107 Holm Crescent, Thornhill, Ontario, Canada (www.predictiveonline.com) 10 Netiv Hacarmel, Nesher, Israel

PredictiveOnLine™ Cloud Monitoring System

PHASE ANGLE DIAGNOSTICS OF ROTATING EQUIPMENT

Table of Contents

GENERAL

A key element of PSE's flagship *PredictiveOnLine* system is its proprietary method of motor current analysis that detects mechanical failures in machines driven by induction motors and generators. It's based on the on-line detection of the *phase angle* of the induction machine which is proportional to motor torque and a proprietary algorithm for phase Angle analysis.

Analyzing the phase angle—rather than current—avoids the influence of a non-stable power voltage or frequency that usually makes it difficult to detect minor disturbances in motor current signatures.

The Phase Angle readings reflect the small mechanical disturbances or fluctuations in a machine driven by an induction motor. This uncomplicated and inexpensive method of evaluating motor torque allows recognizing incipient failures on a wide range of equipment such as pumps, compressors, mixers, etc.

Phase Angle Diagnostics uses an induction motor as a diagnostic tool for predicting/recognizing failures not only in the induction motor itself, but also in the rotating equipment driven by that motor. It monitors operation of the induction motor and compares characteristics of the motor in operation with base line characteristics determined in advance. Variations of the motor's characteristics from the known base line indicate an actual or approaching failure.

PHASE ANGLE DIAGNOSTICS BACKGROUND

The Phase Angle in the induction motor or generator means a value of delay of a Current Sine from a Voltage sign. This delay is illustrated by segment A-B, Figure 1.

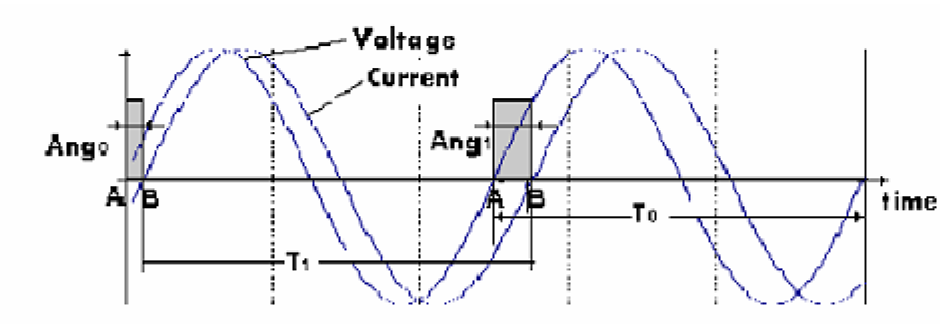

Figure 1

Phase angle signals are proportional to values of electrical motor torque.

The torque could be considered as a sum of two components: a mean value which is proportional to the load and another one caused by the mechanical events in the machine driven by an electrical motor, friction losses in bearings, load fluctuations, events in the motor itself, etc. These fluctuations are relatively small but could be recognized by a signal processing such as Spectral Analysis and other.

