

VIBRATION MONITORING FOR FAULT DETECTION AND PROCESS CONTROL OF THE MOTOR-MIXER AGREGATE IN FENI INDUSTRY- MACEDONIA

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Abstract: One of the larger aggregates for production nickel in Feni – INDUSTRIES- Macedonia, is assembly machine mixer 1 and mixer 2. The proper functioning of aggregate depends on the prevention and early detection of damaged parts. Given that the aggregate works non-stop for 24 hours, its failure means termination of operation of furnaces for nickel, and thus the entire production. It means a loss of time, deviation from the production plan, loss of markets and loss of a lot of money. It is a very important to constantly monitor the vital parts rightness. Therefore regularly perform frequency analysis of engine bearings and mixer bearings. Aggregate is composed of: motor, hydro coupling, reducer, mechanics coupling, and mixer.

This paper provides the results of frequency analysis of measured vibration of these parts, compared with limited values and recommendations for quick actions in removing the damaged parts in time periods with the least losses. That means pre timely delivery of bearings, preparation of aggregates for quick repairs with a short downtime. You will also be given a techno - economic analysis to save funds by using this method.

KEYWORDS: SIGNAL PROCESSING, VIBRATION ANALYSIS, BEARINGS, CONDITION MONITORING

1. Introduction

Production of nickel is an intensive process that uses robust and rotating equipment where it is exposed to intense workload and high temperatures, whereas the susceptibility of equipment failures poses a serious threat. In critical positions in flow of the production process include crushers, rotary dryers (x4), mills (x2), rotary kilns (x2) and the main hydraulic oil lubrication systems that use large electric motors and reduction enclosures, in addition to electric furnaces (x2), converters (x2), arc furnace (x1), granulation system (x1) and vats that are susceptible to decline bricks and large transformers.

By exploiting the plant comes to unwanted accidents due to the occurrence of illicit vibration. In order to avoid these phenomena are often performed unnecessarily replacing the elements of the plant, although they can still be used.

The latest trends tend to maintain fixed time intervals for replacement of mechanical elements, to be replaced by interval control state of the plant. The basic principle of this system maintenance vibration diagnostics is to defining discrete air forces imply irregular operation of the plant [1].

Modern equipment for measurement, analysis and diagnostics, along with knowledge and experience of professional staff who manage it, guarantee to resolve the complex side effects that occur during the operation of the plant. All rotating machines during operation generate vibrations that are inevitable occurrence in their exploitation. Their full elimination is impossible, but it is the same loft in boundaries defined by the equipment manufacturer or adopted global standards and norms, such as: VDI 2056 recommendations; DIN 45.666 norms ISO 10816 standards; E 90-100 French norm.

The fact that irregular work of some mechanical element with particular intensity and frequency determined exactly unique to that part of the plant, is used for determining and defining exactly inertial forces that cause the dynamic state of the plant.

Nature of inertial forces can be various different [2],[3],[7]:

- imbalance in the rotating masses ;
- misalignment - axis of the shaft ;
- mechanical damage in rolling bearings ;
- irregularity in the operation of the sliding bearings ;
- work in terms of resonance phenomena ;
- Excitation aerodynamic and hydraulic forces ;
- Electromagnetic vibration and more.

The choice of balancing rotors in their own bearings has that advantage:

- Corrects imbalances of the total rotating mass of the entire composition.
- There are no transport costs;
- Avoided mistakes are repeated editing.

The following example will show the measurement and diagnosis of two motor-mixer aggregates used permanently in Feni - INDUSTRIES- Kavadarci, R.Macedonia. (fig.1)



Fig.1.FENI INDUSTRY KAVADARCI –MACEDONIA

2. Material and methods

The basic goal of this investigation is measuring the vibration of all rotating machinery in Feni Industry in critical points of the vital slops with PResenoted the results in period before failure of the bearings.

For that purpose was used VIBROTEST 60 (Brüel&Kjaer) instrument with appropriate modules.

