2 Fundamental Requirements of Effective Preventive/Predictive Maintenance

When most people think of preventive maintenance, they visualize scheduled, fixed interval maintenance that is done every day, every month, every quarter, every season, or at some other predetermined intervals. Timing may be based on days, or on intervals such as miles, gallons, activations, or hours of use. The use of performance intervals is itself a step toward basing preventive tasks on actual need, instead of just on a generality.

The two main elements of fixed interval preventive maintenance are procedure and discipline. Procedure means that the correct tasks are done, the right lubricants applied, and consumables replaced at the best interval. Discipline requires that all the tasks are planned and controlled so that everything is done when it should be done. Both these areas deserve attention. The topic of procedures is covered in detail in following sections.

Discipline is a major problem in many organizations. This is obvious when one considers the fact that many organizations do not have an established program. Further, organizations that do claim to have a program often fail to establish a good planning and control procedure to assure accomplishment. Elements of such a procedure include:

1 Listing of all equipment and the intervals at which it must receive PMs;

2 A master schedule for the year that breaks down tasks by month, week, and possibly even by the day;

3 Assignment of responsible persons to do the work;

4 Inspection by the responsible supervisor to make sure that quality work is done on time;

5 Updating of records to show when the work was done and when the next preventive task is due;

6 Follow-up as necessary to correct any discrepancies.

Fundamental Requirements of Effective Maintenance

Effective maintenance is not magic, nor is it dependent on exotic technologies or expensive instruments or systems. Instead, it is dependent on doing simple, basic tasks that will result in reliable plant systems. These basics include:

Inspections

Careful inspection, which can be done without "tearing down" the machine, saves both technician time and exposure of the equipment to possible damage. Rotating components find their own best relationship to surrounding components. For example, piston rings in an engine or compressor cylinder quickly wear to the cylinder wall configuration. If they are removed for inspection, chances are that they will not easily fit back into the same pattern. As a result, additional wear will occur, and the rings will have to be replaced much sooner than if they were left intact and performance-tested for pressure produced and metal particles in the lubricating oil.

Human Senses

We humans have a great capability for sensing unusual sights, sounds, smells, tastes, vibrations, and touches. Every maintenance manager should make a concerted effort to increase the sensitivity of his own and that of his personnel's human senses. Experience is generally the best teacher. Often, however, we experience things without knowing what we are experiencing. A few hours of training in what to look for could have high payoff.

Human senses are able to detect large differences but are generally not sensitive to small changes. Time tends to have a dulling effect. Have you ever tried to determine if one color was the same as another without having a sample of each to compare side by side? If you have, you will understand the need for standards. A standard is any example that can be compared to the existing situation as a measurement. Quantitative specifications, photographs, recordings, and actual samples should be provided. The critical parameters should be clearly marked on them with displays as to what is good and what is bad.

As the reliability-based preventive maintenance program develops, samples should be collected that will help to pinpoint with maximum accuracy how much wear can take place before problems will occur. A display where craftsmen gather can be effective. A framed $4' \times 4'$ pegboard works well since shafts, bearings, gears, and other components can be easily wired to it or hung on hooks for display. An effective, but little used, display area where notices can be posted is above the urinal or on the inside of the toilet stall door. Those are frequently viewed locations and allow people to make dual use of their time.

Sensors

Since humans are not continually alert or sensitive to small changes and cannot get inside small spaces, especially when operating, it is necessary to use sensors that will measure conditions and transmit information to external indicators.

Sensor technology is progressing rapidly; there have been considerable improvements in capability, accuracy, size, and cost. Pressure transducers, temperature thermocouples, electrical ammeters, revolution counters, and a liquid height level float are examples found in most automobiles.

Accelerometers, eddy-current proximity sensors, and velocity seismic transducers are enabling the techniques of motion, position, and expansion analysis to be increasingly applied to large numbers of rotating equipment. Motors, turbines, compressors, jet engines, and generators can use vibration analysis. The normal pattern of operation, called its "signature," is established by measuring the performance of equipment under known good conditions. Comparisons are made at routine intervals, such as every thirty days, to determine if any of the parameters are changing erratically, and further, what the effect of such changes may be.

