Managing Machinery Assets Using Predictive Maintenance

Written By

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Introduction

Abstract: Much of the content, case histories, and figures for this paper were supplied by the author's colleagues at the Vibration Institute and for that I am appreciative. The paper also encompasses the author's 40 plus years of experience in vibration analysis, condition monitoring, and personal experience in what makes programs successful or fail. This paper is intended as an overview for managers and supervisors that would like to know more about the benefits, cost, and commitments required for starting a predictive maintenance program; how to determine if such a program will benefit their company; and if so, how to get started.

Vibration Institute: The Vibration Institute is a not-for-profit professional organization that is "Dedicated to the dissemination of practical information on evaluating machinery behavior". It provides training and certification in the field of vibration analysis and condition monitoring of rotating machinery and works with both ANSI and ISO committees in the development of pertinent standards in these areas.

Introduction: Today's literature is littered with information on Reliability Methods such as Predictive, Preventive, Proactive Maintenance, Condition Monitoring, Asset Management and Reliability Centered Maintenance and it is often difficult to distinguish where one ends and the other begins as it relates to machinery health and availability. As it turns out, this author believes they have a lot of overlap. In the end, they all imply doing what is necessary to ensure that a machine keeps on working, adequately performing its intended function, and without experiencing unexpected downtime or catastrophic failure.

This paper is broken into four (4) parts.

Part 1: Avoiding Disaster

Part 2: Predictive Maintenance Systems

Part 3: Skill Required

Part 4: Justification and Benefits

Part 1: Avoiding Disaster

Disaster: On August 1, 2007 disaster struck the 8-lane, I-35W Bridge over the Mississippi River in Minneapolis when it collapsed during the evening rush hour killing 13 people and injuring 145, Figure 1. We all know that disaster can strike at any time, without warning, and have terrible consequences. The purpose of this paper is to show that in many cases, particularly on rotating machinery, monitoring systems can be put in place to avoid unexpected failure and disaster.

Figure 1: Photo of Minnesota bridge collapse [2]

Investigation by the NTSB and others determined that the collapse was caused by undersized gusset plates that were inadequate to support the intended load of the bridge.[1] An obvious question to ask is could this disaster have been avoided if the bridge had been instrumented with a monitoring system? That is a question to be answered by structural and civil engineers, but most likely, no one can say for sure. However, in order to monitor the bridge or any other structure or machine, the appropriate parameter or parameters must be identified and monitored properly if faults are to be detected prior to a failure. The trick is to choose a parameter that provides reliable health information on the machine or structure, to monitor it regularly, and then to act upon a warning. This paper discusses how to do this on rotating machinery.

Monitor The Right Parameter: It was stated above that it is possible that the bridge collapse or many other failures could be detected if the proper parameter can be identified and monitored on a regular basis. That is not necessarily as easy as it sounds. This example illustrates how the parameter selected matters in detecting a fault.

Consider the case of a typical centrifugal pump with a faulted rolling element bearing. Figure 2 shows three overall vibration trend plots of data collected with the IMI Echo® Wireless Vibration Monitoring System that only collects overall data. It should be noted that all three trend plots were generated from data collected with the same sensor, mounted at the same location on the pump. The data were processed differently to show the different measured parameters.

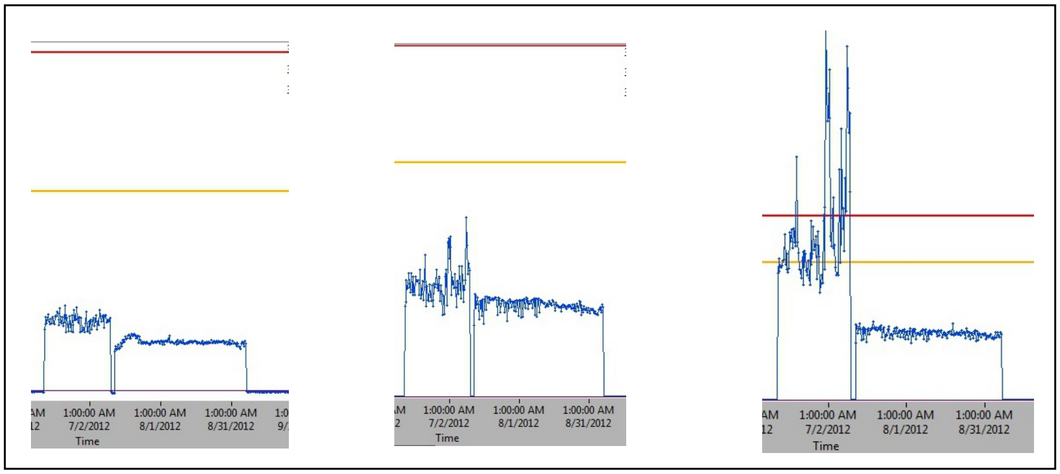


Figure 2: Velocity, acceleration, and true peak acceleration plots of a faulted bearing collected with the Echo® Wireless Vibration System.

The overall vibration trend plots in Figure 2 that include warning and critical alarm levels are, in order, rms velocity, rms acceleration, and a high pass filtered true peak acceleration. It is clearly seen that true peak acceleration is the parameter that is most sensitive to the bearing fault. If this measurement had not been monitored, it is not clear that the fault would have been caught in time. Some predictive maintenance programs use velocity trends as their primary indicator of a developing fault. With today's fast and capable systems, there is no reason not to monitor and trend all pertinent parameters.

Monitoring Techniques and Asset Management: While there are many valuable and viable techniques for monitoring the condition of rotating machinery and rolling element bearings, such as Thermography, Oil Analysis, Ultrasonic Analysis, and Acoustic Emission Monitoring, this paper is focused on monitoring Vibration as a measure of machinery condition. Thus, Assets (machinery) will be managed using Predictive Maintenance of which Condition Monitoring is a key factor. This becomes an input that drives Reliability Centered Maintenance since maintenance actions, in part, are dictated by the results of the Predictive Maintenance program.

There are many aspects to Predictive Maintenance and Asset Management of production equipment. Some are relatively easy to implement and some extremely difficult. *Basic Predictive Maintenance programs can be put into place with relatively little experience* while robust programs require dedicated and highly trained individuals. While the benefits to any well run program will generally more than offset the cost of such a program, it can be a daunting task for management to approve one considering the startup costs, training requirements, commitment of personnel, non-familiarity with the science, and not knowing where to start.

This paper will attempt to answer the questions: why do it, what does it cost, how much training and commitment is required to achieve success, and how does one get started?

