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Condition Monitoring and Maintenance Program of Two Stage Reciprocating Air Compressor

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Abstract: ***Reciprocating air compressor is an important equipment of industries such as food packing plants, bottle manufacturing, glass manufacturing, and even non manufacturing systems etc. A sudden or unexpected failures of such significant components due to miscellaneous reasons affects the operating system leading to system seizure. The present article highlights the different failure modes of reciprocating compressor under varied operating conditions along with the appropriate maintenance strategies to diagnose and tackle the problems occurring very often. Condition monitoring technique is a vital step in maintaining the condition of working equipment at normalcy. It helps in detecting the premature and catastrophic failures leading to drastic productivity and system deterioration. This techniques gives sufficient time to develop a suitable maintenance program for each and every failure modes. In this work the maintenance program for reciprocating compressor has been developed keeping in view the failure modes of individual component.***

Keywords: Reciprocating Compressor, Condition Monitoring, Maintenance Program. Compressor Maintenance Strategies, Failure mode of compressor, Application of compressor.

1. Introduction

Compressor An air compressor is a device which converting mechanical energy into pneumatic energy. A compressor is a machine for compressing air from intake pressure to higher exhaust pressure.

There are many types of compressor with different working principles and working condition. The function of all is to draw air from atmosphere and produce higher pressure air for different application. There are different kinds of compressor which is shown in figure 1.

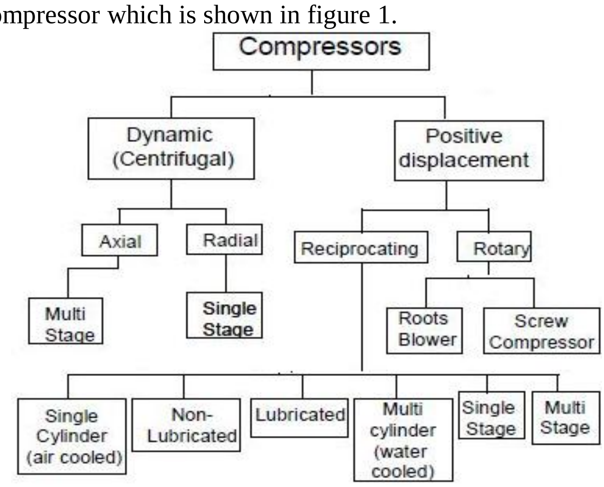

Figure 1: Types of compressor [1]

1.1. Reciprocating Compressor

Reciprocating compressors are the type of the positive displacement compressor. They work on the same principle of bicycle pump, such a means of a piston in a cylinder. The piston moves downward in the cylinder, it compresses the gas or air into a very smaller space, thus it raising pressure and as well as temperature. The basic reciprocating compression element is a single cylinder compressing on one side of the piston . A unit compressing on both sides of the piston consists of two basic single-acting elements operating in parallel in one casting. Generally of the compressors in use are of the double-acting type. Fig 2 . Shows single acting compressor and Fig 3 shows a cross section of V-shape, two-stage, double-acting compressor.

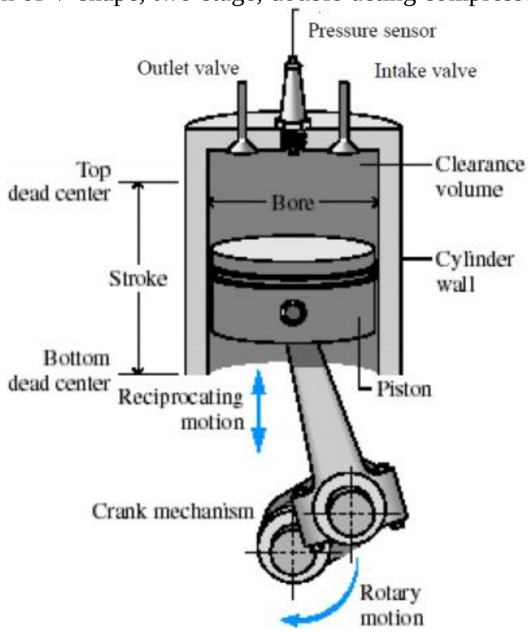

Figure 2: Single-acting Reciprocating Compressor[2]

