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Original Research Article

Turbine vibration condition monitoring in region 3

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ABSTRACT: The present study aims to investigate the vibration monitoring status in region three of gas transmission operations in Iran. Vibration monitoring is a strong tool for troubleshooting and protecting equipment (turbines). For this purpose, the vibration condition monitoring systems in a gas compression station have been studied. The number and location of vibration sensors, vibration signal transmission to the control room, alarm and stop command, and the ability to perform advanced vibration analysis for troubleshooting and data storage are taken into consideration. The favorable situation of vibration monitoring is provided for the purpose of comparison and conclusions about the status of vibration monitoring and needs have been made.

KEYWORDS: vibration monitoring; gas turbine; maintenance and repair; condition monitoring

1. Introduction

Gas turbines are widely used in various industries, including oil and gas, marine, power generation, aerospace, etc., due to several reasons. High speed, low start-up time, and low power to weight ratio are the main reasons for the use of these machines. Gas turbines have played a significant role in the transmission of natural gas in region three of Iran's gas transmission operations. Today, gas turbines alone have a great role in power generation. Despite all the above-mentioned benefits of using gas turbines, their use at high temperature sometimes leads to the emergence of many problems and costs a lot to repair. Today, long-term use of gas turbines with minimal damage, estimating the remaining life of the various components, especially hot components, as well as their maximum efficiency in different environmental conditions and exploitation of knowledge are problems of these machines.

The status of the implementation of condition monitoring (CM) in gas compression stations is investigated in this study. Gas compression stations include new and old stations. Therefore, the status of the implementation of CM in gas compression stations in the past and present is specified. Cases considered in this study include:

1) Condition monitoring techniques used at the station;
2) Vibrating equipment installed at the station;
3) Vibration analysis used in station;
4) The way of recording vibrations history of turbines;
5) The role of vibration signal in decision-making and planning for repairs.

2. The necessity and importance of research

The use of the maintenance and repair system can play a very important role in reducing the finished price of the final product. But these effects are not only limited to the cost, and the speed of product delivery in the entire supply chain, product quality, reliability, organizational agility and other such factors will also have their own effects, each of which will be a place for reflection. Therefore, it is possible to realize the important role and impact of different maintenance and repair strategies on the business of an economic enterprise. Undoubtedly, in most industrial, production and service units, a large part of the total cost is the repair and maintenance cost. And for this reason, the reforms that take place in this field are short-term. Generally, the main factors that cause abnormal repair and maintenance costs in an industrial unit are: until the improvements are made, the product is not accepted; the downtime related to the timing of repairs and the usual costs of repairs; and maintenance, which are an indication of the organization's need for a repair and maintenance system. If the equipment is not repaired on time, the following factors may occur:

1) Reduce or stop production;
2) Unemployment of human resources directly or indirectly;
3) Delay or stoppage in other production matters in a production line;
4) Creating additional costs;
5) Dissatisfaction and morale destruction of technical and operational staff.

3. Research objectives

In most organizations, preventive maintenance and repair systems need fundamental improvement and optimization. Most maintenance and repair systems are not designed and implemented based on the principles of maintenance and repair management and are formed based on the needs of the time and the needs of the organization little by little, and this issue has caused many of the prominent and key points of the management systems. Preventive maintenance and repairs are neglected. Therefore, for the first step of improvement and optimization, unfortunately, they resort to maintenance and repair software, and a lot of time and energy of the organization is spent on it, and with the passage of time and changes in managers and human resources, the system remains unfulfilled. In this research, the main goal is to improve the status of maintenance and preventive maintenance systems in the area of three gas transmission operations, and this goal is to achieve the following partial goals:

1) Unplanned malfunction of equipment and rework;
2) Prevent parts from being scrapped;
3) Preventing shutdown of production lines and reduction of product;
4) Increasing the quality of repairs and periodic maintenance in the area of three gas transmission operations;
5) Increasing the reliability of the equipment;
6) Reducing the time of repairs and maintenance of equipment in the area of three gas transmission operations.

According to the definitions provided and its wide applications in organizations, the officials of the repair and maintenance unit have not used this concept to improve the performance of the repair and maintenance unit in this area, and in this research, we use the concept of six sigma to improve. We have used the performance of the maintenance and repair unit of the three-gas region so that the officials of this region can compete in the global competitive markets by implementing this method in this region, and it causes cost reduction, high competitiveness, continuous improvement, and increasing the quality and quantity of the product, lack of natural resources and energy, etc.

4. Research background

Taghipour et al.[1] studied "Risk analysis in the management of urban construction projects from the perspective of the employer and the contractor."

Mahboobi et al.[2] discussed "Assessing ergonomic risk factors using combined data envelopment analysis and conventional methods for an auto parts manufacturer", occupational injuries are currently a major contributor to job loss around the world.

