# PLANNED PREVENTIVE MAINTENANCE—THE KEY TO LOWER OPERATING COSTS FOR ENGINES AND COMPRESSORS

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## INTRODUCTION

Know-how about things mechanical is a part of our national character. The knack of making complicated machinery work is an American tradition. Good old "Yankee Ingenuity" applied to machines has produced countless achievements from the steamboat of yesteryear to Apollo 17 of today. Equally outstanding but not so well known examples of this native ability of ours are the stationary gas engines and reciprocating compressors found in the oil and gas industry. These machines, in various forms, have been around for well over 50 years and it is not at all uncommon to find 30-year-old installations still operating at full capacity, day in and day out. They range from small units of a few horsepower to giants of several thousand horsepower.

These machines have served the oil and gas industry exceptionally well for a long time under extreme service conditions. Their durability and efficient performance certainly are a tribute to their designers and builders, and to the people who have operated and maintained them through the years.

The purpose of this paper is to take a critical look at the "current state of the art" concerning the operation and maintenance of these machines and to comment in general on the subject of preventive maintenance in an effort to put some of the many aspects in proper perspective. The topic is far too broad and complex to cover in specific terms and each individual installation has many unique features that require special consideration. Therefore, this review will only attempt to point out certain guidelines and critical requirements that in the writer's opinion a sound preventive maintenance program should have. Then each location can be examined to determine if present methods have any deficiencies that should be changed.

## IS PREVENTIVE MAINTENANCE NECESSARY?

The extent to which gas engine/compressor units are maintained has always varied from a "run it 'til it quits" sort of do-nothing negative approach that might be associated with a "poor boy" type of marginal operation, to a "regular complete overhaul" kind of elaborate program that could be regarded as "gold plated" and is usually only found as part of a highly profitable venture. The "poor boy" extreme will always exist but probably can never be justified; the "gold plated" extreme is very costly but has some strong points. Either of these is expensive and somewhere in between there is an optimum that will provide adequate service from the equipment at a minimum cost.

If you are responsible for gas engine/gas compressor operation, it is your job to keep this equipment in safe, reliable running condition at the lowest possible cost. This means that you should be following applicable governmental regulations, industry codes, and company guidelines to insure that the equipment operates with minimum risk to the safety of personnel and property. You also must see that it can be depended on to perform as required to handle the duties that it was designed and installed for. It is equally essential that these requirements be accomplished at a cost low enough to permit the facility to earn an adequate profit on the money invested in it. The achievement of safe reliable operation at an affordable cost is difficult, at best, and is continually getting harder to do.

If you don't have a solid plan for performing your maintenance work, you may be failing your responsibility on all three counts.

For many years, preventive maintenance was done on engine/compressor units on a time basis. Parts and labor were much less costly then and engineering knowledge was not as advanced; so in many cases it was a sound practice to do regularly scheduled dismantling inspections and complete overhauls in order to get the maximum service from the equipment and minimize major breakdowns. However, it was very easy to overdo this sort of preventive maintenance program. Unnecessary work was often done, requiring too much manpower. Normally operating parts such as bearings and piston rings were disturbed and frequently replaced even though the amount of wear was nominal. The result was that valuable down-time was wasted requiring larger maintenance crews. In addition, large warehouse stocks of spare parts were required to support such an elaborate program. All of this caused costs to be high and many had reservations about preventive maintenance programs such as this because the justification was questionable in most cases.

The rapid increase in labor and parts costs in recent years, as part of the general price-cost squeeze that business has been faced with, has made it necessary to reduce expenses. This meant that preventive maintenance programs had to be trimmed way back or almost scrapped altogether in many places.

Things usually didn't go completely to pieces because of this change in maintenance practice. Most plants found that longer periods of operation were possible without complete overhauls, and major breakdowns and excessive down-time were not occurring with great frequency. Most locations abandoned time-based preventive maintenance nearly altogether, and much of the industry began to perform more on-line inspections with special analyzer instruments to predict when a moving part might fail and added safety shutdowns to protect the machinery in case of a random failure or malfunction of a component.

The development of these types of devices and the greater engineering knowledge that went into improving mechanical designs, metallurgy, lubricants, and lubrication systems, all combined to make possible better reliability from the machinery with less down-time and expense. This has been offset, at least in part, by closer design on new equipment and the uprating of existing machines to increase the work load required from them. Examples of this have been the emergence of high speed turbocharged four-cycle engines, and the turbocharging of existing two-cycle engines to get more horsepower at lower initial cost with the expectation that maintenance costs would be higher.

