Enhanced API 670 monitoring of gearboxes

Use of SKF acceleration enveloping with the SKF Multilog On-line System DMx

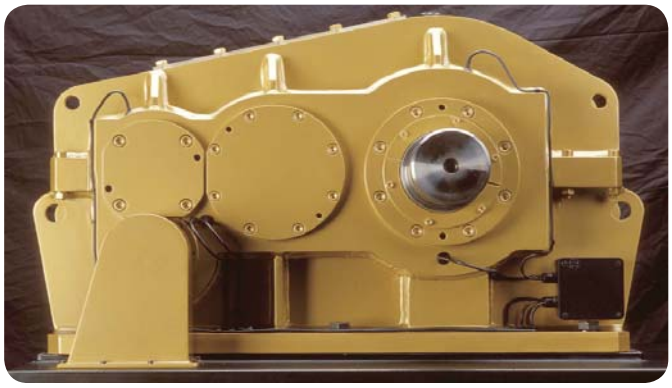
By Chris James and Oscar van Dijk • SKF

Introduction

Many critical machines instrumented by API 670 class protection systems include monitoring of large gearboxes. One measurement of vibration used is that of *broadband acceleration*.

For many years, SKF has successfully used its patented implementation of the *acceleration enveloping* technique to provide an early detection of defects in both rolling element bearings and gears.

The SKF Multilog On-line System DMx module.



In addition, SKF has developed a new concept in vibration monitoring in the form of its SKF Multilog On-line System DMx. This system provides API 670 machine protection, and condition monitoring in a distributed, modular device that is intrinsically safe for hazardous area use.

The combination of *acceleration enveloping and the SKF Multilog DMx* device allows for enhanced monitoring of gearboxes within an API 670 system, offering earlier detection of developing problems compared to the simple broadband acceleration method. This application note discusses the implementation.

API 670 and gearbox monitoring

API 670 (4th Edition, December 2000) illustrates instrumentation that is recommended for monitoring large machine trains. Appendix H of the standard shows typical system arrangements, including a double-helical gearbox – see **Figure 1**.

Instrumentation

In the example shown in **Figure 1**, there are three pairs of eddy current probes:

- Radial vibration at the input shaft drive end bearing (designated 4X, 3Y)
- Radial vibration at the output shaft non-drive end bearing (6X, 5Y)
- Axial position at the input shaft thrust bearing (P1, P2)

There is an eddy current probe used as a phase reference (ø1) on the output shaft, and two accelerometers (A1, A2), one per shaft. All sensors are terminated in a local junction box, which also houses the probe drivers (oscillator-demodulators).

Dual path signal processing

API 670 Appendix E discusses "GEARBOX CASING VIBRATION CONSIDERATIONS." These considerations specify that accelerometers shall be used, and the monitors should provide "Dual Path" processing.

"Dual Path" processing means the incoming acceleration signal is split across two channels (internally or externally by wiring) and then processed in two ways:

- **Path 1.** Acceleration in G's, true peak, with a 1 to 10 kHz band pass filter. *"These frequencies are associated with gear mesh and provide information on mesh condition."* This wide broadband value is used for information only, and the channel is ***not*** "armed for trip."
- **Path 2.** Velocity in mm/sec true RMS, with a 10 to 1 000 Hz band pass filter, for *"vibration of rotating elements."* Depending on end-user practices, this channel ***may*** be "armed for trip."
- The detection circuitry in the monitor must be consistent with the displayed units.