Why Monitor Equipment: Consider a critical overhead crane in a metal processing plant whose operation is required to produce over $1 MM worth of product a day. Consider also that when the crane is down, much of the lost production cannot be made up. How much is it worth to the company to monitor the crane so it can be taken down for maintenance at a convenient time when both parts and personnel are available for a quick fix, rather than have a catastrophic failure that will probably cause additional damage to the machine resulting in it being down for several days and costing more in repairs, personnel time, and downtime?

Figure 3 is a simple trend plot, collected using the EchoPlus® Wireless Junction Box mounted on the crane, showing that the overall vibration (rms velocity) increased from around 1 ips (inch per second) to about 3 or 4 ips. When the unit was inspected, the brake/clutch assembly was clearly about to fail and maintenance crews were able to make necessary repairs in just a few hours. In this case, the use of simple overall level monitoring was sufficient to catch this fault, avoid a potentially dangerous catastrophic failure, and save hundreds of thousands of dollars, perhaps millions, in lost production. Are they all this easy to catch? Of course not, but with simple monitoring and trending, you'll catch many faults, which is better than catching none!

Note: The data in the trend plot is somewhat erratic because it was collected with the Echo® Wireless Vibration System that transmits measurements on a pre-programmed time interval. Thus, low levels readings are received when the crane is not operating and higher levels when it is. Even with this limitation, it was clear that the vibration had gotten much worse. Note: The Echo® System can now be used with the EchoPlus® Remote Trigger option to collect data on demand, which works well for overhead cranes.

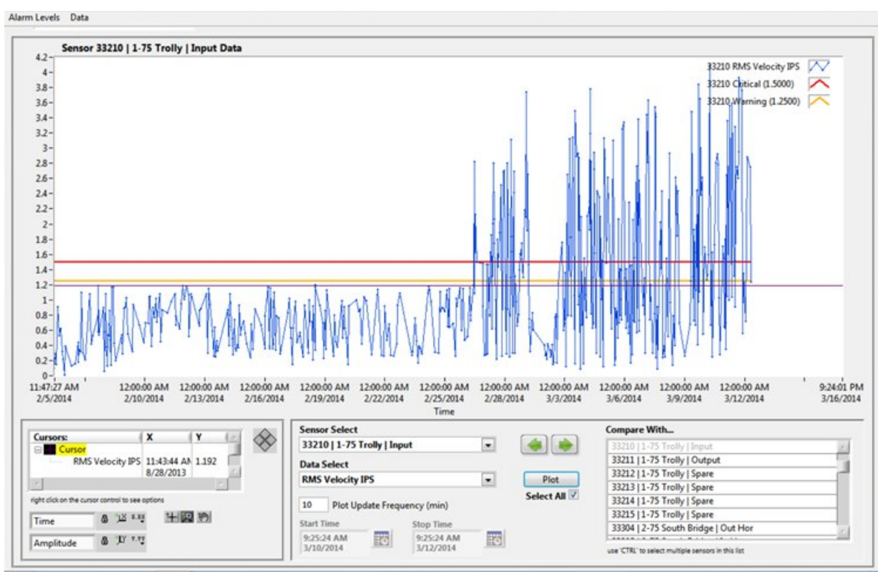


Figure 3: Trend plot of overhead crane overall vibration data using the EchoPlus® Wireless Junction Box

Monitoring to catch these types of potential failures may seem like a "no brainer" but many companies experience these types of failures and losses all the time and do nothing to improve, probably because they don't know where to start. This paper attempts to show how to start, improve, and develop a first class Predictive Maintenance program.

In this author's opinion, it takes 4 key elements, listed below, to start and run an effective predictive maintenance program. In this author's experience, the biggest stumbling block and why many programs fail is lack of ongoing commitment. Once the original purchase is made, ongoing support of the program is critical to its success. That includes support of ongoing training for the people involved and for system updates.

- justification (fiscal and technical)
- dedicated people (it can't be done in your "spare time")
- investment in tools and training
- ongoing commitment to the program and training

How Bad Can It Get: On August 17, 2009 at the Sayano- Shushenskaya Hydroelectric Power Station in Khakassia, Russia, a turbine broke apart violently killing 75 people, damaging 9 out of 10 turbines and lost the entire plant's output of 6400 MW leading to widespread power failure, see Figures 4A and 4B. The official report on the accident stated "***the accident was primarily caused by the turbine vibrations*** which lead to the fatigue damage of the mountings of the turbine". It went on to say, "It was also found that at the moment of accident at least six nuts were missing from the bolts securing the turbine cover."[3] How difficult, how much time, and what would the cost have been to replace the nuts on six bolts? One of the functions a technician is trained to do when running a route (collecting data on a predefined list of machinery) is to inspect the machine for problems such as oil leaks, loose belts, and missing nuts on bolts! These types of problems are recorded and reported with the other data collected.

It appears from this report that a vibration monitoring program would have caught the problem, and perhaps even did. However, in order for a predictive maintenance program to be effective, when a problem is identified someone needs to act upon the diagnosis, not ignore it, to avoid a catastrophic failure. This obviously did not happen. As is typical in many plants, production rules and companies continue to run equipment they know may fail but hope they don't. Sooner or later something will fail, the only questions are when and how big will the consequences be?

Figure 4A & 4B: Severe damage at the Power Station [4, 5]

In this author's experience, when it comes to plant operations it seems ***there is always time and money available to put out a fire but there is often no time or money available to prevent one****.* In the end, even seemingly small failures can lead to big consequences. So, it boils down to this question, ***"How much risk are you willing to take?"***

Success planning: Don't wait until disaster strikes before you change. Or, as Jack Welch, former CEO of GE said, "Change before you have to."

Part 2: Predictive Maintenance Systems

Predictive Maintenance: What if there was a relatively simple process that would alert you to a developing problem in a critical production machine? What if this alert gave you enough warning not only to determine what the problem is but also to order the parts and schedule the people necessary to repair it? What if this warning also gave you the luxury to schedule the maintenance during a planned outage rather than at an inopportune time? This is Predictive Maintenance and it has been used successfully in many industries for decades, yet many companies still avoid it.

Condition Monitoring: Condition monitoring is an important component in Predictive Maintenance. It is the process of monitoring and trending one or more parameters, such as vibration, oil particles, and/or temperature that indicate when a fault is developing in a machine. When the parameter indicates a problem is developing, it allows maintenance to be scheduled and thus avoiding machinery failure and lost production. When this is done on a regular basis, ***it allows trained personnel to make informed decisions on the availability of machinery assets***, which is what the production manager and management in general, want. ***If a program is to be successful, a trained analyst must translate data into useful information.***

Diagnosis versus Prognosis: Figure 5 is a spectrum plot of a motor bearing showing both a BPFI fault (inner race fault frequency) at 4.2 orders (4.2 x running speed) and a BPFO fault (outer race fault frequency) at 3.2 orders and their harmonics (integer multiples of the fault frequency). There are also FTF (bearing train or cage frequency) sidebands present around the fault frequencies. This may as well be Greek or hieroglyphics to the average person and perhaps the reader.

