Using Operating Deflection Shapes to Detect Faults in Rotating Equipment: Three Case Studies

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ABSTRACT

In this paper, we present three case studies of the use of operational deflection shapes (ODS's) of a rotating machine as a means of detecting shaft misalignment and unbalance in its rotating components. Our purpose is to show that a significant change in the ODS can be used as an early warning indicator of mechanical faults in rotating machines.

INTRODUCTION

Unscheduled maintenance of rotating machinery in a process plant can account for a significant percentage of the plant's downtime. Not only is equipment downtime expensive because of lost production revenue, but most machine faults will result in increased costs of replacement parts, inventory, and energy consumption.

Traditionally, *vibration signatures* (level profiling of single-point vibration spectra), and time domain based *orbit plots* have been the preferred tools for *detecting and diagnosing* machine faults. Although these tools may be effective when used by an expert, ODS comparison offers a simpler, more straightforward approach for fault detection. Many machine faults are more easily characterized by a visual as well as a numerical comparison of a machine's ODS when compared with its Baseline ODS.

Case #1: Shaft Misalignment

Tests were performed on a machinery fault simulator under various degrees of shaft misalignment. Since misalignment produces dominant motion at the machine running speed, this data is used to construct and compare ODS's.

Case #2: Unbalance

Tests were performed on a machinery fault simulator under various conditions of unbalance. It is shown that unbalance also produces a change in the ODS at the rotor running speed and its harmonics. ODS data was extracted from frequency domain functions which were calculated from acquired acceleration data.

Case #3: Using Proximity Probes

In this study, vibration data was simultaneously acquired from accelerometers and proximity probes on a rotating machine. Both misalignment and unbalance cases were simulated, and ODS data was extracted from frequency domain functions of the acceleration and displacement responses of the machine.

Two different numerical measures were used to quantify changes in the ODS of the machine. These changes can be used in an automated warning level (alert, alarm, and abort) detection scheme to give early warnings of machine faults. The results of this work provide a new method for detecting machinery faults, and offer a simplified approach for on-line health monitoring of rotating equipment.

What is an ODS?

An ODS is the ***deflection of two or more points on a machine or structure***. Stated differently, an ODS is the deflection of one point relative to all others. Deflection is a vector quantity, meaning that it has both *location & direction* associated with it. Deflection measured at a point in a specific direction is called a DOF (Degree of Freedom).

An ODS can be calculated from vibration data, either at a moment in time, or at a specific frequency. Different types of *frequency domain functions (*Linear spectra (FFTs), Auto & Cross spectra, Frequency Response Functions, Transmissibility's, or ODS FRFs [4]), can be used to define an ODS.

Measuring an ODS

In general, an ODS is defined with a *magnitude & phase* value for each DOF that is measured on a machine or structure. This requires that either all response DOFs be acquired simultaneously, or that they are acquired under conditions which guarantee their correct magnitude & phase relative to all other DOFs. Simultaneous measurement requires a multi-channel acquisition system that can synchronously acquire all responses. Sequential acquisition requires that cross-channel measurements be calculated between a (fixed) *reference* response and all other *roving* responses. This ensures that each DOF of the resulting ODS has the *correct magnitude & phase relative to all other DOFs*.

Baseline ODS versus Current ODS

The hypothesis of this fault detection method is the following;

Machine Fault Hypothesis: *When a rotating machine encounters a mechanical fault, its ODS will change.*

Mechanical faults will cause a change in the vibration levels in many parts of a rotating machine. Therefore, an important question is; "*What constitutes a significant change in vibration level*?" This will be answered by calculating a change in the ODS of the machine. In order to measure a change, the current ODS of a machine during operation is compared with its ODS when it is operating properly, called the Baseline ODS.

Numerical Comparison of ODS's

Two different numerical methods are used to compare two ODS's from before a machine fault (Baseline ODS) and after a fault (Fault ODS). One method is called the SCC (Shape Correlation Coefficient), and the other is the SPD (Shape Percent Difference). Both of these calculations yield a percentage value. The SCC measures the ***co-linearity*** of the two ODS vectors, and the SPD is the ***difference*** between the two ODS vectors as a percentage of the Baseline ODS.

SCC (Shape Correlation Coefficient)

An ODS is a *complex* vector with two or more *complex* components, each component having a *magnitude & phase*. Each component of the ODS is obtained from a vibration signal measured at a single DOF on the machine. The SCC calculation measures the similarity between two complex vectors. When this coefficient is used to compare two mode shapes, it is called a MAC (Modal Assurance Criterion) [3]. The SCC is defined as;

$$\mathrm{SCC} = \frac{\left\| \mathrm{ODS_F} \circ \mathrm{ODS_B^*} \right\|}{\left\| \mathrm{ODS_F} \right\| \left\| \mathrm{ODS_B} \right\|}$$

where: $\mathrm{ODS_B} = \text{Baseline ODS}$

$\mathrm{ODS_F} = \text{Fault ODS}$

$\mathrm{ODS_B^*} =$ complex conjugate of $\mathrm{ODS_B}$

$\| \ \|$ indicates the magnitude squared

$\circ$ indicates the DOT product between two vectors

The SCC is a *normalized DOT product* between two complex ODS vectors. It has values between 0 and 1. A value of 1 indicates that the two vectors are the same. As a "*rule of thumb*", an SCC value greater than 0.90 indicates a small change in the ODS. *A value less than 0.90 indicates a substantial change in the ODS.*

The SCC provides a single numerical measure of a change in the ODS of an operating machine. The ODS can have as many DOFs as are necessary for detecting machine faults. Many DOFs may be required in order to detect certain kinds of faults. The location and direction of the sensors will vary from machine to machine.