All measurements of rotating machines via a memory card of the VIBROTEST 60 were transferred to a computer. The computer has installed XMS software where all measurements are recorded on the machine. XMS (extended monitoring software) is the professional software for optimum implementation of the concept "condition-oriented machine maintenance" and provides perfect support through an intelligent database. By measuring the route covered all machines in the factory (Fig.2). By measuring the vibrations in this program and register at the same time frequency analysis are too.

But if there's a problem of the machines are made more frequent measurement to monitor the amount of vibration and to determine whether resulting from lineups: Bad bearings in electric motor or the working circuit. Sometimes a problem with the clutch which can be damaged by irregular lubrication of electric motor with a working circuit, or by imbalances that may occur with consumption of the fins from the working circuit. Spending the fins can occur from hot air and dust that is in him. To determine what caused the vibration, it has been establish measurements and software through the frequency analysis of all bearings, and it is seen from the pictures (Fig.9-). In images, if any of the peaks coincided with the

red vertical lines (1-5), who read part of the slot is damaged, (read from right image)

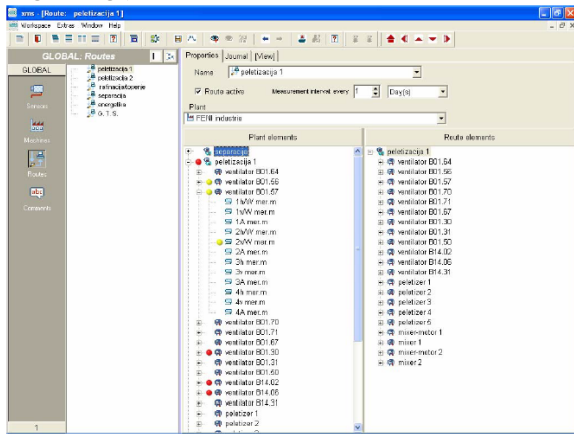


Fig.2. xms software used in FENI Industry - Kavadarci

If the vibrations are caused by damage to the bearings, then take a further reading of the frequency analysis. When you determine what caused the vibrations, we look in the documentation that the manufacturer of that machine in which boundaries are allowed to run. According to the number of revolutions we see what the allowable vibrations are.

The bearing frequencies can easily be calculated from the bearing geometry using the formulae given in Fig. 3[1].

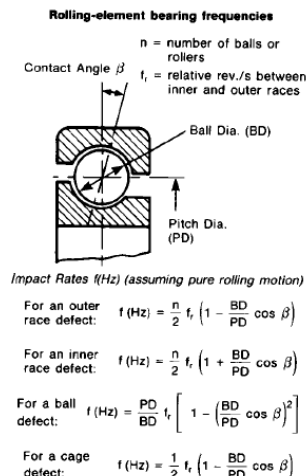


Fig.3. Formulas for calculating bearing frequencies

The most widely used standard as an indicator of vibration severity is ISO 2372 (BS 4675)[1]. The standard can be used to determine acceptable vibration levels for various classes of machinery. Thus, to use this ISO standard, it is necessary to first classify the machine of interest. Reading across the chart we can correlate the severity of the machine condition with vibration. The standard uses the parameter of velocity-rms to indicate severity.

ISO 2372 – ISO Guideline for Machinery Vibration Severity					
Ranges of Vibration severity		Examples of quality judgment for separate classes of machines			
Velocity – in/s – Peak	Velocity – mm/s – rms	Class I	Class II	Class III	Class IV
0.015	0.28				
0.025	0.45				
0.039	0.71				
0.062	1.12				
0.099	1.8				
0.154	2.8				
0.248	4.5				
0.392	7.1				
0.617	11.2				
0.993	18				
1.54	28				
2.48	45				
3.94	71				

A – Good
 B – Acceptable
 C – Still acceptable
 D – Not acceptable

ISO 2372 – ISO guideline for machinery vibration severity

Fig.3. ISO 2372 standard for evaluate vibrations impact

The letters A, B, C and D as seen in Figure 2.13, classify the severity. *Class I* Individual parts of engines and machines integrally connected with a complete machine in its normal operating condition (production electrical motors of up to 15 Kw are typical examples of machines in this category).