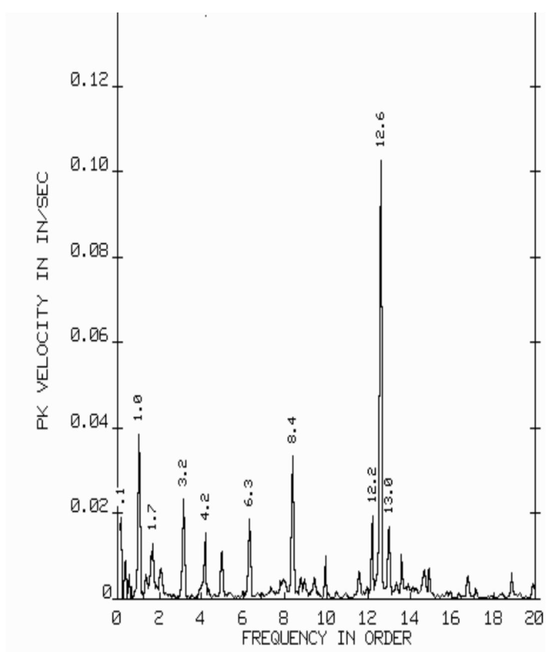


Figure 5: Spectrum plot of a bad motor bearing (Plot courtesy of Predictive Maintenance Services, Inc.)

Fortunately, a ***trained vibration analyst*** could easily diagnose this as a bearing that is in pretty bad shape. The diagnosis in this case, is actually quite easy. The prognosis, on the other hand, is not so easy to determine. How long will it last? Even the best most experienced analysts can't say for sure, however, if you choose to leave it in service, you are waiting for disaster to strike! How much risk are you willing to take?

Vibration Monitoring Systems: With today's technology, it would be hard to make a bad purchasing decision on a vibration monitoring system. Most major conferences involving condition monitoring equipment will have vendor areas showing a wide selection of vibration monitoring systems ranging from simple walk-around models to the most advanced online continuous monitoring systems. There are generally a lot of vibration consultants around the conferences as well that can provide advice on what you need if you just ask them. Attendance at such a conference, like the Vibration Institute's Annual Training Conference, is a great way to shop, compare, and learn.

There are three main components to a vibration monitoring system.

- Sensors, including cables and junction boxes
- Data collection device
- Monitoring/analysis software

The data collector or data collection device will have many options as will the software. The options selected will dramatically affect the cost of the system. Additionally, if you have machinery that requires permanently mounted sensors due to accessibility or safety concerns, then additional cost will be incurred for sensors, cabling, and junction boxes. IMI Sensors offers a wide variety of sensor options for use with all popular data collection devices.

Sensors and Data Collectors: Before any assessment of a machine's condition can be made, data must be collected on a regular basis. Today's portable data collectors coupled with modern industrial accelerometers, Figure 6 and 7, make the collection of good vibration data relatively easy. Most predictive maintenance programs start out using a magnetically mounted accelerometer (typically included with systems) coupled with a portable data collector, Figure 8, to run routes and collect data. ***Most skilled trade personnel can learn to collect good vibration data quickly with a minimum of training.*** The key is to collect it on a regular basis and to look at it. Too often one hears stories about a failure that would have been caught if someone had just looked at the data they collected!

Figure 6: The Commtest vb5 and Emerson Process Management, CSI 2140 are typical portable data collectors available in entry level to advanced configurations (Photos courtesy of Commtest and Emerson Process Management)

Figure 7: Typical top and side exit industrial ICP® accelerometers that can be used with magnets for walk-around monitoring or permanently installed.

Figure 8: Data collection using a walk around data collector with a magnetically mounted high

frequency ICP® accelerometer (Photo courtesy of Praxair)

Permanently mounted sensors wired to junction boxes can be used for better data consistency, safer operation, and quicker data collection with walk around data collectors, Figures 9 and 10. They are also used with online, continuous monitoring systems. Dedicated continuous monitoring system, while more expensive, can provide immediate warning of a developing machine fault on highly critical machines and even shut down critical systems based on a pre-established shutdown (critical alarm) limits.

Figure 9: Permanently mounted ICP® accelerometer on a motor.

Figure 10: Data collection using a walk around data collector, permanently mounted ICP® accelerometers, and an IMI junction box.

Vibration transmitters can be used to continuously monitor machinery using standard plant monitoring systems like a PLC, DCS, or PI system that accept a 4 – 20 mA signal, Figure 11. This may be preferable on a highly critical machine, especially if it has a short failure cycle. However, as stated above, most programs start with a simple walk around system, Figure 8.

Figure 11: Permanently mounted IMI 4---20 mA output sensors on a vertical pump that are being continuously monitored by a PLC. (Photo courtesy of Monroe County Water Authority).

Wireless vibration sensors and systems, Figure 12, are a new breed of monitoring systems that are starting to become popular. Unlike online systems that monitor continuously, these systems typically collect data and check it against alarm levels a few times a day. They have the advantage that they don't require any personnel to collect data on healthy machines (however, personnel may need to collect additional data when a fault is suspected) and don't require expensive cable runs. They also have the advantage that they can "look" at a machine daily rather than monthly, which is an advantage over walk around systems, particularly when a machine has a faster failure mode.

Figure 12: The Echo® Wireless Vibration Monitoring System can be used with both stand-alone vibration sensors and a wireless junction box with standard ICP® accelerometers

Monitoring Software: Monitoring software is the heart of a predictive maintenance system. It contains a database that houses the machinery, alarm, and route information; all data collected; and includes all of the tools needed to enter, analyze, and report data. The software has modules to enter a machine database, create routes, download and unload route data, run reports, and analyze data. It may also have some way of showing the overall status of machines being monitored as in Figure 13, which shows there are only 4 points of all those being monitored that are tripping a critical (red) alarm. Note: This particular database is monitoring about 200 points. The Echo® Smart Alarm Panel display brings the problem points to the top of the list. How can anyone argue with the value of such information, the status of the machinery in your plant at-a-glance?

Figure 13: Smart alarm panel from the Echo® software showing the status of all machines being monitored

Part 3: Skill Required

Skill Required for PdM Program: There is no question of the value of a well-run predictive maintenance program and anyone can easily purchase a good quality system capable of achieving one. However, if a system is purchased, what is required of the individuals to start and run a program? And, what sort of results can be expected?

