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A Methodology for Identifying Defective Cycloidal Reduction Components Using Vibration Analysis and Techniques

By V. Cochran and T. Bobak,
Sumitomo Drive Technologies

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Virgil Cochran and Todd Bobak, Sumitomo Drive Technologies

[The statements and opinions contained herein are those of the author and should not be construed as an official action or opinion of the American Gear Manufacturers Association.]

Abstract

For several years predictive maintenance has been gaining popularity as a method for preventing costly and time-consuming machine breakdowns. Vibration analysis is the cornerstone of predictive maintenance programs, and the equations for calculating expected vibration frequencies for bearings and toothed gear sets are widely available. Cycloidal reducers present a special case due to the nature of their reduction mechanism. This paper will describe a method for utilizing vibration analysis in order to identify a defective cycloidal ring gear housing, disc, and eccentric bearing.

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American Gear Manufacturers Association
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Introduction

Predictive maintenance is becoming a popular method for preventing costly and time-consuming equipment failure. It's applied most often to assembly lines, where the unexpected failure of a critical machine can lead to thousands of lost dollars per hour of downtime. Predictive maintenance via vibration analysis can indicate, before failure occurs, whether internal machine components are worn and require replacement. The advanced notification that predictive maintenance provides allows users to repair their machines during scheduled downtime, thereby preventing unexpected failures during production hours. The benefits are maintenance and spare parts cost reductions along with increases in production time. Product quality increases are also realized since machines can be maintained in good condition consistently (1).

Some vibration analysis software packages include bearing frequency and gear mesh information in their databases, and by entering system information the software provides the user with the operating frequencies of interest.

Cycloidal reducers, however, are more complex than toothed gear systems. They contain more rolling components than toothed gear sets, which makes calculating the expected operating frequencies difficult, see figure 1. However, predictive maintenance can still be applied to cycloidal reducers.

The rotational frequencies of bearings and toothed gear sets are common items monitored by predictive maintenance practitioners. Bearing rotational frequencies can be obtained from bearing suppliers or calculated, given the relevant system information. Frequencies suggested for monitoring are $1 \times \text{shaft rpm}$ for inner race faults and $1 \times \text{FTF}$ (fundamental train frequency) for rolling element faults (2).

A cycloidal eccentric bearing presents an uncommon case since both bearing races rotate. Cycloidal discs mesh with pins or rollers located along the inner perimeter of the ring gear housing. As the discs and the pins (or rollers) mesh, a contact frequency is created which can be monitored. See figures 2 - 4. The user can calculate the cycloidal disc mesh frequency by using:

$$\text{Cycloidal Disc Mesh Frequency} \sim DMF = \frac{\text{No. of Pins} \times \text{Output RPM}}{60} \text{ Hz}$$