Class II Medium-sized machines (typically electrical motors with 15–75 kW output) without special foundations, rigidly mounted engines or machines (up to 300 kW) on special foundations.

Class III Large prime movers and other large machines with rotating masses mounted on rigid and heavy foundations, which are relatively stiff in the direction of vibration.

Class IV Large prime movers and other large machines with rotating masses mounted on foundations, which are relatively soft in the direction of vibration measurement (for example – turbogenerator sets, especially those with lightweight substructures).

Motor-mixer aggregates 1,2 in this paper are in class III, according the parameters they possess.

3. RESULTS AND DISCUSSION

3.1. Results of the measuring vibrations of the motor mixer No1 before the critical moment of failure

One of the larger aggregates to production nickel in Feni-INDUSTRIES, are mixer 1 and mixer 2... Its proper functioning depends on the prevention and early detection of damaged parts. Therefore regularly perform frequency analysis of engine bearings and mixer bearings. Each of the aggregates is composed of: electric, hydro coupling, gearbox, mechanics coupling and mixer (Fig.4).

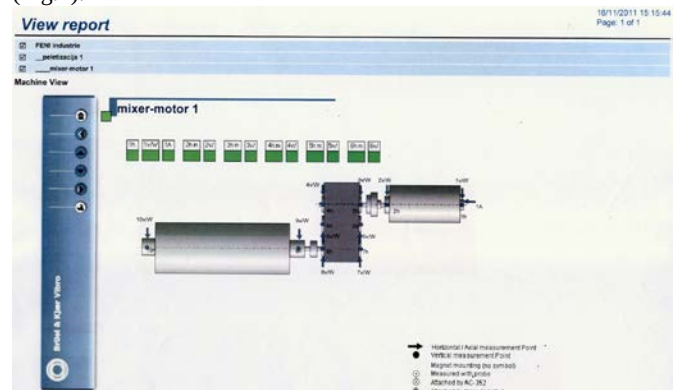


Fig.4. Motor-mixer aggregate No1 – measurement point's

Frequency of the bearings elements on points 1.2 on motor, for the type SKF 6228 are given in Fig 5.

Marker factors					
Factor	Notes	Manufacturer	Type		
4.19	Outer-race ball-pass frequency	SKF	6228		
5.91	Inner-race ball-pass frequency	SKF	6228		
2.99	Rolling-element rotational frequ	SKF	6228		
5.98	Rolling-element ball-pass frequ	SKF	6228		
0.419	Cage ball-pass frequency	SKF	6228		

Fig.5. Frequency of the bearings on points 1.2 types SKF 6228

The aggregate working conditions are very difficult. The air contents of a high concentration of dust pollution. Its function is mixing ground ore in micron dust and water. The generator runs continuously twenty four hours every day. His problem produced a slowdown in manufacturing with the big negatively consequences on efficiency the whole factory. Because of that, to perform the daily visual, and measurement controls and regular frequency analysis is necessary.

Measuring the frequency analysis is performed on:

- Bearing number -1, 2 of the motor with $n=1450\text{r/min}$,
- Bearing number 9,10 of the mixer $n=86.5\text{r/min}$ ($i=16.76$)

The measurement is done horizontally, vertically and axially. Fig.4, 5 shows the measurements performed on bearing type 6228 of motor mixer 1, point 1 and point 2 (see Fig. 6). This measurement is done before the bearings failure. The critical FFT diagram is on fig.6