An example of Phase Angle spectra is shown on the Figure 2, which

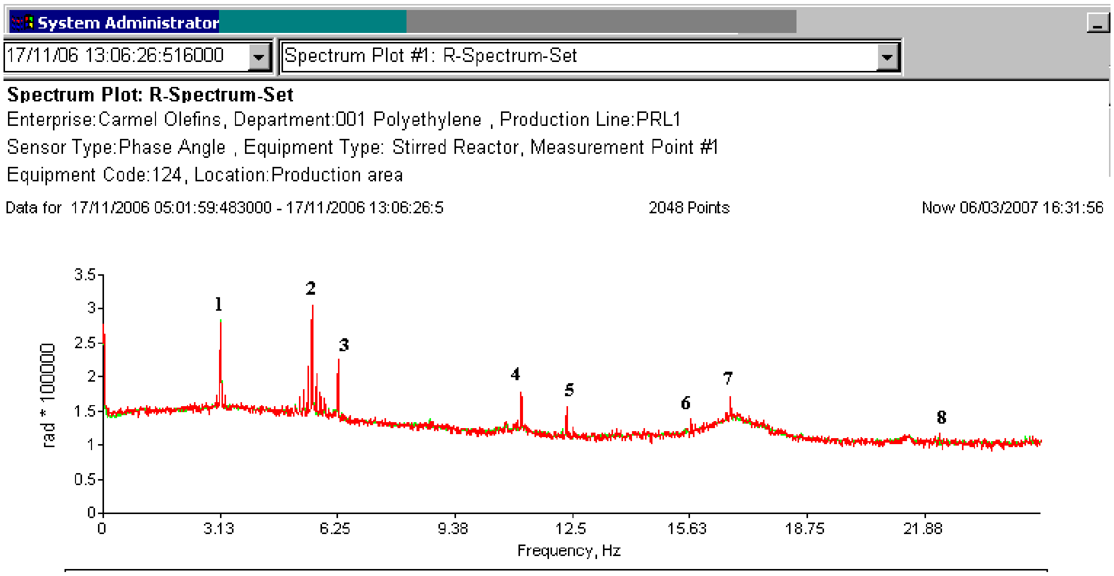

Figure 2

illustrates the Phase Angle Spectrum obtained on the Stirred Reactor from Polyethylene production line.

The spectrum peaks on the spectrum, Figure 2, relate to different parameters of stirred reactor.

Peak 1, (3.13 Hz) – is associated with motor slip x 8. The stirred reactor motor has 8 poles (4 pole pairs)

Peak 3 – (6.26 Hz) is a second harmonics of peak 1.

Peak 6 - (15.56 Hz) is associated with the fifth harmonics of peak 1.

Peak 2 – (5.56 Hz) is associated with a mean bearing separator frequency. It has to be mentioned that separator frequency of all stirrer bearings have close value and cannot be analyzed separately.

Peak 4 – (11.13 Hz) is a second harmonics of peak 2.

Peak 5 – (12.2 Hz) is associated with the stirrer shaft frequency

Peak 7 (16.7) is associated with the stirrer natural frequencies.

Phase Angle diagnostics deals with small deformations of spectra. It is done by a special technology that eliminates the linear dependencies between various condition indicators and introduces weighting factors for relatively small but diagnostically important indicators listed above.

MECHANICAL FAILURES DETECTED

Phase Angle diagnostics reveals mechanical failures in the rotating equipment.

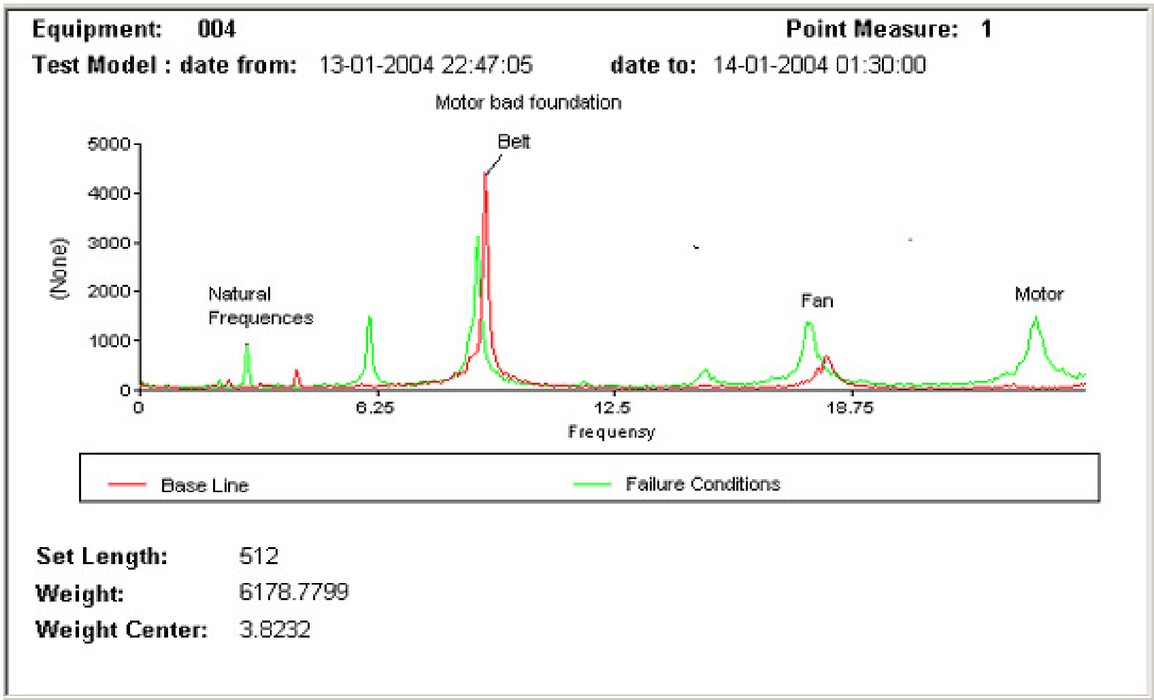

Figure 3

Figure 3 illustrates a Phase Angle spectrum of a fan motor with loose foundation.