The evolvement of all these trends in recent years has left the concept of preventive maintenance on a planned basis is no longer neces- somewhat clouded and confused. The result has been that some locations may be paying for a "program" that provides spotty coverage at best and often overlooks many common-sense low-cost methods that were used in the past but have largely been discarded in the rush to reduce costs by adopting new "gadgets" without integrating them into an overall plan.

Does all of this mean that preventive maintenance on a planned basis is no longer necessary and justifiable? Not at all. It means that an effective and economical preventive maintenance program which will give the equipment thorough coverage must be designed to incorporate all of the applicable technology and thereby reduce the cost of labor and parts required to perform only essential and timely inspection and maintenance which will keep engines and compressors in sound dependable operating condition.

## THE ESSENTIALS OF GOOD PREVENTIVE MAINTENANCE

A good preventive maintenance program for engines and compressors should be planned around five basic elements, (Fig. 1):

1. A well-designed lubrication system that provides the proper amount of lubricant to all vital points, using quality lubricants compounded for that service
2. A carefully engineered operation monitoring and safeguard system that maintains reliable surveillance of all critical functions of the machinery
3. Regular daily routine on-line operations checks and minor running maintenance
4. Scheduled down-time inspection, testing, tune-up, and simple repairs

5. A program of diagnostic inspection by engine/compressor analyzer and/or lubricating oil spectrographic analysis for wear metals.

Such a program must be geared to each installation; and it must be firmly established and diligently carried out. Adequate records must also be kept on each piece of equipment to provide a good history of work done and costs.

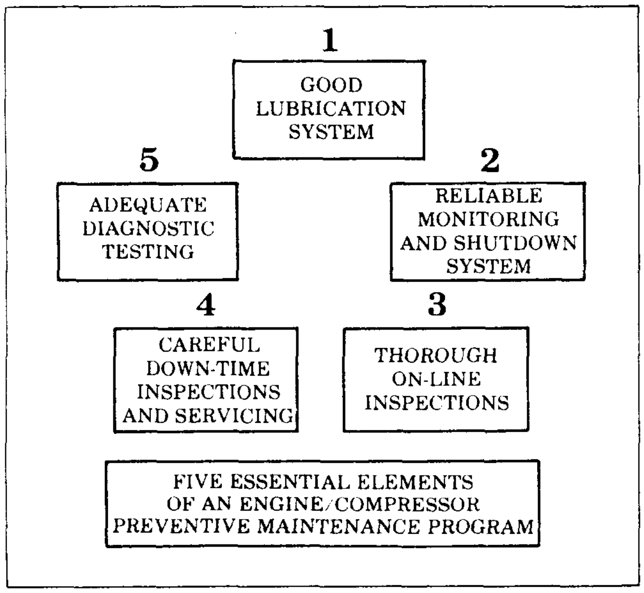


FIG. 1

The maintenance supervisor should design a preventive maintenance program for each engine/compressor unit with consideration for the type of equipment, service severity, location accessibility, quality of installation, and critical nature of the operation. The manufacturer's recommendations along with one's own experiences should establish the criteria for inspection and maintenance of each component of the installation. The plan must strive at upgrading the condition of the equipment to increase reliability, reduce down-time, eliminate unneoessary wear and tear, and reduce unneeded labor costs. The emphasis must be on improving techniques for locating and correcting minor problems before they develop into major ones, not on increasing proficiency at making repairs.

Manufacturers recommend definite procedures for installation and operation of their equipment and these generally are followed fairly well in the beginning. However, the usual tendency is to relax in keeping close to the instructions, and a degree of inattention sets in. Certainly, once a piece of equipment is operating normally there is no need to watch it constantly, but regular routine inspections recommended by the manufacturer should not be abandoned. If trouble-free operation and efficient performance are to be expected at a reasonable cost, a well-designed preventive maintenance program is essential. Extensive inspection and testing procedures are costly and cannot be justified; furthermore, they are not necessary.

Many advances have been made in mechanical design, materials, lubricants, lubrication systems, safety shutdown devices and diagnostic instruments. Equipment today is generally more reliable than it used to be and major breakdowns occur less frequently even though the equipment is operated under more severe conditions. This is possible because in nearly all cases, minor defects can be detected and corrected before they develop into big problems, if a well-planned and executed preventive maintenance program is used.

## ENGINE AND COMPRESSOR SERVICING

Before going into the details of the basic elements of a preventive maintenance program it seems appropriate to include some comments on the general subject of servicing engine and compressor equipment. After so much emphasis on the importance of preventive maintenance inspections and testing, we might tend to lose sight of the fact that parts do wear out no matter how carefully we try to protect them to extend their service life and prevent major breakdowns. It is inevitable that you will have to spend between $5 and $30 per year per installed horsepower for labor and parts to keep your machinery operating safely, reliably, and efficiently.

