Once the source of the problem is determined, the best repair activity can be chosen. If the engineering limit is set low enough, there will still be plenty of time to correct the problem before further damage occurs.

A work request is usually written to start the repair process. Correction of the root problem allows the equipment to reenter the periodic monitoring program.

The spectrum of PDM

There has been a historical misconception that equipment failures cannot be predicted. However, with predictive technology, a vast number of equipment failures can be predicted. Vibration measurement on rotating equipment is probably the best known of current predictive applications, but other categories of industrial equipment also benefit from a predictive approach. (See Table 1, "Spectrum of predictive maintenance.")

Spectrum of Predictive Maintenance

Equipment Category	Equipment Types	Failure Mode	Failure Cause	Detection Method
Rotating Machinery	Pumps, Motors, Compressors, Blowers	Premature Bearing Loss	Excessive Force	Vibration and Lube Analysis
		Lubrication Failure	Over, Under, or Improper Lube; Heat and Moisture	Spectrographic & Ferrographic Analysis
Electrical Equipment	Motors, Cable, Starters, Transformers	Insulation Failure	Heat, Moisture	Time / Resistance Tests, I/R Scans Oil Analysis
		Corona Discharge	Moisture Splice Methods	Ultrasound
Heat Transfer Equipment	Exchangers, Condensers	Fouling	Sediment / Material Buildup	Heat Transfer Calculations
Containment and Transfer Equipment	Tanks, Piping, Reactors	Corrosion	Chemical Attack	Corrosion Meters, Thickness Checks
		Stress cracks	Metal Fatigue	Acoustic Emission

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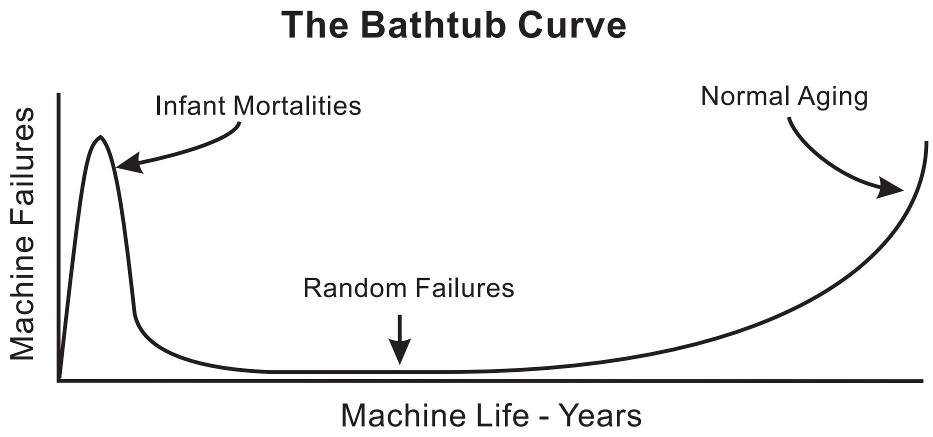
The mortality of machinery

Researchers into the reliability of equipment recognize that within a collection of machines there is a definite pattern of life spans. In practice, this pattern manifests itself when a collection of machinery is subjected to rigorous operation. The plot of typical life spans is shown in the so-called *bathtub curve*.



Among collections of equipment, there is a rather high incidence of early failures, called infant mortalities. Most equipment that survives infancy will continue to perform with few failures occurring. In time, however, the failures begin to increase until the last of the group succumbs.

Finding the parameters

The failures that form the latter part of the curve are caused by identifiable physical phenomena. Depending upon the complexity of the machine, there may be several aging processes at work in a single piece of equipment, any of which may cause the ultimate failure. These processes are usually related to the basic physics of the materials and how the machine is used.

Knowledge of the physical properties of materials comes from either theoretically or empirically derived conclusions. To understand how failures can be predicted, the *mortality of machinery* and the *finding of parameters* need to be understood.

For example, Ohm's law and the theory of potential difference follow theoretically from Maxwell's equations for electromagnetic fields and define the nature of electrical current in conductors and insulators. By contrast, many parameters used to predict failures follow from empirical studies and the application of statistical analysis to actual failures. For example, experiments in the 1930s showed that measurement of forces on bearings can be accomplished by measuring the total movement of the machine during operation along with the speed of this movement. Of course, this movement is vibration. Thus, forces on bearings can be determined by measuring vibration at or near the bearings.

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Defining limits

The measurement of a physical parameter in itself is not enough to detect the destructive effects on a machine or process. As noted, it is important to establish a limit or rate of change in the parameter that may be excessive or damaging.

One method of developing a limit requires that a number of failures be observed before a safe limit is established. This method is understandably objectionable to people operating a facility. Prudent management of a PDM program requires that limits be tested at the same time as the monitoring of other factors on a device. Whenever time permits, the device in question is taken out of service and thoroughly inspected for the defect or failure mode in question. Ideally the limit will be set at a measurement value just below the point corresponding to the first discovery of irreparable or costly defects.

Many engineered limits have already been established for equipment by manufacturers, professional societies and industrial groups. For example, the *Vibration Institute*, a not-for-profit professional organization, and other organizations have established levels of equipment health as a function of vibration velocity based on experiments. A simplification of this equipment health data is shown in Table 2, "Rotating machinery ratings." This table is useful for categorizing vibration levels on *most* industrial equipment operating between 600 rpm and 3600 rpm.

Rotating Machinery Ratings

Rating	Vibration Level	Necessary Action
Good	Less than .15 ips	Continue to Trend
Fair	.15 ips to .30 ips	Continue to Trend
Poor	.30 ips & above	Analyze & Correct

Limits based on product quality

A vibration level below 0.3 ips may be acceptable for most rotating equipment, but it may not be sufficient for some processes or operations. A new area of predictive maintenance focuses not only on the reliability of the device being monitored but also on the *quality of the product* being manufactured.

For example, observation of many plastic injection molding operations reveals that vibration levels above 0.2 ips on hydraulic pumps may not result in pump failure but often result in lower product quality. Vanes on hydraulic pumps begin to wear as a normal mode of the design. As the wear increases, clearances between the vanes and the housing begin to increase. This usually results in increased vibration, but more importantly, it also results in fluctuating output pressure. Fluctuating hydraulic pressure tends to cause incomplete closure of some plastic molds. The result is a sub-standard product or excessively high rework. Rebuilding the pump when a vibration limit of 0.2 ips is reached has been found to reduce rejects and help ensure a consistent product.

To cite another example, spindle machinery used in the manufacture of precision aircraft and automotive parts often operates at speeds in excess of 10,000 rpm. Normal vibration velocity limits do not apply to this equipment.

In the past, quality inspectors used laser light gages to determine physical parameters such as roughness and waviness. They then compared these measurements to manufacturing and customer guidelines. If a part or group of parts fell outside the standards set for the process, a complete rebuilding of the spindle machinery was usually required. This after-the-fact measurement of quality became increasingly objectionable because of the costs associated with repair, downtime, and rework.

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Tests to determine if a correlation existed between the quality of the machined surface and spindle machine vibration revealed that product quality could be predicted by measuring vibration *acceleration*. So, plant personnel established new limits that reduced product rework by 93%. The new limits also helped eliminate some root problems in the machinery that were previously unknown to company engineers.

This article was written by a consultant from **New Standard Institute**, Inc. For other articles on Maintenance-related subjects, view our website at http://www.newstandardinstitute.com or contact us via email at nsi@newstandardinstitute.com or call **(203) 783-1582** to discuss the subject with one of our consultants.

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