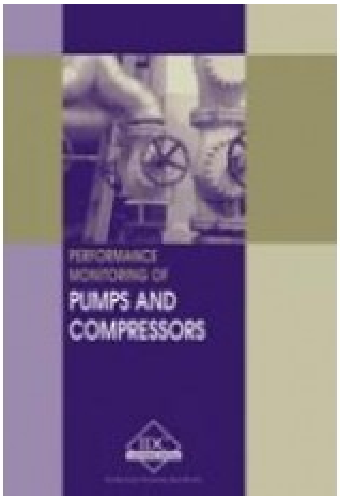
PU-E - Performance Monitoring of Pumps and Compressors



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Short Description

This manual covers in detail, the technique of performance monitoring as applied to centrifugal pumps and positive displacement, centrifugal and axial flow compressors. The topics of discussion include: Principles of operation Thermodynamic and hydraulic evaluation Important performance parameters and selection considerations Methods to derive the above from first principles and empirical relationships Handling gas and gas mixture properties Interpretation of results This manual will be of immense benefit to those involved in the procurement, operation and maintenance of pumps and compressors.

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Introduction and Fundamentals

This chapter begins with a detailed overview of the degradation mechanisms and failure modes of mechanical equipments in general and the factors responsible for these occurrences. Ways and means of optimizing equipment performance is also included in the discussion. An attempt is also made to obtain a clear understanding of the procedures involved in establishing best maintenance practices in mechanical equipments of the likes of pumps and compressors. The concept of performance monitoring is touched upon in detail along with the strategies and techniques associated with the technique.

Learning objectives

- Understanding how equipments deteriorate with time and the various mechanisms associated with equipment degradation.
- Studying ways of establishing best maintenance practices and of optimizing equipment performance.
- Enabling a clear understanding of the fundamentals associated with performance monitoring and appreciating its importance in regard to enhancing equipment efficiency and performance.

1.1 Equipment degradation and loss in efficiency

Equipment degradation can be defined in terms of loss of performance of an engineering system which in turn can relate to many parameters. An example may be the loss in mechanical strength of a structural component due to faulty material or improper operation. All components of equipment have a critical minimum level of performance. The degradation proceeds at a rate that varies with local conditions and failure tends to occur when performance declines to below the critical level. Efficiency loss takes place if performance declines but remains above the critical performance level during the service life of the concerned component.

Starting from new, a properly built component tends to operate at a particular level of performance, which ideally is its design condition. Degradation occurs with progression in the operating life of the component. This implies that the component can no longer meet its original service requirements and that there is a fall in its performance level. A typical degradation process is illustrated below. After a period of normal operation, there occurs a change occurs that affects the performance of the concerned equipment. This gradual change or rapid change may worsen to a point wherein the equipment cannot reliably and safely deliver its intended duty. When continued in operation, the component will ultimately fail.

Figure 1.1

Component degradation

Following are some of the important factors influencing equipment degradation and failure:

- Faulty Material
- Improper fabrication and construction
- Design error
- Improper operation
- Inadequate Maintenance
- Maintenance errors

Efficiency loss in components may be caused on account of a wide variety of factors, important among these being:

- Wear
- Erosion/corrosion
- Operation away from best efficiency point

- Ineffective maintenance

There are various degradation mechanisms that are responsible for deterioration in the condition of the equipment. Chief among these are overloading, fatigue, overheating corrosion and erosion, mechanical wear, age related deterioration, oxidation and chemical attack. Let us go ahead and briefly discuss each of these parameters individually.

Overloading: This refers to the loading of equipment or its component beyond its stated capacity, leading to premature failure.

Fatigue: This is the failure that may occur when an equipment or component is subjected to dynamic, fluctuating stresses. This accounts for a high percentage of metallic failures and is often catastrophic in nature.

Overheating: This occurs when equipments are subjected to extreme heat conditions or very high temperatures. Under these conditions, the material may give way, leading to premature failure.

