Recommended Initial Alarm Criteria for Bearing Condition Assessment Using Enveloped Acceleration Measurements

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Introduction

This application note presents a set of guidelines for initially establishing Alert and Danger alarm thresholds for enveloped acceleration measurements for early detection of rolling element bearing damage. The criteria recommended herein should be used to determine initial alarm thresholds only. As with all commonly published severity charts and tables, this method provides target thresholds for new, refurbished and recently maintained equipment. Once a good operating baseline is established and sufficient data and experience have been acquired for high confidence statistical alarm calculation on a point-by-point basis, the prudent analyst will abandon these guideline thresholds in favor of an automatically calculated trend-based or statistically-based change technique.

Specific details on the enveloped acceleration technique may be found in the SKF Reliability System's Application Note, publication CM3013, *"Frequency Asked Questions About Enveloping"*.

- An accurate enveloped acceleration measurement alarm provides early indication that a bearing is approaching the end of its usable lifetime. Upon such an alarm, the reliability person should more closely monitor the bearing using FFT signature analysis with bearing fault frequency markers to verify the bearing defect and determine proactive maintenance measures, or to plan the most efficient bearing replacement during a scheduled machine outage.

Background

SKF, supplier of 20% of the world's bearings, has extensive experience in the use of enveloped acceleration measurements to detect problems in rolling element bearings. The technique has been used as a quality assurance measurement in SKF bearing factories since the early 1970's. To support SKF's objective of providing the world's most reliable bearings, acceleration enveloping is the primary measurement for identifying the earliest stages of bearing degradation in SKF research and development laboratories during life cycle, stress, fatigue and induced fault run-to-failure tests at the SKF Engineering Research Centre in the Netherlands and the SKF North American Technical Center near Detroit, Michigan in the USA. In the late 1980's, enveloped acceleration technology was incorporated into SKF's vibration data acquisition instruments designed to support industrial reliability improvement through predictive maintenance techniques. Since enveloped acceleration's introduction into SKF's condition monitoring instrumentation, extensive experience has been gained by monitoring hundreds of thousands of bearings in both the laboratory and industrial service environments.

Recommendation

The formulas for setting enveloped acceleration alarm thresholds for bearing monitoring were established using statistical analysis of existing databases. The database study concluded that critical factors in enveloped acceleration alarm threshold establishment are the bearing diameter and the rotating speed of the shaft, with analysis bandwidth and fmax as user specified input parameters. Once these critical factors were determined, the formulas were developed and applied to existing data for validation. **Table 1** presents the results using simplified formula, suitable for a simple handheld calculator, for the most commonly used SKF instrument configurations.

Table 1

Simplified formula results for setting initial enveloped acceleration alarm thresholds

SKF product	fmax	Danger level equation: Metric N (Kcpm) D (mm)	Danger level equation: English N (Kcpm) D (in.)	Example: N = 3,6 Kcpm D = 76,2 mm (3 in.): Danger (gE)	Example: N = 3,6 Kcpm D = 76,2 mm (3 in.): Alert (1/3 of Danger gE)
Filter #3 [SKF Microlog, LMU and Wireless Sensor System]	**40 × N**	N/3 × √(N×D)	1,67 × N × √(N×D)	19,8	6,6
Filter #3 [SKF Microlog, LMU and Wireless Sensor System]	**20 × N**	N/4 × √(N×D)	1,25 × N × √(N×D)	15,0	5,0
Filter #3 [SKF Microlog, LMU and Wireless Sensor System]	**1 000 Hz**	N/3 × √D	8,75 × N × √D	0,0	2,7
Filter #3 [SKF Microlog, LMU and Wireless Sensor System]	**500 Hz**	N/4 × √D	71,25 × N × √D	0,8	2,6
Filter #4 [Machine condition transmitter (MCT)]	**4 kHz**	3/4 × N × √D	3,75 × N × √D	23,5	7,8
Filter #3 [Machine condition transmitter (MCT)]	**1 kHz**	N/3 × √D	1,70 × N × √D	10,4	3,5
Machine condition detector (MCD)	**1,5 kHz**	N/2 × √D	12,50 × N × √D	5,7	5,2

SKF Microlog portable data collector / FFT analyzer.

