectrogram of vibrations
at 35 bar and for 0 to 20º rotation angle

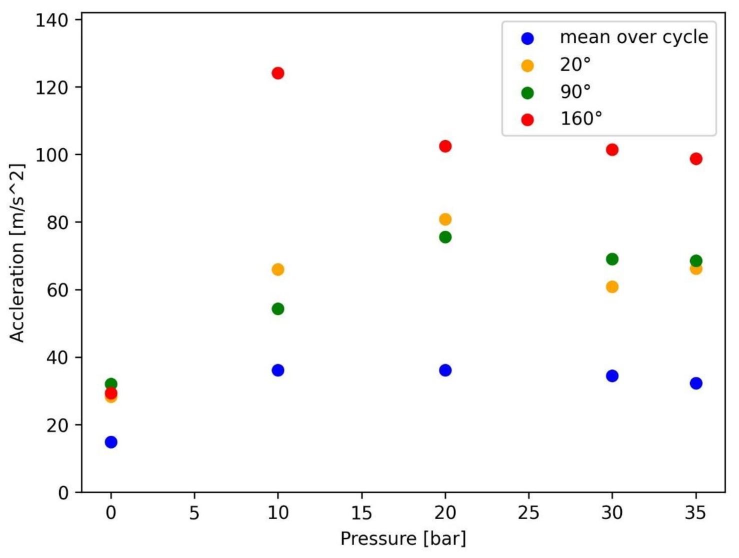

Figure 6. Acceleration over system pressure for specific rotation angle and the mean value for a cycle

- Figures 4 & 5 show different vibration behavior for 0 and 35 bar. With higher system pressure, the flex hose's mechanical stiffness increases, and it reduces the slip stick effect.
- At 0 bar, the peak acceleration frequency is observed around 275 Hz, while at 35 bar, no clear main frequency is distinguished.
- Figure 6 shows the mean vibration acceleration for a mechanical cycle. It increases from 14.9 to 36.1 m/s^2 at 0 and 10 bar. It stabilizes at 36.1 m/s^2 until 20 bar to progressively decrease to 32.3 m/s^2 at 35 bar.

Effect of cycling on vibration measurements

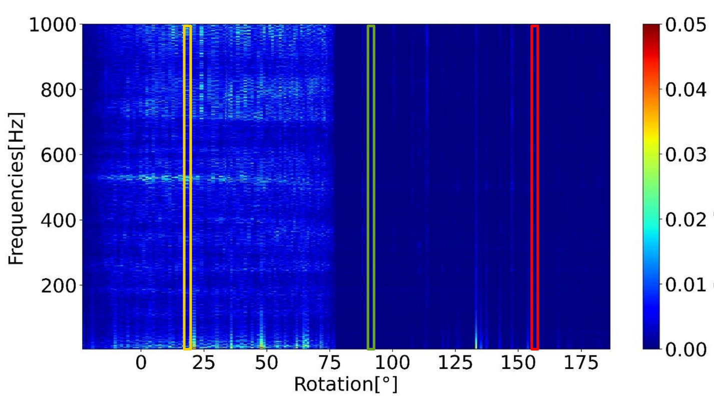

Figure 7. Cycle number 5 vibrations spectrogram for -23.5 to 187º rotation angle

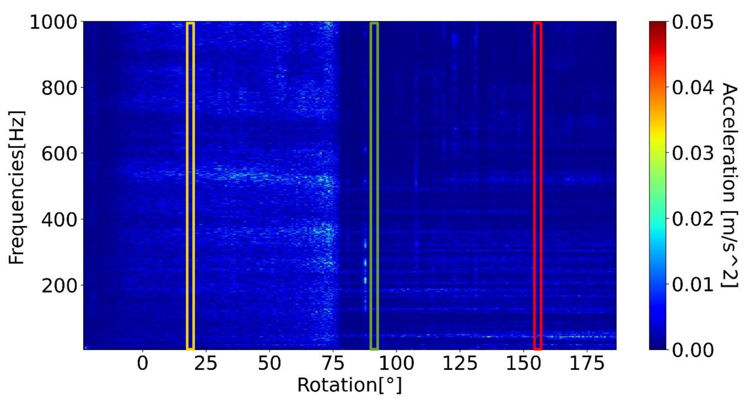

Figure 8. Cycle number 3650 vibrations spectrogram for -23.5 to 187º rotation angle

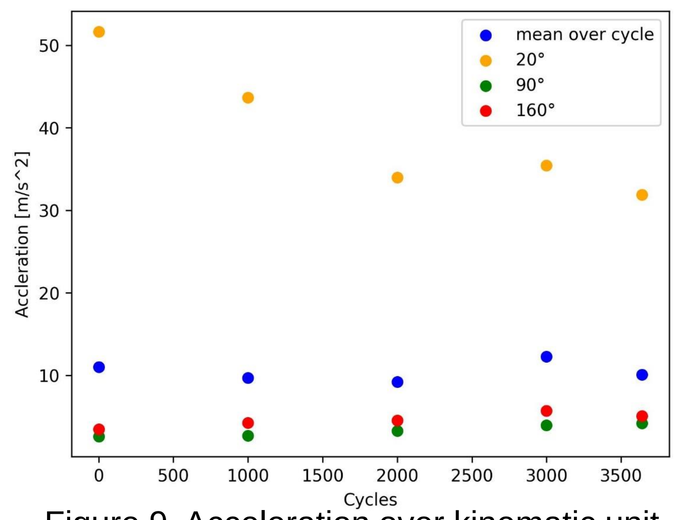

Figure 9. Acceleration over kinematic unit cycle number for specific rotation angle, and the mean value for the specified cycle

- For cycle number 5 (Figure 7) and between -23.5º and 75º, the principal frequencies are measured from 5 to 20 Hz and around 530 Hz, whereas there is no clear main frequency within this angle range for cycle number 3650 (Figure 8)
- During cycle 5 and between -23.5º and 75º rotation angle it shows a larger amplitude of vibrations than during cycle number 3650 at this angle range.
- In Figure 9 one can see that despite a stable mean value over a cycle and at 90º and 160º, at 20º rotation angle the vibrations decrease over the number of cycles.

Conclusions

In this work, the influence of system pressure and mechanical cycling influences in swivel joint vibration behavior were successfully distinguished with accelerometers.

Vibration measurements show to be a promising method for REPA characterization. To be able to implement reliable condition based maintenance more experimental data have to be gathered including REPA failure situations.

References

[1] J. Leon and al. , "Test loop for inter-connections of PTC plants", SolarPACES 2017
[2] G. Saliou and al. "Segregation of Influences on Flexible Pipe Connectors Force under Field Operation Condition for PTC plants", SolarPACES 2021

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