Corrosion: This phenomenon is caused by the flow of electrons from one metal to another or from one part of the surface of one metal to another part of the surface of the same metal. Corrosion results in significant loss of metal.

Erosion: Erosion refers to the recession of metal surface resulting from repeated localized mechanical trauma. An example of this is the action of suspended abrasive particles within a moving fluid. Erosion can also occur from non-abrasive fluid mixtures as in the case of the cavitation phenomenon in pumps.

Mechanical wear: This can be defined as both material loss and deformation at contact surfaces. Mechanical wear results in particle generation and surface degradation.

Age-related deterioration: As the name suggests, this refers to degradation of an equipment or component with age. Most metals undergo a change in their physical and chemical properties with passage of time, resulting in performance-related deterioration.

Oxidation and Chemical attack: Oxidation is the interaction of oxygen molecules with the elements of a substance. It can be quite destructive as in the case of rusting. But, sometimes oxidation proves beneficial as in the case of super durable anodized aluminum. Chemical attack refers to the action of chemicals on a material.

Maintenance related decisions are normally based on the following failure characteristics:

- Wear-in-failure also known as infant mortality failure
    - *Dominated by weak members.*
    - *Related to manufacturing defects, installation, maintenance or startup errors.*
- Random failure:
    - *Not predictable by time.*
    - *Dominated by chance failures.*
    - *Caused due to sudden stresses, extreme conditions and random human errors.*
- Wear-out failure:
    - *Dominated by end-of-useful life issues.*

The following graphic depicts the life period of equipment.

Figure 1.2

Equipment life period

By identifying which of the three failure characteristics is representative of the failure mode, a proper maintenance strategy can be devised. For example, patterns without distinct wear-out regions may not benefit from maintenance tasks involving the rebuilding and replacement of items. Rebuilding and replacement may be appropriate if the failure mode exhibits a definite wear-out pattern.

1.2 Optimizing Equipment Performance and Establishing Best Maintenance Practices

Optimization of Equipment Performance

The first indicator of equipment performance is equipment availability. It refers to the percentage of time that a given equipment is available in a given period of time, in order to serve the purpose for which it is intended. Availability usually ranges from 65 to 99.9%. In reality, this figure may vary because higher the availability, more expensive it is. Therefore, production cost must be used to determine availability levels. A company striving for 99% availability when only 90% is needed is spending too much on its maintenance program. The best practice percentage has to be determined by each organization for each piece of equipment or process.

The next indicator of performance is equipment efficiency. Here the actual output of an equipment is compared to its design input. The benchmark value for efficiency varies between 75 and 95%. Best efficiency levels may be 95% or more. Whether a particular percentage efficiency is sufficient, depends on the product. It may not prove cost-effective to try and gain the last percentage or two of efficiency from a piece of equipment. But normally, 95% is a best practice threshold.

Another important performance indicator is overall equipment effectiveness. This may range anywhere between 20% and 85%. The best practice percentage may vary with the needs of the organization. Some companies may spend too much to obtain effectiveness in the range of 85%.While this cost may in fact not be justified for some; it may be too low for some others.

Establishing Best Maintenance Practices

Earlier, maintenance was largely seen as a cost-saving exercise. But maintenance evolution over the years has seen its scope expand vastly to encompass newer areas. Presently the emphasis is more on preventing equipment breakdowns through the use of proactive maintenance strategies, rather than acting on fixing a problem.

Best maintenance practices include the following areas:

- Leadership and Policy Deployment
- Organizational Structure
- Inventory Control
- Computerized Maintenance Management Systems
- Preventive Maintenance
- Predictive Maintenance
- Planning and Scheduling
- Work Flow
- Financial Control
- Operational Involvement
- Staffing and Development

- Continuous Improvement

Organizations may adopt different maintenance strategies based on a wide range of parameters and operating capabilities. Some of the important factors that help determine the type of maintenance strategy to be adopted include:

- Production needs
- Equipment type and importance
- Maintenance costs
- Availability of skilled manpower
- Access to latest technology and processes
- Flow of spare parts