Taghipour et al.[3] studied "The impact of ICT on knowledge sharing obstacles in knowledge management process (including case-study)."

Khalilpour et al.[4] studied "The impact of accountant's ethical approaches on the disclosure quality of corporate social responsibility information an Islamic perspective in Iran."

Mirzaie et al.[5] studied "The relationship between social bearing capacities with conflict as a result, in the perception of the visiting historical sites."

Alamdar Khoolaki et al.[6] studied "Effect of integrated marketing communication on brand value with the role of agencys reputation (including case study)."

Taghipouret et al.[7] studied "A survey of BPL technology and feasibility of its application in Iran (Gilan Province)."

Seddigh Marvasti et al.[8] studied "Assessing the effect of the FRP system on compressive and shear bending strength of concrete elements."

Jalili et al.[9] studied "Comparative study of Khaje Rashid al-Din views on Rab-e Rashidi Islamic Utopia and Kevin Lynch ideas."

Taghipour et al.[10] studied "Insurance performance evaluation using BSC-AHP combined technique."

Rezvani et al.[11] discussed "The design of high-rise building with ecological approach in Iran (Alborz Province)."

Taghipour et al.[12] studied "The identification and prioritization of effective indices on optimal implementation of customer relationship management using TOPSIS, AHP methods."

Taghipour and Yazdi[13] studied "Seismic analysis (non-linear static analysis (pushover) and nonlinear dynamic) on Cable-Stayed Bridge."

Taghipour et al.[14] studied "Investigating the relationship between competitive strategies and corporates performance (case study: Parsian Banks of Tehran)."

Taghipour and Moosavi[15] studied "A look at gas turbine vibration condition monitoring in region 3 of gas transmission operation."

Rahmani et al.[16] studied "Providing health, safety and environmental management (HSE) program in metal mining industry (including case study)."

Taghipour and Vaezi.[17] studied "Safe power outlet."

Azarian and Taghipour.[18] studied "The impact of implementing inclusive quality management on organizational trust (case study: educatin)."

Mohammadi et al.[19] studied "Investigating the role and impact of using ICT tools on evaluating the performance of service organizations."

Abdi et al.[20] studied "Predicting entrepreneurial marketing through strategic planning (including case study)."

Khorasani and Taghipour[21] studied "The location of industrial complex using combined model of fuzzy multiple criteria decision making (including case study)."

Taghipour et al.[22] studied "Risk assessment and analysis of the state DAM construction projects using FMEA technique."

Hoseinpour et al.[23] studied "The problem solving of bi-objective hybrid production with the possibility of production outsourcing through Imperialist Algorithm, NSGA-II, GAPSO Hybid Algorithms."

Taghipour and Sarchoghaei[24] studied "Evalation of tourist attractions in Bourujerd County with emphasis on development of new markets by using Topsis Model."

Safdarpour et al.[25] studied "The effect of government support on innovation ability (including a case study)."

Ganjali et al.[26] studied "Strategic analysis of household hazardous waste reduction."

Taghipour et al.[27] studied "The impact of managerial factors on increasing the productivity of low-level employees (including case study)."

Ganjali et al.[28] studied "Investigating the relationship between environmental awareness and the level of education and occupation of people."

Baghipour Saramiet et al.[29] studied "Modeling of nurses' shift work schedules according to ergonomics: a case study in Imam Sajjad (As) Hospital of Ramsar."

Taghipour et al.[30] studied "The impact of motives from obtaining ISO 9001 certification on organization performance (including case study)."

Molavi and Taghipour[31] studied "A survey on electrical cars advantages."

Safdarpour et al.[32] studied "The effect of communication on learning ability (including a case study)."

Akbarnezhadbaei et al.[33] studied "Modeling the application of knowledge management system in order to improve the technology governance in the automotive industry of Iran using the data mining environment."

Molavi and Taghipour[34] studied "An overview of electric vehicle concepts and its features."

5. Maintenance and repair practices

Maintenance and repair costs in industry are typically 5% to 6% of fixed capital, which reaches 12% in big and heavy industries. Low-quality products should also be added to these costs. Maintenance and repair minimize the total cost by reducing the number of downtimes, stoppages and improving safety.

The industrialists have taken different ways for maintenance and repair. Each of these methods has advantages and disadvantages that can improve or weaken the overall system performance, which is why weak methods are gradually excluded from industrial competition and the old methods of maintenance and repair are employed. Employing advanced methods is essential to achieving sustainable industrial development. The main objective of the changes made to the previous techniques is to reduce maintenance costs, reduce the frequency of stopping the machine (increasing the availability of devices), and identify and fix defects in the machines. Accordingly, the following methods have been used for the maintenance of machines so far:

1) Reactive maintenance;
2) Time base maintenance (TBM);
3) Condition base maintenance (CBM);
4) Proactive maintenance.