One difficulty with the SCC is that it only measures a difference in the "shape" of two vectors. In other words, two vectors can be *co-linear*, meaning that they lie along the same line, but they can still have different magnitudes. If the vibration levels increase in a machine but the "shape" of the ODS does not change, the SCC will still have a value of "1", indicating no change.

SPD (Shape Percent Difference)

A different measure of change in an ODS is the SPD (Shape Percent Difference). The SPD measures both a change in level and in shape. The SPD measures the percentage change in the Fault ODS relative to the Baseline ODS. A value of 0 is no change, and a value of 1 is a 100% change from the Baseline ODS.

$$\mathrm{SPD} = \frac{\left| \mathrm{ODS_F} - \mathrm{ODS_B} \right|}{\left| \mathrm{ODS_B} \right|}$$

where: $| \ |$ indicates the magnitude of the vector

If $\left|\mathrm{ODS}_F\right| < \left|\mathrm{ODS}_B\right|$ then the SPD is negative

To summarize, when a machine is operating properly, the *SCC will be at or near 1*, and the *SPD will be at or near 0*. As a fault condition begins to occur, the *SCC will decrease toward 0*, and the *SPD* will *increase* or *decrease* depending on the change in machine vibration levels.

CASE #1: SHAFT MISALIGNMENT

A survey of the literature [1], [2] reveals that:

- Misalignment produces significant changes in vibration levels.
- A machine can have parallel misalignment without exhibiting significant 2X vibration levels.
- Misalignment is strongly influenced by machine speed and coupling stiffness.
- Softer couplings are more forgiving, and tend to produce less vibration.
- Level profiling of a single-point vibration spectrum for a given operating condition does not provide a reliable indication of shaft misalignment.

Data Acquisition

To verify our fault hypothesis, tests were performed using the machinery fault simulator. Accelerometers were attached to the top of both bearing housings, the motor, and the base plate of the machine, as shown in Figure 1. The baseline ODS was measured using a 16 channel analyzer, which simultaneously acquired a tachometer signal on channel 1, and 15 accelerometer signals on the remaining channels. Data was taken in two different acquisitions (or measurement sets), providing ODS's with a total of 29 DOFs in them. Figure 2 shows where data was acquired for 14 DOFs of the motor and bearing housings. The remaining 15 DOFs were measured at 5 locations on the base plate using tri-axial accelerometers.

Data was acquired at two different operating speeds; 2000 and 4000 RPM. Time domain accelerometer data were synchronously acquired on 29 channels at a sampling rate of 5120 Hz over a 25.6 second time period, providing 131,071 samples of per channel. This data was then transformed into its Fourier (Linear) spectrum using an FFT for each channel.

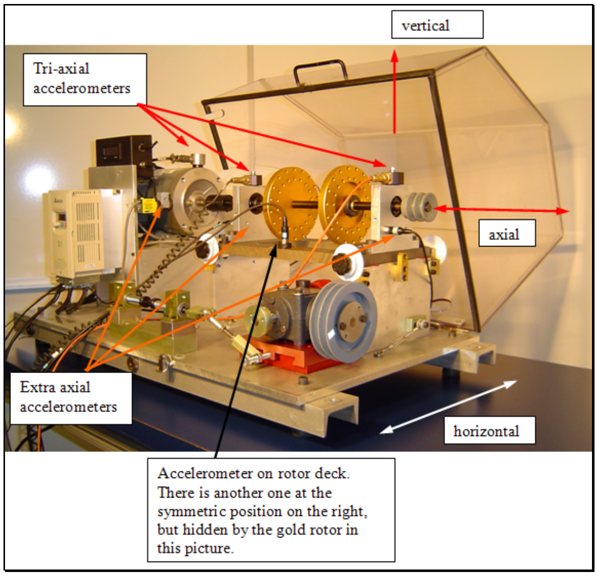


Figure 1. Simulator Showing Accelerometers on Motor & Bearings.

Comparing Baseline ODS's

Table 1 shows the SCC values between the 2000 & 4000 RPM baseline ODS's. In this case, *the ODS is the peak values of the Fourier spectra of the machine accelerations at running speed.* Table 1 breaks down the ODS's further by comparing their SCC values on the base plate, the motor & bearings, and all 29 DOFs.

DOFs	**SCC**
Base Plate	**0.22**
Motor & Bearings	**0.03**
All DOFs	**0.02**

Table 1. Baseline SCC values - 2000 & 4000 RPM.