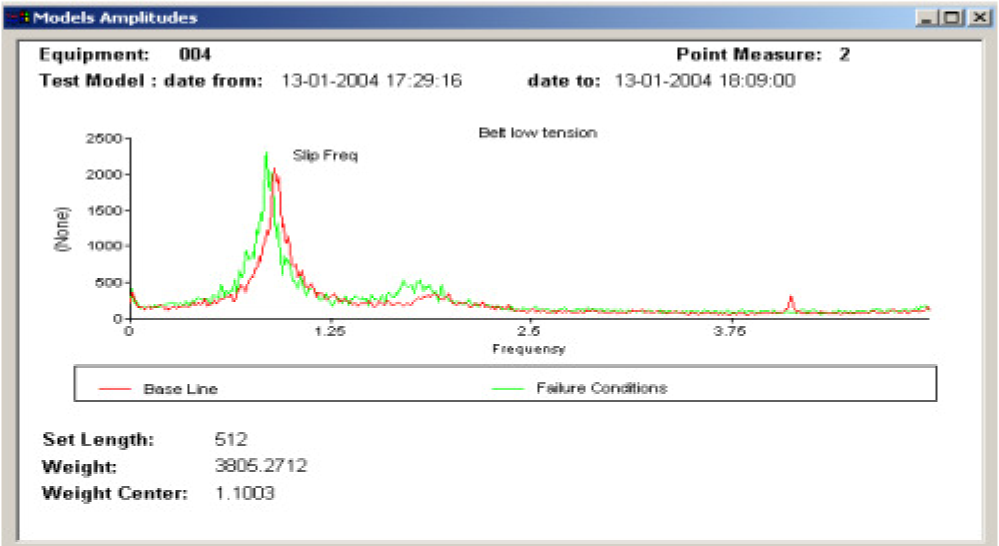

Figure 4

Figure 4 shows a spectrum of a motor phase angle with low belt tension.

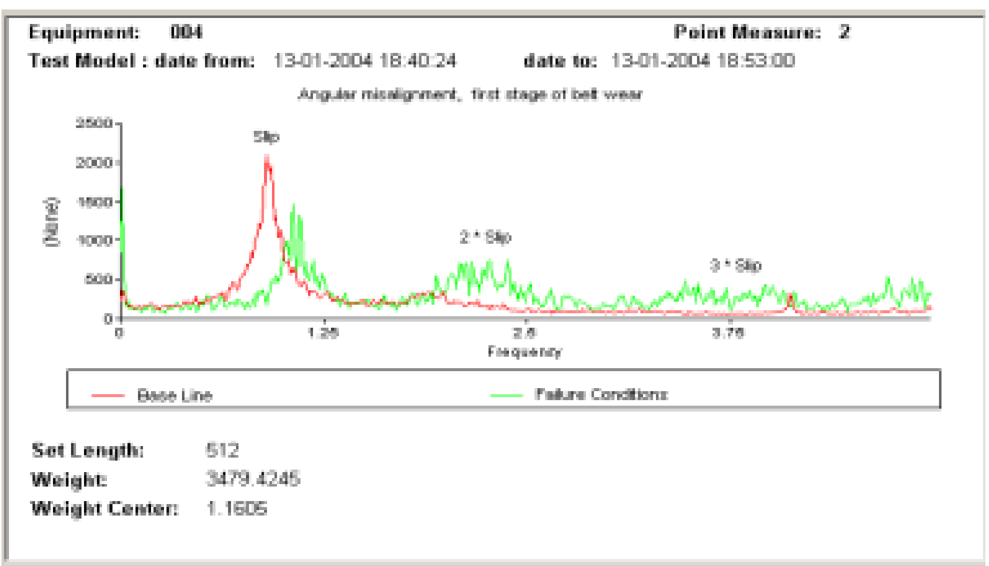

Figure 5

Figure 5 illustrates the influence of angular misalignment, etc.

