State-of-the-art predictive maintenance programs

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A program emphasizing accurate diagnosis of rotating machinery problems can help increase production and reduce costs.

During the last few years, many articles have been published on various predictive maintenance programs. These articles have varied from the "Parable of the Sower" to detailed descriptions of various plant programs. All have espoused the virtues of condition monitoring and trending. Very few have discussed accurate diagnosis of rotating machinery problems.

During our travels throughout the United States, Canada, South and Latin America, and the South Pacific, we have found very few predictive maintenance programs actually involved in accurate diagnostics. The diagnosis performed is normally limited to routine bearing defects, along with some press roll and nip problems. Accurate diagnosis involves the calculation of the frequencies a machine can generate, accurate measurement of the frequencies that are generated, and the use of applied technology, such as that found in *The Vibration Analysis Handbook*,* to diagnose machinery problems accurately and identify the various degrees of severity.

Problems with existing programs

We know that existing predictive maintenance programs have been saving the industry millions of dollars annually by avoiding lost production and wasted man-hours and materials. However, this is only a drop in the bucket when the full potential is considered. Accurate diagnosis can save industry billions of dollars annually. With today's high-speed machinery costing more than US$ 20,000 per hour of downtime, it is easy to obtain a 10:1 return on money invested for accurate diagnosis of machinery problems.

Hardware, software, and technology are available for accurate diagnosis and have been available in varying degrees for years. Given this fact, what is the problem? With most predictive maintenance programs, the answer is lack of skilled people. Imperfect knowledge is prevalent at all levels from management down to the worker. This imperfect knowledge results in the following:

1. Management does not know what to expect from predictive maintenance.
2. The wrong equipment is often purchased.

1. Priority list for maintenance

VCI PRIORITY LISTING
GROUP: 4MT SECTION: PRES

The following are considered Priority 1 for repair:

Point	Problem
1. 1PFR5	Loose–PR13(-0.10), Outer-PR11, Inner-PR13(0.09), Cage-PR12, Roller-PR13; ID-(32/51); Overall-PR11
2. 1PFSR4	Loose-PR11, Outer-PR13, Inner-PR11; ID-(26/45); Overall-PR11
3. 1PRF1	Loose-PR11, Outer-PR13, Inner-PR13; ID-(23/49); Overall-PR11
4. 1PTOP	Inner-PR11, Roller-PR13, ID-(6/37); Overall-PR11
5. 2PFR1	Loose-PR11, Inner-PR13, Cage-PR13(-0.06); ID-(23/47); Overall-PR11
6. 2PFR2	Loose-PR11, Outer-PR13(-0.09), Inner-PR12(-0.10); ID-(33/50); Overall-PR11
7. 2PFSR3	Loose-PR11, Outer-PR13, Inner-PR12, Roller-PR13; ID-(27/43); Overall-PR11
8. 2PFR4	Loose-PR11, Oouter-PR13(-0.07), Inner-PR13, Cage-PR13; ID-(18/44); Overall-PR11

3. The wrong types and numbers of personnel are assigned to predictive maintenance.
4. Assigned personnel are not provided with adequate training.
5. Far too many managers and vendors believe in and are pushing "quick fixes" and gimmicks.

Where to start

Management should demand accurate diagnoses of all machinery problems. Generalities such as "There is a vibration problem," "The alarm went off," "The trend is up," or "It's making a noise" should not be accepted. A specific diagnosis should be provided, such as imbalance, horizontal or vertical offset, angular misalignment, defect on inner and/or outer race, looseness, eccentric and/or misaligned gears, etc., as shown in **Fig. 1.** Each identified problem must be assigned a priority to identify the severity. Every problem diagnosed should be identified as either normal wear and tear or a premature failure. If the failure is premature, the cause of

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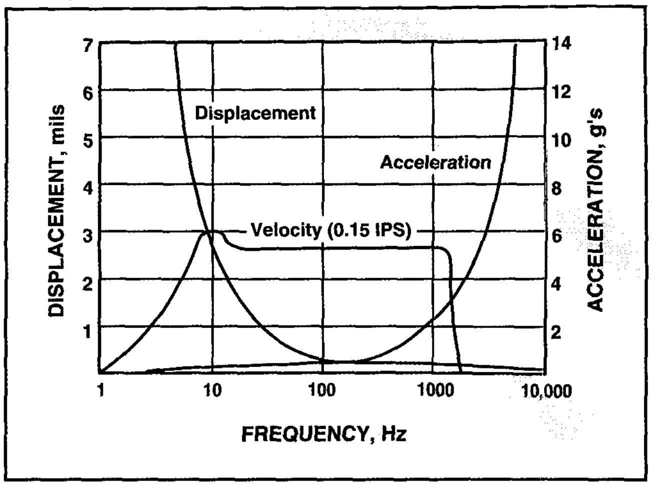
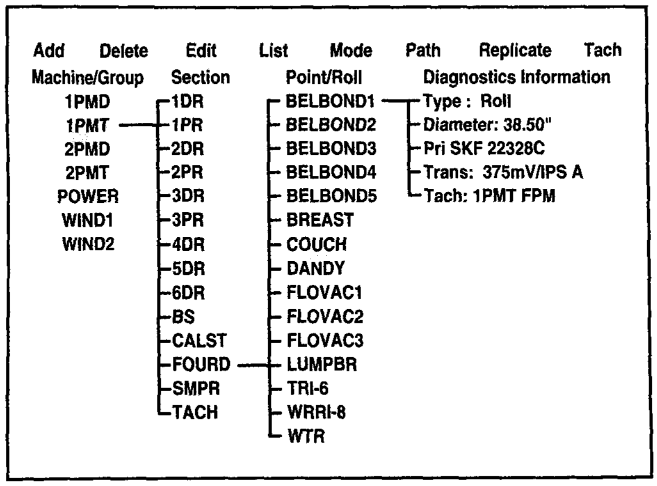
2. Frequency response curves