Every engine and compressor manufacturer has recommended servicing schedules that are provided for his equipment. These are usually based on a time schedule for each component. Although preventive maintenance is probably no longer economical on a straight time schedule as these usually recommend, it is worthwhile to review the typical service and maintenance requirements for this type of equipment.

*Most Frequent Inspection and Service*
(Daily, weekly, or monthly regularity)

*Air Intake System*
Clean air filters
Check turbocharger

*Fuel Gas System*
Check scrubber
Check governor
Check metering valve setting
Check regulators
Check injection valves
Reset tappet clearance

*Ignition System*
Clean spark plugs, check and replace if necessary
Check wiring and connections
Check magneto breaker points and regap if needed

*Exhaust System*
Clean exhaust valves, regrind if needed
Reset tappet clearance

*Lubricating System*
Check oil filters, clean or replace as needed
Check external lines and connections for leaks
Check lubricator

*Jacket Water System*
Check pump packing
Check lines and connections for leaks
Check cylinder jackets for leaks
Check pump driving equipment

*Starting Air System*
Drain air volume tanks
Check air pressure
Check air compressor operating condition, lubrication, etc.
Check air lines

*Compressor*
Check lubrication
Check rod packing
Check suction and discharge valves
Check clearance pockets

*Engine*
Check exhaust temperatures
Check power cylinder pressures
Check engine balance
Take indicator cards

*General*
Check loose nuts, bolts, connections

*Moderately Frequent Inspection and Service*
(Bi-monthly, quarterly and semi-annual regularity)

*Air Intake System*
Check intake manifold condition
Check regulating valve
Clean after-cooler

*Fuel Gas System*
Clean gas timing valves
Grind intake valves
Check meter

*Ignition System*
Check coils

*Exhaust System*
Check pyrometer thermocouples
Check pyrometer wiring

*Lubricating System*
Oil change
Crankcase cleanout
Oil analysis
Check oil pump and driver
Check oil cooler
Check crank case breather

*Jacket Water System*
Water passages cleanout, both engine and compressor

*Starting Air System*
Check air starting valve
Check relief valves
Starting air compressor valves
Check air distributor

*Compressor*
Clean suction and discharge valves
Clean valve ports
Clean clearance pocket valves
Clean clearance pockets

*Engine*
Check governor operation

*General*
Test all controls
Test all alarms
Test all shutdowns
Check all anchor bolts

*Infrequent Inspection and Service*
(Annual or bi-annual regularity)

*Air Intake System*
Overhaul turbocharger
Check inlet valve guides

*Fuel Gas System*
Scrubber and piping cleanout
Regasket and repack fittings and valves

*Ignition System*
Magneto overhaul
Check ground connections
Check switches

*Exhaust System*
Replace manifold gaskets
Check manifold
Check exhaust valve guides
Check muffler
Check piping

*Lubricating System*
Piping cleanout
Oil pump overhaul
Passages cleanout
Test relief valves
Test check valves
Replace gaskets

*Jacket Water System*
Clean out jackets and passages
Pump overhaul
Check packing
Overhaul pump driving equipment

*Starting Air System*
Clean air tanks and lines
Overhaul air compressor
Replace gaskets

*Compressor*
Overhaul suction and discharge valves
Overhaul valve seats and guards
Renew gaskets
Inspect cylinder bore
Inspect pistons and piston rings
Check piston rod packing
Repack clearance pocket control valves

*Engines*
Clean power pistons
Check piston rings
Check main bearings
Check crank pin bearings
Check wrist pin bushings
Check crankshaft deflection and wear
Check cylinder liners
Check timing gear
Check springs
Check cams
Check camshaft bearings
Check cam rollers
Check push rods
Check push rod guides
Overhaul governor
Check fly wheel fit

*General*
Test pressure gauges
Test thermometers
Check controller linkages

This list won't fit all situations and individual makes of equipment; particular installations may have different components and priorities for checking.

The function of a planned preventive maintenance program, then, is to perform the servicing, inspection and testing phase of the overall maintenance requirements as thoroughly as possible with a minimum of down-time and at the lowest possible cost. This will largely eliminate major breakdowns and malfunctions and permit the necessary repairs to be made on a scheduled basis.

A preventive maintenance program designed on the five basic elements and utilizing new technology as well as long-established practical methods can successfully meet all of these requirements for sound engine/compressor operation and maintenance at the lowest possible price.

## LUBRICATION

The importance of proper lubricants and a sound lubrication system (Fig. 2) cannot be overstated. This is not the place to try to save money on a new installation; and it should be examined very critically when frequent or unusual problems arise on existing equipment.