The phase angle spectra are not the only machine health signature used by Phase Angle Diagnostics.

PHASE ANGLE FRACTAL A USEFUL DIAGNOSTIC SIGNATURE.

Motor torque changes in course of shaft revolution. The analysis of these changes is helpful for diagnostics of electromechanical and mechanical failures in the rotating equipment. It could be done by building of Phase Angle Fractal that is the polar diagrams of motor torque as a function of rotor angle position. It is an accumulated diagrams obtained in the course of a number of shaft revolutions. The form of a fractal signals machine health conditions. The fractal shown on the Figure 6 relates to a machine normal performance.

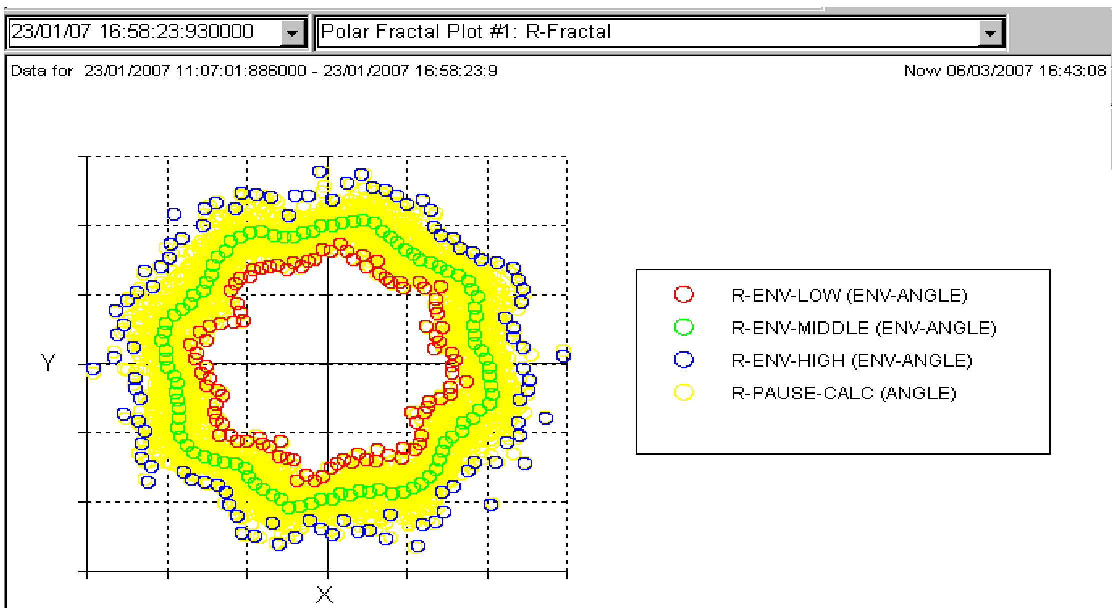

Figure 6.