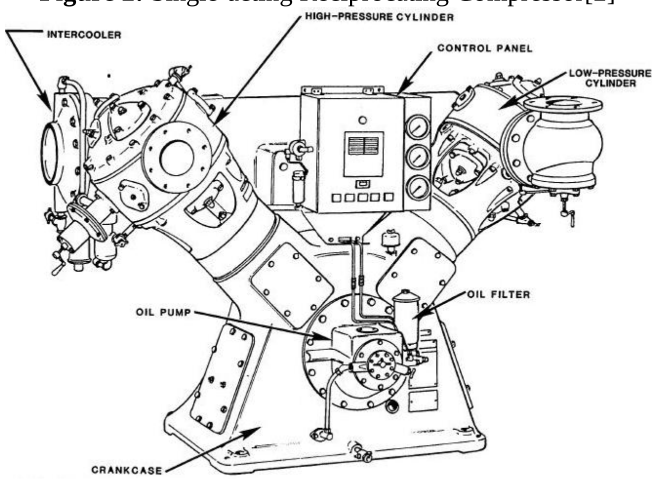

Figure 3: Double-acting Reciprocating Compressor in V-arrangement.[2]

Rotary motion provided by electric motor, diesel engine and other arrangement to the compressor shaft is converted to reciprocating motion by use of a crosshead, connecting rod and a crankshaft between the two. One end of the connect with crankpin to crankshaft, and the other is connected with crosshead pin to the crosshead .The crankshaft start , reciprocates in a linear motion. Intake and discharge valves are located in the top and bottom of the cylinder. These are basically check valves which permitting gas to flow in one direction only. The motion of the piston to the top of the cylinder creates a partial vacuum is create in the lower end of the cylinder; the pressure differential between vacuum and intake pressure across the intake valve then causes the valves to open and allow the air to flow into the cylinder from the intake side. On the return stroke, when the pressure in the cylinder exceeds the pressure in the discharge line, the discharge valve opens and allow air to be discharged from the cylinder into the discharge line. This action is called "single-acting" Compression when on one side of the piston only, and when on both sides of the piston, it is called "double-acting" Compression. Application of reciprocating compressor in manufacturing and non-manufacturing sectors are as follows shown in Table 1,2:

Table 1: Application of air compressor in manufacturing sector [3]

Industries	**Application of compressed air by reciprocating compressor.**
Automobile	Tool powering, stamping, controls and actuators, forming, conveying
Chemical	Conveying, controls and actuators
Food	Dehydration, bottling, conveying, coating, cleaning, vacuum packing.
General manufacturing	Clamping, stamping, tool powering and cleaning, controls and actuators
Lumber and wood	Sawing, hoisting, clamping, pressure treatment, controls and actuators.
Metal fabrication	Assembly station powering, tool powering, controls and actuators, injection molding, spraying
Petroleum	Process gas compressing, controls and actuators
Pulp and paper	Conveying, controls and actuators
Rubber and plastics	Tool powering, coating, controls and actuators, molding, forming
Glass	Conveying, blending, mixing, glass blowing and mixing
Textiles	Loom jet waving, spinning, texturing, automated equipment.

Table 2: Application of air compressor in non-manufacturing sector [3]

Industries	*Application of compressed air by reciprocating compressor.*
Agriculture	Farm equipment, spray of crops, material handling
Mining	Pneumatic tools, hoist, controls and actuators
Power generation	Starting gas turbine, automatic controls, emission controls
Services industries	Pneumatic tools, air brake system, hospital respiration
Transportation	Hoist, Pneumatic tools, air brake system
Water treatment	Vacuum filter, conveying.