Machine condition detector (MCD Pro IS).

Local monitoring unit (LMU).

Wireless sensor system.

Machine condition transmitters (MCT).

Mathematical model for initial enveloped acceleration alarm guidelines

Based on SKF's extensive bearing condition monitoring and evaluation experience, a generic empirical formula using major parameters affecting enveloped acceleration measurements is determined as follows:

- $L = (f_{max}/1000)^{a_1} \times a_2 \times n^{a_3} \times d^{a_4}$ (gE)

Where:

- **L** = Alarm setting for enveloped acceleration measurement
- **f_{max}** = Maximum frequency in Hz for spectrum band amplitude computation
- **n** = Running speed in r/min
- **d** = Bore diameter of the bearing (load indicator)
- **a_1, a_2, a_3, a_4** = Empirical coefficients to be determined statistically using existing databases

The four coefficients in the generic formula were obtained following the steps below:

1. Evaluate available databases using statistical method to obtain alarm levels that are statistically significant to each database. Consult application engineers and experts to ensure that all the field experience from the past are included.
2. Use a curve fitting method to calculate the coefficients in the generic formula to fit alarm levels obtained in the previous step.

Without including detailed mathematical deductions, the empirical formulae for danger and warning levels are given below.

Danger level:

- $L_D = (f_{max}/1000)^{0,43} \times 3,26 \times 10^{-4} \times n \times d^{0,55}$ (gE) (Equation 1)

Alert level:

- $L_A = (f_{max}/1000)^{0,43} \times 1,09 \times 10^{-4} \times n \times d^{0,55}$ (gE) (Equation 2)

These two formulas are derived from both high and low speed machinery. To represent higher speed machinery, data was taken from pumps and motors running 3 600 r/min. Lower speed machinery was represented with paper machine rolls running at 400 r/min. The confidence level for these results is 90%.

Applying the criteria in detail

The mathematical equations describing alarm criteria for enveloped acceleration measurements are plotted in **fig. 1**. Bearing bore diameters and rotating speeds used in **fig. 1** represent the majority of bearings used in various industries for rotating machinery. The plot in **fig. 1** was created for an fmax of 1 000 Hz (60 000 CPM). If a different fmax value is required for a measurement, an fmax scaling is required. The scaling factor for fmax compensation is shown in **fig. 2**. To utilize **figs. 1** and **2**, the following parameters must be known:

- Bearing bore diameter in mm; if the bearing bore diameter is unknown, multiply the last two digits of the bearing number by 5 to obtain the bearing bore diameter in mm
- Shaft speed in r/min
- Fmax

The following example describes proper use of **figs. 1** and **2**. Assumptions are:

- Bearing bore diameter: 100 mm
- Shaft speed: 1 800 r/min
- Fmax: 500 Hz (30 000 CPM)

Use the charts in **figs. 1** and **2** to determine this enveloped acceleration measurement's alert and danger alarm settings:

1 In **fig. 1**, locate 100 mm on the shaft diameter axis.
2 Follow the vertical line representing 100 mm to the point where it intersects the 1 800 r/min running speed line (the dark circle on the chart). This is your reference point.
3 From your reference point, follow the horizontal lines left to the danger setting (gE) axis to determine your initial danger alarm setting (7,5 gE).
4 From your reference point, follow the horizontal lines right to the alert setting (gE) axis to determine your initial alert alarm setting (2,5 gE).
5 In **fig. 2**, find 500 Hz on the Fmax axis.
6 Follow the vertical line representing 500 Hz to the point where it intersects the scaling curve.
7 Read the ***Scaling Factor*** value (0,75).
8 Multiply the alarm settings obtained in steps 3 and 4 by the scaling factor.