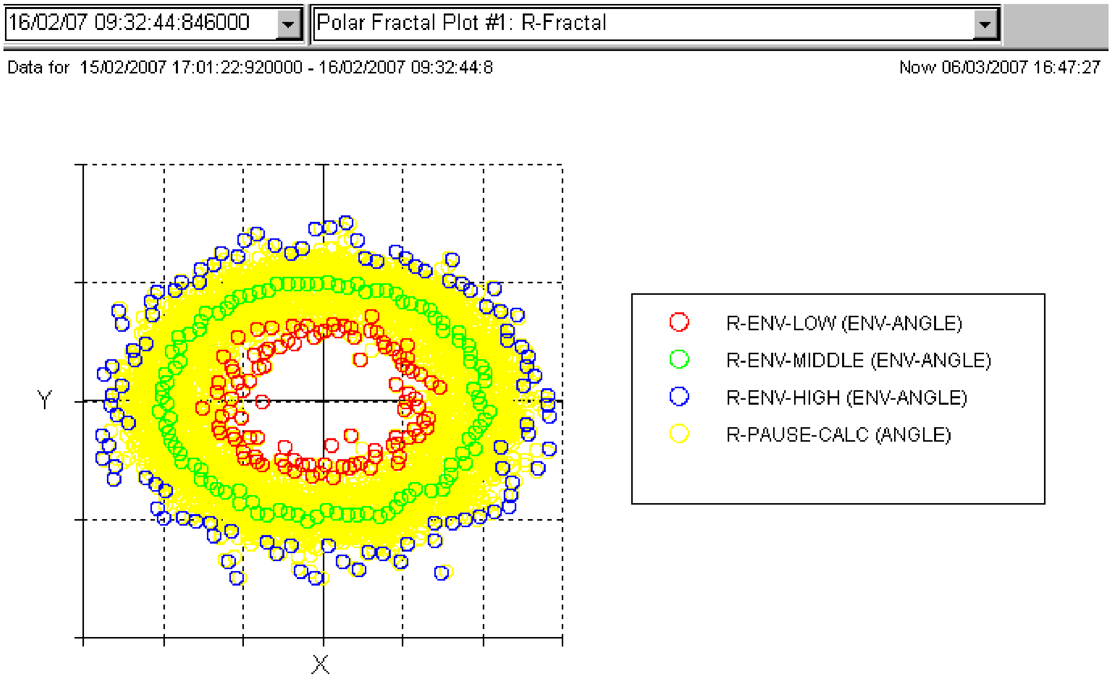

Figure 7

The fractal on the Figure 7 has an elliptical form. This form is associated with some initial abnormality in the bearing of stirred reactor.

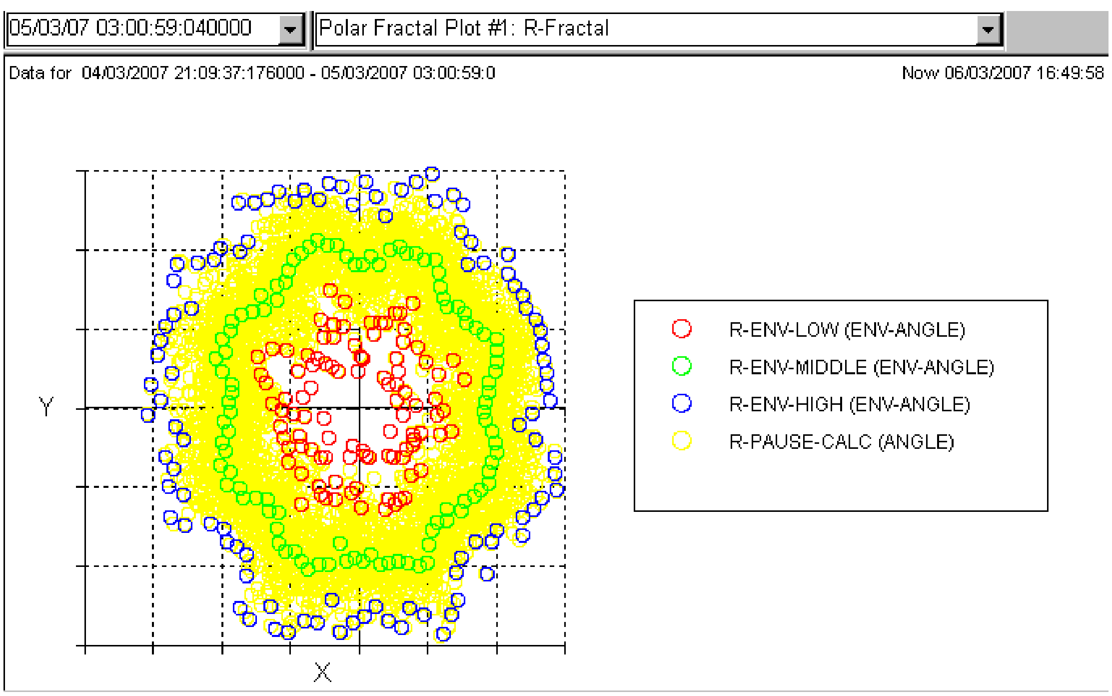

Figure 8

Figure 8 that was registered very close to stirrer outage shows the unstable movement of the shaft inside bearings disclosed by an increased value of fractal dispersion. Other examples of usefulness of fractals for failure detection is shown on the Figures 9,10,11 obtained on an industrial centrifuged fan.