Beginner Skill Required: Routine data collection requires an Introductory Level of skill and can be learned quickly. It is recommended that a person involved in data collection take an introductory level vibration analysis class, like the Vibration Institute's, Introduction to Machinery Vibration (IMV) class. Validation of understanding can be achieved by taking the Category I Certification Examination and being certified as a Vibration Analyst by a Certifying Body in accordance with ISO/IEC 18436-2:2014, *Condition monitoring and diagnostics of machines – Requirements for qualification and assessment of personnel – Part 2: Vibration Condition monitoring and diagnostics*. In order to sit for the Category I exam, the Standard requires that the candidate have a minimum of 30 hours of appropriate training and 6 months of experience. Figure 14 shows a typical slide from an introductory course indicating the proper locations to mount accelerometers for data collection.

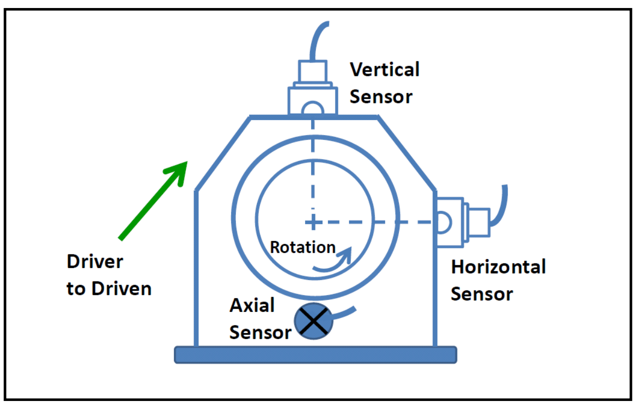


Figure 14: Diagram showing the proper locations to mount sensors for vibration monitoring [6]

An introductory level is simply a stepping stone. You cannot expect to run a successful ongoing program if your analyst only has introductory level training and a Category I certification. They must continue their training to achieve a minimum of a basic level of skill.

Alarms & Trending: Most vibration systems come with trending and fault analysis software that automatically looks at overall data versus alarm levels when unloaded from a data collector. Reasonable alarm levels can be determined with a moderate effort by using recommendations found in many ISO, ANSI, API and other Standards, such as, ISO 10816-1 *Mechanical vibration – Evaluation of machine vibration by measurements on non-rotating parts*, ISO 7919 *Mechanical vibration of non-reciprocating machines – Measurements on rotating shafts and evaluation criteria*, and API 670 *Machinery Protection Systems*, as well as other published resources such as the Blake Chart, Figure 15, or a simple R/C (p-p displacement / diametrical bearing clearance) for fluid film bearings, Figure 16.

Other good ways of setting reasonable alarm levels are consulting with a Certified Vibration Consultant or getting involved with one or more Professional Organizations such as the Vibration Institute, http://www.vi-institute.org/, the Canadian Machinery Vibration Association, http://cmva.com/, or more a specialized organization like the Cooling Technology Institute, http://www.cti.org/.

Coupling data collection with good alarm levels should provide a warning when a machine is developing a fault. Viewing trend plots will add insight as to how fast the machine is deteriorating and how soon corrective action needs to be taken. All this can be accomplished with a moderate effort and a little determination.

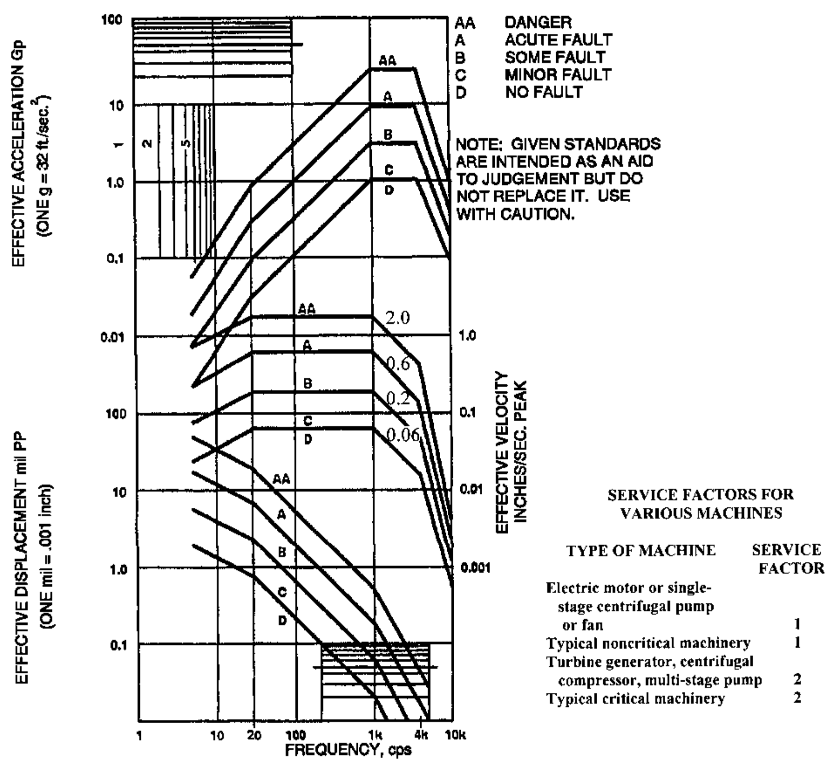


Figure 15: The Blake Chart has been shown to be a good reference for machine condition in the absence of other specific historical data. [6]

Maintenance	Allowable R/C	
	3,600 RPM	10,000 RPM
Normal	0.3	0.2
Surveillance	0.3-0.5	0.2-0.4
Shut down at next convenient time	0.5	0.4
Shut down immediately	0.7	0.6

Figure 16: Allowable R/C for evaluation of fluid film bearings [6]

Basic Skill Required: Determining what points should be monitored, what measurements should be made, what alarm levels to set, and perform basic trending and spectrum analysis requires a Basic Level of skill as a vibration analyst. It is recommended that in addition to an introductory level class, a basic level class like the Vibration Institute's Basic Machinery Vibration (BMV) class be taken. Validation at this level can be achieved by taking the Category II Certification Examination. In order to sit for the Category II exam, the Standard requires that the candidate have a minimum of 38 additional hours of appropriate formal training and a total of at least 18 months of experience. ***Note: Many, if not most, successful predictive maintenance programs are run by Category II Certified Vibration Analysts.***

Fault Analysis: This is where the bar starts to raise. Once an alarm is triggered and it is seen in the trend plot that the condition is getting worse, Figure 17, a skilled vibration analyst must now look at the data, including; time waveform, spectra, High Frequency Energy (HFE), and demodulated data, such as Spike Energy™ or PeakVue™ to determine what the fault is. This action requires a trained vibration analyst to get an accurate diagnosis of the particular fault. In the plot below, the overall peak velocity has triggered a warning (ALERT) alarm so there is still some time to do diagnostic analysis and schedule a repair before the critical (FAULT) alarm is reached.