These very low SCC values confirm that a *machine's ODS will change significantly with operating speed*, even when it is properly aligned. This speed dependency of the ODS also means that ODS data must be acquired at *approximately the same machine speed* as the baseline ODS in order to detect a change in the ODS due to a machine fault.

Parallel Misalignment

Figure 2 depicts both the parallel and angular misalignment that were simulated with the machine fault simulator. To simulate a parallel misalignment of the rotor shaft with the motor shaft, the center of the rotor shaft was offset from the motor shaft by 25 mils at both bearing blocks, as depicted in Figure 4b.

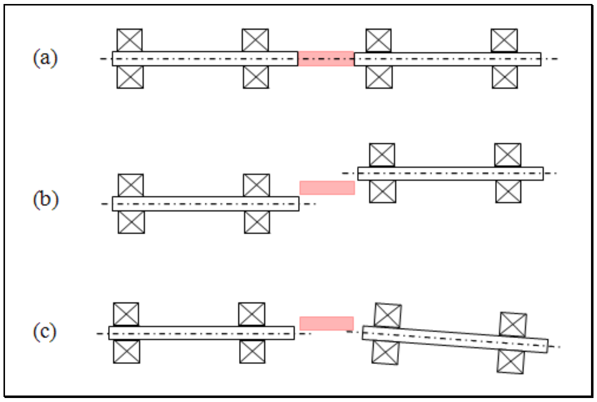


Figure 2. Parallel (b) & Angular (c) Misalignment.

RPM	DOFs	SCC
2000	Base Plate	0.99
2000	Motor & Bearings	0.00
2000	All DOFs	0.51
4000	Base Plate	0.84
4000	Motor & Bearings	0.94
4000	All DOFs	0.83

Table 2. SCC Values for Parallel Misalignment.

Table 2 shows the SCC values between the baseline ODS with the misalignment ODS at 2000 RPM. The SSC value for all DOFs (**0.51**) ***strongly indicates parallel misalignment***. Notice also that the base plate ODS has *not changed* (**0.99**), whereas the motor & bearing ODS has *changed significantly* (**0.00**) due to the shaft misalignment.

The results for parallel misalignment at 4000 RPM are also shown in Table 2. *These SCC values reveal a different dynamic behavior than at 2000 RPM, however*. At 4000 RPM, the shaft & motor ODS has *not changed* (**0.94**), but the base plate ODS has *changed significantly* (**0.84**). Perhaps resonances of the base plate are being excited at this operating speed. Nevertheless, the overall ODS has also *changed significantly* (**0.83**) to indicate the parallel misalignment problem.

Angular Misalignment

To simulate an angular misalignment of the rotor shaft with the motor shaft, the inboard and outboard bearings were offset by 6.2 mils and 26 mils respectively to obtain about 0.1 degrees of rotor shaft misalignment, as depicted in Figure 4c. Figure 6 shows a comparison of the baseline ODS with the fault ODS following an angular misalignment. Again, a low SCC value (**0.69**) ***strongly indicates angular misalignment*** at 2000 RPM.

RPM	DOFs	SCC
2000	Base Plate	0.95
2000	Motor & Bearings	0.29
2000	All DOFs	0.69
4000	Base Plate	0.77
4000	Motor & Bearings	0.89
4000	All DOFs	0.85

Table 3. SCC Values for Angular Misalignment.

The breakdown of SCC values in Table 3 again shows that the base plate ODS has *not changed* (**0.95**), while the motor & bearing ODS has *changed significantly* (**0.29**). The results for angular misalignment at 4000 RPM are also shown in Table 3. At 4000 RPM, the shaft & motor ODS has *changed* (**0.89**) less than the base plate ODS (**0.77**), but the overall ODS has *changed significantly* (**0.85**) to indicate the angular misalignment problem.

CASE #2: UNBALANCE

Vibration data was acquired from a machine simulator when it was considered to be in balance (the baseline condition), and under seven different unbalance conditions. Unbalance was created by adding weights to either or both of the rotors on the simulator, as indicated in Figure 2. Data was acquired for each of the following unbalance conditions;

1. Small unbalance (11.25 grams) - Inboard rotor
2. Small unbalance - Outboard rotor
3. Large unbalance (22.5 grams) - Inboard rotor
4. Large unbalance - Outboard rotor
5. Two large unbalances - 0 degrees apart
6. Two large unbalances - 90 degrees apart
7. Two large unbalances - 180 degrees apart

ODSFRFs

To calculate ODS's, first a set of ODSFRFs was calculated between each of the channels of data and a single reference channel. An ODSFRF is a *"hybrid"* cross-channel measurement, involving both an Auto spectrum and a Cross spectrum. It is formed by *adding the phase* of the Cross spectrum between a roving and a reference (fixed) accelerometer signal to the Auto spectrum of the roving response signal. The magnitude of an ODSFRF is a true measure of the structural response at its roving DOF. A typical ODSFRF from the simulator is shown in Figure 3. It is clear that the ODSFRF contains peaks at the machine running speed (first order) and its higher orders (multiples of the running speed). The ODS was obtained by saving the *peak cursor values* at the running speed, or one of its orders, as shown in Figure 3.