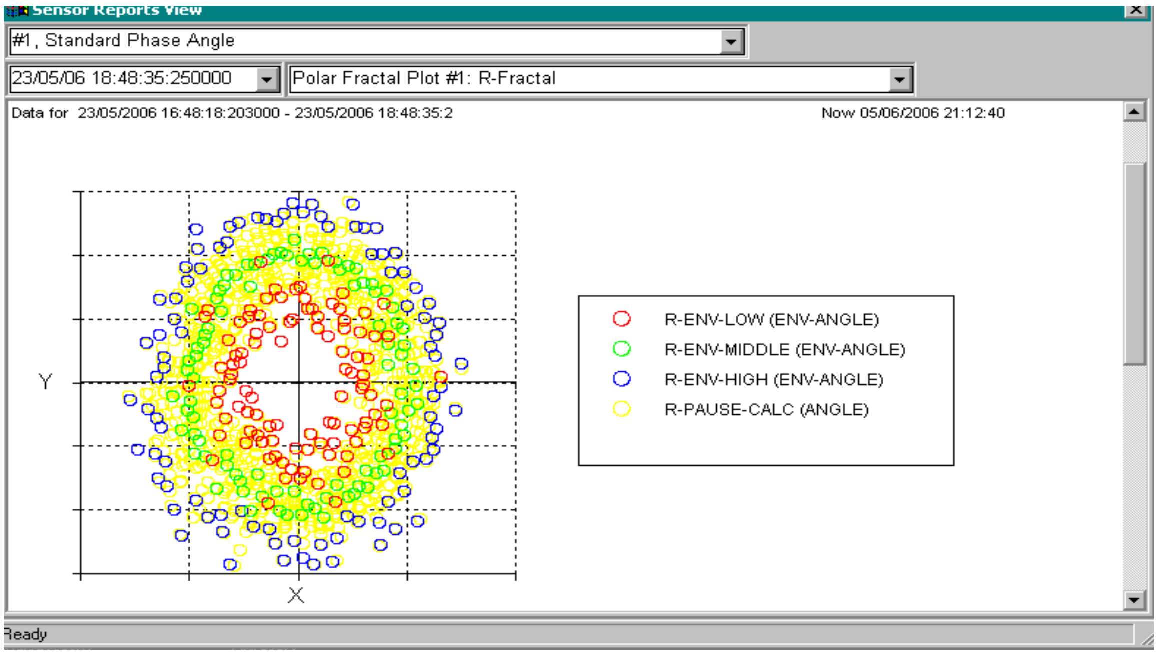

Figure 9.

The disruption of the fan journal bearings was associated with growing of fractal asymmetry.

Figure 10 shows the trend of the fractal diameters ratio in course of bearing disruption.

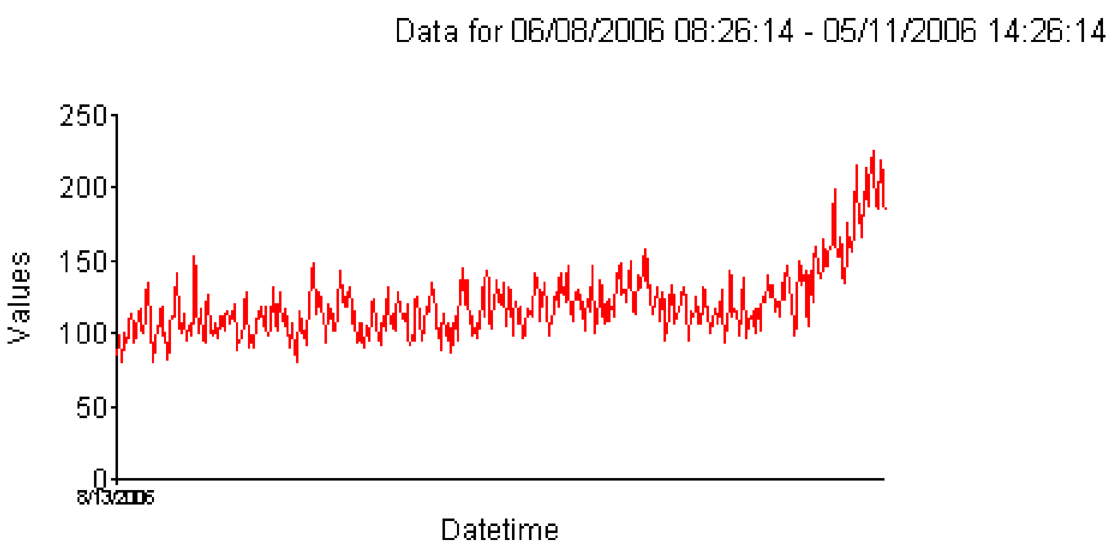

Figure 10.