It is important for an organization to choose the correct maintenance strategy to meet strategic company goals such as improved plant output, performance predictability, improved equipment utilization and availability, meeting production schedules, product quality, improved standards of customer service, safety, environmental control etc. An organization must evaluate on an asset-by-asset basis the following:

- Cost of failure
- Cost of monitoring the health of the asset
- Cost of maintenance operations

Cost of failure must be evaluated both in terms of not meeting business objectives and any extra cost due to unplanned or even emergency repairs. One must also understand the cost of maintenance for the asset. When cost of failure and cost of maintenance are low, one can justify the use of a strategy whereby an asset is simply fixed, when it breaks down. When cost of failure is low but cost of maintenance is high, one has to minimize the amount of maintenance required. This may be best undertaken by waiting for the asset to break down, before expending any maintenance cost. Where the cost of failure is high and the cost of maintenance is low, one has to be logically more proactive and accept more maintenance cost, in order to ensure that asset will not fail. Here, the best choice would be a time-based preventive maintenance strategy. When both cost of failure and cost of maintenance are high, one needs to use RCM (Reliability Centered Maintenance) concepts and optimally manage the health of the asset. This is done to avoid failures, while minimizing maintenance. The maintenance approach to be adopted for a particular machine or system is illustrated in the following graphic.

Figure 1.3*: Maintenance Approach*

Well implemented maintenance programs can often recognize degradation in the incipient stage itself. In some cases, the root cause can be identified and mitigated before any further damage could be done. In others, developing problems can be carefully monitored and trended allowing planned maintenance, instead of addressing unplanned outages. Vibration monitoring is an excellent technique for measuring and trending rotating equipment balance, alignment and bearing conditions. Analysis and trending software programs have automated detection and alarming of many critical degradation mechanisms that vibration measurements can detect. Some equipment need dedicated, full-time monitoring with remote indication and alarm.

Frequency of monitoring is usually dictated by criticality and previous measurement results. For example, if a pump bearing shows early signs of wear, monitoring interval may be dropped from quarterly to monthly. Other predictive methods that are effective in equipment monitoring include

- Lubricant analysis
- Infrared thermography
- Ultrasonics
- Radiography
- Magnetic particle

Scope of equipment

While certain equipment may warrant continuous monitoring, some others can be effectively managed by periodic checks. An important point to consider is that some equipment simply do not warrant the time and expense associated with diagnostic monitoring. Important factors to be considered when selecting equipment to be monitored on priority include safety and reliability, downtime, cost of repair, redundancy and potential environmental release.

1.3 Introduction to Performance monitoring

Equipment reliability and efficient operations are critical for long-term profitability and safety. Dynamic nature of processes means performance of equipment like pumps and compressors deteriorates over time. This results in a rise in operating costs. As operating plants get larger, the financial implications of even relatively short outages are quite severe. It is difficult to address problems or make improvements without knowing the exact equipment performance and location of the process problems.

Performance Monitoring is the process of:

- Measuring the performance of existing operating assets.
- Understanding the deviation from targeted performance.
- Quantifying the impact of performance degradation.

Performance Monitoring is a part of the “Condition Monitoring” process and involves the thermodynamic and hydraulic evaluation of the equipment. The primary goal of Performance Monitoring is to extract useful and consistent information from raw process data and to support high-quality operational decision-making. Application of this information may lead to fault detection, process improvements and improved maintenance cycles.

The Performance Monitoring technique is relatively simple but is very powerful toola to detect failures, save costs and improve plant efficiency. In performance monitoring, we define parameters that generally describe the efficiency of a system. The system can be a complete plant, or mechanical sub-systems within a plant. Performance monitoring is crucial to ensure that a system is running at optimal energy consumption. It can not only be employed to avoid economic losses due to operation at low efficiency, but also to ensure optimal availability of machinery and avoid costly breakdowns. Performance monitoring is useful from a maintenance perspective because efficiency is usually directly linked mechanical defects. A defect such as wear will often cause lower efficiency and hence performance monitoring is a very useful early indicator of failures. For performance monitoring to be effective, performance parameters should be monitored at regular intervals or on a continuous basis. The use of a performance monitoring system could assist in optimizing maintenance schedules, matching system performance and demands, improving scheduling of multiple systems, and improving energy consumption. Typical systems that are often subject to performance monitoring include pumps, fans, boilers, turbines, condensers and electrical drives.