1.2. Maintenance Strategies

A maintenance strategies define the sequence of proper maintenance work held in industries. Many maintenance strategies are available few of them are as follows:

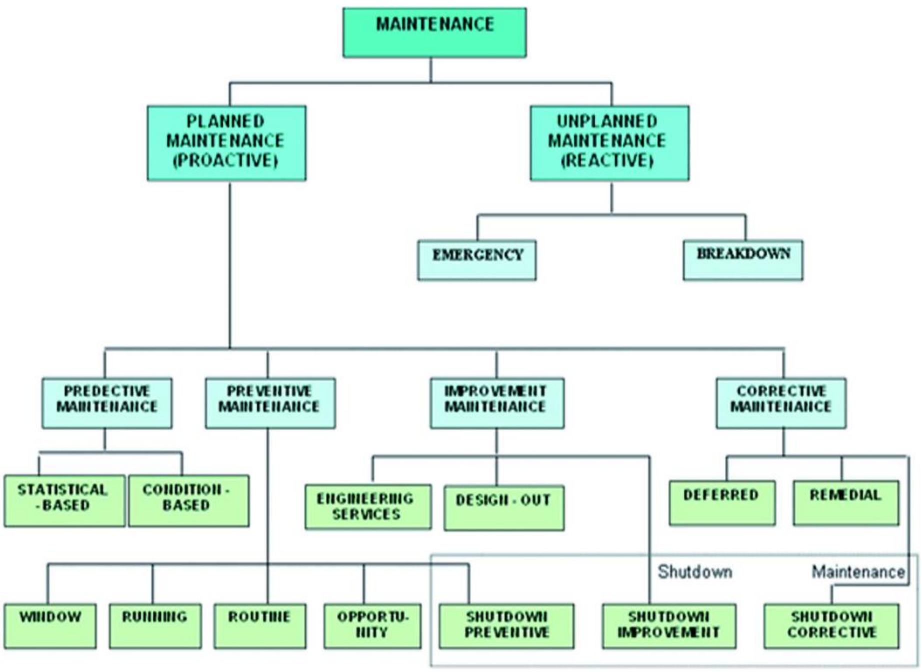

Figure 4: Maintenance strategies [1,2]

1.2.1. Reactive or Breakdown Maintenance

This type of maintenance includes the repair of equipment after it has failed, and in one word it called , "run-to-failure." It is unplanned, undesirable, expensive, and, if the other types of maintenance are performed, usually unavoidable.

1.2.2. Routine Maintenance

This maintenance includes lubrication and proactive repair. Lubrication should be done on a regular schedule. Proactive repair is an equipment repair based on a higher level of maintenance. This higher level founds that, if the repair does not at the time then a breakdown will occur.

1.2.3. Corrective Maintenance

This includes adjusting or calibrating of equipment. Corrective maintenance improves either the quality or the performance of the machine. Generally the application for corrective maintenance results from preventive or predictive maintenance observations.

1.2.4. Preventive Maintenance

This includes scheduled periodic inspection. Preventive maintenance is a continuous process. Its objective is to minimize both future maintenance problems and the need for breakdown maintenance.

1.2.5. Predictive Maintenance

This maintenance predicts potential problems by sensing operations of equipment. This type of maintenance monitoring operations, pinpoints potential problems and diagnoses undesirable methods. Its simplest type and an operator hearing a change in sound made by the equipment predicts a potential problem. This then leads to either corrective or routine maintenance.

2. Condition Monitoring

Condition monitoring is knowledge of machines condition and its rate of change of behavior, which can be selecting a suitable parameter for measuring premature failure and recording its value at intervals either on a regular or continuous basis. This is done when the machine is in operating condition. The data obtained may then be analyzed to give a component failure. This activity is called as condition monitoring. Condition monitoring mainly involves regular inspection of machine using human sensory facilities and a mixture of simple instruments. The central emphasis is however on the fact that most inspections should be preferably done while the machine is operating condition.

