# Product tech note – compressor gear set

## Wilcoxon Sensing Technologies accelerometers detect low frequencies for monitoring of critical turbo-compressors

The gear set on a critical turbo-compressor was monitored with a standard industrial accelerometer at very low frequencies. Severe vibrations at the hunting tooth frequency were found to be amplified by a compressor surge modulation. Diagnostic evaluation and repair effectively eliminated the surge and hunting tooth vibrations – returning the compressor to proper operation.

### Introduction

Chlorine manufacturers liquefy chlorine gas for transportation to pulp and paper plants. Dynamic Signal Analysis performs vibration testing for a Canadian chemical company and evaluates their critical compressor trains prior to semiannual shutdowns. Following shutdown and refurbishment of a compressor section start up vibration spectra were recorded on a chlorine liquefier to ensure safe operation. The data was collected with a Wilcoxon model 766 industrial accelerometer and a spectrum analyzer.

### Machinery diagnostics

Measurements on the speed increaser indicated significant high amplitude, low frequency vibrations from the high-speed coupled end of the gear box. The spectra shown in figure 1 reveals a very low frequency pulsation at 0.075 Hz (4.5 cpm), and a 1.26 ips vibration at the hunting tooth frequency (HTF) of 0.99 Hz (59.4 cpm). Harmonics of the HTF and sidebands of the pulsation signal are also visible.

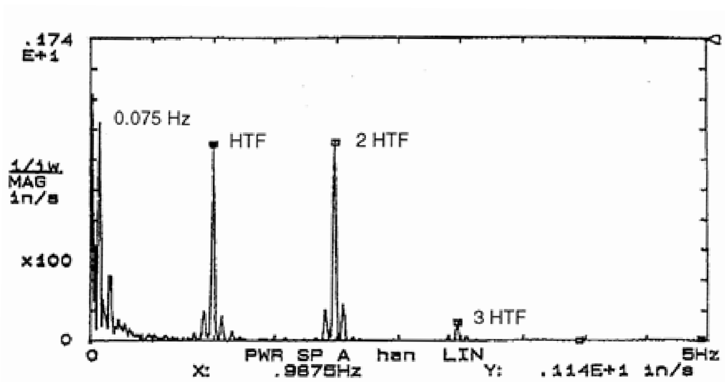


Figure 1: Surge frequency and hunting tooth harmonics from speed increaser measurement

The HTF corresponds to the rate at which a specific tooth on the gear will contact a specific tooth on the pinion (see table 1); it is due to abnormalities or uniqueness of individual gear and pinion teeth.

| | |
|---|---|
| Compressor/pinion speed | $N_C$ = 119.90 Hz |
| Motor/gear speed | N = 29.75 units |
| Number of pinion teeth | $T_P$ = 30 |
| Number of gear teeth | $T_G$ = 121 |
| HTF = $N_C/T_G$ = 119.90/121 = 0.99 Hz, or | |
| HTF = $N/T_P$ = 29.75/30 = 0.99 Hz | |

Table 1: Hunting tooth frequency calculation

The pulsation produced a beat every 13 seconds (see figure 1b) and was believed to be process related, resulting from surge. The surge was caused by trapped pockets of air in the influent lines of the chiller. The time waveforms and sidebands around the HTF, suggested that the surge pulsation was amplitude modulating the hunting tooth harmonics.

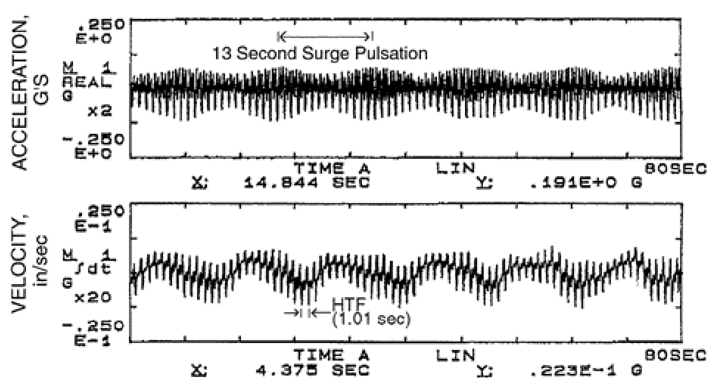


Figure 1b: Time waveform showing modulating effects of surge pulsation


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## Systems repairs

In order to decrease the pulsation, the refrigerant in the delivery system was purged of air. Follow up measurements indicated that purging had completely removed the low frequency surge (see figures 2a and 2b) and substantially reduced the modulated HTF amplitude from 1.16 ips to 0.11 ips.