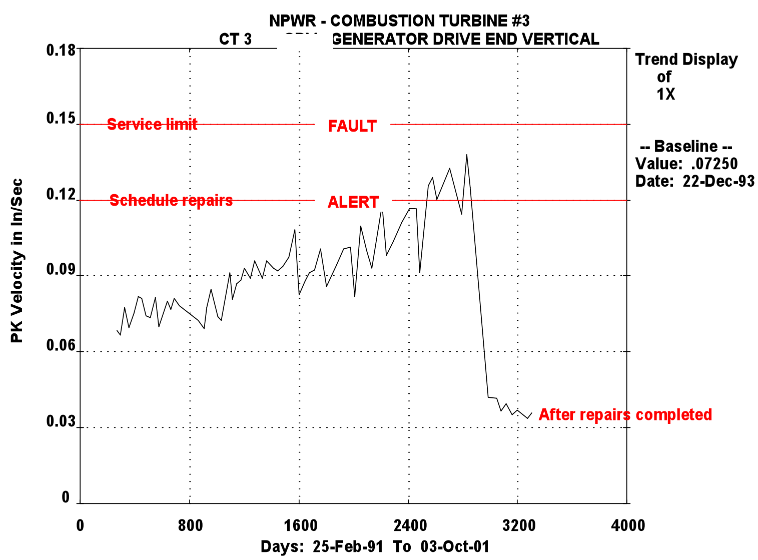


Figure 17: Trend plot on a turbine tripping a warning alarm. (Plot courtesy of Predictive Maintenance Services, Inc.)

As in most fields of study, the more training and experience a person has, the better they are. As the following equation shows, skill is developed with a combination of training and experience; the more you have of both, the better you get. People make the mistake of thinking that they will become more and more skilled through experience only. While this is partially true, they never will actually get to the next level without more formal training as well.

Vibration Analyst Equation:
Training + Experience = Skilled Vibration Analyst

To the untrained eye, the time waveform and spectrum plots in Figures 18 and 19 are basically meaningless. However, to a trained certified vibration analysis, they provide data that can be analyzed and the fault determined.

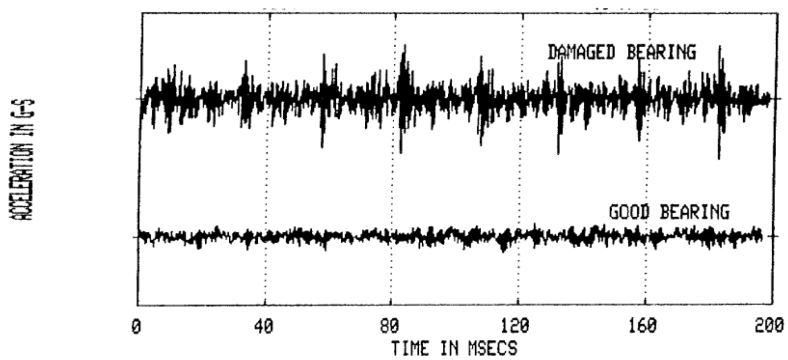


Figure 18: Time waveforms of both good (bottom plot) and bad (top plot) rolling element bearings (Plot courtesy of Predictive Maintenance Services, Inc.)

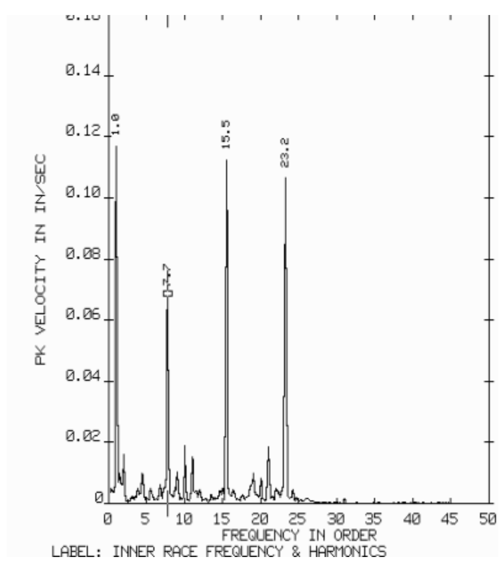


Figure 19: Spectrum plot showing a rolling element bearing with an inner race (BPFI) defect (Plot courtesy of Predictive Maintenance Services, Inc.)

A Category II Vibration Analyst can certainly do basic fault analysis, particularly for common, easier diagnosed faults such as unbalance, looseness, misalignment, and some rolling element bearing faults such as shown above. However, as things get more complex, Figures 20 and 21, additional training beyond the basic level classes is recommended. Additionally, an analyst may want to study some corrective technologies such as dynamic balancing and shaft alignment to be able to fix two of the most common problems found in machinery.

The example below is a more complicated diagnostic problem than those above. Early detection of this problem was reported by the use of a High Frequency Detection (HFD) technique, PeakVue™. Since the analyst understood advanced diagnostics, he could recognize there was a developing fault and then analyze it using the velocity trend and spectrum plots, Figure 21. It can be seen that the trend increased quickly in the last couple of months when the gearbox was **not** being monitored but was caught just in time to save the gearbox from catastrophic failure. This makes a strong case for monitoring equipment on a regular basis and not skipping a scheduled data collection because someone is too busy. This happens all the time!

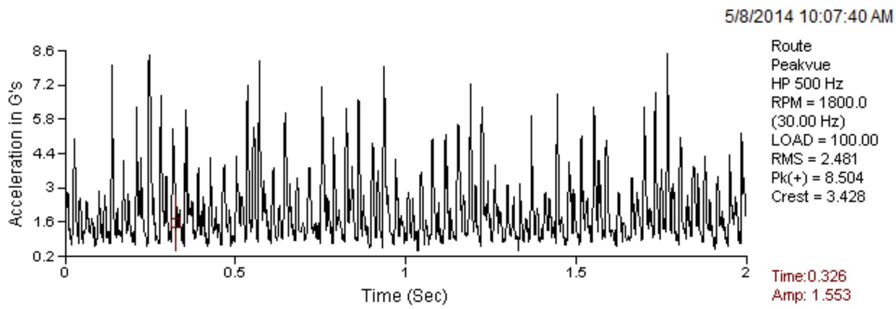


Figure 20: Demodulated time waveform on a gearbox indicates a problem (Plot courtesy of ABM Technical Services)