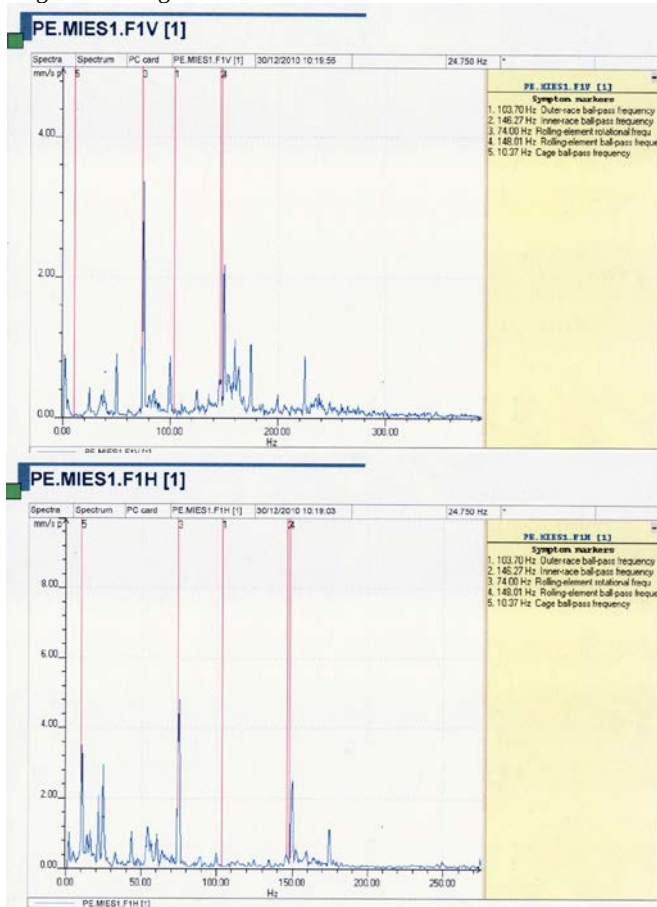


Fig.6. Bearing SKF 6228 –FFT on motor: a) Measuring on 1 vertically 3.4mm/s max peak a) on 1 horizontally 4.95mm/s max peak

The diagrams present that the point number - 1 (horizontal vibrations on motor) show high amplitude in line 5 and the line 3. It assumed the red line 5 approved bearing damage from the cage, while the line 3 present damage to the bearing balls. This early detection allows us timely preparation and change the bearing. The same can be proved from the vertical vibration - frequency analysis point -1 vertically. And this diagram reflected the damage of bearing balls (fig.7). There are pitting on the balls as results of a high concentration of dust and dirty with the problems in lubrications and high contact pressure between balls and the inner ring... Overlapping line - 3 with the largest amplitude was shown on the diagram on fig.6



Fig.7. Damaged rolling elements of the SKF 6228 on motor

The same situation exists on another main point's where vibrations are measured in both directions on motor point 2. FFT diagrams shows on fig.8 measuring in time before failure of the bearings.