The performance of a system can be characterized in different ways. A typical performance characteristic would be overall efficiency. In this case, the energy consumption of a system is compared with the energy that it delivers. For example, the true power consumption of a pump can be compared with the actual energy it imparts to the fluid. The power consumption of a pump P_c, can be determined by measuring the electricity consumption of the motor that drives. The energy that is delivered to the fluid is given by

$$P_w = ?gQH$$

Where

? = density [kg/m^3]

g = 9.81 m/s^2

Q = flow rate [m^3/s]

H = head [m]

The efficiency, which is the main parameter for performance monitoring, can now be determined using the equation

$$? = P_w / P_c$$

A downward trend in pump efficiency could indicate worn parts, cavitation, unbalance, misalignment, looseness, excessive hydraulic losses, electrical problems and other mechanical defects.

The most important performance monitoring parameters for components such as pumps are specific consumption, efficiency and head. When it is not possible or impractical to calculate the on-line pump efficiency, other parameters such as pump outlet flow rate, pressure (head) and temperature can also be used as individual performance characteristics.

Today, a number of companies offer software that can assist in setting up a complete performance monitoring program. Many of these software packages are web-enabled and therefore performance parameters can be tracked from virtually anywhere, through the internet. The software usually offers easy to interpret graphical representations of the data, customized reports and easy access to historical performance data. Typical advantages of software-based performance monitoring systems are:

- Helps in developing a predictive maintenance program.
- Increases throughput, availability and reliability.
- Prevents catastrophic failures and avoids costly unplanned shutdowns.
- Increases plant profitability.

- Determines optimal maintenance strategy.
- Analyzes the impact of maintenance activities.
- Helps meet production targets.
- Benchmarks equipment performance, leverages knowledge and helps establish best maintenance practices.
- Tracks the monetary cost of the degradation in equipment performance.
- Detects faulty or poorly calibrated instrumentation.

Condition vs. Performance Monitoring

Condition monitoring helps identify mechanical faults in equipment such as bearing wear and imbalance in rotating machinery. It helps measure vibration, evaluate oil levels and assess the mechanical health of key process equipment. Condition monitoring does not provide sufficient information on actual inherent performance such as thermodynamic efficiency. In fact, actual equipment performance can be masked by process changes such as:

- Ambient conditions
- Stream compositions
- Operating conditions
- Other normal process changes

Performance Monitoring (PM) can account for process and feed changes of a large section of a process unit and not just focusing narrowly on an individual piece of equipment. A structured model-based “PM” approach allows accurate comparison of actual vs. targeted or design performance. “PM” can also often signal degradation in inherent equipment performance before the manifestation of any mechanical degradation. An ideal solution would be to combine both CM and PM for an accurate picture of short-term mechanical performance and long-term inherent performance. Both the short-term effects on operations and long-term performance degradation can be examined to determine the optimal maintenance strategy.

1.4 Performance Monitoring Strategies and Techniques for Pumps and Compressors

PM Techniques for Pumps

In order to understand how a pump is performing, the following six parameters must be monitored.

- Suction pressure
- Discharge pressure
- Flow
- Power
- Pump speed
- Pump efficiency

It is easy to measure power when the driver is an electric motor. This is done using portable instruments. These devices are clipped on electrical phase cables and used to measure voltage, ampere, power factor and power. Suction and discharge pressures are measured using calibrated pressure gauges screwed on fittings provided on pipelines with isolation valves. Flow measurements are done using venturi tubes, orifice plates and pitot tubes. Efficiency can be computed in conjunction with process parameters such as flow rate, suction and discharge pressures and fluid characteristics. This can be benchmarked with those provided by the OEM.