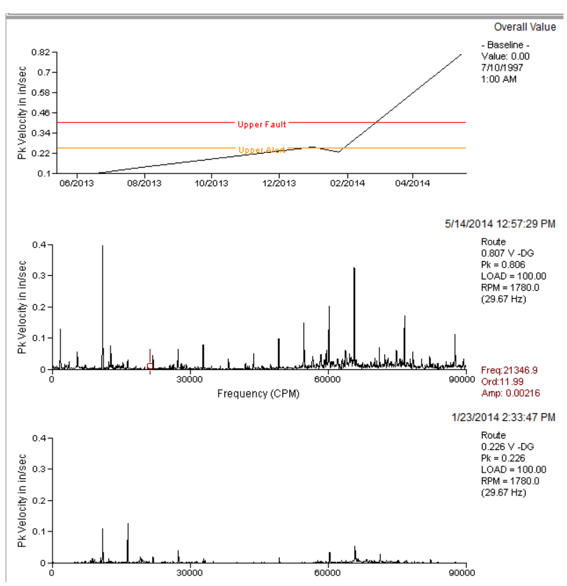


Figure 21: Trend plot and two spectra showing the progression of the fault (Plot courtesy of ABM Technical Services)

Intermediate Skill Required: *If a person has responsibility for a Predictive Maintenance program, needs to direct the efforts of others, or simply wants to be better at detection and diagnosis of faults, an Intermediate Level of skill is recommended.* Recommended classes include an intermediate level vibration class such as the Vibration Institute's Machinery Vibration Analysis (MVA) class plus a dynamic balancing class such as the Vibration Institute's Balancing of Rotating Machinery (BRM) class. An analyst may also want to consider purchasing a shaft alignment system and take a Basic Shaft Alignment class. Validation at this level can be achieved by taking the Category III Certification Examination. In order to sit for the Category III exam, the Standard requires that the candidate have a valid Category II certification, a minimum of 38 additional hours of appropriate training (although more is recommended) and a total of at least 36 months of experience. While a shaft alignment is not required for the vibration certification, it is highly recommended if your plant has a lot of shaft alignment issues, which are very common whether you know it or not. If you have pumps, you can bet you have alignment problems.

Prognostics (Condition/Severity Assessment) or Predicting the Future: Maintenance supervisors and plant manager don't really care if the problem is a crack in the outer race of a bearing, misaligned shafts, looseness in the foundation or a seal rub. What they want is information. Can I run the machine? How long can I run the machine? When will the machine fail or be unable to perform its intended function? This is prognostics and is difficult at best to do well. The time between the detection of a fault and either failure or significant performance degradation is difficult to predict and requires the knowledge of a Skilled Vibration Analyst.

As shown in the condition monitoring equation below, it takes good data and a skilled vibration analyst to provide useful information. And it turns out, the more training and experience an analyst has, the more skilled they become, particularly at prognostics.

Condition Monitoring Equation:
Good Data + Skilled Vibration Analyst = Useful Information

Another way of looking at it is that *instruments can collect data but skilled people analyze, diagnose, and do prognostics of faults*. Even the best analysts can't make any guarantees when it comes to prognostics. However, the more training and experience they have, the more likely they will be close.

Useful information is the desired outcome of a Predictive Maintenance Program for the purpose of effective Asset Management. This requires ongoing professional development for the analyst and the accumulation of diagnostic experience. ***The more training and experience the analyst has, the better the information that can be provided for critical asset management decisions and optimized production.***

The Trap: Beware, there is a trap! What if the information provided by the Skilled Vibration Analyst is not entirely accurate? What if the production manager decides to ignore the recommendation of the analyst and lets the machine continue to run and it doesn't fail or stop performing its intended function? What if the Skilled Vibration Analyst says to continue to run and the machine fails? Is it time to abandon the program, this author says no! No one, no process, and nothing is perfect; we just don't get everything right all the time. Use these seemingly "failure" situations as opportunities to hone your alarms and program effectiveness, not cancel them. If a machine does fail, you have incredibly valuable information in your database; you now know where the machine will most likely fail the next time. Simply reset your alarms and the next time you are likely to be spot-on in your prognosis. Remember the turbine? How much risk are you willing to take?

Advanced Skill Required: Advanced diagnostics and good prognostic analysis require an Advanced Level of skills and experience. It requires training in advanced topics such as rotor dynamics, transient and forced vibration, modal analysis, and advanced signal processing. In order to achieve a Category IV Vibration Analyst certification, the Vibration Institute recommends three classes Advanced Vibration Control (AVC), Rotor Dynamics and Modeling (RDM), and Advanced Vibration Analysis (AVA) a tall order by anyone's standards. Validation at this level can be achieved by taking the Category IV Certification Examination, a very difficult exam. In order to sit for the Category IV exam, the Standard requires that the candidate have a valid Category III certification, a minimum of 64 additional hours of appropriate training and a total of at least 60 months of experience. Frankly, this level of certification is not easy to achieve and is left to the most serious analysts to pursue. The more training and experience the analyst has, the better are their chances of making accurate assessments. Few analysts make it to this level as it requires a huge commitment to professional development and a minimum of 5-years of experience.

Root Cause Analysis and Life Extension – Even if an analyst becomes very good at all of the above functions, including prognostics, it would be better if the root cause of a chronic problem were determined and modifications made to the machine to extend its service life. This is generally only done if there is a chronic problem and a short life cycle for a critical machine. Often, this type of action requires the assistance of an experienced vibration consultant and possibly the manufacturer or aftermarket service organization. It generally requires an in depth understanding of advanced vibration analysis techniques, machinery, machinery components, and maintenance procedures for this type of analysis and machinery modification.

This may be a job left for the experts or the best in the business. While a good analyst can take a shot at this, it may be a good time to call in a seasoned certified vibration consultant that specializes in the type of machinery with the problem. Certified Vibration Consultants that are certified by the Vibration Institute are listed on the Vibration Institute website at http://www.vi-institute.org/certifiedconsultants by Category for easy reference.

Part 4: Justification and Benefits

Financial Documentation and Records – In order to get management support for funding equipment, training, and other professional development, maintenance must show a reasonable ROI (Return on Investment). Since the people directly involved in these programs are usually technical, they may not know how to determine ROI and generally do not do a good job of documenting costs and savings. So while the actual ROI may be huge, management doesn't know it and thus doesn't provide ongoing funding, especially for training and professional development. This can and often does spell disaster for a predictive maintenance program.

Another way to provide justification to management is to provide them with overall machine status, availability and other statistics. An example of this type of plot is shown in the "Machine Status Report" in Figure 22. How many plants can state the current status of all of the current critical machinery as shown in the Machine Status Report below? At a glance, the overall status of the plant is known; how can anyone argue with the value of such information? But, someone needs to be dedicated to the program.