6. Condition base maintenance (CBM)

Condition-based maintenance and repair, which is also called predictive maintenance and repair, maintenance and repair based on technical requirements, and contingency maintenance and repair, is the most effective strategy for managing physical assets and is one of the essential elements of RCM besides preventive maintenance (PM), failure finding techniques, redesign, etc. Condition monitoring (CM) tool is used for the establishment and operation of condition based maintenance. In fact, situation or condition monitoring is at the core of this strategy. This strategy is based on the belief that most of the failures of machines and industrial equipment have signs after reaching a certain stage that can be identified in the form of vibration, sound, ultrasonic waves, particle attrition, temperature, and failure can be predicted. Therefore, before reaching a critical stage, the progress of failure can be prevented by planning repair programs and implementing them.

Some of the common techniques in condition monitoring are:

1) The use of the five senses;
2) Vibration analysis;
3) Sound analysis;
4) Ultrasonic analysis;
5) Thermography;
6) Performance analysis;
7) Oil and tribology analysis;
8) The motor circuit analysis and other electrical tests.

The use of predictive maintenance can greatly help reduce maintenance and repair costs. In many productive and administrative activities, maintenance and repair is the most important costly but manageable factor known to increase productivity. According to universally accepted estimates, the cost of maintenance and repair will be reduced to 25% by performing CM programs, while savings resulting from the prevention of reduced production is doubled that is not considered in these estimates.

7. Perspectives in the field of vibration monitoring

What is vibration?

Vibration or mechanical vibrations refer to a kind of dynamical system's oscillatory movement (reciprocity) that is repeated over a period of time (**Figure 1**).

In its simplest form, this type of movement can be simulated with a mass and a spring. With the induction of a shift in mass attached to a spring and dropping it, oscillation occurs, and its scope can be expressed by a sinusoidal function.

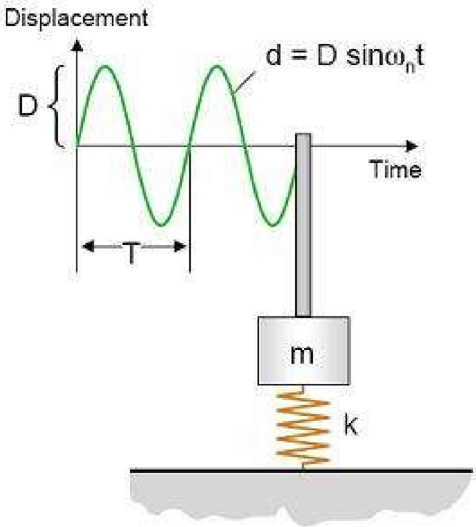

Figure 1. The sinusoidal function of oscillating motion of vibrations.

7.1. Basic concepts of vibration

The important characteristics of vibration include:

- Amplitude, which is a measure of the intensity of vibration.
- Frequency, which is a measure of the rate per unit of time.
- Phase, which is a measure of movement sequence relative to a reference.

Vibration scope can be expressed through three different parameters:

- Displacement;
- Velocity;
- Acceleration.

7.2. What is displacement?

The primary parameter of scope that is about the mass-spring system that gives the position of mass at any moment.

Displacement measurement units:
In the SI system: μm.
In the inch system: mils that is equal to a thousandth of an inch.

7.3. What is velocity?

Velocity is mathematically derived from displacement that shows the rate of change of displacement per unit of time.

Velocity measurement units:
In the metric system: mm/s.
In the inch system: in/s.

7.4. What is acceleration?

Acceleration is mathematically derived from velocity that shows the rate of change of velocity per unit of time.

Acceleration measurement units:

In the metric system: g or m/s2.
In the inch system: g or in/s2.

7.5. The relationship between displacement, velocity and acceleration?

Displacement, $x = A\sin(\omega t + \alpha)$
Velocity, $v = dx/dt = \omega A\cos(\omega t + \alpha)$
Acceleration, $a = dv/dt = -\omega^2 A\sin(\omega t + \alpha)$

In general, the amplitude of each sine wave can be determined in three ways (**Figure 2**):

1) 0–*p* value: zero to peak;
2) *p*–*p* value;
3) Rms value or effective value.

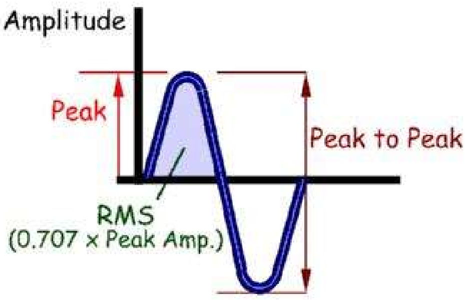

Figure 2. Amplitude of sine wave.