The equipment manufacturer's recommendations should be followed in selecting lubricants for a particular application. Most lubricating oil manufacturers offer suitable lubricants for just about any service and usually have oils and greases of superior quality that exceed the factory recommendation. Be cautious about using high-performance specialty lubricants; they may be great for some specific applications or narrow range of conditions, but might not be best suited for your particular installation; or, as is more often the case, you may be paying for a premium product that is of no great benefit to your equipment. Check with the engine or compressor manufacturer and the lubricant manufacturer first before trying such oils; it may save you some problems and some money.

The lubrication system's function is to reduce friction between moving parts, to prevent corrosion, to remove heat and combustion products, and to seal rings, packing, and valves. To do this properly it must put the right amount of oil in the right places. Too much oil in some places is almost as harmful as too little. Engine and compressor rings can accumulate excessive deposits if too much oil is supplied. This applies to compressor rod packing as well. Excessive oil consumption is also very costly. Lubrication rates should be met according to the manufacturer's recommendation and checked regularly. If local practice is greatly different from the manufacturer's recommendation, the reasons should be checked and reconfirmed.

**1**

LUBRICATION SYSTEMS ESSENTIALS

- GOOD SYSTEMS DESIGN
- GOOD FILTRATION EQUIPMENT
- PROPER LUBRICANTS
- CORRECT LUBRICATION RATES
- REGULAR LUBRICANT TESTING

FIG. 2

Cleanliness is an absolute must in any oil system. Dirt, abrasives, water, and diluents must be kept out in any circumstance; their effect on moving parts requires no description. Filters must be checked regularly and changed when needed. Dirty gas is often the source of oil contamination. Properly designed and sized scrubbers are effective in controlling this source of trouble.

Lubricating oil must be tested regularly to see that it is in good condition and it must be changed promptly when it reaches service limits. Engine/compressor manufacturers and oil manufacturers have specific oil condemnation limits for such properties as viscosity, suspended solids, acidity, gum, water, diluents, and perhaps others. Every location should be equipped to perform the tests or have an outside service firm do them.

Operators of high speed engines have found that the oil will reach the condemnation limits on viscosity, and perhaps other properties, in four to twelve weeks, and will change oil on a strict time-basis without the usual testing. On the other hand, slow speed engines are often run for years without requiring oil change; regular testing of the oil is important. In either case the oil should be examined regularly just to check its appearance to see that it looks normal and has not suddenly changed in color and consistency.

With the lubrication systems that are available today, there is usually no excuse for lubrication-caused problems, if they are properly maintained and regularly checked. If a lubrication problem is suspected and no apparent causes found, the equipment manufacturers should be consulted.

## SAFETY SHUTDOWNS

Every engine/compressor installation should have an adequate monitoring system (Fig. 3), that will shut down the engine whenever abnormal conditions are detected. Critical functions should at least include engine, compressor and fan vibration, cooling water temperature and pressure, high and low gas pressures, scrubber high level, high gas discharge temperature, high engine exhaust temperatures, engine overspeed, turbocharger low discharge air pressure, and lubricating oil pressure and flow.

The shutdown system should not be considered as the only line of defense against engine/compressor breakdowns. It is the last line only, to help protect the equipment and personnel in the event of sudden random failure than cannot normally be detected by any other means, and against occasional other operational upsets or malfunctions that could cause serious problems with the engine/compressor unit if not cleared up promptly. It is a serious mistake to rely only on the safeguard system to protect the machinery against major breakdown. By the time the vibration or other shutdown device does its job, the mechanical damage may have become serious.

In recent years, there have been rapid advances in the development of shutdown systems and detection elements. The equipment is much more durable, more reliable, easier to test, and simpler to maintain; but regular testing is still an absolute must for all such devices. These usually have to operate only rarely; in the meantime they can collect rust, sludge, dirt, or moisture and may not work when needed. These devices should be tested at least every six months, preferably by actually causing the engine to shut down.

**2**

MONITORING AND SHUT DOWN SYSTEM ESSENTIALS

- GOOD DESIGN
- RELIABLE COMPONENTS
- REGULAR COMPONENT TESTING PROGRAM
- ON-LINE TESTING CAPABILITY
- STRICT POLICY AGAINST BYPASSING SAFEGUARDS

FIG. 3

Another serious problem is the practice that is encountered occasionally where people intentionally deactivate these devices rather than take the time to locate and correct the problem causing the shut-down. Needless to say, this should not be tolerated under any circumstances.

To some, perhaps these monitoring systems represent total automation, and no other surveillance is necessary. This is a serious mistake. They are the only means of continuous checking available, but there are many gaps in the coverage they provide and these must be filled by other means. Perhaps eventually there will be more complete systems that can continuously check everything but this will be very costly and may be a long way off for all but the larger and more complex installations.