Condition monitoring is concerned with the analysis and interpretation of signals from sensors and transducers installed on operational machinery, mounting transducers positioned outside the machine parts and often remove from the machine components being monitored and normally does the monitoring of a machine condition, operating condition and health, using developed techniques, the analysis of information provided by the transducer output and interpretation of the evaluated out put is the needed to develop what strategies to be taken. It can also be a test and quality assurance gives system for continuous processes as well as discrete component manufacture. It increases the performance of the industries assets by monitoring their condition and defining that they are installed and maintained properly, it aims of detecting condition leading to catastrophic breakdowns and loss of service, reducing maintenance overhauls, maintenance cost, fine turning of operating equipment increasing reliability, production and operating efficiency and minimizing the replacement parts inventory. This is due to readily monitor able parameter of deterioration can be found in each and every plant, equipment and probabilistic element in future prediction is highly reduced or almost eliminated thus maximizing the items life by minimizing the effect of failure.

Condition Monitoring Techniques:

There are following main techniques of condition monitoring. They are:

a) Visual monitoring
b) Contaminant or debris monitoring
c) Performance and behavior monitoring
d) Corrosion monitoring and thermograph
e) Sound monitoring.
f) Shock pulse monitoring.
g) Vibration monitoring

2.1 Visual Inspection

This is a common method of data acquisition, data analysis, and quality control. Visual Inspection is used in maintenance of machines and inspection of equipment and structures using either or all of main human senses such as hearing, vision, touch and smell and any non-specialized inspection equipment. Inspections requiring X-Ray equipment, Infra-red, and Ultrasonic etc. They are not typically regarded as Visual Inspection as these Inspection methodologies require specialized training, equipment and certification.

2.2 Contamination and Debris Analysis

It has proven in many times to be a main indicator compared to vibration analysis to identify wear modes and wear mechanisms present in a machine. There are numerous types of wear mechanisms such as abrasion, corrosion, erosion, adhesion, fatigue, and fretting. Common examples of failure modes include wear particles, contamination, lubricant degradation, oxidation, load, and speed. Contamination and debris analysis is the study of the chemical composition, color, concentration, size distribution and morphologies of wear particles. A particular wear mechanism typically generates one or several types of wear debris, which can be identified by their characteristics. There are six common particle types that are typically found within machinery corresponding to rubbing particles, cutting, fatigue, severe sliding and spherical particles. For each and every particle types, there may be variations in surface texture, concentration, size and color depending on the severity, the rate of wear and material source.

2.3 Performance and Behavior Monitoring

The performance of compressor, gas turbine, heat engine and other types of process equipment or machines deteriorates over time and their efficiency decreases, power consumption goes up, throughout is reduces production and operating cost rises. The most common forms of deterioration occur due to physical changes of machine components. This may be mechanical wear as a result of prolonged operation, physical wears such as pump impeller corrosion, or surface degradation a on heat exchanger plates. The most important elements of performance monitoring is the distillation of large amount of data available into useful information that can be acted upon. Application of this information may leads to maintenance cycle, fault detection and rectification and process improvement identified through performance behavior trends.

2.4 Corrosion Monitoring and Thermograph

The area of corrosion measurement, control, and prevention covers a very wide spectrum of technical activities. Within the limits of corrosion control and prevention, there are many technical ways such as anodic and cathodic protection, chemical dosing, materials selection, and the application of external and internal coatings. Corrosion measurement develops a lots of techniques to determine how corrosive the environment is and at what rate metal oxidation is experienced. The corrosion measurement methods are help to the effectiveness of corrosion control and prevention techniques can be determine and provides the feedback to enable corrosion prevention and control methods to be optimized. Temperature is also one of the important parameters to play the condition of parts, internal process, quantity and even quality of the valuable output. A qualitative conclusion can be drawn by observing the temperature profile of any components of machine. On the other words directly we can say higher temperature also indicates obvious loss of energy. Therefore temperature monitoring give indication of the condition of the components, process quality, material and explore possibility of energy conservation. In recent years lots of temperature monitoring techniques have been in use in our industries. These techniques find out their application based on the measurable temperature range and ease in application.