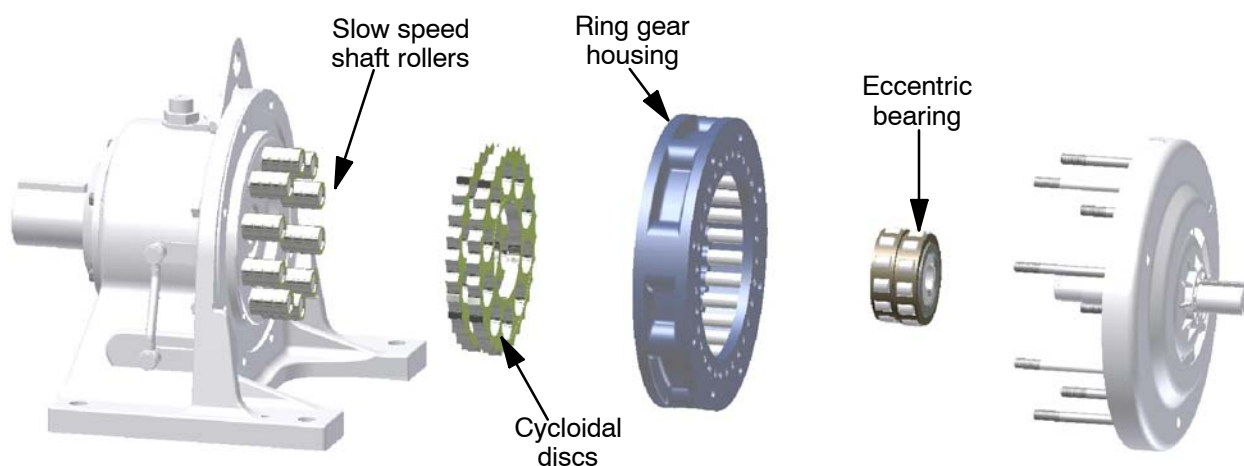


Figure 1. Exploded view of cycloidal reduction components

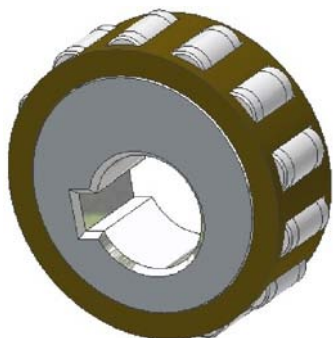


Figure 2. Cycloidal eccentric bearing



Figure 3. Cycloidal disc

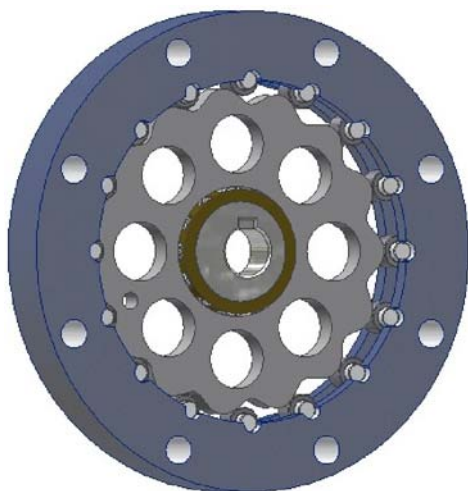


Figure 4. Cycloidal disc meshes with pins or rollers

Predictive maintenance procedure

The key to successful predictive maintenance programs for cycloidal reducers and gearmotors is to record a baseline of a cycloidal unit's vibration frequencies for use as a reference as soon as possible

after a unit is placed into service. As long as the unit is installed securely, aligned correctly, and its operating loads and conditions match those used for the unit selection, the resulting baseline will be accurate.

A predictive maintenance program for cycloidal speed reducers and gearmotors utilizing vibration analysis is implemented as follows:

1. Install the unit according to the manufacturer's instructions, making sure the unit is mounted securely and aligned correctly. A poor installation will result in an inaccurate baseline.
2. Run the unit under nominal application conditions until it reaches operating temperature.
3. Record a vibration measurement, and note the amplitudes of the eccentric cam and the eccentric bearing fundamental train frequencies.
4. Store this measurement record for future reference. This is the baseline against which all future measurements should be compared.
5. Periodically record a vibration measurement and compare it against the baseline, checking for vibration amplitude increases. The measurement interval will depend on a unit's operating loads and conditions. It's recommended to record measurements frequently at the beginning of a predictive maintenance program, and then adjust the interval according to the unit's maintenance requirements (3).
6. When vibration amplitude increases are noted at the eccentric cam or the eccentric bearing fundamental train frequencies, eccentric bearing wear may have begun. Decrease the vibration measurement interval in order to compare the unit's condition to its baseline more often.
7. Once vibration amplitude increases are noted at higher frequencies, schedule the unit for repair. Advanced wear has most likely begun, so the unit should be removed from service in order to replace worn internal components before catastrophic failure occurs.

Test procedure

A cycloidal reducer was returned which had suffered the typical damage associated with overload or inadequate lubrication: a worn eccentric bearing, pressure marks in the surface of the cycloidal discs' center holes, and burned grease. With the exception of burned grease, this damage also

occurs at the end of a properly selected unit's useful life. Therefore, it was selected as the subject for this study. The unit's eccentric bearing FTF was calculated to be 11.20 Hz, and its cam frequency was determined to be 29.17 Hz. The cycloidal DMF was calculated as 14.75 Hz.

A new, identical unit was assembled in order to obtain a baseline measurement. After obtaining the baseline with a vibration data collector as shown in figure 5, the new unit's eccentric bearing, cycloidal discs, and ring gear assembly were exchanged for those from the damaged unit in a progressive manner in order to simulate the progression of typical wear. If a unit's eccentric bearing becomes worn and the unit continues to operate, wear progresses to the cycloidal discs. Further operation leads to wear within the ring gear assembly. The wear's progression is due to the flow of metallic particles between the internal components by way of the lubricant.

During the last phase, the worn components were installed in the new unit individually in an attempt to isolate the operating frequencies characteristic of those components. The ring gear assembly fre-

quencies were of particular interest, for they are difficult to calculate.

Testing Procedure

All tests were conducted under full load.