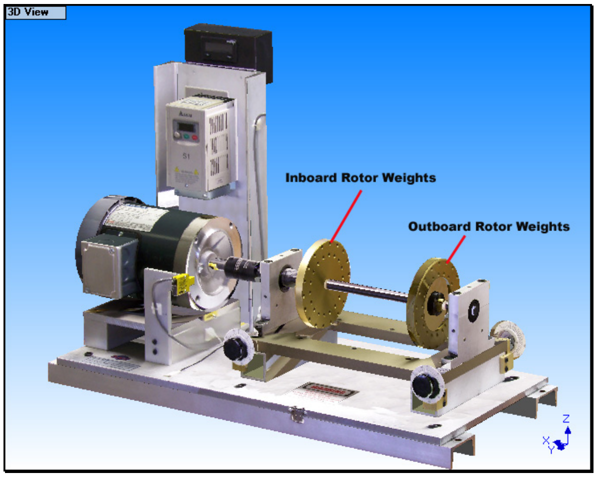


Figure 2. Unbalance Weights Attached to Rotors

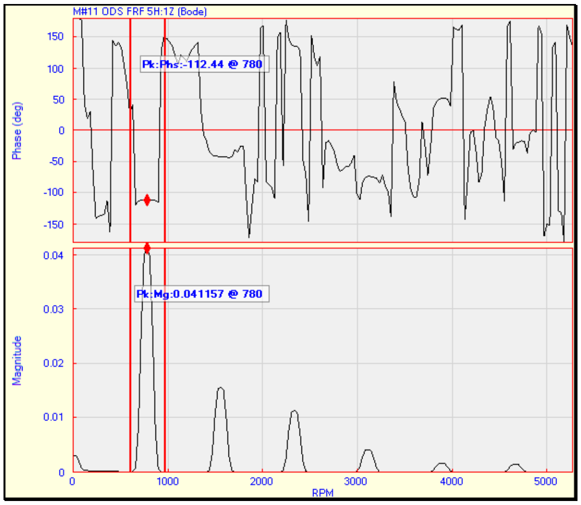
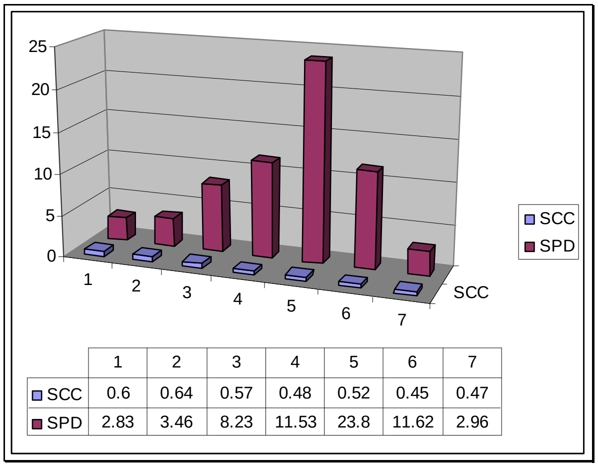


Figure 3 ODSFRF Showing Peaks at Machine Orders



	1	2	3	4	5	6	7
■ SCC	0.6	0.64	0.57	0.48	0.52	0.45	0.47
■ SPD	2.83	3.46	8.23	11.53	23.8	11.62	2.96

Figure 4. First Order (2000 RPM) ODS Comparisons

An ODS is a collection of peak values from a set of ODSFRFs at one of the orders of the machine.

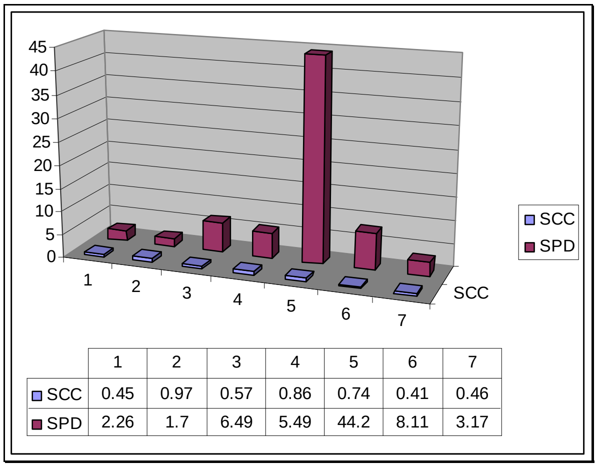
Figure 4 contains the SCC and SPD values for the ODS's created from peak values at the running speed or first order (2000 RPM) of the machine. Both the SCC and SPD *strongly indicate* the unbalance condition for all seven cases. However, the SPD also indicates the vibration level or severity of the fault. Cases 1 through 4 indicate an increasing level of vibration from the inboard to outboard rotor, and also from the use of the smaller to the larger unbalance weight.