Analysis of efficiency can help determine if losses are due to internal recirculation, hydraulic losses or mechanical losses. Direct reading thermodynamic pump efficiency monitors (Yates meter) can interpret the operating efficiency of a pump in a dynamic manner. This is done by measuring and computing the temperature increase of the fluid as it moves from suction to discharge. Highly sensitive temperature probes and pressure transducers positioned on suction and discharge pipes measure the temperature and pressure values.

A power meter may be used to provide information on power absorbed by the motor. Motor efficiency (obtained from manufacturer) and drive losses are factored into the PM software to calculate the pump’s operating efficiency. This could be compared with the pump’s commissioning data, in order to determine the drop in efficiency or performance.

Let us try and get a further insight into how performance monitoring of pumps is carried out with the help of the following examples.

PM data for a new pump

Figure 1.4: *PM data for new pump*

An optimization rating of 97.8 indicates that it is an excellent pump.

PM data for a significantly degraded pump

Figure 1.5: *PM data for degraded pump*

In this second example, the pump is found to have failed catastrophically a few months after the measurement.

PM techniques for Compressors

Compressor health is measured by comparing current performance with manufacturer’s data. Raw operating data like discharge pressure or pressure ratio are not adequate indicators of compressor performance. This is because these parameters can change with inlet temperature and pressure. But head and efficiency are accurate indicators as they are unaffected by process conditions. Work input represents energy transferred from the impeller blades to the gas. By calculating the work input, it can be confirmed if the input data is accurate. Any degradation in inter-stage seals, corrosion or fouling shows up as loss in efficiency and head. But work input remains unchanged despite these losses. For determining work input, head and efficiency; raw data such as pressures, temperatures, speeds and flow rates are processed by Performance Monitoring software. These values are often displayed on charts along with OEM performance curves.

From these values, the difference between the actual and predicted values can be noted. By logging these differences over a time period, any change in compressor conditions can be determined. These logs also help in troubleshooting and formulating maintenance schedules. Online Performance Monitoring indicates where the equipment is operating on its curve, thereby helping prevent mechanical problems like impeller failures. This also aids in troubleshooting efforts. Recording of choke and surge events may help in tracking the root failure causes. This helps operators in changing operating procedures and preventing future failures.

In order to enable a better understanding how performance monitoring of compressors is carried out, some sample live data and related calculations are shown below in the form of graphic representations.

Live compressor data chart indicating design vs. actual head, work and efficiency.

Figure 1.6: *Live compressor data chart*

Operating work input falls right on the curve and this indicates the accuracy of the instruments and that analysis is good.

Polymer buildup in the diffuser passage of a cracked gas compressor

Figure 1.7: *Polymer buildup in diffuser*

Live compressor information received by software and calculation results

Figure 1.8: *Sample of Live compressor data from software calculations*

A time series chart showing trending of efficiency over a period of time

Figure 1.9: *Time series chart*

1.5 Benefits of Performance Monitoring

As already discussed, performance monitoring can help in detecting and addressing a failure before an unplanned disruption could occur. Some of the major benefits associated with this technique are as follows.

- Ensures safe and reliable operation.
- Maximizes revenue and minimizes maintenance expenses.
- Faster troubleshooting that helps minimize downtime and production loss.
- Optimal plant performance and reliability.
- Allows accurate comparison of actual vs. targeted or design performance.
- Helps determine optimal maintenance strategy.
- Helps synergize business and operation goals.
- Results in decreased system downtime and optimum use of critical components.
- Higher component/system efficiency and higher availability.
- Helps determine the efficiency with which energy conversions occur in the equipment.
- Enables computation of energy requirements, thereby helping benchmark equipment performance.
- Useful tool in sizing, selection and re-rating of the equipment.
- Provides prior warnings of potential failures and performance deterioration.
- Optimizes maintenance Schedules.
- Helps in immediate evaluation of effects of process changes.
- Helps in better selection of operating regimes and maintenance schedules.
- Trending helps isolate operating points that may have led to faulty condition.
- Improves scheduling of multiple systems.