SIGNATURE STABILITY

The phase angle signals typically are very stable. Figure 11 and 12 show the results of two checking machine condition by Phase diagnostics. The time interval between first check – green line and a second check – red line is about 4 years. Both of checks were executed after periodical maintenance. The spectra were identical. A smaller peak on the red plot related to the latest check is explained by machine improvement.

Spectrum Plot: R-Spectrum-Set
Enterprise:Mitsui Chemical Engineering Co., Ltd, Department:001 Iwakuni - Ohtake, Production Line:1P
Sensor Type:Phase Angle , Equipment Type:001003 Agitator-J303-B, Measurement Point #1
Equipment Code:J-303B, Location:1Room1

Data for 10/10/10 17:36:28.266 - 11/10/10 05:36:45.030
Now 17/10/10 02:13:43

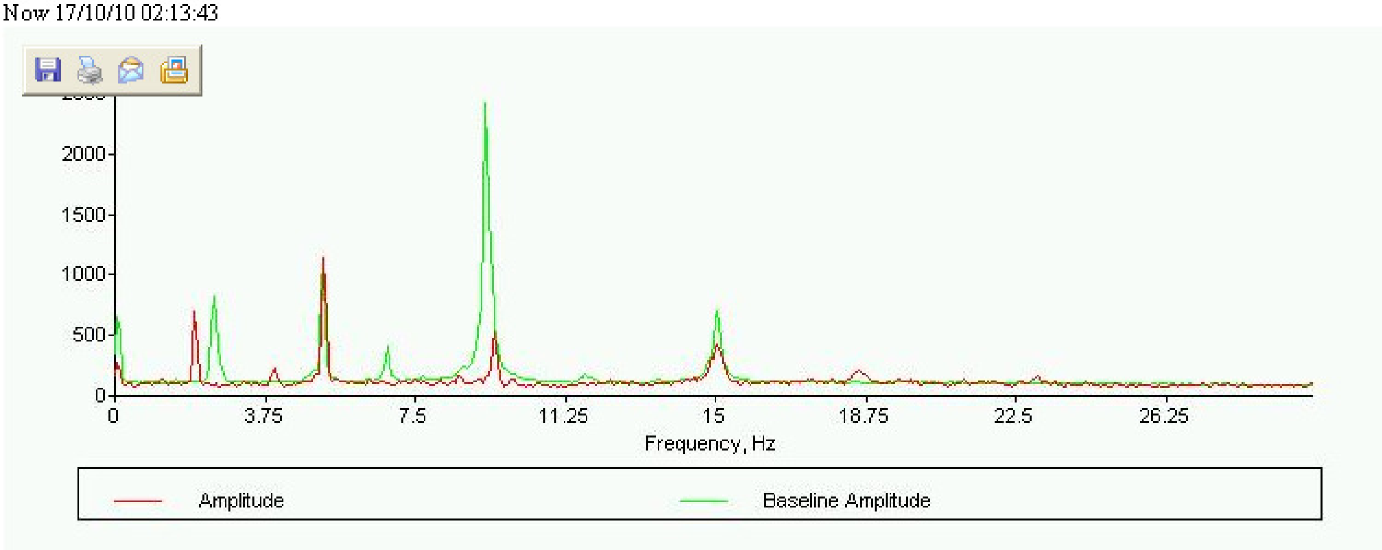

Figure 11

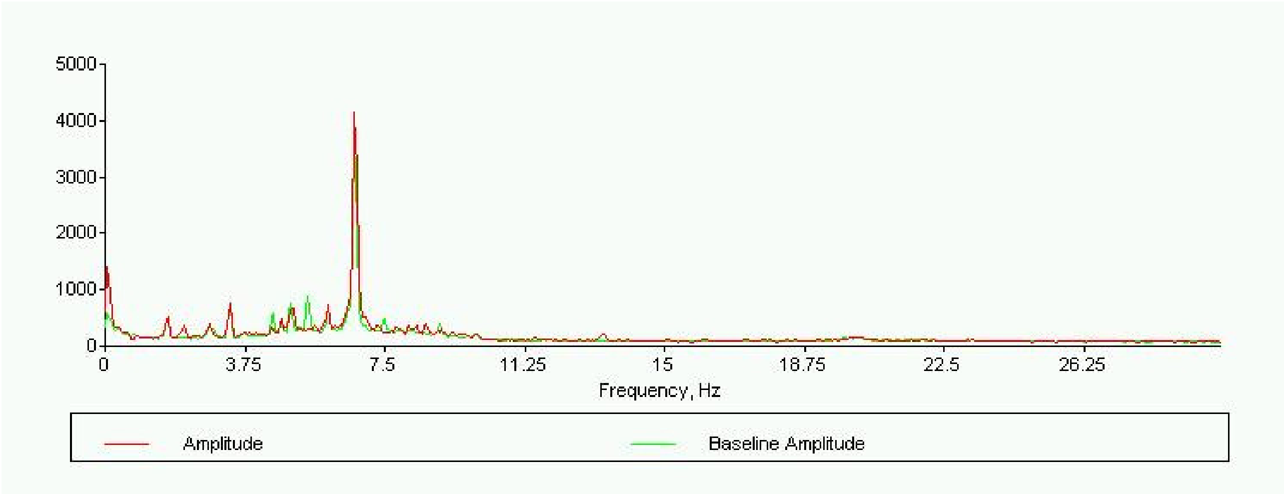

Figure 12, Pre crystallizer.

The stability of Phase Angle signals depends on the kind of machinery.

Sometimes Phase Angle signals have spikes. It happens when the machine conditions are unstable. Such spikes are typical, for example, for a stirred reactor at polyethylene production line.

This machine operates without steady liquid lubrication. The lubrication is provided by drops of lubricant contained in the flow of ethylene entering the reactor.

The quantity of lubricant is not sufficient for regular lubrication of the upper bearings.