Cases 5, 6, & 7 show how the vibration level is affected by the locations of the weights on the two rotors. Case 5 gave the highest SPD value because the two large unbalance weights were aligned with one another on both rotors, thus providing the maximum amount of unbalance. The SPD values also show that case 7, with the two large unbalance weights 180 degrees apart, created about the same change in the vibration level as case 2, with the single small weight attached to the inboard rotor.

Figure 5 contains the SCC and SPD values for the ODS's at the second order (4000 RPM). The second order ODS comparisons give the same results as the first order comparisons. Figure 6 contains the SCC and SPD values for the ODS's at the third order (6000 RPM). One incorrect result appears in these results. The SCC value of **0.97** indicates a ***balanced condition*** for Case 2. However, the SPD results are similar to those from the first and second order comparisons, but don't quantify the severity of the unbalance conditions as well as the first and second order comparisons.

Figure 5 contains the SCC and SPD values for the ODS's at the second order (4000 RPM). The second order ODS comparisons give the same results as the first order comparisons.

Figure 6 contains the SCC and SPD values for the ODS's at the third order (6000 RPM). One incorrect result appears in these results. The SCC value of **0.97** indicates a ***balanced condition*** for Case 2. However, the SPD results are similar to those from the first and second order comparisons, but don't quantify the severity of the unbalance conditions as well as the first and second order comparisons.



	1	2	3	4	5	6	7
SCC	0.45	0.97	0.57	0.86	0.74	0.41	0.46
SPD	2.26	1.7	6.49	5.49	44.2	8.11	3.17

Figure 6. Third Order (6000 RPM) ODS Comparisons

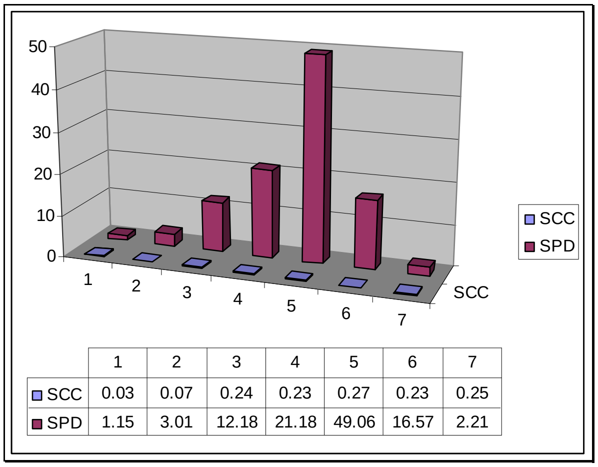
CASE #3: USING PROXIMITY PROBES

To further verify our hypothesis, tests were performed using the machinery fault simulator shown in Figure 11. Accelerometers and proximity probes were used to measure the vibration. The accelerometers provided 7 signals and the proximity probes provided 6 signals. These 13 channels of vibration data were synchronously acquired with a multi-channel data acquisition system.

Time domain records were acquired at a sample rate of 5000Hz for a total of 15.565 seconds, providing 77824 samples of data for each channel. This data was post-processed, and ODSFRFs were calculated between all channels and a single reference channel.

Comparing Baseline ODS's

First, Baseline ODS's from four different operating speeds were compared to quantify their differences. Baseline ODSs were compared in the following cases;



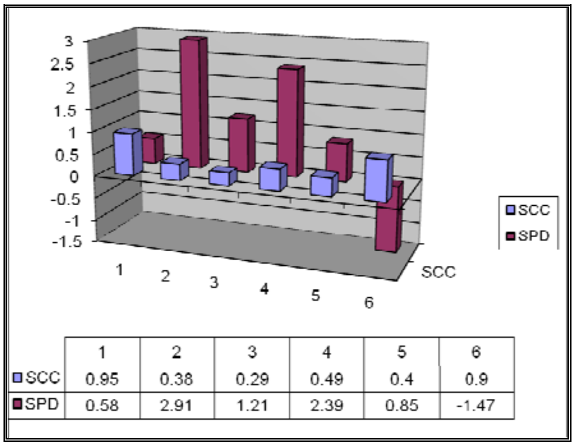
	1	2	3	4	5	6	7
SCC	0.03	0.07	0.24	0.23	0.27	0.23	0.25
SPD	1.15	3.01	12.18	21.18	49.06	16.57	2.21

Figure 5. Second Order (4000 RPM) ODS Comparison

Case 1: 800 versus 1000 RPM
Case 2: 800 versus 2000 RPM
Case 3: 800 versus 3000 RPM
Case 4: 1000 versus 2000 RPM
Case 5: 1000 versus 3000 RPM
Case 6: 2000 versus 3000 RPM

Both the SCC and SPD values for these 6 cases are shown in Figure 7. For Case 1, the SCC value (0.95) indicates that the Baseline ODS at 800 RPM is essentially the same as at 1000 RPM. However, the SPD indicates that the vibration level has grown by 58% from 800 to 1000 RPM.