The *spectrometric oil analysis* process is useful for any mechanical moving device that uses oil for lubrication. It tests for the presence of metals, water, glycol, fuel dilution, viscosity, and solid particles. Automotive engines, compressors, and turbines all benefit from oil analysis. Most major oil companies will provide this service if you purchase lubricants from them.

The major advantage of spectrometric oil analysis is early detection of component wear. Not only does it evaluate when oil is no longer lubricating properly and should be replaced, it also identifies and measures small quantities of metals that are wearing from the moving surfaces. The metallic elements found, and their quantity, can indicate what components are wearing and to what degree so that maintenance and overhaul can be carefully planned. For example, presence of chrome would indicate cylinder-head wear, phosphor bronze would probably be from the main bearings, and stainless steel would point toward lifters. Experience with particular equipment naturally leads to improved diagnosis.

Thresholds

Now that instrumentation is becoming available to measure equipment performance, it is still necessary to determine when that performance is "go" and when it is "no go." A human must establish the threshold point, which can then be controlled by manual, semiautomatic, or automatic means. First, let's decide how the threshold is set and then discuss how to control it.

To set the threshold, one must gather information on what measurements can exist while equipment is running safely and what the measurements are just prior to or at the time of failure. Equipment manufacturers, and especially their experienced field representatives, will be a good starting source of information. Most manufacturers will run equipment until failure in their laboratories as part of their tests to evaluate quality, reliability, maintainability, and maintenance procedures. Such data are necessary to determine under actual operating conditions how much stress can be put on a device before it will break. Many devices, such as nuclear reactors and flying airplanes, should not be taken to the breaking point under operating conditions, but they can be made to fail under secure test conditions so that the knowledge can be used to keep them safe during actual use.

Once the breaking point is determined, a margin of safety should be added to account for variations in individual components, environments, and operating conditions. Depending on the severity of failure, that safety margin could be anywhere from one to three standard deviations before the average failure point. One standard deviation on each side of the mean will include 68% of all variations, two standard deviations include 95%, and three standard deviations are 98.7%. Where our mission is to prevent failures, however, only the left half of the distribution is applicable. This single-sided distribution also shows that we are dealing with probabilities and risk.

The earlier the threshold is set and effective preventive maintenance done, the greater is the assurance that it will be done prior to failure. If the mean time between failures (MTBF) is 9,000 miles with a standard deviation of 1,750 miles, then proper preventive maintenance at 5,500 miles could eliminate almost 98% of the failures. Note the word "proper," meaning that no new problems are injected. That also means, however, that costs will be higher than need be since components will be replaced before the end of their useful life, and more labor is required.

Once the threshold set point has been determined, it should be monitored to detect when it is exceeded. The investment in monitoring depends on the period over which deterioration may occur, means of detection, and benefit value. If failure conditions build up quickly, a human may not easily detect the condition, and the relatively high cost of automatic instrumentation will be repaid.

Lubrication

Friction of two materials moving relative to each other causes heat and wear. Friction-related problems cost industries over $1 billion per annum. Technology intended to improve wear resistance of metal, plastics, and other surfaces in motion has greatly improved over recent years, but planning, scheduling, and control of the lubricating program is often reminiscent of a plant handyman wandering around with his long-spouted oil can.

Anything that is introduced onto or between moving surfaces in order to reduce friction is called a lubricant. Oils and greases are the most commonly used substances, although many other materials may be suitable. Other liquids and even gases are being used as lubricants. Air bearings, for example, are used in gyroscopes and other sensitive devices in which friction must be minimal. The functions of a lubricant are to:

1 Separate moving materials from each other in order to prevent wear, scoring, and seizure;

2 Reduce heat;

3 Keep out contaminants;

4 Protect against corrosion;

5 Wash away worn materials.

Good lubrication requires two conditions: sound technical design for lubrication and a management program to assure that every item of equipment is properly lubricated.