## DAILY ON-LINE VISUAL INSPECTION (FIG. 4)

A lot of the old-time "tricks of the trade" have been lost or discarded in recent years with the advent of a multitude of sophisticated instruments and one of the most effective and least expensive parts of a preventive maintenance program is overlooked in many cases. A lot of quick and simple routine checks can be made that tell a great deal about the condition of a machine. These don't take much time to do and they don't take a lot of experience and training to be able to do them. All that is required is a good basic knowledge of the installation and the equipment, some common sense, a kr[illegible] of observing things that your eyes, ears, n[illegible], and touch tell you, a few simple instruments, and a check list to follow to assure that nothing is overlooked.

A lot of people have an aversion to writing things down. Perhaps it is believed that they can keep everything they need to know or remember in their heads. Maybe so, but a check list can be of value to veteran and inexperienced man alike if it is posted in a prominent place by the machine. After all, even highly trained experts like astronauts and airplane pilots use them religiously in checking routine operations or carrying out critical operating procedures.

**3**

ON-LINE INSPECTION ESSENTIALS

- RELIABLE BASIC INSTRUMENTATION
- COMPREHENSIVE CHECK LIST SYSTEM
- GOOD CONCISE OPERATING PROCEDURES
- FOLLOW UP ON SUSPECTED PROBLEMS
- THOROUGH OPERATOR TRAINING

FIG. 4

Every machine should have good pressure gauges and thermometers to accurately show the operator all of the vital operating conditions. Far too often an installation will have an elaborate monitoring system but most of the gauges and thermometers will be missing or broken. When this is the case, it is fairly certain that very little on-line checking is done and one might wonder if the rest of the instrumentation is in similar shape.

Pressure gauges and thermometers should be checked regularly and replaced when defective.

A daily on-line inspection check list should include the following items:

- knocks and unusual noises
- excessive vibration
- compressor suction and discharge pressures and temperatures for all stages
- engine speed
- lubrication system pressures, flows, levels, temperatures, and filter pressure drop
- crankcase oil appearance
- compressor rod packing vent for excessive gas leakage
- compressor rod packing oil drain for discolored oil
- engine manifold pressure
- turbocharger speed and vibration
- jacket water temperatures, flows, pressures and levels
- oil and water leaks
- engine exhaust temperatures
- governor oil level
- scavenging air pressure
- fan belts
- ignition wiring
- fuel gas pressure
- fuel gas scrubber liquids
- suction and discharge scrubber liquids
- starting air receiver water level
- loose anchor bolts, crosshead bolts, head bolts, and flange bolts
- housekeeping
- others as recommended by manufacturers or learned from practical experience.

These simple checks can be made rapidly while the equipment is in operation and they require no special instruments. Mostly they are just basic common sense and careful observations by a trained and conscientious operator. They are so elementary and taken for granted, they may be overlooked. However, they can be applied to any modern installation with much benefit. Too often we tend to forget the basics and depend on exotic instruments. This can be damaging to the equipment and expensive. The instruments are here to stay and are highly recommended if used properly in a sensible way along with some good old-fashioned routine visual checking.

Some of the items listed above to be checked on a regular basis are worth discussing a bit further. Listening for unusual knocks, noise and vibration is very important as a sure sign of impending trouble, but these can be misleading. The operator or mechanic doing the checking must be familiar with the natural rhythm of the machinery in operation. Unusual knocks, noises, or vibration can be caused by a multitude of things and none of them are good. However, an experienced man can usually pinpoint the location of the abnormal sound and deduce the cause.

All operating conditions are very important and should be logged and compared to the normal by the operator. When temperatures, pressures, flows, levels, etc. are observed that are outside the normal operating range, the cause should be sought and action taken to correct it or the abnormality should be noted and rechecked for possible further changes. All too often we depend on the automation alone to tell us when problems are developing and don't take the little bit of extra time required to look things over carefully.

Discolored lubricating oil can be a vital clue to impending trouble. Part of the routine daily check should be to observe the appearance of the engine and compressor crankcase oil and the compressor rod packing drain oil. Noticeable changes in the color and appearance of the oil will indicate that something is wrong before other sensors or observations detect anything. All it takes is a critical eye and a few extra seconds per day.

In conjunction with the discussion of on-line inspections and the importance of regular careful checks by operators, it is also worthwhile to stress the vital necessity of good operating procedures for the equipment. Probably the most severe strains are placed on engines and compressors when they are being started up and loaded, and unloaded and shutdown. This stress can be greatly magnified by improper procedures, carelessness, and mistakes. Sometimes the error will result in an immediate and sometimes disastrous breakdown, but more often it just causes wear and tear equivalent to thousands of hours of normal running time and the ultimate result is a premature breakdown for which there is no apparent cause.