1. The returned unit was measured with a vibration analyzer. This provided the data for the total failure condition.
2. A new unit identical to the returned unit was assembled.
3. The new unit was measured with the vibration analyzer to record a baseline.
4. The new unit's eccentric bearing was exchanged for the returned unit's worn eccentric bearing, and the vibrations of the new unit were measured. This provided data for the failure mode of eccentric bearing damage.
5. Keeping the worn eccentric bearing in the new unit, the unit's cycloidal discs were exchanged for the returned unit's discs. The vibrations of the new unit having the worn eccentric bearing and cycloidal discs were measured to obtain data showing the next stage of wear.

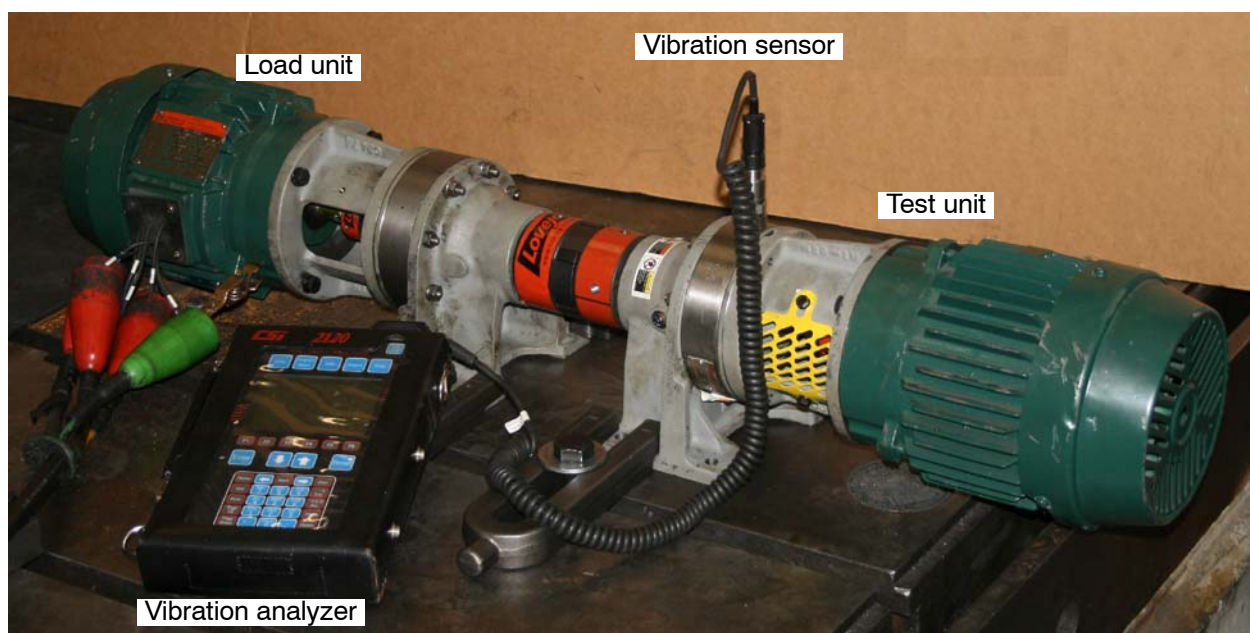


Figure 5. Vibration measurement set-up

6. With the worn eccentric bearing and discs in the new unit, the returned unit's ring gear assembly was installed, see figure 6. The new unit's vibrations were measured to obtain data showing the final level of progressive cycloidal failure – eccentric bearing failure combined with disc and ring gear assembly damage.

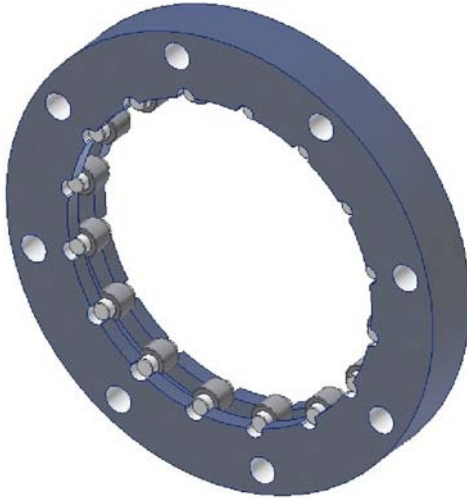


Figure 6. Cycloidal ring gear assembly

7. The new eccentric bearing and ring gear assembly were returned to the new unit. With the worn cycloidal discs still in the new unit, the new unit's vibrations were measured to obtain data showing how cycloidal disc wear contributes to the vibration graph.
8. The cycloidal discs and ring gear assemblies were exchanged between the units, so that the new unit had the new eccentric bearing, the new cycloidal discs, and the worn ring gear assembly. The new unit was measured to obtain data showing how ring gear assembly wear contributes to the vibration graph.