Lubrication Program Development

Information for developing lubrication specifications can come from four main sources:

1 Equipment manufacturers;

2 Lubricant vendors;

3 Other equipment users;

4 Individuals' own experience.

Like most other preventive maintenance elements, initial guidance on lubrication should come from manufacturers. They should have extensive experience with their own equipment both in their test laboratories and in customer locations. They should know what parts wear and are frequently replaced. Therein lies a caution: a manufacturer could, in fact, make short-term profits by selling large numbers of spare parts to replace worn ones. Over the long term, however, that strategy will backfire, and other vendors, whose equipment is less prone to wear and failure, will replace them.

Lubricant suppliers can be a valuable source of information. Most major oil companies will invest considerable time and effort in evaluating their customers' equipment to select the best lubricants and intervals for change. Naturally, these vendors hope that the consumer will purchase their lubricants, but the total result can be beneficial to everyone. Lubricant vendors perform a valuable service of communicating and applying knowledge gained from many users to their customers' specific problems and opportunities.

Experience gained under similar operating conditions by other users or in your own facilities can be one of the best teachers. Personnel, including operators and mechanics, have a major impact on lubrication programs.

A major step in developing the lubrication program is to assign specific responsibility and authority for the lubrication program to a competent maintainability or maintenance engineer. The primary functions and steps involved in developing the program are to:

1 Identify every piece of equipment that requires lubrication;

2 Assure that all major equipment is uniquely identified, preferably with a prominently displayed number;

3 Assure that equipment records are complete for manufacturer and physical location;

4 Determine locations on each piece of equipment that needs to be lubricated;

5 Identify lubricant to be used;

6 Determine the best method of application;

7 Establish the frequency or interval of lubrication;

8 Determine if the equipment can be safely lubricated while operating, or if it must be shut down;

9 Decide who should be responsible for any human involvement;

10 Standardize lubrication methods;

11 Package the above elements into a lubrication program;

12 Establish storage and handling procedures;

13 Evaluate new lubricants to take advantage of state of the art;

14 Analyze any failures involving lubrication and initiate necessary corrective actions.

An individual supervisor in the maintenance department should be assigned the responsibility for implementation and continued operation of the lubrication program. This person's primary functions are to:

1 Establish lubrication service actions and schedules;

2 Define the lubrication routes by building, area, and organization;

3 Assign responsibilities to specific persons;

4 Train lubricators;

5 Assure supplies of proper lubricants through the storeroom;

6 Establish feedback that assures completion of assigned lubrication and follows up on any discrepancies;

7 Develop a manual or computerized lubrication scheduling and control system as part of the larger maintenance management program;

8 Motivate lubrication personnel to check equipment for other problems and to create work requests where feasible;

9 Assure continued operation of the lubrication system.

It is important that a responsible person who recognizes the value of thorough lubrication be placed in charge. As with any activity, interest diminishes over time, equipment is modified without corresponding changes to the lubrication procedures, and state-of-the-art advances in lubricating technology may not be undertaken. A factory may have thousands of lubricating points that require attention. Lubrication is no less important to computer systems, even though they are often perceived as electronic. The computer field engineer must provide proper lubrication to printers, tape drives, and disks that spin at 3,600 rpm. A lot of maintenance time is invested in lubrication. The effect on production uptime can be measured nationally in billions of dollars.

Calibration

Calibration is a special form of preventive maintenance whose objective is to keep measurement and control instruments within specified limits. A "standard" must be used to calibrate the equipment. Standards are derived from parameters established by the National Bureau of Standards (NBS). Secondary standards that have been manufactured to close tolerances and set against the primary standard are available through many test and calibration laboratories and often in industrial and university tool rooms and research labs. Ohmmeters are examples of equipment that should be calibrated at least once a year and before further use if subjected to sudden shock or stress.