Cases 2, 3, and 4 indicate the greatest changes in the ODS between two different operating speeds. The *first critical speed* of the machine shaft is **1590 RPM**, so large changes in the ODS are expected near this speed. In Case 6, the SCC value (0.90) indicates that the ODS's are *co-linear* (similar in shape), but the SPD value (-1.47) indicates that the ODS has *decreased* in magnitude from 2000 to 3000 RPM. This *decrease* in vibration level occurred because at 3000 RPM, the machine is operating beyond its critical operating speed.



	1	2	3	4	5	6
SCC	0.95	0.38	0.29	0.49	0.4	0.9
SPD	0.58	2.91	1.21	2.39	0.85	-1.47

Figure 7. Baseline ODS Comparisons

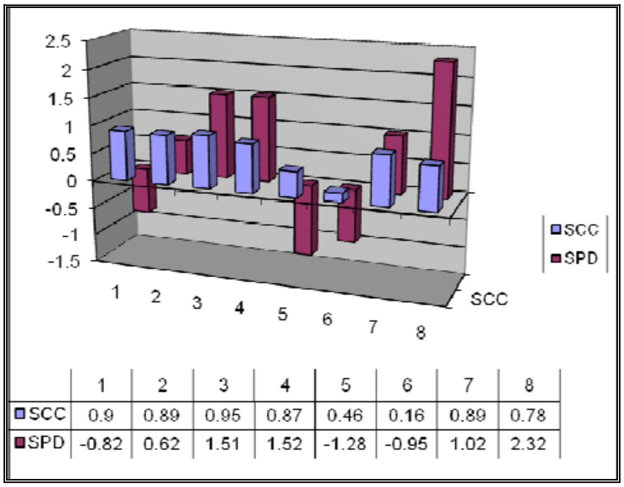
Unbalance Faults

Two unbalance faults were simulated in the rotating machine simulator by adding unbalance screws to the (gold) rotors on the shaft. Fault 1 was created by adding an unbalance weight of 4 grams to the inboard rotor, and fault 2 by adding an unbalance weight of 4 grams to each of the rotors. ODS data was obtained for the following 8 cases.

Case 1: Fault 1 (One 4 gram unbalance) at 800 RPM
Case 2: Fault 1 at 1000 RPM
Case 3: Fault 1 at 2000 RPM
Case 4: Fault 1 at 3000 RPM

Case 5: Fault 2 (Two 4 gram unbalances) at 800 RPM
Case 6: Fault 2 at 1000 RPM
Case 7: Fault 2 at 2000 RPM
Case 8: Fault 2 at 3000 RPM

The SCC and SPD values for these 8 cases are plotted in Figure 8. In each case the Baseline ODS for a different machine speed is compared with the Fault ODS at the same speed. The values in Figure 6 clearly indicate that Fault 1 is less severe than Fault 2. The SCC is on the borderline of no change in the ODS for Cases 1 to 4, but indicates a significant change for Cases 5 to 8. The SPD indicates a significant change in all cases, with the smallest change being 62% difference in the ODS for Case 2.



	1	2	3	4	5	6	7	8
SCC	0.9	0.89	0.95	0.87	0.46	0.16	0.89	0.78
SPD	-0.82	0.62	1.51	1.52	-1.28	-0.95	1.02	2.32

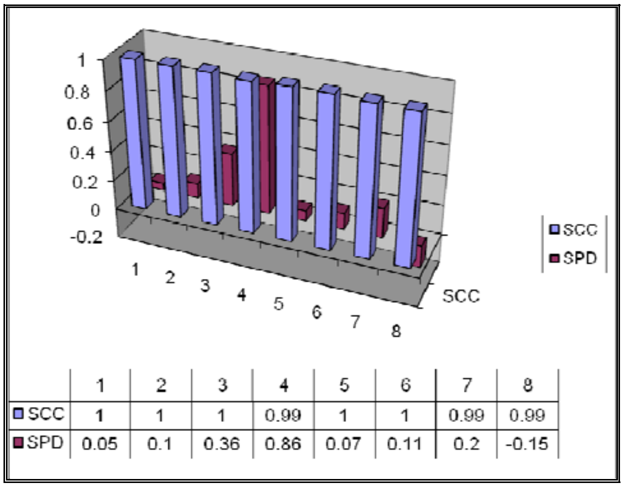
Figure 8. Unbalance ODS Comparisons

Angular Misalignment Faults

Two angular misalignment faults were simulated in the rotating machine simulator by turning screws at the base of each shaft bearing block to misalign it with the motor shaft. Fault 3 was created by adding 10 mils of misalignment to the outboard bearing block. Fault 4 was created by adding 20 mils of misalignment to the outboard bearing block. ODS data was obtained for the following 8 cases.