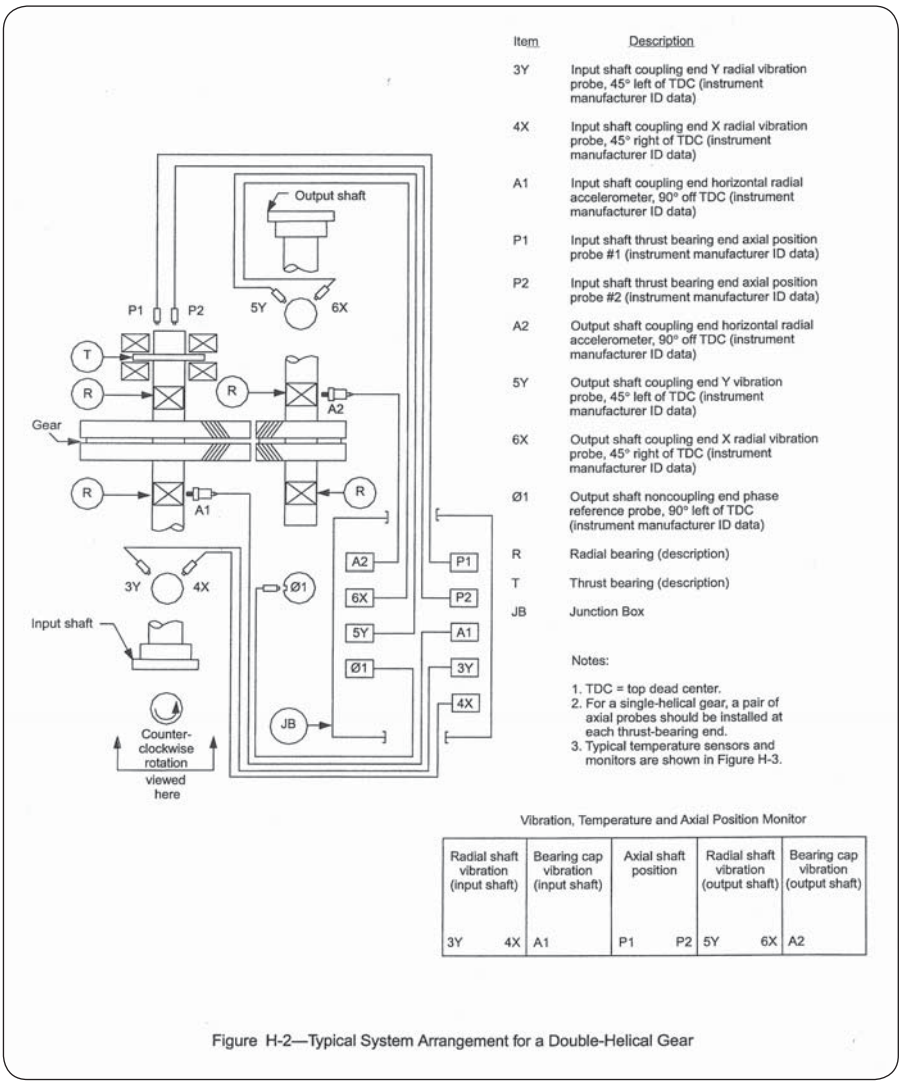


Figure 1. Extract from API 670 Appendix H showing sensor arrangement.

SKF Multilog DMx configuration for dual path processing

The layout of the SKF Multilog DMx modules required to address the gearbox in **Figure 1** is shown in **Table 1**. Three SKF Multilog DMx modules are needed.

- The internal digital drivers (oscillator/demodulators) are utilized in two CMMA 9910 modules to support the eddy current probes.
- The two accelerometers are powered and processed by a CMMA 9920. One of the two digital drivers available in this CMMA 9920 is used to support the phase reference eddy current probe.
- There are two unused channels.

SKF acceleration enveloping

SKF acceleration enveloping is a technique successfully employed by SKF in the condition monitoring of rolling-element (anti-friction) bearings. The technique is also applicable for gear monitoring. The technique takes an acceleration signal and performs the following three-step process:

Band pass filter

One of three band pass filters (designated ENV1, ENV2, ENV3) is applied to the time-waveform signal. The filter is selected such that the high pass value is above the highest expected rotational component (such as 1 x speed and its harmonics).