The government sets forth calibration system requirements in MIL-C-45662 and provides a good outline in the military standardization handbook MIL-HDBK-52, *Evaluation of Contractor's Calibration System.* The principles are equally applicable to any industrial or commercial situation. The purpose of a calibration system is to provide for the prevention of tool inaccuracy through prompt detection of deficiencies and timely application of corrective action. Every organization should prepare a written description of its calibration system. This description should cover the measuring of test equipment and standards, and should:

1 Establish realistic calibration intervals;

2 List all measurement standards;

3 List all environmental conditions for calibration;

4 Ensure the use of calibration procedures for all equipment and standards;

5 Coordinate the calibration system with all users;

6 Assure that equipment is frequently checked by periodic system or cross-checks in order to detect damage, inoperative instruments, erratic readings, and other performance degrading factors that cannot be anticipated or provided for by calibration intervals;

7 Provide for timely and positive correction action;

8 Establish decals, reject tags, and records for calibration labeling;

9 Maintain formal records to assure proper controls.

The checking interval may be in terms of time—hourly, weekly, monthly—or based on amount of use—every 5,000 parts, or every lot. For electrical test equipment, the *power-on* time may be the critical factor and can be measured through an electrical elapsed-time indicator.

Adherence to the checking schedule makes or breaks the system. The interval should be based on stability, purpose, and degree of usage. If initial records indicate that the equipment remains within the required accuracy for successive calibrations, then the intervals may be lengthened. On the other hand, if equipment requires frequent adjustment or repair, the intervals should be shortened. Any equipment that does not have specific calibration intervals should be (1) examined at least every six months, and (2) calibrated at intervals of no longer than one year. Adjustments or assignment of calibration intervals should be done in such a way that a minimum of 95% of equipment, or standards of the same type, is within tolerance when submitted for regularly scheduled recalibration. In other words, if more than 5% of a particular type of equipment is out of tolerance at the end of its interval, then the interval should be reduced until less than 5% is defective when checked.

A record system should be kept on every instrument, including:

1 History of use;

2 Accuracy;

3 Present location;

4 Calibration interval and when due;

5 Calibration procedures and necessary controls;

6 Actual values of latest calibration;

7 History of maintenance and repairs.

Test equipment and measurement standards should be labeled to indicate the date of last calibration, by whom it was calibrated, and when the next calibration is due. When the size of the equipment limits the application of labels, an identifying code should be applied to reflect the serviceability and due date for the next calibration. This provides a visual indication of the calibration serviceability status. Both the headquarters calibration organization and the instrument user should maintain a two-way check on calibration. A simple means of doing this is to have a small form for each instrument with a calendar of weeks or months (depending on the interval required) across the top, which can be punched and noticed to indicate the calibration due date.

Planning and Estimating

Planning is the heart of good inspection and preventive maintenance. As described earlier, the first thing to establish is what items must be maintained and what the best procedure is for performing that task. Establishing good procedures requires a good deal of time and talent. This can be a good activity for a new graduate engineer, perhaps as part of a training process that rotates him or her through various disciplines in a plant or field organization. This experience can be excellent training for a future design engineer.

Writing ability is an important qualification, along with pragmatic experience in maintenance practices. The language used should be clear and concise, using short sentences. Who, what, when, where, why, and how should be clearly described. The following points should be noted from this typical procedure:

1 Every procedure has an identifying number and title;

2 The purpose is outlined;

3 Tools, reference documents, and any parts are listed;

4 Safety and operating cautions are prominently displayed;

5 A location is clearly provided for the maintenance mechanic to indicate performance as either satisfactory or deficient. If deficient,

details are written in the space provided at the bottom for planning further work.

The procedure may be printed on a reusable, plastic-covered card that can be pulled from the file, marked, and returned when the work order is complete; on a standard preprinted form; or on a form that is uniquely printed by computer each time a related work order is prepared. Whatever the medium of the form, it should be given to the preventive maintenance craftsperson together with the work order so that he has all the necessary information at his fingertips. The computer version has the advantage of single-point control that may be uniformly distributed to many locations. This makes it easy for an engineer at headquarters to prepare a new procedure or to make any changes directly on the computer and have them instantly available to any user in the latest version.