2.5 Sound Monitoring

The noise or sound signal from machine can contain numerous information about the internal process and can provide important information about a machine running condition. Noise or sound signal are measured in a reason proximity to the external surface of the machine. Most noise analysis instruments utilize a Fast Fourier Transform (FFT) which is a special case of the generalized Discrete Fourier Transform. This Frequency domain representation of the time history is called frequency spectra. When a machine operates in good condition then noise frequency spectra possess certain standard shape. In case of any fauly operation in machine spectra change is seen where the desired signals are mixed with some unwanted and undesirable signal. Therefore, analysis of these changed spectra needs some specialized signal processing to relate it with the actual cause of fault in machines and equipment.

2.6 Shock Pulse Monitoring

It is an abbreviation for Shock Pulse Method, that is a patented technique for using signals from rolling bearings as the basis for effective condition monitoring of machines.The innovation of this method in 1969 and it has now been further developed and broadened. Now a worldwide accepted philosophy for condition monitoring of rolling bearings and machine maintenance.

2.7 Vibration Monitoring

It measures the frequency and amplitude of vibrations. Mechanical reciprocating or rotating machines generate their own vibration signatures during operation. However such signals contain a lot of background noise that makes it complicated or even impossible to extract useful information by simply measuring the overall signal. It is thus necessary to develop an appropriate filter to remove the operationally and environmentally contaminated components of signals so as to reveal the clear signals generated by the parts under study. To get useful condition monitoring data and vibration should be measured at precisely chosen points and directions.

Vibration monitoring is a well established method for determining the physical Movements of the machine or structure due to imbalance mounting an alignment this method can be found as simple. Vibration monitoring easy to use and understand or sophisticated real time analysis and it usually involves the attachment of a transducer to a machine to record its vibration level special equipment are also available for using the output from sensor to indicate nature vibration problem and even its precise cause. Transducers for the measurement of vibrations employ electromagnetic, capacitive, piezoelectric, out of these piezoelectric accelerometers is most widely used. Among the monitoring techniques vibration monitoring as gained considerable importance because of following fundamental factors:

a) All rotation and reciprocating machines vibrate either to a smaller or greater extent machines vibrate because of defects in system
b) When inaccuracies or more it results in increased vibration each kind of defect provides a vibration characterized in the unique way.

3. Prevalent Maintenance Philosophy in Industries

It may be either impossible or uneconomical to manufacture and design the machinery for zero maintenance or perfect reliability with infinite life. Realistically the two principal maintenance philosophies are prevalent in industry and any other plants.

- The first philosophy is called "breakdown maintenance," is rarely justifiable on economic and risk management grounds. Considering the safety risk alone should convince us of the potential danger of this approach. The compressor is repaired as quickly or as cheaply as possible and is returned to service. Inevitably, the next emergency is just around the corner.
- The second philosophy will prove most profitable when used in conjunction with a conscientiously implemented program of predictive maintenance. Although such a comprehensive program will require forethought and organization, its long-term profitability has been demonstrated beyond much doubt. Maintain the equipment in excellent condition, thus optimizing both equipment reliability and availability. Downtime events for preventive maintenance are planned, and the probability of an unexpected breakdown is minimized

A well-structured compressor maintenance program will thus bring about several important benefits, including, of course, improved safety, reliability, efficiency, run-time, housekeeping and environmental/regulatory compliance. The final product cost will be materially decreased by this program. When increased production adds substantially to the profits of a plant, the minor expense of a well-structured maintenance program is insignificant. Dependability is a vital factor in any operation. The degree of dependability attained is in direct proportion to the effectiveness of the preventive maintenance program.