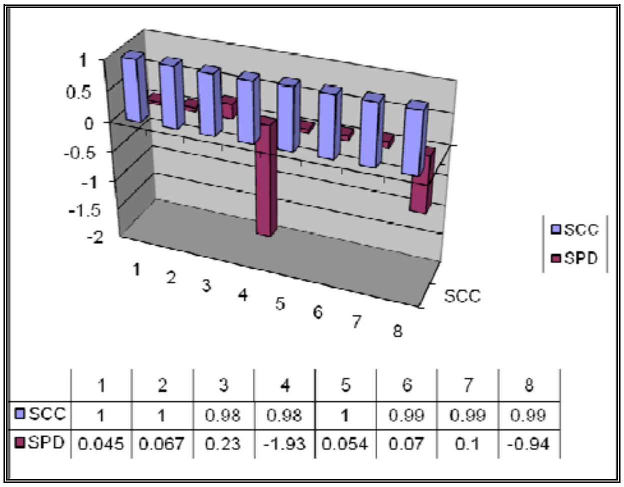
Case 1: Fault 3 (10 mil angular misalign) at 800 RPM
Case 2: Fault 3 at 1000 RPM
Case 3: Fault 3 at 2000 RPM
Case 4: Fault 3 at 3000 RPM
Case 5: Fault 4 (20 mil angular misalign) at 800 RPM
Case 6: Fault 4 at 1000 RPM
Case 7: Fault 4 at 2000 RPM
Case 8: Fault 4 at 3000 RPM

The SCC and SPD values for the 8 angular misalignment cases are plotted in Figure 9. The values in Figure 9 give a mixed result. The SCC is nearly 1.0 in all cases, meaning that the Baseline and Fault ODS were *co-linear* at all speeds. However, the SPD indicates a change of the ODS in all cases, and its magnitude increased with machine speed, except for the last case. In Case 8, the SPD magnitude was slightly less than the magnitude for Case 7, but still indicated a 15% change in the ODS.



	1	2	3	4	5	6	7	8
SCC	1	1	1	0.99	1	1	0.99	0.99
SPD	0.05	0.1	0.36	0.86	0.07	0.11	0.2	-0.15

Figure 9. Angular Misalignment ODS Comparisons



	1	2	3	4	5	6	7	8
SCC	1	1	0.98	0.98	1	0.99	0.99	0.99
SPD	0.045	0.067	0.23	-1.93	0.054	0.07	0.1	-0.94

Figure 10. Parallel Misalignment ODS Comparisons

Parallel Misalignment Faults

Two parallel misalignment faults were simulated in the rotating machine simulator. Fault 5 was created by adding **10 mils** of misalignment to both bearing blocks. Fault 6 was created by adding **20 mils** of misalignment to both bearing blocks. ODS data was obtained for the following 8 cases.

Case 1: Fault 5 (10 mil parallel misalign) at 800 RPM
Case 2: Fault 5 at 1000 RPM
Case 3: Fault 5 at 2000 RPM
Case 4: Fault 5 at 3000 RPM

Case 5: Fault 6 (20 mil parallel misalign) at 800 RPM
Case 6: Fault 6 at 1000 RPM
Case 7: Fault 6 at 2000 RPM
Case 8: Fault 6 at 3000 RPM

The SCC and SPD values for the 8 parallel misalignment cases are plotted in Figure 10. These values also give a mixed result. The SCC is close to 1.0 for all cases, meaning that the Baseline ODS and Fault ODS are *co-linear* at all speeds. On the other hand, the SPD indicates a change of the ODS in all cases, and the magnitude of the SPD increased with increased machine speed in all cases.

CONCLUSIONS

Three case studies were performed to validate the correlation between a machine fault and changes in its ODS. Multiple unbalance and misalignment cases were investigated. Both accelerometers and proximity probes were used to measure the simulator's vibration.

Two different numerical measures of the difference between the Baseline and Fault ODS were used; the SCC (Shape Correlation Coefficient) and SPD (Shape Percent Difference). The SCC indicates whether or not the two shapes are *co-linear*. The SPD measures the percent *difference* between the two ODS's, hence it also measures the *severity* of the machine fault.

Case#1: Shaft Misalignment

In this study, accelerometer data from 14 DOFs on the motor & bearings and 15 DOFs on the base plate was used to detect machine faults. ODS's were constructed using the peak data values of the Fourier spectra of the accelerometer signals, for operating speeds of 2000 & 4000 RPM. Comparisons of baseline ODS's with the ODS's after induced misalignment showed a *significant change in the ODS in all cases.* These results prove that shaft misalignment in a rotating machine is clearly indicated by changes in its ODS at operating speed.

The results also showed that the sensitivity of the ODS change depends on the *locations & directions* of the accelerometers used to measure the ODS. A*ccelerometer signals taken only from the base plate did not indicate misalignment at 2000 RPM*. Conversely, *accelerometer signals taken only from the motor & bearings did not indicate misalignment at 4000 RPM.* These results clearly showed that the placement and use of a sufficient number of transducers on a machine is critical for detecting misalignment from changes in its ODS.

Case#2: Unbalance

In this study, seven different cases of unbalance were simulated using a rotating machine fault simulator. Accelerometer data from 9 DOFs on the motor & bearings and 5 DOFs on the base plate was acquired using a 16 channel data acquisition system, with the machine running at 2000 RPM. ODS's were constructed using the peak values from sets of ODSFRF functions at the first, second, and third order frequencies.