Two slightly different philosophies exist for accomplishing the unscheduled actions that are necessary to repair defects found during inspection and preventive maintenance. One is to fix them on the spot. The other is to identify them clearly for later corrective action. If a "priority one" defect that could hurt a person or cause severe damage is observed, the equipment should be immediately stopped and "46 red tagged" so that it will not be used until repairs are made. Maintenance management should establish a guideline such as, "Fix anything that can be corrected within ten minutes, but if it will take longer, write a separate work request." The policy time limit should be set based on:

1 Travel time to that work location;

2 Effect on production;

3 Need to keep the craftsperson on a precise time schedule.

The inspector who finds them can effect many small repairs the most quickly. This avoids the need for someone else to travel to that location, identify the problem, and correct it. And it provides immediate customer satisfaction. More time-consuming repairs would disrupt the inspector's plans, which could cause other, even more serious problems to go undetected. The inspector is like a general practitioner, who performs a physical exam and may give advice on proper diet and exercise but who refers any problems he may find to a specialist.

The inspection or preventive maintenance procedure form should have space where any additional action required can be indicated. When the procedure is completed and turned into maintenance control, the planner or scheduler should note any additional work required and see that it gets done according to priority.

Estimating Time

Since inspection or preventive maintenance is a standardized procedure with little variation, the tasks and time required can be accurately estimated. Methods of developing time estimates include consideration of such resources as:

1 Equipment manufacturers' recommendations;

2 National standards such as *Chilton's* on automotive or *Means'* for facilities;

3 Industrial engineering time-and-motion studies;

4 Historical experience.

Experience is the best teacher, but it must be carefully critiqued to make sure that the "one best way" is being used and that the pace of work is reasonable.

The challenge in estimating is to plan a large percentage of the work (preferably at least 90%) so that the time constraints are challenging but achievable without a compromise in high quality. The trade-off between reasonable time and quality requires continuous surveillance by experienced supervisors. Naturally, if a maintenance mechanic knows that his work is being time studied, he will follow every procedure specifically and will methodically check off each step of the procedure. When the industrial engineer goes away, the mechanic will do what he feels are necessary items, in an order that may or may not be satisfactory. As discussed earlier in regard to motivation, an experienced preventive maintenance inspector mechanic can vary performance as much as 50% either way from the standard without most maintenance supervisors recognizing a problem or opportunity for improvement. Periodic checking against national or time-and-motion standards, as well as trend analysis of repetitive tasks, will help keep preventive task times at a high level of effectiveness.

Estimating Labor Cost

Cost estimates follow from time estimates simply by multiplying the hours required by the required labor rates. Beware of coordination problems where multiple crafts are involved. For example, one Fortune 100 company has trade jurisdictions that require the following personnel in order to remove an electric motor: a tinsmith to remove the cover, an electrician to disconnect the electrical supply, a millwright to unbolt the mounts, and one or more laborers to remove the motor from its mound. That situation is fraught with inefficiency and high labor costs, since all four trades must be scheduled together, with at least three people watching while the fourth is at work. The cost will be at least four times what it could be, and is often greater if one of the trades does not show up on time. The best a scheduler can hope for is if he has the latitude to schedule the cover removal at, say, 8:00 A.M., and the other functions at reasonable time intervals thereafter: electrician at 9:00, millwright at 10:00, and laborers at 11:00.

It is recommended that estimates be prepared on "pure" time. In other words, the exact hours and minutes that would be required under perfect scheduling conditions should be used. Likewise, it should be assumed that equipment would be immediately available from production. Delay time should be reported, and scheduling problems should be identified so that they can be addressed separately from the hands-on procedure times. Note that people think in hours and minutes, so one hour and ten minutes is easier to understand than 1.17 hours.

Estimating Materials

Most parts and materials that are used for preventive maintenance are well known and can be identified in advance. The quantity of each item planned should be multiplied by the cost of the item in inventory. The sum of those extended costs will be the material cost estimate. Consumables such as transmission oil should be enumerated as direct costs, but grease and other supplies used from bulk should be included in overhead costs.