Sometimes it causes disorders in the bearing performance but after time the stirrer returns to normal operation.

Figure 13 illustrates the trend of a diagnostics parameter referred to as a Failure Factor. It is an aggregated parameter computed from the peak amplitudes of phase angle spectra, fractal symmetry value, fractal dispersion, etc.

Phase Angle Diagnostics Technology operates with a number of failure factors related to different failures.

The increasing of value of a Failure Factor signals an abnormality in a machine component associated with this factor. The trend on the Figure 13 had spikes twice during a one month period. After this, the stirrer came back to normal operation.

Trend Plot: Failure Factor 3
Enterprise:Carmel Olefins, Department:001 Polyethylene Plant, Production Line:PRL1
Equipment Type: Stirred Reactor
Equipment Code:124, Location:Production area

Data for 24/12/11 01:47:42.793 - 23/01/12 01:47:42.793
Now 23/01/12 02:05:15

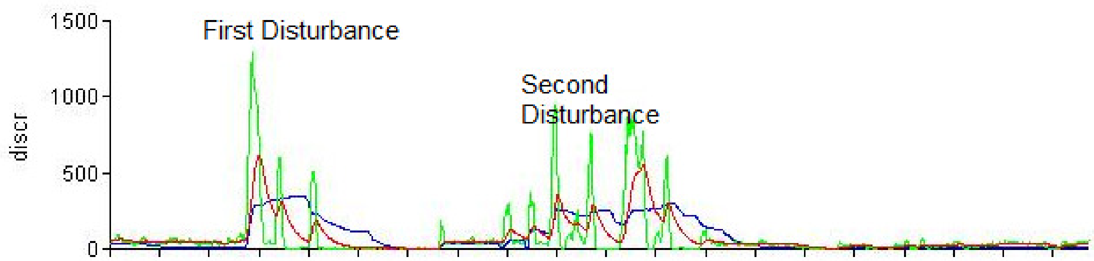

Figure 13

PHASE ANGLE DIAGNOSTICS SENSITIVITY

Phase angle diagnostics is quite sensitive. Mitsui Chemical, Iwakuni, Japan, had performed a testing of the sensitivity of continuous monitoring by the Phase Angle Technology comparing the Vibration inspections provided every four hours.

The test had shown that Phase Angle Diagnostics reveals fan misbalance much earlier than vibration measurements.