Comparisons between baseline (balanced) ODS's and the ODS's of seven different unbalance cases were compared. These results strongly confirmed our machine fault hypothesis; namely, ***"When an operating machine becomes unbalanced, its ODS will change"***.

Case #3: Using Proximity Probes

In case studies #1 & #2, only accelerometer data was used to sense machine vibrations. In this case, proximity probes, which measured the displacement of the shaft relative to its bearing housings, were also used. Three different types of common machinery faults were simulated; unbalance, angular misalignment, and parallel misalignment. A total of 24 different fault cases were evaluated.

Seven DOFs of vibration data were acquired from the motor & bearings using accelerometers, and 6 DOFs were acquired from the shaft bearings using proximity probes. These 13 channels of acquired data were post-processed, and a set of ODSFRFs was calculated for each fault condition. ODS's were then created by using the peak values at the first order (running speed) of the machine from each set of ODSFRF functions.

Operating data was acquired at 4 different operating speeds, 800, 1000, 2000 & 3000 RPM. The first critical speed of the machine was at 1590 RPM. By comparing Baseline (no fault) ODS's for the different operating speeds, it was clear that the ODS's for speeds below the critical speed were quite different from the ODS's above the operating speed. This is expected whenever a resonance is excited.

In all cases, the SPD indicated a *"significant"* change in the ODS when faults were introduced. The high values of the SPD shown in most cases indicated that it has a strong sensitivity to changes in the ODS. Therefore, the SPD could be used to detect lesser changes in machine responses, providing early detection of impending fault conditions.

Other machine faults such as bearing oil whirl, loose connections, gear tooth faults, soft foot (improper foundation) might also be detected by ODS comparisons. In addition to vibration data, an *"operating shape"* could also contain other data such as temperatures, pressures, voltages, currents, and flow rates. These parameters could also be correlated with certain kinds of machine faults. The simplicity of this approach to machinery fault detection makes it a strong candidate for implementation in an online machine health monitoring system.

The machinery fault simulator used to obtain these results is a product of Spectra Quest, Inc. The ODS analysis software is part of a MechaniCom Machine Surveillance System™, a product of Vibrant Technology, Inc.

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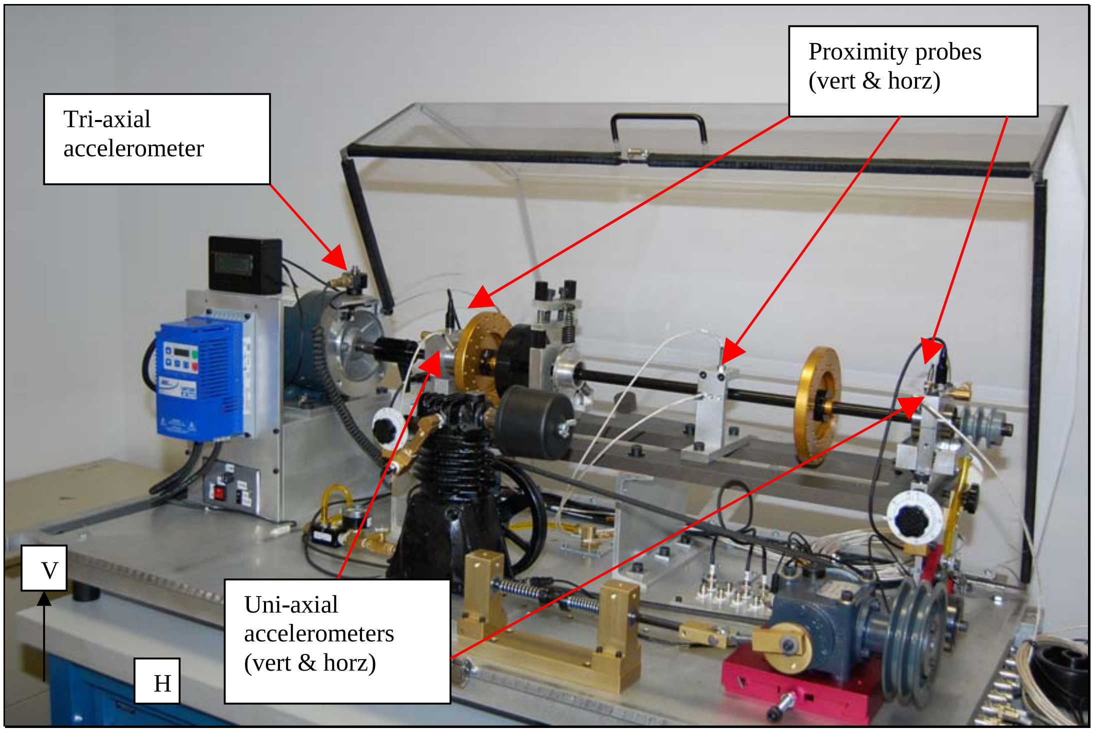

Figure 11. Case Study #3 Sensor Locations