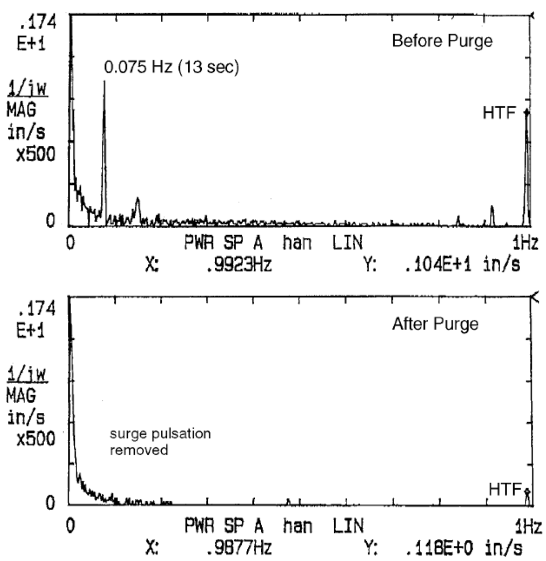


Figure 2a: Surge pulsation before and after purging of refrigerant

The modulating effects of the HTF upon the gear/motor running speed harmonics were also reduced as shown in figure 3.

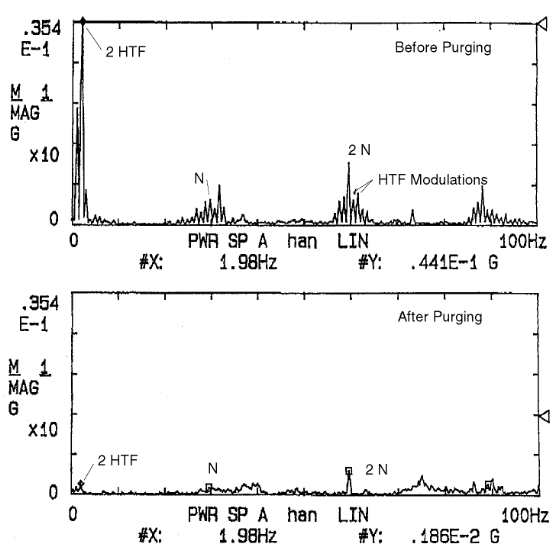


Figure 3: HTF sidebands and gear mesh harmonics before and after repair

Unfortunately, the HTF component was still prominent and indicated a potential problem with specific teeth on the gear set. Hunting tooth faults can be very difficult to physically isolate and evaluate in terms of reliability. A gear transmission consultant was therefore hired to inspect the gear set. Detailed examination revealed that an indentation had been made on corresponding pinion and gear teeth to mark the phase of assembly when the gear set was rebuilt. The gears were repaired with a fine tooth file and re-installed for start-up.

Baseline measurements retaken on the compressor showed the hunting tooth vibration nearly eliminated (see figures 4a through 4d). The final measurement of 0.03 ips at 0.99 Hz was determined to be an acceptable vibration level for this gear set. The compressor was placed on-line without further interruption.