All operating and maintenance personnel should be carefully trained in proper startup, warming up, loading, unloading, shutdown, and emergency procedures so that they are thoroughly familiar with them. In addition, these should be written up in concise form and posted on the instrument panel board for handy reference.

Everyone should understand the serious problems that can result from excessive compressor rod loads. Major wrecks, such as broken rods, crosshead damage, pin bushing wear, and frame failures can result in just a few revolutions if rod loads are exceeded. Operating instructions should clearly point out the rod load limits and the extremes of discharge and suction pressures that must be avoided to keep within these bounds.

All too often, operating instructions are passed on to new people by word of mouth and if written procedures exist they are buried somewhere in a manual on a bookshelf. The new man may well understand what he is told, but he may forget something in an emergency and doesn't have time to check the manual. Help him to do his job right and avoid possible serious damage to equipment by posting the operating proceures where he can refer to them easily when necessary.

## SHUT DOWN INSPECTIONS, (FIG. 5)

Another basic cornerstone of any preventive maintenance program is the internal inspection of engine and compressor parts which can be performed only with the equipment shut down. The checks covered in this category include those which are quick visual inspections similar to those performed externally while the unit is operating. These can be performed during routine down-time for tune-ups and other minor servicing. Other inspections mentioned here will require additional down-time because they may need some disassembly and will take time to perform. However, they are important because often they check vital components that perhaps cannot be adequately inspected in any other way. Generally the tests in this group are necessary only on an annual or longer basis.

Whenever an engine is shut down for routine servicing such as oil changing, oil filter change, spark plug or magneto change, or any of a number of other reasons, some of the following routine checks can be made as required with little or no extra down-time:

- Check compressor rods for signs of excessive wear.
- Check compressor cylinder walls for unusual wear by pulling top valve from outboard end of compressor cylinder and, spotting the piston at crank end. A light and inspection mirror will help. (All safety precautions should be taken while doing this.)
- Check fan belts for wear.
- If oil is being changed, remove cover plate from engine crankcase and check the internals—look for metal cuttings in the crankcase, and sludge deposits and look at all bearing caps for signs of overheating, loose bolts, and other evidence of possible trouble.
- If filters are being changed, check old filter elements for metal cuttings.
- Check combustion and scavenging air filters and clean when needed.
- With crankcase open, check power cylinder liners for scuffing and wear by spotting each piston at TDC. (Take all necessary safety precautions.)
- If spark plugs are being changed, run a compression check on each power cylinder.
- Check valve tappet clearance.
- Check cylinder jackets or engine and compressor for scaling, corrosion, etc.
- Check oil and jacket water coolers for scale, corrosion, leaks, etc.
- Check any other internal inspection points that may be accessible without excessive dismantling.

**4**

DOWN-TIME INSPECTION AND SERVICING ESSENTIALS

— MAINTAIN OPERATING EFFICIENCY
— PLANNED PROGRAM
— LOOK FOR FAULTS NOT DETECTABLE OTHERWISE
— BACK UP CHECKS FOR OTHER SYSTEMS
— TAKE ACTION TO CORRECT DEFICIENCIES

FIG. 5

The normal servicing down-time affords an opportunity to perform these inspections and at whatever frequency that you have determined they should be made. Some should be performed fairly frequently, others only occasionally. All of them can be done fairly easily with a minimum of extra time and effort, very little dismantling, and no special tools or equipment.

One may feel that some of these checks are not needed and that engine analyzer, oil analysis, or other diagnostic techniques can maintain adequate surveillance over these possible sources of trouble. This is probably true in many cases and this question has to be decided in each individual situation depending on the diagnostic tools available. These checks are pointed out here as an "old fashioned" simple way of inspecting the engine and compressor internals that may be overlooked and might be very useful if more sophisticated inspection devices are not readily available, or they may be valuable as a backup check which can be easily done at little or no added expense.

There are other, more involved, internal inspections that should be performed periodically. Here also, other diagnostic techniques can be used to some extent for checking without requiring the extra down-time and disassembly expense. The balance between the two means of testing must be decided for each individual location based on available testing means, experience, and other factors.

These internal inspections primarily apply to the engine and compressor crankshaft, main bearings, and connecting rod bearings. The checks include:

- crankshaft deflection measurement
- main bearing clearances
- pull power piston and check connecting rod bearings, wrist pins, piston rings and pistons
- pull power cylinder heads and check injection and exhaust valves and seats
- others as recommended by manufacturer and/or local experience.

As mentioned previously, these internal inspections, both the quick and simple, and the more lengthy and involved ones, are performed when the equipment is down for normal routine servicing.