- Danger level = 7,5 gE × 0,75 = 5,6 gE ∫ 6,0 gE
- Alert level = 2,5 gE × 0,75 = 1,9 gE ∫ 2,0 gE

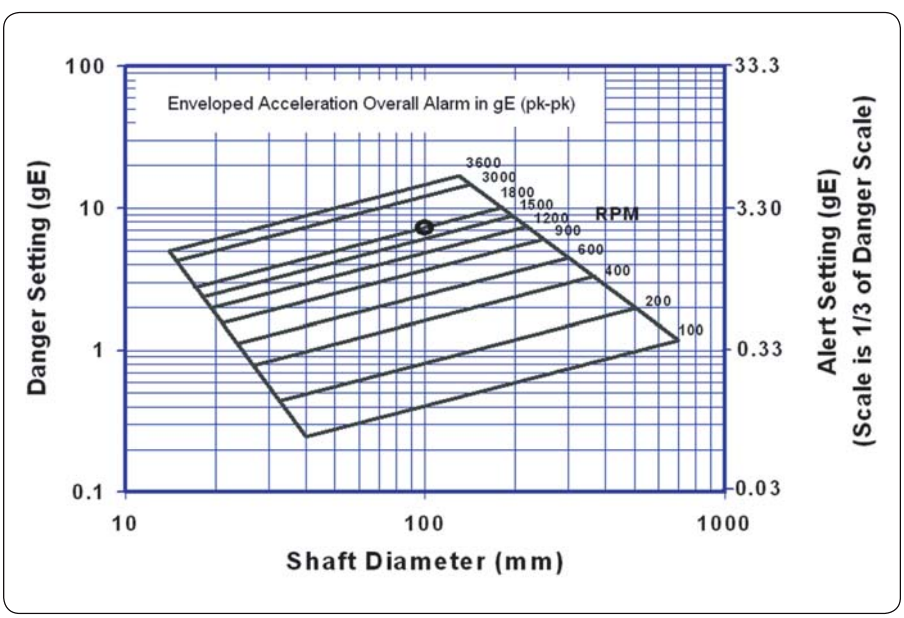

Fig. 1. Initial enveloped acceleration alarm chart (Fmax = 1 000 Hz, 60 000 CPM).

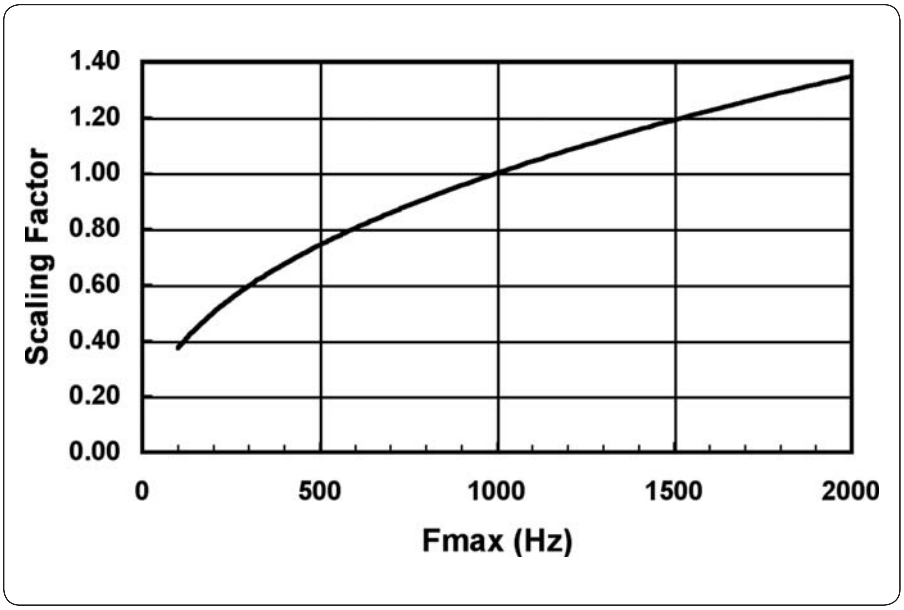

Fig. 2. Scaling factor for Fmax compensation for enveloped acceleration measurements.

Conclusion

This application note presents a method for initial enveloped acceleration alarm criteria for use with new, refurbished and recently maintained machinery. This method is based on extensive review of empirical data and is 90% effective in identifying bearings at the earliest possible stages of degradation. Once sufficient experience is gained, on a measurement point-by-point basis, this method should be replaced in the user's database with trend-based or statistically-based alarm settings.

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