Demodulation

The filtered signal is then demodulated. This has the effect of producing an "envelope" around repetitive peaks in the post-filter time-waveform. The envelope is itself a waveform signal.

FFT

The enveloped signal is then passed through an FFT processor.

The principal benefit of this technique is that it has been proven to be able to "extract" low amplitude repetitive events from the background vibration "noise." These low amplitude repetitive events are created by defects on bearing raceways and chips on gear teeth.

Example: Acceleration Enveloping processing with the SKF Multilog DMx

The following is example data captured by an SKF Multilog DMx system and displayed in SKF @ptitude Analyst software.

Consider a gearbox with a small defect in a rolling element bearing, or small damage to the gears. The defects can produce a low energy bandwidth vibration signal. **Figure 2** shows an FFT from the source vibration signal from an accelerometer, measured by the velocity channel required by API 670 dual path processing. The "vibration of rotating elements" described by the standard are seen, indicating conditions such as unbalance and misalignments.

Figure 3 shows an FFT from the source signal, measured by the broadband acceleration channel required by API 670 dual path processing. A 1 to 10 kHz acceleration signal will contain many vibration components – both random and repetitive, including the small signals from gear teeth. The defect frequencies are difficult to spot – a small "haystack" around 5 kHz indicates some high frequency phenomena like a gear defect. ***When represented as a single overall true peak value, this gear damage will have to progress to a severe condition before it is noticed as a significant rise in the overall level.***

Table 1. SKF Multilog DMx layout for API 670 Appendix H-1 gearbox layout.

Module	Channel	Tag	Location	Measurement	Units, Detection
SKF Multilog DMx 1 (CMMA 9910)	1	4X	DE bearing	Radial displacement	µm, True Peak-Peak
	2	3Y	DE bearing	Radial displacement	µm, True Peak-Peak
	3	P1	Thrust bearing	Axial displacement	mm
	4	P2	Thrust bearing	Axial displacement	mm
SKF Multilog DMx 2 (CMMA 9920)	1	A1	DE bearing	Acceleration	G's, true peak
	2	A2	NDE bearing	Acceleration	G's, true peak
	3	-	-	*Unused channel*	-
	4	-	-	*Unused channel*	-
	4a	ø1	DE bearing	Phase reference	Volts/RPM
SKF Multilog DMx 3 (CMMA 9910)	1	-	DE bearing	Velocity	mm/sec, true RMS
	2	-	NDE bearing	Velocity	mm/sec, true RMS
	3	5Y	NDE bearing	Radial displacement	µm, True Peak-Peak
	4	6X	NDE bearing	Radial displacement	µm, True Peak-Peak

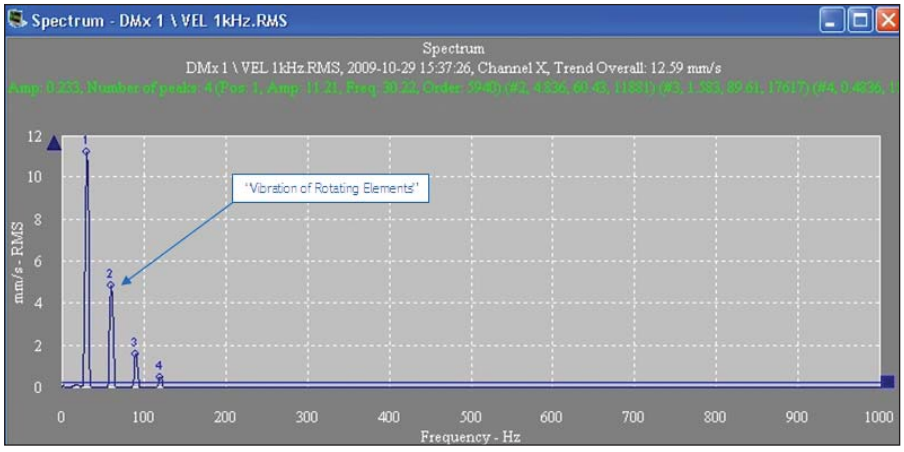


Figure 2. FFT from signal processed for velocity.