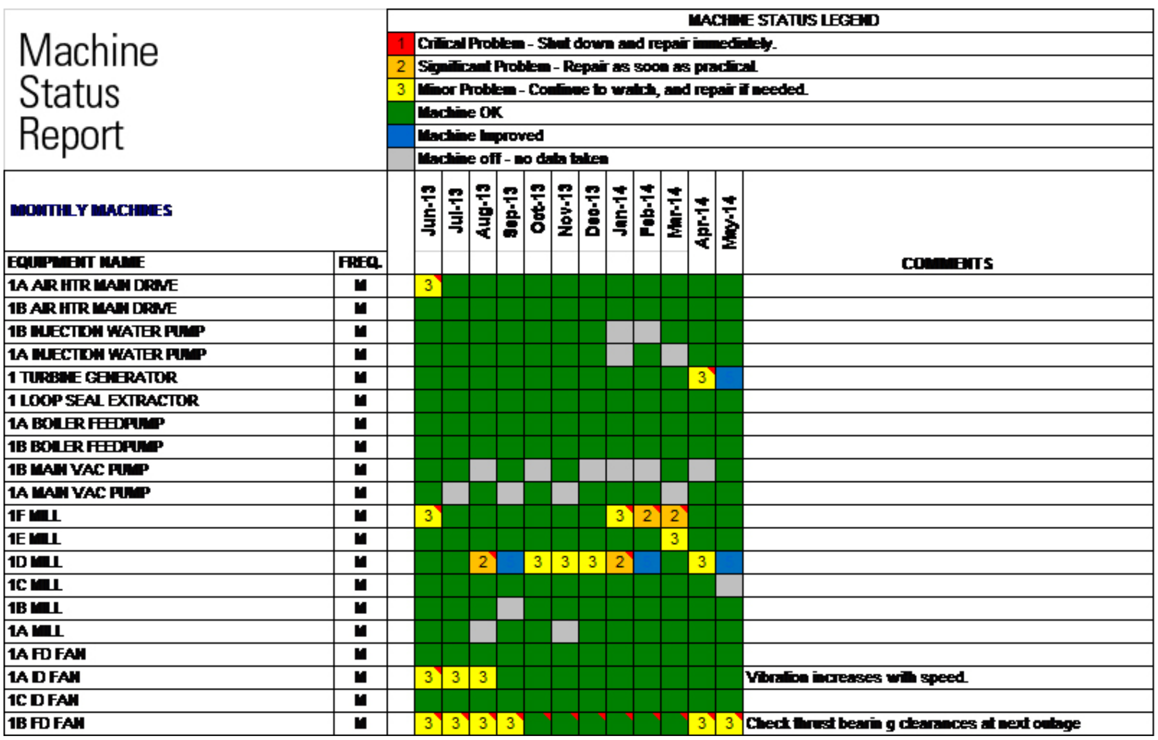


Figure 22: Machine Status Report showing machine fault status. (Plot courtesy of ABM Technical Services)

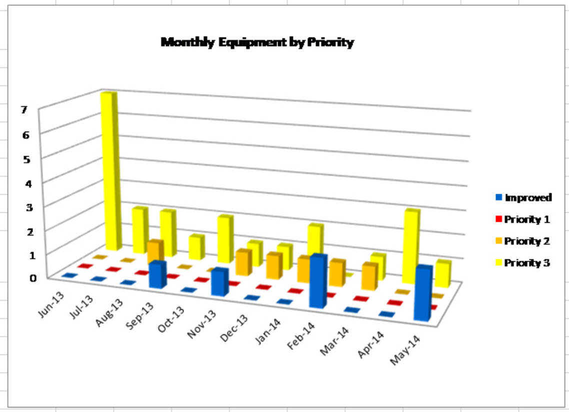
Another way of watching the effectiveness or thoroughness of a Predictive Maintenance Program is to track machine Monitoring Statistics, Figure 23. This report shows that equipment is being monitored and more importantly, that the machines are in good condition and under control, as is evident with the lack of Priority 1 problems. How many plants can report the same?

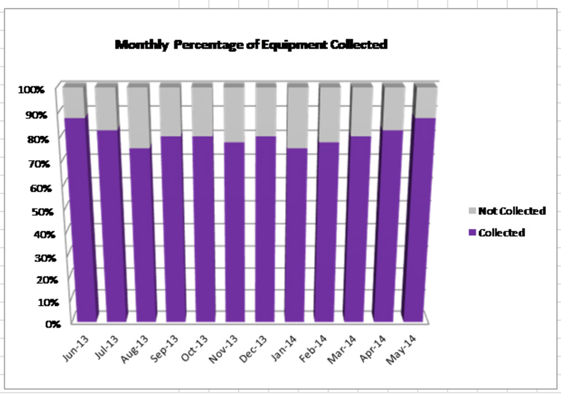
Data Type vs Number of Equipment

UNIT 1 MONTHLY		Jun-13	Jul-13	Aug-13	Sep-13	Oct-13	Nov-13	Dec-13	Jan-14	Feb-14	Mar-14	Apr-14	May-14
Machine Improved		0	0	0	1	0	1	0	0	2	0	0	2
Critical Problem - Priority 1		0	0	0	0	0	0	0	0	0	0	0	0
Significant Problem - Priority 2		0	0	1	0	0	1	1	1	1	1	0	0
Minor Problem - Priority 3		7	2	2	1	2	1	1	2	0	1	3	1
Machine OK		29	32	28	31	31	29	31	28	29	31	31	33
Machine off - no data collected		5	7	10	8	8	9	8	10	9	8	7	5
Total Machines Collected		36	34	31	33	33	32	33	31	32	33	34	36
Total Machines on Route		41	41	41	41	41	41	41	41	41	41	41	41

Data Type vs Percentages

UNIT 1 MONTHLY		Jun-13	Jul-13	Aug-13	Sep-13	Oct-13	Nov-13	Dec-13	Jan-14	Feb-14	Mar-14	Apr-14	May-14
Machine Improved		0%	0%	0%	2%	0%	2%	0%	0%	5%	0%	0%	5%
Critical Problem - Priority 1		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Significant Problem - Priority 2		0%	0%	2%	0%	0%	2%	2%	2%	2%	2%	0%	0%
Minor Problem - Priority 3		17%	5%	5%	2%	5%	2%	2%	5%	0%	2%	7%	2%
Machine OK		71%	78%	68%	76%	76%	71%	76%	68%	71%	76%	76%	80%
Machine off - no data collected		12%	17%	24%	20%	20%	22%	20%	24%	22%	20%	17%	12%
Total Machines Collected		88%	83%	76%	80%	80%	78%	80%	76%	78%	80%	83%	88%