3. Automatic system sample tree database



failure must be identified and eliminated. If the cause of failure is not identified and corrected, the machine will fail prematurely again. This leads into quality control/assurance and equipment reliability and maintainability. If you don't believe this is a problem in your plant, ask, "Who is in charge of maintenance quality control and equipment reliability and maintainability?"

The wrong types and numbers of equipment are being purchased everyday because of imperfect knowledge on the part of the buyer—and sometimes on the part of the seller. The story heard most often is, "Someone else bought the equipment and I have to use it." If the people in predictive maintenance bought the wrong equipment, they are often afraid to admit that a mistake was made. The economic fact is this: Once a piece of equipment is bought, the price paid for the equipment becomes a sunk cost that may not be recovered. The price paid for such equipment has nothing to do with the decision to buy other equipment. The factors that must be used to determine if new equipment should be purchased are cost, return on investment (ROI), and payback period.

The cost of a good off-line diagnostic system is about US$ 50,000. This includes hardware, software, and training. The ROI in medium-sized plants is about 200% per year. The payback period is about every six months. In larger plants, annual savings could be US$ 1 million or more, which is a 2000% return. The cost of a 300-point on-line expert system is about US$ 200,000. The ROI is substantial with either system.

The primary requirement for personnel selection in predictive maintenance is, "They have to want to do it." If the individuals under consideration are looking for a retirement position, they should be encouraged to look elsewhere.

The next requirement is education. It is desirable to have the most education possible in maintenance and instrumentation. Mechanical engineers are preferred over millwrights and machinists. However, some of the best programs in the country are run by millwrights. If engineers are not assigned, predictive maintenance must have access to an engineer. Assigned personnel must be "company" people and must promote the best interests of the company.

A few words must be said about gimmicks and quick fixes. First of all, there would be no market for these items if the mentality of "I want a $300 meter that does everything" did not exist. Second, anyone who thinks "A demodulator will improve the accuracy of your analysis" or "You can identify defects in a bearing with a pen" has some surprises in store.

Production-wise, a motivated, skilled employee with the right hardware and software should be able to collect, process, and analyze 100 routine points of data per eight-hour day. It could take four hours to diagnose a multiple reduction gearbox that has more than one problem. Synchronous time averaging on a press section could take all day.

Program requirements

Hardware

A state-of-the-art real time analyzer (RTA) is required in every predictive maintenance program. Essential features include computer control, alias frequency protection, frequency translation or zoom (not to be confused with expansion), a good time domain signal, and synchronous time averaging capability. If an RTA is not available or is not being used, accurate diagnoses cannot be performed in all cases.

The following transducers are also required:

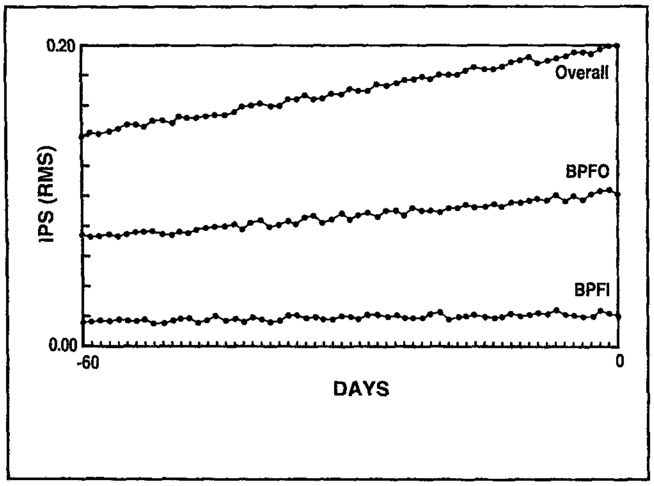
1. Velocity transducer
2. Low-, medium-, and high-frequency accelerometers
3. Contacting and noncontacting displacement transducers
4. Several pressure transducers, depending on installed equipment.