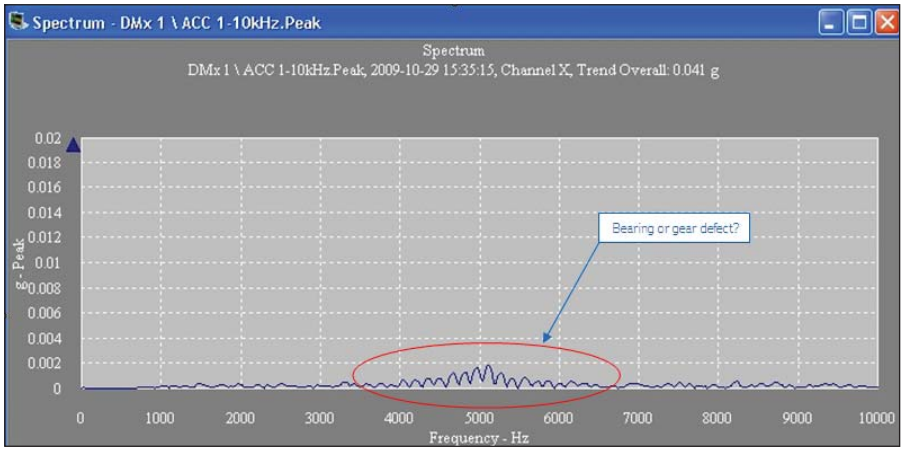


Figure 3. FFT from signal processed for acceleration with 1 to 10 kHz filter.

Figure 4 shows the enveloped FFT from the same source signal. The defect frequencies associated with the bearings and gears are clearly seen – and so can be trended against time to view deterioration. Hence, the acceleration enveloping process will detect the damage at a much earlier stage than broad-band acceleration.

Configuring the SKF Multilog DMx for acceleration enveloping

The layout of the SKF Multilog DMx to add acceleration enveloping to the API 670 example of Figure 1 is illustrated in **Table 2**.

For each accelerometer, A1 and A2, the input signal is split into three paths by wiring – see **Figure 5**.

- The accelerometers are input into the first pair of channels on SKF Multilog DMx 2 – to perform broadband acceleration monitoring and comply to API 670. The transducers are powered by the CMMA 9920 module.
- The accelerometer signal and ground lines are jumpered to the input of second channel pair on SKF Multilog DMx 2, to perform acceleration enveloping monitoring. In this case the ENV 3 filter is selected in SKF Multilog DMx Manager software – see **Figure 6**. The transducer power on this pair is switched off.
- The accelerometer signal and ground lines are jumpered to the input of the first channel pair on SKF Multilog DMx 3, to perform velocity monitoring, and/or protection. The CMMA 9910 module provides no transducer power.

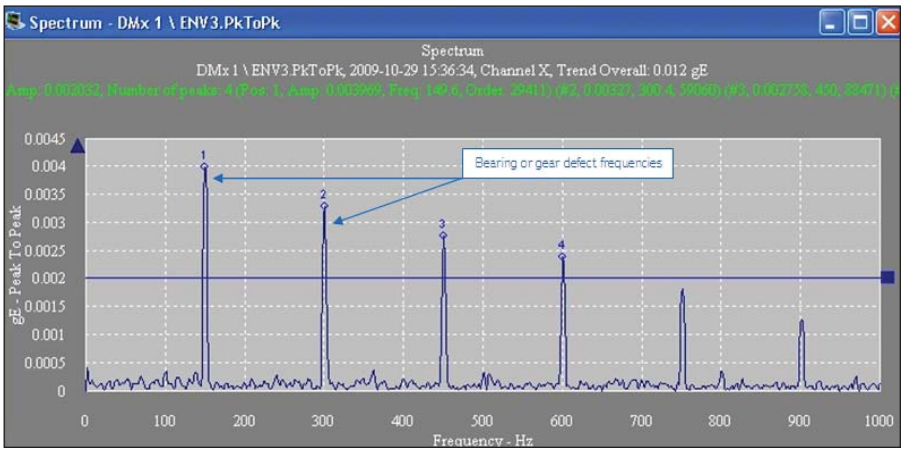


Figure 4. Enveloped FFT from acceleration signal.