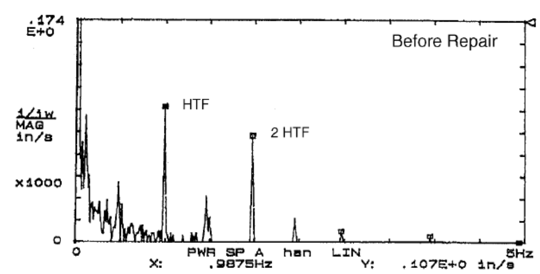


Figure 4a: Surge pulsation before and after purging of refrigerant

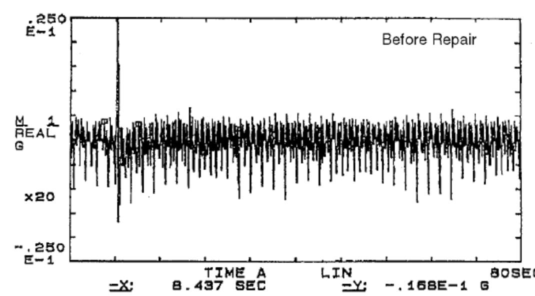


Figure 4b: Time waveform before repair

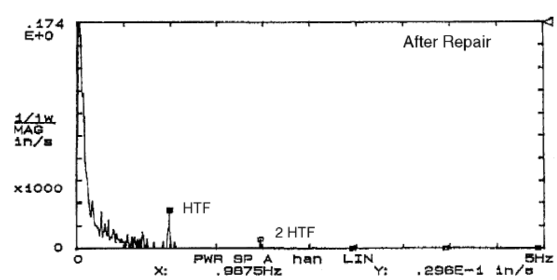


Figure 4c: Hunting tooth harmonics after gear set repair

## Sensor considerations

In this particular application, the Wilcoxon Model 766 accelerometer successfully obtained vibration data usually reserved for specialized low frequency sensors. A combination of high amplitude signals and the low noise floor of the piezoceramic sensor enabled it to perform the measurement.

All piezoelectric accelerometers contain a high pass filter in the amplifier to remove near DC signals. Unless low noise electronics are employed, spectral data below the specified sensor bandwidth will be overcome by 1/f noise. Figures 5a and 5b show the low frequency attenuation of the Wilcoxon model 766 output due to filtering, and the low noise floor. The output of the sensor, relative to the 100 Hz calibrated sensitivity, is attenuated by 1 dB (9%) at the hunting tooth frequency, and 26dB (95%) at the surge frequency. Even at 0.075 Hz unadjusted surge amplitude had a signal-to-noise ratio of greater than 10:1.

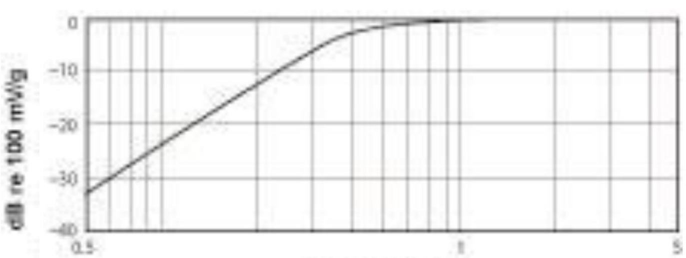


Figure 5a: Low frequency response of Wilcoxon model 766

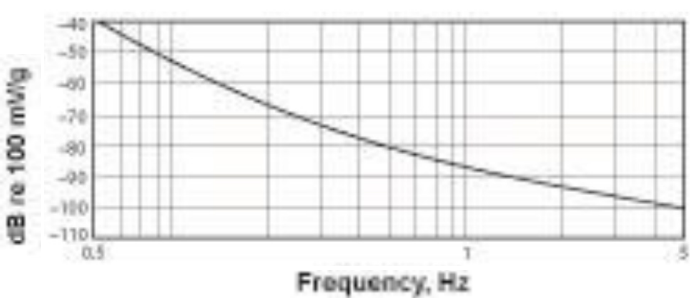


Figure 5b: Low frequency floor of Wilcoxon model 766

Table 2 shows the amplitudes of the pulsation, HTF harmonics, and sidebands, before and after filter adjustment. In cases where unexpected spectral data is measured below the specified bandwidth of the sensor, the filter attenuation may be obtained from the sensor manufacturer. This enables amplitude data (where required) to be adjusted to the correct value.

| Power spectrum: channel A | | | | |
|---|---|---|---|---|
| **Point** | **Frequency (Hz)** | **Measured amp (IPS)** | **Adjusted amp (IPS)** | **Represents** |
| 1 | 0.0750 | 1.26 | 25.20 | Surge pulsation |
| 2 | 0.1500 | 0.375 | 2.37 | 2x surge |
| 3 | 0.9125 | 0.177 | 0.21 | HTF + surge |
| 4 | 0.9875 | 1.14 | 1.28 | HTF |
| 5 | 1.0625 | 0.148 | 0.162 | HTF + surge |
| 6 | 1.9125 | 0.184 | 0.188 | 2x HTF – surge |
| 7 | 1.9875 | 1.15 | 1.16 | 2x HTF |
| 8 | 2.0650 | 0.171 | 0.172 | 2x HTF + surge |
| 9 | 2.9750 | 0.103 | 0.103 | 3x HTF |

Table 2: Gear fault spectrum before and after filter compensation

## Conclusion

The gear set tested exhibited high amplitude hunting tooth vibrations being modulated by compressor surge. Purging the influent refrigerant lines, and refurbishing the gears set teeth, eliminated the problem and allowed the chlorine liquefier to operate safely. These measurements required the vibration sensor to perform beyond its specification. Trained test engineers and quality measurement equipment allowed this critical piece of machinery to return quickly to an online condition without fear of unexpected failure.