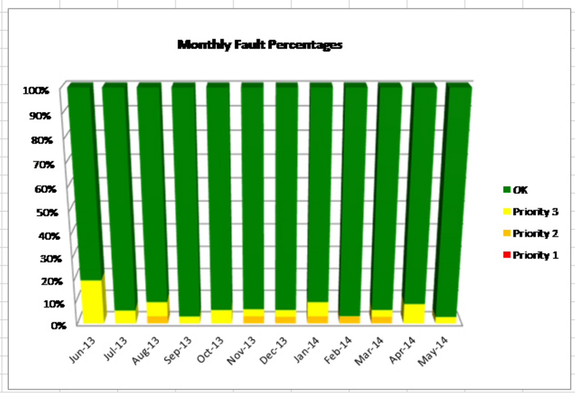


Figure 23: Monitoring Statistics Report (Plot courtesy of ABM Technical Services)

The Training Paradox - More often than not, the employees involved in driving and working vibration analysis programs are skilled trades and millwrights, not engineers. Because of this, management is often reluctant to send them to off-site training classes or technical conferences. This results in a confusing paradox to this author. Management wants these same skilled trades people to make extremely important decisions on machine availability that affect production and profits, which they do based on their skill set as a vibration analyst. Then, more often than not, management doesn't feel it's in the company's best interest to invest in their professional development. They seem to have less of a problem sending engineers and other professional people to training and conferences but not the trades' people. ***Without ongoing professional development and formal training, those involved in vibration analysis cannot expect to achieve a high level of performance.***

Program Cost and Budgeting – The cost of a good portable vibration monitoring system, including data collector, sensor, and software, can start as low as $20,000 and go up to $50,000 or more depending on the features desired. Often, the system vendor will include some basic startup training in the system cost but even if it is not included, it is offered as an option. ***If you buy a system, include the startup and system training; it is well worth the investment.*** How often have you thought, if I could only sit in on a day or two training on some software program you were using, how much more effective I could be. The same is true here. Predictive maintenance software packages have tremendous capabilities, if and only if, you know how to use them.

Don't mistake the vendor's startup training as vibration training. While vendors do offer vibration training, their startup training is generally focused on the setup and use of the system you purchased. Be sure to budget for a vibration analysis class to be taken about 6 months, for a beginner, after setting up your system and having an opportunity to collect some data. Then, budget for ongoing training and/or professional development each year.

Introductory or Basic machinery vibration training, including certification testing costs about $2000 plus travel and requires a full week commitment by the individual. Don't be part of the Paradox mentioned above; invest the time and funds to get started the right way. Further training is recommended at various intervals; typically at least once per year. Other than a person's time, it is relatively inexpensive to get started when compared to the probable cost savings. I'll say it again, budget for both the startup and ongoing training and professional development, it will pay off in the long run.

Inventory Savings – When a developing fault is identified, there is generally time to order parts for the repair. Thus, in some cases, companies can have less costly inventory in stock that is tying up money and possibly costing more at the end of the year in taxes. This should, however, be considered carefully for highly critical machinery.

Increased Damage Due to Failure - The cost to replace a bearing, time and materials, may be minimal if the right parts and people are available for the repair. However, if the machine fails catastrophically which causes additional damage to the shaft and other machine components, then the parts needed and the time required can increase significantly costing more to repair the machine and losing more production time.

Lost Production – Some processes run 24/7 and companies can sell 100% of the product that they make. In cases like this, when a machine is down, the lost sales cannot be recuperated. This can be and often is the largest part of the financial loss model. When a process is down unexpectedly for several days due to an unexpected failure, production losses can be in the hundreds of thousands to millions of dollars. How does that compare to the cost of a system?

Reduced Insurance Costs – Some insurance companies will charge lower rates on equipment breakdown insurance if a company can show they have a predictive maintenance program that reduces risk and some even offer services to help mitigate the risk. CNA insurance company says in their brochure, "We recognize that the least disruptive loss is one that never occurs". To control risk, they offer services in predictive and preventive maintenance and other risk control services.[7] Zurich says in their online brochure they provide site risk assessment including predictive maintenance.[8] Thus, it is obvious that the insurance companies that provide the coverage believe in predictive and preventive maintenance.

How to get started – Getting started is a bit of a Catch 22 situation. You can't get started because you probably don't have much knowledge of Predictive Maintenance, even less of vibration analysis, and most likely no experience at all. And, it is recommended that someone have a Category II certification before setting up a machine database and routes. And by the way, it takes a minimum of two classes and 18 months of experience to get the certification. ***You can't start a vibration program because you don't have the experience and you can't get the experience because you don't have a vibration program, catch 22. So, where do you start?***

First, does it make financial sense? Assemble the appropriate people and have the following discussions. Determine what machines are critical to your operation and what machines have chronic problems. Determine also what other machinery, even if reliable, supports a critical operation and could cause a slowdown or stop production if it failed. Determine as accurately as possible what it has cost in the past when these machines went down unexpectedly and what it would cost if they failed now. That should provide a financial baseline for what it is worth to your company to invest in condition monitoring.

Just start! Short of hiring a Certified Vibration Consultant to startup a program, which isn't a bad investment, Just Start? Buy a system from one of the many reputable vendors in this business. You can hardly go wrong with any of the systems available today. Vendors are anxious to get new business, so get them to help you install the system and get it up and running.

You need training. If you can't get the vendor to do the installation at no charge, pay to have them help you and take their startup class on system operation. **M*any programs fail right off the bat because companies don't want to pay for startup help.*** Don't let this be you. You need it so, as Nike says, Just Do It! If you really want to jump start the program, bring in a consultant for a few days or periodically on a contract basis over the course of 6-months to a year to help you set up some routes, establish alarms, and get started in data collection. If you start on your own, ***start small***. Set up a few machines, collect data on them, and start establishing some trends. ***Don't try to setup the whole plant up front, it won't work.***

Take advantage of similar machines. If you have several of the same machines, collect data on them all and compare the readings. I once did a demonstration in a plant where they had 6 of the exact same compressors. We took data on all six units and one had much higher vibration than the others. The customer called the compressor manufacturer, told them of our results, and was told by the vendor to shut down the machine immediately! Take advantage of having similar machines.

Seek out advice. If you feel like you don't have a clue, go to a local Vibration Institute or CMVA Chapter meeting, conference, seminar, or similar event and talk to the analysts there. You will find that they are happy to help other people. Networking is a great benefit of professional organizations and is sorely overlooked. After you have dabbled in it for 6 months, take an introductory class and if you're bold enough, take the Category I certification exam. Now you can start building your program.

Don't be afraid to make a call. If vibration doubles something is wrong and the machine should be evaluated. Tell someone and if it is a critical piece of equipment, this may be a good time to spend a few extra dollars and bring in a Certified Vibration Consultant. It will serve two purposes. First, you will find out the status of the machine and, second, it will be a great learning experience for you.

Conclusion – Affordable tools are available to conduct effective Predictive Maintenance programs in most plants. A consistently run Predictive Maintenance program can identify faults and save significant amounts of money for companies, but it takes three ingredients to succeed; desire by an individual, support by a company, and commitment to succeed.

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