The load and test units were identical, and the input motors operated at a 1750 rpm input speed. A CSI (Computational Systems Incorporated) 2120 single channel machinery analyzer, model A212001, was used to measure the test unit's vibration. The analyzer's parameters were established as shown in figure 7.

The vibration measurements were documented using CSI's MasterTrend RBMWare version 4.60, dated September 4, 2001.

VIEW PERIODIC ANALYSIS PARAMETER SET INFORMATION	
Set 1	Number of Parameters - 6
FFT: 0.0 - 1000.0 Hz	
LOW FREQUENCY CUT-OFF: 2.0 Hz	
LINES/AVERAGES	: 1600/6
AVERAGING MODE	: Normal
WINDOW TYPE	: Hanning
SPECTRAL WEIGHTING	: None
THIRD-OCTAVE ANALYSIS:	No
SST CONTROL	: No
PRE-CONDITIONING UNIT	: Disabled
FILTER SETTING	: None
PEAK ANALYSIS METHOD:	None
SPECIAL TIME WAVEFORM:	No
FMAX	: 10.50 Hz
DATA UNITS	: Default
NUMBER OF POINTS	: 1024
TRIGGER	: None

Figure 7. Vibration analyzer measurement parameters

Results

It's important to note that the cycloidal operating frequencies a customer will see on a vibration graph will depend on a unit's size and speed reduction ratio. The graphs shown in figures 8 – 19 and 25 – 48 are specific to the units we tested. The operating frequencies we measured are not applicable to all cycloidal reducers.

Figures 8 – 13 show the vibration graphs a customer

might see if the customer were to measure a worn cycloidal reducer. Figure 6 reveals some activity.

An evaluation of the vibrations in more detail, however, reveals areas of concern. In figure 10 we see the acceleration frequencies. The presence of peaks at the higher frequencies indicates there may be roller bearing problems. Sidebands accompanying these peaks are another indication. At this point, the operating frequencies of the eccentric bearing should be examined.