Table 2. Enhanced SKF Multilog DMx layout for API 670 Appendix H-1 gearbox layout.

Module	Channel	Tag	Location	Measurement	Units, Detection
SKF Multilog DMx 1 (CMMA 9910)	1	4X	DE bearing	Radial displacement	µm, True Peak-Peak
	2	3Y	DE bearing	Radial displacement	µm, True Peak-Peak
	3	P1	Thrust bearing	Axial displacement	mm
	4	P2	Thrust bearing	Axial displacement	mm
SKF Multilog DMx 2 (CMMA 9920)	1	A1	DE bearing	Acceleration	G's, true peak
	2	A2	NDE bearing	Acceleration	G's, true peak
	3	-	DE bearing	Acceleration envelope ENV 3	G_{ENV}, peak
	4	-	NDE bearing	Acceleration envelope ENV 3	G_{ENV}, peak
	4a	ø1	DE bearing	Phase reference	Volts/RPM
SKF Multilog DMx 3 (CMMA 9910)	1	-	DE bearing	Velocity	mm/sec, true RMS
	2	-	NDE bearing	Velocity	mm/sec, true RMS
	3	5Y	NDE bearing	Radial displacement	µm, True Peak-Peak
	4	6X	NDE bearing	Radial displacement	µm, True Peak-Peak