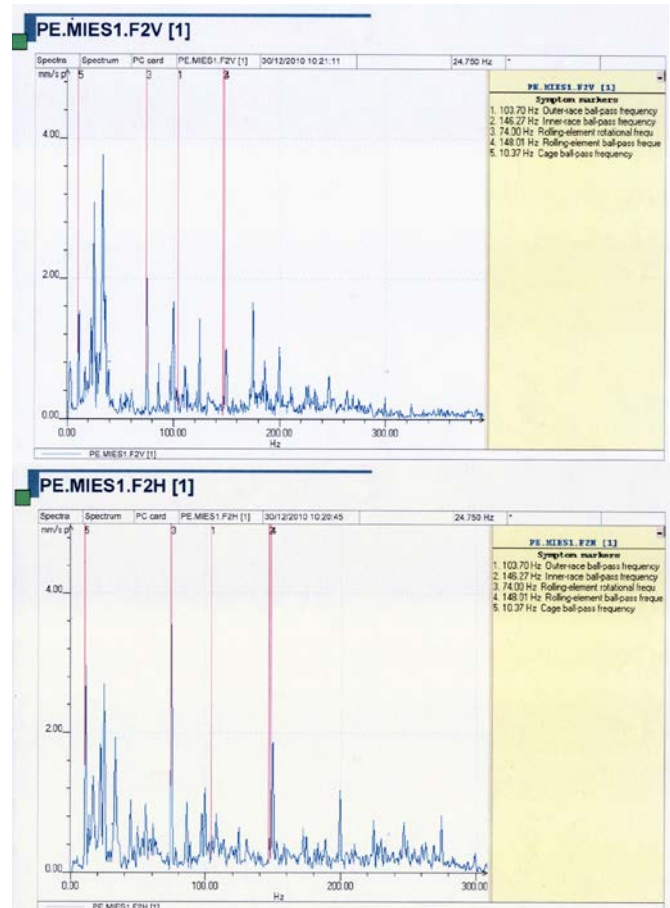


Fig.8. Bearing SKF 6228 –FFT on point 2-motor before failure a) Vertical measuring max peak 3,8mm/s b) horizontal measuring 3.6mm/s max peak

Permanent monitoring and measured results of the vibrations (Fig.9,10) at the characteristic points in three directions showed that the rolling bearings SKF 6228 defined with the point 1 and 2 in Fig.3 are most sensitive of the electric motor.

Two types of bearing defects, namely, rolling elements and cage defects were studied. Measurements were carried out on two sets of bearings. The defective bearing was replaced by good bearing after predicting the failure with vibration signal analysis.

After dismantling the bearing, the photo showed the place where it caused the failure of the bearing cage (Fig.9).



Fig.9. Damaged cage of the SKF 6228 rolling bearing



Fig.10 Damaged outer race SKF 6228 rolling bearing

Defects on the rolling elements (Fig.7, 10) can generate a frequency at twice ball spin frequency and harmonics and the fundamental train frequency. Twice the rolling element spin frequency can be generated when the defect strikes both raceways, but sometimes the frequency may not be this high because the ball is not always in the load zone when the defect strikes and energy is lost as the signal passes through other structural interfaces as it strikes the inner raceway. Also, when a defect on a ball is orientated in the axial direction it will not always contact the inner and outer raceway and therefore may be difficult to detect.

The bearing cage tends to rotate at, typically, 0.4 times inner ring speed, has a low mass and, therefore, unless there is a defect from the manufacturing process, is generally not visible. Unlike raceway defects, cage failures do not usually excite specific ringing frequencies and this limits the effectiveness of the envelope spectrum. In the case of cage failure, the signature is likely to have random bursts of vibration as the balls slide and the cage starts to wear or deform and a wide band of frequencies is likely to occur.

2.2. Results of the measuring vibrations before the critical moment of failure the motor mixer No2

Motor – mixer aggregate No2 is similar the same with No1. Each of the aggregates is composed of: electric, hydro coupling, gearbox, mechanics coupling and mixer (Fig.11).

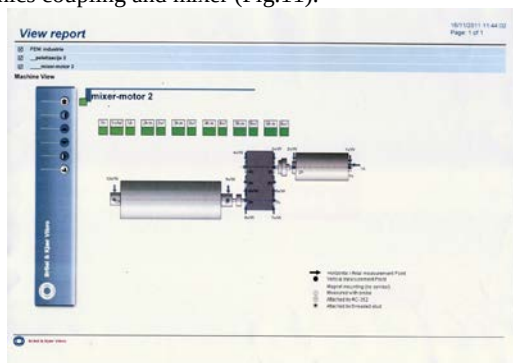


Fig.11. Motor-mixer aggregate No1 – measurement point's

The frequencies of the elements of bearings 9, 10 Type SKF 22240 (spherical) given on Fig.12

Marker factors	Factor	Notes	Manufacturer	Type
☒	8.18	Outer-race ball-pass frequency	SKF	22240CCW33
☒	10.9	Inner-race ball-pass frequency	SKF	22240CCW33
☒	3.465	Rolling-element rotational frequ	SKF	22240CCW33
☒	6.93	Rolling-element ball-pass frequ	SKF	22240CCW33
☒	0.43	Cage ball-pass frequency	SKF	22240CCW33

Fig.12. Frequency of the bearings on points 9.10 type SKF 22240

Measuring the frequency analysis is performed on bearings: - number 9 and - 10 of the mixer, spherical bearings with the power to adapting the shaft deformations without any problems of cinematic and dynamics influence.