4. Maintenance Program

4.1. Maintenance Improvement

Problems associated with machine up-time and quality output involve many functional areas. Many people are from plant manager to engineers and operators, make decisions and take actions that indirectly or directly affect equipment performance. Manufacturing, production, maintenance personnel, engineering, and purchasing as well as outside stores and vendors use their own internal methods, systems, processes, policies, procedures, and practices to manage their departments of the business enterprise. These organizational systems to interact with one or another, depend on one or another, and constrain one or another in a variety of ways. These constraints can have destroyer consequences on equipment reliability.

4.2. Evaluating Inspection Data

Recording inspection data serves several purposes:
1) To establish the exact condition of all wearing parts.
2) To establish the wear rate of parts, which, if promptly replaced, will not deteriorate to such a degree that associated parts will be damaged and will also require replacement.
3) To determine which parts require reconditioning and which parts can be reconditioned to like-new condition.

4.3. Maintenance Costs

Perhaps the most frequent problem maintenance departments face is the rising cost and probable diminishing resources. While being constantly confronted with budget questions and the pressure to reduce costs, maintenance managers are still expected to raise the level of service in the plant-Maintenance often falls victim to budget cuts because management mistakenly believes maintenance can be deferred. It is thus important to effectively allocate and spend money. The observation data and records can diffidently be used to show what must be done to optimize the reliability of the compressor and to determine logical shutdown intervals.

5. Failure Modes of Reciprocating Compressor:

The failure of air compressor may be results of many factors such as Electrical and Mechanical. In electrical failure includes system control problems, overheating and single phasing. In mechanical failure includes cylinder leakage, inoperative suction and discharge valves, damage piston rings, damage crankshaft, cylinder fail to move, damage connecting rods and unbalance of crankshaft. Some time air compressor fail due to improper operation, improper application, and improper cleaning purpose. Table 3 represents the failure modes of air reciprocating compressor due to different causes and effects of these failure on compressor.

Table 3: Failure modes, cause and effect[2,3]

Failure types	Cause of failure	Effect of failure
1. Cylinder fail to move	valves fail to open	Loss of gas output
2. Cylinder leakage	Mechanical wear, Damage seal	Reduces compressor efficiency
3. Damage piston rings	Low compressor oil, Wear out	Permanent compressor failure
4. Inoperative suction and discharge valve	Valve leakage, Discharge valve open to fail	Reduces compressor efficiency
5. Damage cylinder packing rings	Moisture entering cylinder	Permanent valve damage, Reduces compressor efficiency
6. Damage crankshaft, connecting rod	Mechanical bending, Loss of lubricants	Noisy compressor, Shutdown of compressor
7. Unbalance crankshaft	Misalignment, Mechanical bending	Noisy compressor,
8. Failure of piston rod	Wear, Excessive duty cycle	Compressor failure

6. Maintenance Procedures

Although monitoring of reciprocating compressors is not as simple and definitive as monitoring other rotating equipment, there are some things that can be and should be monitored. The first step in the program is to decide what is to be monitored. An effective predictive maintenance program should include the following:

6.1. Daily Operating Reports and Logs

These are used to observe operating parameters, temperature, flows,pressure etc. These are overlooked and recorded as part of the operator's duties but not referred to until after a problem develops. Continual monitoring can show trends of developing problems.

6.2. Maintenance Records and Wear Measurements

These are taken as part of the overall maintenance program covered previously. These records are the most important of all parts of the program. Inspection records will allow spotting of trends and prediction of possible parts failure. These records use as the foundation of planning for shutdown and replacement of worn and failing components.

6.3. Infrared Thermography

Infrared thermography of the valve covers temperatures . This very simple procedure is an important part of any maintenance program and used to predict valve problems that can be taken care of before a major failure occurs. It should be a part of every maintenance plan.