## DIAGNOSTIC TESTING, (FIG. 6)

As noted earlier, many engine and compressor components do not necessarily have to be inspected by traditional methods which require shutting down and disassembling in all cases. The development in recent years of two diagnostic tools has made possible the on-stream examination of many moving parts in a quantitative sense so that the limit of their service life can be predicted fairly accurately. These are the engine/compressor vibration, ignition, and pressure analyzer and the lubricating oil spectrographic metals content analysis equipment.

**5**

DIAGNOSTIC TESTING
ESSENTIALS

— PLANNED PROGRAM
— FIT PROGRAM TO SITUATION
— REPORT RESULTS
— FOLLOW UP ACTION
— HISTORICAL RECORDS

FIG. 6

Engine/compressor analyzers have been around, in various forms, for a number of years, and it is not an overstatement to say that they have revolutionized preventive maintenance to a large extent. The analyzer examines the condition of many engine and compressor moving components while in operation. This affords the opportunity to prevent major breakdown by detecting impending failure of parts in the early stages. With this information it is possible to reduce down-time and maintenance costs by knowing which parts need to be replaced. The analyzer can also be used to measure engine power cylinder horsepower output, compressor cylinder horsepower consumption, engine and compressor valve performance, diagnosis of ignition system problems, and other information to quantitatively examine engine and compressor operating efficiency.

The specific information that an analyzer can provide includes the following:

- power cylinder horsepower readout
- compressor cylinder horsepower readout
- engine speed readout
- compressor volumetric efficiency
- compressor cylinder pressure-volume oscilloscope display
- power cylinder pressure-time oscilloscope display
- vibration-time oscilloscope display
- ignition-time oscilloscope display

With this information, the following analyses of the engine/compressor performance can be made:

- power losses
- bad engine and compressor valves
- defective rings and bearings
- scored parts
- carbon deposits in parts
- scored cylinder walls
- piston slap
- faulty ignition components

The information provided will vary with the type of instrument and the most basic do not provide the horsepower readout features. The subject of engine/compressor analyzer applications and techniques is far too complex to include in this discussion, but it is a powerful diagnostic tool when properly applied.

There are several limitations of engine/compressor analyzers and their role in a preventive maintenance program must take these into account. The analyzer cannot reliably detect crankshaft main bearing or connecting rod bearing problems. This means that the wear rates of these parts cannot be accurately measured or predicted and other inspection means must be used.

The application of analyzers to high speed (900 rpm) four-cycle engines is limited also. Oscilloscope displays of vibration patterns are usually difficult to interpret because of interference. This means that broken rings, worn wrist pins, and other problems that vibration patterns indicate often cannot be detected and must be revealed by other methods. Pressure connections on power cylinder heads are usually lacking unless specially provided. However, if they are available, adequate pressure data can be obtained.

Ignition patterns can be obtained, but a common practice is to overhaul the magnetos on a time basis, usually every six months, and to replace other components as required so that routine analyzer checks are usually not needed. The high speed compressors can be inspected with the analyzer without any particular problems.

The entire concept of preventive maintenance applied to high-speed engine/compressor units must be approached a bit differently than for the slow speed ones. Maintenance costs will normally be about double per installed horsepower for the high speed equipment. Parts operating at 1000 rpm will naturally wear out at a higher rate than those operating at 300 rpm. The engine analyzer has proven to be very accurate and reliable in detecting problems in two-cycle slow-speed engines but in the four-cycle high-speed ones its record is not nearly so good. It simply is unable to detect impending problems in many instances and failures occur soon after an analyzer check has indicated that the machine is in good condition. The reason for this is probably that in high speed engines and compressors, the time span between detectable wear and ultimate failure is much shorter than in slow speed equipment. Therefore, unless the high speed installation is checked with the analyzer at much greater frequency, the incidence of unexpected failures will be much higher.

The result has been that many operators of high speed engines and compressors have largely discontinued the use of analyzers on a routine basis as a preventive maintenance tool and use them only for special problems. In some cases they have found that for engines that have to be operated fully loaded on a continuous basis, it is necessary to give them a fairly thorough overhaul at one to two-year intervals simply because the normal wear and tear on nearly all moving parts requires this.

In the past five years, oil analysis has been coming more and more into general use as a diagnostic tool in preventive maintenance programs for engines and compressors. Spectroscopic analysis of lubricating oil for traces of metals, with quantitative results, provides a quick, simple and low cost method of monitoring engine and compressor operations for indications of wear. All moving parts in the machinery lose metal as they wear during operation.

This wear is in the form of ultra-small metal particles suspended in the lubricating oil system which are not filtered out. The lubricating oil also picks up other contaminants such as combustion products and degradation products from the oil itself. The spectroscopic analysis of the oil reveals 15 metallic elements in precise amounts and this provides an instant indication of the rate at which the machinery parts are wearing. The presence of metals such as lead, copper, tin, aluminum, and silver is an indicator of bearing wear; iron, chromium, and nickel show cylinder liner or piston ring wear; silicon is a contaminant from the air intake system, boron and sodium come from cooling water; and phosphorus, zinc, calcium, and barium are related to the oil additives.