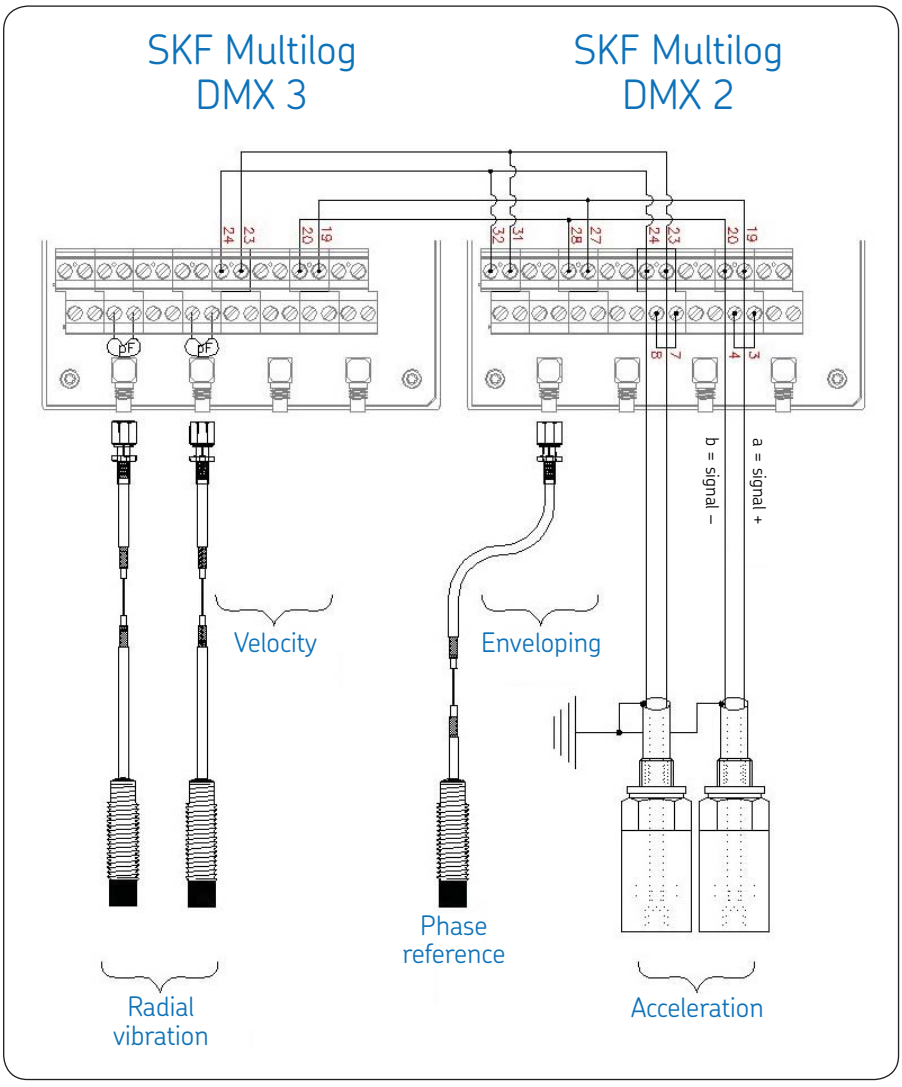


Figure 5. Dual path wiring with additional enveloping channel into the SKF Multilog DMx.

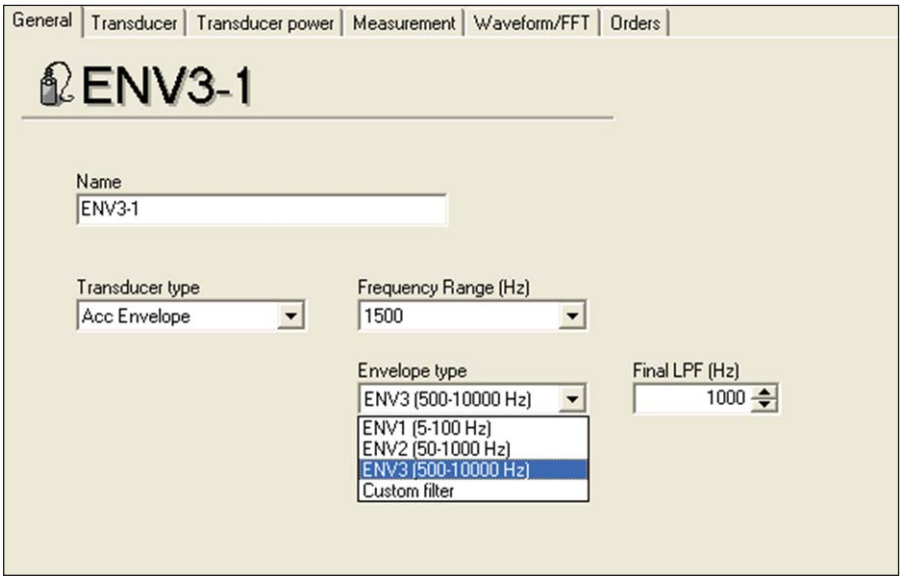


Figure 6. Acceleration Enveloping selection in SKF Multilog DMx Manager Software – ENV 3.

Summary

The SKF Multilog On-line System DMx provides a comprehensive solution to API 670 class monitoring of gearboxes, along with the significant reduction in installation costs offered by a distributed architecture.

API 670 recommends "Dual Path" monitoring of gearboxes using casing mounted accelerometers. The accelerometer signals should be split into two overall level measurements – acceleration and velocity – from two different frequency bands. This is a long-standing method and fully supported by the SKF Multilog DMx.

The SKF Multilog DMx can enhance the Dual Path method to provide earlier warning of a potential problem with the gears. This is done by means of acceleration enveloping – a signal processing technique that extracts the small repetitive impact events (generated by rolling element bearings and gears) from the background machine vibration.

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