The measurement is done horizontally and vertically.

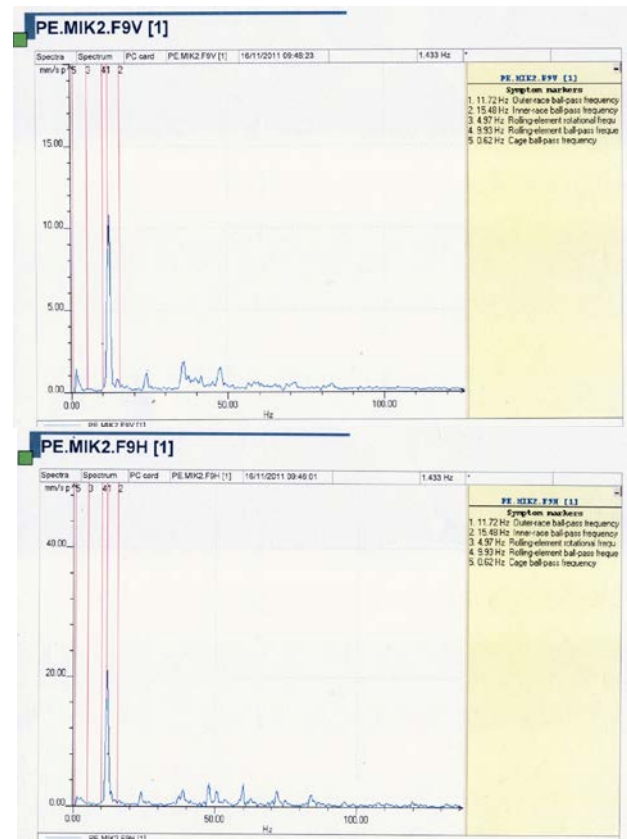


Fig.13. Bearing SKF 22240 CC/W33 –FFT on point 9-mixer
a)vertical 10.9 mm/s max peak b)horizontal measuring 29.5mm/s

Same can check the diagram in the frequency measurement point number -10 V. Line Number - 1 coincide with the maximum amplitude of diagram. So it is confirmed that there is damage to the outer ring of the bearing 22240 CC/W33

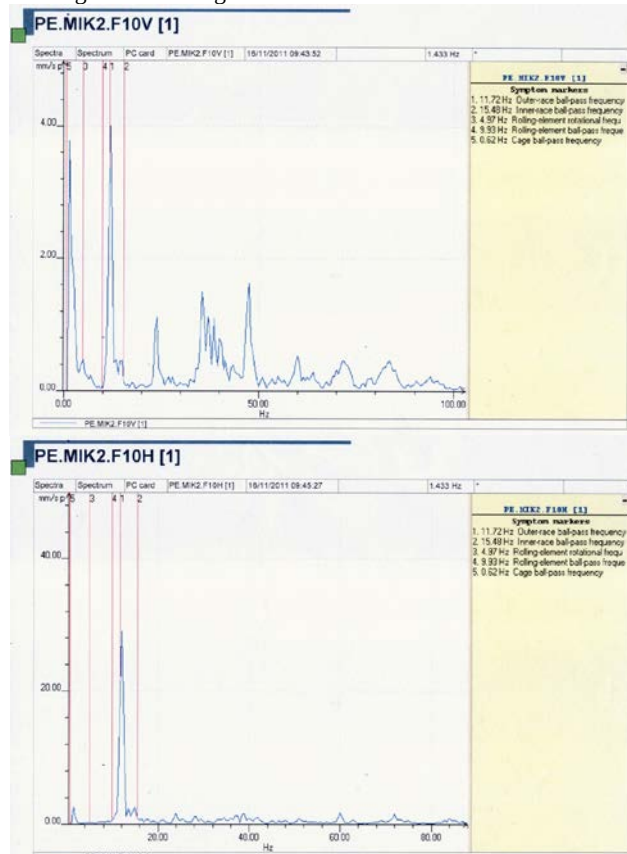


Fig.14. Bearing SKF 22240 CC/W33 –FFT on mixer
a) measuring on 1 vertically 4mm/s max peak a) on 1 horizontally 30mm/s max peak