In addition to the metals analysis, physical and chemical properties of the oil are tested to determine the overall lubricating quality. Ordinarily, these would be performed as part of the surveillance of the lubrication system but can be conveniently included with the spectrographic analysis to provide a complete description of the lubricating oil condition.

The lubricating oil analysis service is available from a number of national and local laboratory firms, with samples and analytical results handled through the mail. Routine results are reported promptly by normal mail and special problems are relayed by telephone. The frequency of sampling can be established at any level that the customer requires to maintain adequate surveillance of his equipment.

The oil analysis program has some obvious advantages over the engine/compressor analyzer and some disadvantages. Oil analysis gives coverage of bearing wear that the analyzer cannot do, and can point out sources of wear that are becoming critical before the problem is detectable by the analyzer. Oil analysis and the engine analyzer compliment each other in many ways and both are essential segments of a complete preventive maintenance program. Oil analysis is perhaps the more flexible of the two tools since it requires no special equipment or trained personnel at the location; and at many installations, where engine analyzers may not be available or feasible on a routine basis, it is the only diagnostic tool readily available.

Here also, the balance between these two analytical methods in the preventive maintenance program must be determined for each individual situation based on the equipment and availability of the service.

The field of diagnostic testing is by no means confined to engine analyzers and spectrographic oil analysis. It is a rapidly advancing field and new devices are being developed and made available constantly—ultrasonic detectors, vibration analysis instruments, optical alignment devices, optical internal inspection instruments, pyrometers, special micrometers, and many others that can be used advantageously in any preventive maintenance program. In most cases these are designed to perform a particular function more easily and accurately than the traditional methods.

Diagnostic instruments are here to stay and it is recommended that they be considered carefully to determine if they can be effectively fitted into your preventive maintenance plan. When properly applied, they can help the program in several ways.

We will undoubtedly see development of better and more sophisticated diagnostic instruments in the year ahead and these will be built into the monitoring system so that there will be continuous surveillance of all parts and their functions. This will make possible a preventive maintenance program based almost completely on monitoring diagnostic devices. Shutdowns will then be required only to service and repair indicated troubles.

## ESTABLISHING A PREVENTIVE MAINTENANCE PROGRAM

At this point you are probably thinking that all of this preventive maintenance business is well and good, but where do I find the time to set all of this up, find the people to do the work, and then keep records of what has been done? If you are covered up with work now just trying to keep up with your existing program and in keeping the equipment repaired and in operation, you are probably questioning the idea of trying to expand your program. However, if your repair costs are continuing to rise, downtime is increasing, and your engines and compressors are generally in poor condition, you may have no choice but to seek out better ways and means to get the job done. Better preventive maintenance may be the answer to your problem. To do this you must develop a plan to accomplish it, perhaps, with help from your organization's engineering staff, and approval of your management. Restructure your present plan along the lines outlined here, adding those essential items that are missing. Don't try to make your plan too elaborate at first. Concentrate on the more basic elements of each of the five categories and firmly establish your program on them and then add improvements when you can see a clearcut justification for them.

A good plan is useless if it is not followed diligently, the results evaluated, and improvements made where needed. It is important also to maintain good information files on your engine/compressor units. A well-organized equipment service library and good maintenance history records are an absolute must to make any preventive maintenance program a success. Equipment data books, drawings, parts lists, maintenance manuals, and similar information along with good maintenance records must be kept in good order and readily available when needed.

Many good articles have been published on engine and compressor maintenance in the trade journals in recent years. These are valuable sources of good information on this subject and every maintenance library should include a collection of them.

## CONCLUSIONS

The five basic elements of preventive maintenance—good lubrication system, sound monitoring system, thorough daily on-line inspections, suitable down-time servicing and inspection, and adequate diagnostic testing—if applied diligently and sensibly, will reduce maintenance costs and increase operating efficiency. If an existing program is remodeled along these lines, with emphasis on improving the present procedures and adding new ones that will help to provide more thorough coverage, cost reductions will come automatically. Your preventive maintenance program will be improved because it will have the following essential qualities:

1. The necessary functions are arranged in a logical order.
2. Proper emphasis is placed on all elements of the program.
3. The program is flexible and can be modified as needed to meet changing requirements.
4. The program will have the consistency of approach needed to cope with the complex problems of engine/compressor maintenance.

It makes good sense to apply the best technology available in a scientific manner to obtain optimum performance from highly complex machinery.


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