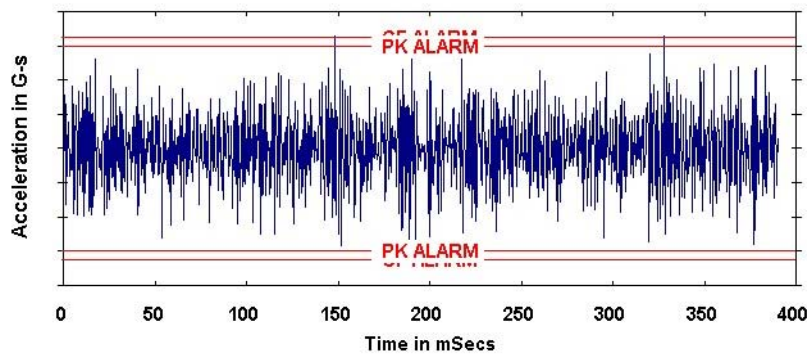


Figure 8. Waveform - returned unit

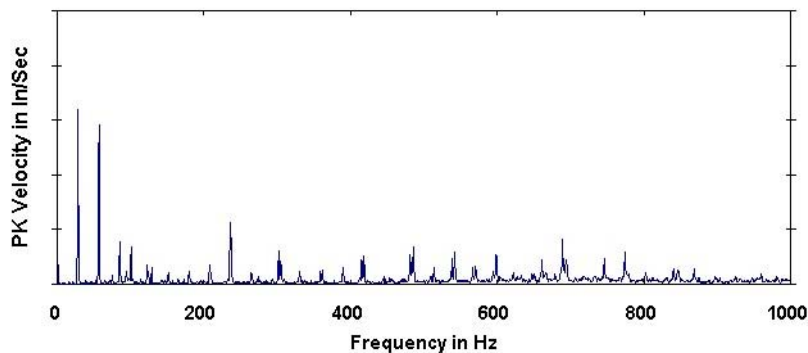


Figure 9. Velocity frequency graph - returned unit

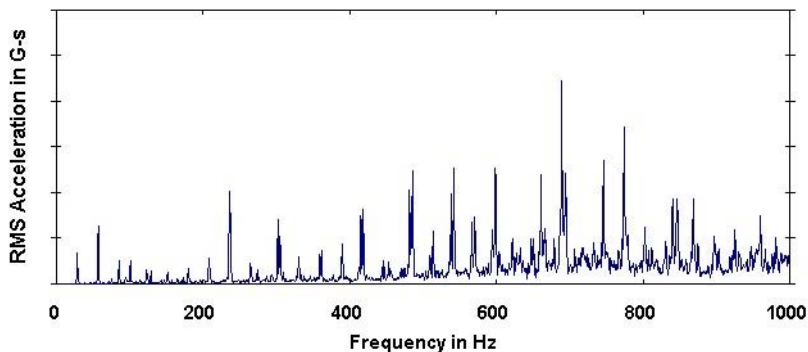


Figure 10. Acceleration frequency graph - returned unit

The velocity frequencies were accessed with the vibration analysis software and the cursor was placed around 29 Hz, the eccentric bearing cam frequency. Figure 11 shows the result. The peak velocity occurs at that frequency, and its second harmonic is not much less.

The cursor was next placed around 11.20 Hz, the eccentric bearing's FTF, to check for eccentric bearing roller faults. Many harmonics were discovered, with the higher ones having sidebands. See figure 12 below.

Finally, the cycloidal disc mesh frequency of 14.75 Hz was checked. Figure 13 shows that harmonics are present, but their velocity levels are low.

If this unit were located in a noisy environment, it would be difficult to hear its operation. Such an environment would make a baseline reference more valuable. The customer in this case did not detect the progression of wear, so the unit wasn't returned until it failed catastrophically after three months. Let's examine how a baseline measurement would have been useful.

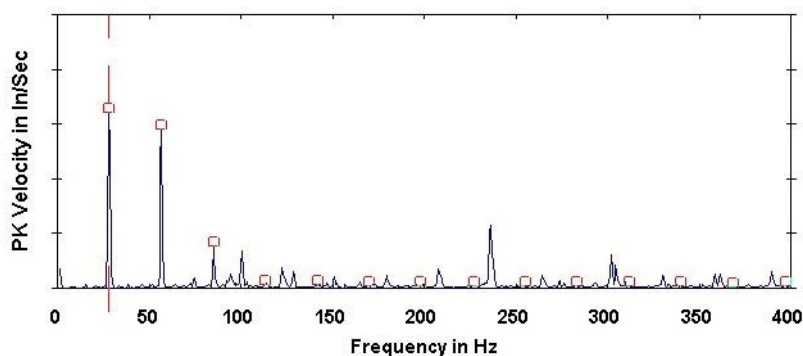


Figure 11. Eccentric bearing cam frequency graph - returned unit

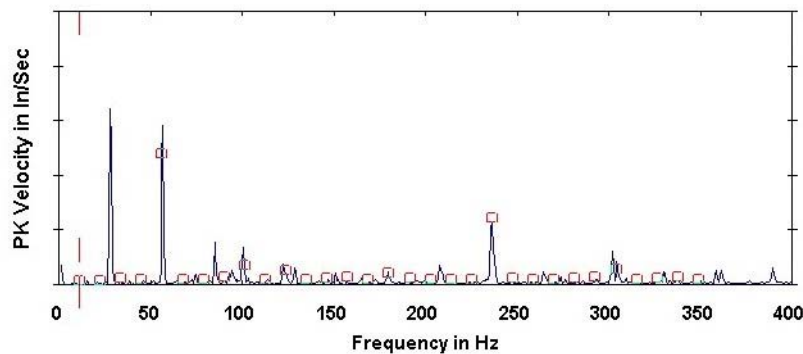


Figure 12. Eccentric bearing rollers frequency graph - returned unit

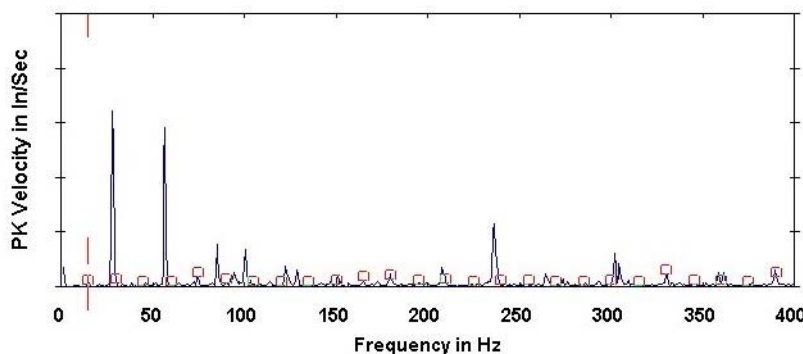


Figure 13. Cycloidal disc mesh frequency graph - returned unit