Damaged outer ring of bearing 22240 CC/W33 is show on next picture.



Fig.15 Damaged outer ring of bearing 22240 CC/W33

4. CONCLUSION

Continuous monitoring of the mechanical assemblies condition is very important and vital for technological process in FENI Industry. Monitoring was done by periodically measured and analyzed vibration detecting by vibration signature.

In the case of two assemblies of motor- mixers in this paper, there are given vibrations signature only measured at critical points of the motor and the mixer in period before the bearings failure. The analysis was done by FFT diagram, permanent change the bearings parts frequency and the amplitude of vibration which through comparison with ISO 2372 standard definition of impact.

In the case of SKF 6228 bearing in point 1 of mixer-motor 1 that belongs to class III according to ISO 2372 in connection with the driving characteristics and fundamentals the maximum amplitude of vibration of 3.6 and 3.8 mm / s are within the eligibility. Changing the frequency of the balls and the cage is a result of the occurrence of misalignment (increased amplitude of low frequency) and large dust pollutants in the atmosphere that violate minimum lubrication.

Amplitudes of vibration measured at a point 9.10 of bearings mixer 2 show another picture. Horizontal vibration of 29.5 mm / s and 30mm / s of SKF 22240 CC/W33 entered the engine-mixer 2 in the area of irregular vibration according to ISO 2372. These results indicate axial looseness of the external to the internal ring and damage rolling elements in the bearings.

The bearing cage tends to rotate at typically 0.4 times inner ring speed, has a low mass and therefore, unless there is a defect from the manufacturing process, is generally not visible.

Unlike raceway defects, cage failures do not usually excite specific ringing frequencies and this limits the effectiveness of the envelope spectrum. In the case of cage failure, the signature is likely to have random bursts of vibration as the balls slide and the cage starts to wear or deform and a wide band of frequencies is likely to occur.

Following are some example of problem that can cause the generation of the fundamental train frequency. These are in addition to other conditions already discussed.

1. In rare cases when one or more rollers are missing from a bearing, the FTF can be generated. The problem occurs as a pulse at the FTF. The frequency spectra contain a series of harmonics of the FTF. The amplitude of the first harmonic is quite low, the second, third, and fourth harmonics are higher in amplitude as determined by the pulse.

2. Sometimes, attempts to lubricate sealed or shielded bearings can cause the seal or shield to deflect inward. If the cage touches the

seal or shield, the FTF and/or two times FTF plus harmonics can be generated.

3. Excessive clearance in an antifriction bearing can cause the generation of a discrete frequency at the FTF and/or modulations of the FTF at rotating speed and harmonics.

Except for defects that occur in bearing components during manufacturing, the cage is usually the last component to fail. The typical failure sequence is as follows: defects form on the races, the balls, and then finally the cage. A severely damaged cage can cause constant frequency shifts that are observable with the use of a real-time analyzer.

When the cage is broken in enough places to allow the balls or rollers to bunch up, wide shifts in frequencies accompanied by loud noises can occur. When these signs are present, bearing seizure is imminent,

Trend of overall frequencies and vibration spectrum provide useful information to analyse defects in roller bearings. Trend indicates severity of vibration in defective bearings. Vibration domain spectrum identifies amplitudes corresponding to defect frequencies and enables to predict presence of defects on inner race and outer race of roller bearings. The distinct and different behaviour of vibration signals from bearings with inner race defect and outer race defect helps in identifying the defects in roller bearings.

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