A total of eight different transducers is required in most plants. There are many reasons why different transducers are required. One is due to the frequency response of the transducers, as indicated in **Fig. 2.** The use of inadequate hardware could introduce an error rate of up to 50%.

Software

The first step in diagnostics is to calculate all frequencies the machine can generate, including the resonant frequencies of

4. History report



beams, shafts, and rotors. The software should also calculate and predict undesirable tooth ratios in gears and undesirable roll ratios for rolls in nip.

The term "user-friendly software" is overworked. Software must be functional. It must do what needs to be done. It should employ maximum use of function keys and pulldown menus. When one entry is made, the computer should automatically make all related changes. For example, if transducer sensitivity is entered for a displacement transducer, the computer should automatically change to the correct engineering unit, select peak-to-peak measurements, and set the amplitude scale. Databases should employ a "tree" structure so all components can be viewed on one screen, as shown in **Fig. 3.** The database software should permit combined entries of identical points. For example, if Motors 1-10 or Felt Rolls 12-27 are identical, they should be entered as one entry.

Using the same logic an engineer would use, expert software systems must perform accurate and specific diagnoses of each problem and assign priorities based on problem severity. Trending of the overall vibration level is often uneventful. Trending is more effective when the overall root means (RMS) value is plotted along with the RMS values of individually diagnosed problems such as imbalance, looseness, bearing defects, gear problems, etc., as shown in **Fig. 4.**

Software that does not calculate frequencies, is slow or otherwise dysfunctional, or is run on outdated computers can introduce an error content of up to 30% and can require an additional man year each year in medium-sized plants.

Technology

Technology is the understanding of calibration, calculation, measurement, and diagnostics. The following understanding of the time domain signal and the basic physics of measurement is required:

1. How signals add, subtract, modulate, and otherwise mix
2. How to determine the phase relationships between the fundamental, harmonics, and other frequencies
3. How frequencies are generated and the cause of harmonics and subharmonics.

Imperfect technical knowledge on the part of analysts, supervisors, and managers at all levels can cause major errors in diagnostics and place unrealistic restraints or demands on the predictive maintenance program.

Skilled personnel

Employing skilled personnel to handle predictive maintenance is not a problem in all programs. However, it may be a problem in most programs. One major contributor is job assignment based on seniority. Also, when an employee is injured or becomes sick and unable to perform the regular job, he or she is often assigned to predictive maintenance. The problem is further compounded when hourly people are assigned to predictive maintenance and the company has a rule that prohibits hourly people from receiving training outside the plant. Most vendors conduct courses in vibration training, but many only teach how to use their own equipment, with very little discussion of diagnostics. One way to control this problem is to purchase a set of course notes and evaluate the content before attending. Finally, most supervisors and managers erroneously believe that sending one person to one training course one time is all that is required.

Diagnoses of rotating machinery problems are complex and require extensive training, experience, and annual update training. The required skill can be achieved in about one year if the right people are selected for the job, they are adequately trained on the best technology, and they have the required hardware and software.

Recommendations

The following test may be helpful in evaluating your program:

1. Is a real-time analyzer being used in predictive maintenance?
2. Does predictive maintenance have velocity transducers, high- and low-frequency accelerometers, portable contacting and noncontacting displacement transducers, and required pressure transducers? Are all of the transducers being used when required?
3. Does predictive maintenance use Toolbox Software that calculates bearing frequencies, harmonics, and contact angle, and compares frequencies from various bearing manufacturers? That calculates gearmesh frequency, harmonics, and subharmonics, along with tooth ratio, hunting tooth frequency, speed, common and uncommon factors, pitch-line velocity, and AGMA gear quality number? That calculates resonant frequencies and mode shapes, shear, moment, slope, and deflection of beams, shafts, bars, and rotors? (The software should also model proposed fixes.) That calculates relationships and frequency response curves for velocity, displacement, and acceleration? That calculates improper roll ratios, cause of barring, and number of bars expected for rolls in nip?
4. Is the time domain signal being used in diagnostics? Are the phase relationships between the fundamental and harmonics being used to identify specific problems?

5. Do all diagnoses identify specific problems and rank them by priorities?

6. Is the amount of misalignment, bend in the shaft, and looseness in the bearing measured and included in the diagnostics?

7. Are special tests, such as synchronous time averaging, coast down/startup, bump test, and relative motion measurements performed when required?

8. Is the correct number of personnel assigned? Have they received adequate training? Do they receive annual advance training?

9. Have management, supervisor, and engineering personnel received enough vibration analysis training to know what to expect from predictive maintenance and the details required for good specification writing?

The effectiveness of a program is measured by the number of "yes" answers to the above questions. If your program scores between 90% and 100%, your program should be yielding good results. Scores between 80% and 90% indicate improvement is needed. Scores below 80% indicate a complete program review is required. ☐

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