6.4. Lubricating Oil Monitoring

This procedure helps to detect the progressive deterioration of components such as bearings. It consists of monthly sampling of the compressor lubricating oil and performing spectrographic analysis that provides an accurate quantitative breakout of individual chemical elements contained in the oil elements as oil additives and contaminants. A comparison of the amount of trace elements in successive oil samples can indicate wear patterns of all wetted parts in the equipment and warn of impending failure. Full benefits of oil analysis can only be achieved by taking frequent samples and trending the data for each compressor. The basic data on each compressor allow the laboratory to build a unique database. Reports then include values from the current tests, the average for the particular compressor, and values from previous tests. A spike in the content of one element indicates a sudden change in the conditions inside the compressor. A comparison with the plant and laboratory averages provides a means of judging the significance of the change. Oil analysis can provide a wealth of information on which to base decisions. However, major payback is rarely possible without a consistent program of sampling in order that data can be trended. While oil sampling and analysis can provide an additional capability to existing preventive maintenance programs, it should not be depended upon to the exclusion of all other techniques. In other words, there are documented instances of bearing failures taking place in operating compressors that, for some reason, were not picked up by sampling the lubricating oil.

6.5. Vibration Monitoring

This monitoring is particularly useful on those compressors that use anti-friction bearings that are the smaller sizes of reciprocating compressors. Because reciprocating compressors have relatively low rotative speeds, they produce low frequency vibrations and unfortunately require more than the traditional vibration velocity monitoring or frequency analysis. However, monitoring packages are available from experienced specialty firms.

6.6. Acoustic Emissions or Ultrasonic Detection

As any gas (air, oxygen, nitrogen, etc.) passes through a leak orifice or leaking gaskets, etc., it generates a turbulent flow with detectable high frequency components By scanning the test area with an ultrasonic detection device, a leak can be heard through the headset as a rushing sound or noted on the ballistic meter. The closer the instrument is to the leak, the louder the rushing sound and the higher the meter reading. Should ambient noise be a problem, a rubber focusing probe may be used to narrow the instrument's reception field and to shield it from conflicting ultrasounds. Performance and condition analysis of compressor cylinders will provide substantial savings to the user. Analysis will:

- *Reduce power consumption by 10% or more
- Increase compressor throughput
- Reduce maintenance costs

6.7. Oscilloscope Analyzers

These devices can be used to observe what is happening internally in the compressor cylinder, and, by comparing the actual pressure, volume, time indicator card, to the theoretical indicator card, the analysis determines if components are malfunctioning. It was noted that piston ring leaks can be detected by placing an ultrasonic microphone in the middle of the cylinder. Scuffing of piston rings or rider bands will show on the scope. A piston that is loose on its rod will show up at the end of the re-expansion and the end of the compression event. It is obvious that reciprocating compressor maintenance programs should include predictive and preventive maintenance elements. Notice, again, that predictive maintenance alone is not enough. It would be foolhardy to completely depend on lubricating oil analysis and vibration monitoring to determine maintenance schedules for compressors. We must take effective practices from both types of programs and merge them into an overall preventive maintenance program.

7. Conclusions

In this article an attempt has been made to diagnosis the problem associated with reciprocating air compressor, providing a solution by suggesting appropriate maintenance strategies. The maintenance program has been reviewed keeping in view of failure modes. The present article highlights the different failure modes of reciprocating compressor under varied operating conditions along with the appropriate maintenance strategies to diagnose and tackle the problems occurring very often. This article helps in detecting the premature and catastrophic failures leading to drastic productivity and system deterioration. This article work is all about of reciprocating compressor failure and prevention of its failure. Condition monitoring is predictive maintenance technique to identify the early failure. A proper maintenance program of reciprocating compressor increases the reliability , availability and decreases the downtime, maintenance cost of machine. Maintenance program also helps in increasing the productivity and effectiveness of reciprocating compressor.

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