Scheduling

Scheduling is, of course, one of the advantages to doing preventive maintenance over waiting until equipment fails and then doing emergency repairs. Like many other activities, the watchword should be "PADA," which stands for "Plan a Day Ahead." In fact, the planning for inspections and preventive activities can be done days, weeks, and even months in advance in order to assure that the most convenient time for production is chosen, that maintenance parts and materials are available, and that the maintenance workload is relatively uniform.

Scheduling is primarily concerned with balancing demand and supply. Demand comes from the equipment's need for preventive maintenance. Supply is the availability of the equipment, craftspeople, and materials that are necessary to do the work. Establishing the demand is partially covered in the chapters on on-condition, condition monitoring, and fixed interval preventive maintenance tasks. Those techniques identify individual equipment as candidates for PM.

Coordination with Production

Equipment is not always available for preventive maintenance just when the maintenance schedulers would like it to be. An overriding influence on coordination should be a cooperative attitude between production and maintenance. This is best achieved by a meeting between the maintenance manager and production management, including the foreman level, so that what will be done to prevent failures, how this will be accomplished, and what production should expect to gain in uptime may all be explained.

The cooperation of the individual machine operators is of prime importance. They are on the spot and most able to detect unusual events that may indicate equipment malfunctions. Once an attitude of general cooperation is established, coordination should be refined to monthly, weekly, daily, and possibly even hourly schedules. Major shutdowns and holidays should be carefully planned so any work that requires "cold" shutdown can be done during those periods. Maintenance will often find that they must do this kind of work on weekends and holidays, when other persons are on vacation. Normal maintenance should be coordinated according to the following considerations:

1 Maintenance should publish a list of all equipment that is needed for inspections, preventive maintenance, and modifications, and the amount of cycle time that such equipment will be required from production.

2 A maintenance planner should negotiate the schedule with production planning so that a balanced workload is available each week.

3 By Wednesday of each week, the schedule for the following week should be negotiated and posted where it is available to all concerned; it should be broken down by days.

4 By the end of the day before the preventive activity is scheduled, the maintenance person who will do the PM should have seen the first-line

production supervisor in charge of the equipment to establish a specific time for the preventive task.

5 The craftsperson should make every effort to do the job according to schedule.

6 As soon as the work is complete, the maintenance person should notify the production supervisor so that the equipment may be put back into use.

Overdue work should be tracked and brought up-to-date. Preventive maintenance scheduling should make sure that the interval is maintained between preventive actions. For example, if a preventive task for May is done on the thirtieth of the month, the next monthly task should be done during the last week of June. It is foolish to do a preventive maintenance task on May 30th and another June 1st, just to be able to say one was done each month. In the case of preventive maintenance, the important thing is not the score but how the game was played.

Assuring Completion

A formal record is desirable for every inspection and preventive maintenance job. If the work is at all detailed, a checklist should be used. The completed checklist should be returned to the maintenance office on completion of the work. Any open preventive maintenance work orders should be kept on report until the supervisor has checked the results for quality assurance and signed off approval. Modern computer technology with handheld computers and pen-based electronic assistants permits paperless checklists and verification. In many situations, a paper work order form is still the most practical media for the field technician. The collected data should then be entered into a computer system for tracking.

Record Keeping

The foundation records for preventive maintenance are the equipment files. In a small operation with less than 200 pieces of complex equipment, the records can easily be maintained on paper. The equipment records provide information for purposes other than preventive maintenance. The essential items include:

- Equipment identification number;
- Equipment name;

- Equipment product/group/class;
- Location;
- Use meter reading;
- PM interval(s)
- Use per day;
- Last PM due;
- Next PM due;
- Cycle time for PM;
- Crafts required, number of persons, and time for each;
- Parts required.

Back to Basics

Obviously, effective maintenance management requires much more than these fundamental tasks. However, these basic tasks must be the foundation of every successful maintenance program. The addition of other tools, such as CMMS, predictive maintenance, etc., cannot replace them.