7.6. What is the frequency and phase of the vibrations?

Time period (T) of a movement is a period that repeats its vibrational cycle. The vibration frequency is actually opposite of the period (**Figure 3**).

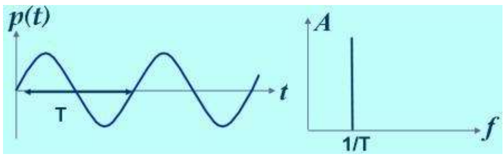

Figure 3. Frequency and phase of vibrations.

Frequency measurement units:
Hertz = 1/s.
cpm = Cycle per minute.
cps = Cycle per second.

Accordingly: 1 Hz = 1 cps = 60 cpm.

Phase is always measured relative to a reference and shows movement sequence relative to that reference.

7.7. Why is it that there is vibration in rotating equipment and machinery?

Generally, there are two types of static and dynamic forces in machines. Vibratory forces are dynamic forces that are created by the existence of shortcomings in the machine. Some of the shortcomings (different from the ideal state) are:

- Design constraints;
- Construction constraints;
- Problems in the initial installation;
- Exploiting problems;
- Failure during repairs;
- And etc.

Since reaching the ideal state is not possible, there is always some vibration on the machines that will be allowed. But with the passage of time and as a result of the subsequent problems, sometimes vibrations increase more than the allowed amount. The situation can be restored to its previous state with analysis and appropriate corrective actions.

The following equation determines the amount of vibration in machine:

$$\text{Vibration} = \text{Vibratory Force}/\text{Impedance}$$

Vibratory forces are usually produced in the car and rotor system (i.e., the rotating section). The impedance is the specification of any mechanical system, including rotating machinery, and describes the vibration transmission path. The vibrations that are normally measured from the static part (stator) of machines, particularly from the bearing housing, are influenced by the two above-mentioned factors. Now these two factors (i.e., the vibratory forces and impedance) are examined separately.

8. Vibratory forces

Some factors causing vibratory forces in the machinery include:

- Misalignment;
- Mass unbalance;
- Abrasion of parts;
- Aerodynamic and hydrodynamic forces;
- Electromagnetic forces;
- Stationary and mobile parts' contact;
- Friction.

9. Impedance

Mechanical impedance or resistance against the movement is one of the characteristics of mechanical systems that has three components: 1). mass; 2). rigidity; and 3). damping. Some factors intensify vibration without producing any force and only by affecting the impedance. The most important ones are:

- Mechanical looseness;
- Stimulating the natural frequency of components (resonance);
- Weaknesses in the foundation or machine chassis;
- The weakness of the structure.

10. Vibrations as indicator of the status of equipment

Vibrations of rotating equipment (both in terms of amplitude and in terms of other specifications of vibrations) are directly related to its status, and any change, even a minor change, in the status of the equipment (in every respect) will be accompanied by a change in the status of vibrations.

10.1. What is change in the status of equipment?

- Change in terms of equipment utilization.
- Failure (mechanical, electrical, etc.) in equipment.
- Change in the load on the equipment.

Therefore, vibration measurement and analysis are one of the main techniques of condition monitoring of rotating equipment.

10.2. Some of the problems that can be detected through vibration analysis

Some of the problems that can be detected with the help of vibration analysis and analysis of vibration signals in machinery:

1) Mass unbalance;
2) Misalignment;
3) Resonance;
4) Mechanical looseness;
5) Bearing failure;
6) Failure of gear;
7) Eccentricity;
8) The curved shaft;
9) Faulty foundation;
10) Electrical problems;
11) Aerodynamic and hydrodynamic problems;
12) Couplings failure;
13) Belt and pulley problems;
14) Piping problems;
15) Distortion.

The key and important factor for troubleshooting through vibration analysis is that any defect in rotating equipment creates vibrations with their own characteristics (in terms of amplitude, frequency, phase, etc).

11. Processing and information management software

In addition to seismograph devices that are designed for the CM program, specialized software is also offered to connect the system to the computer. The software is used for information management (storage, processing, etc.).

12. Types of vibration meter sensors

Vibration meter sensor is the first device needed for measuring vibrations and is a tool that senses the vibrating movement and converts it to an AC electrical signal proportional to the vibrational motion.

By converting vibrations into an electrical signal, it is possible to store, perform subsequent processes, and also observe signals through electronic devices (data mining equipment).

Some important points about sensors are:

- Sensor type;
- Choosing the correct sensor according to the sensor characteristics (sensitivity, frequency response, dynamic range, measuring range, dimensions, weights, operating temperature, type of

connector, direction of measurement, sensors' feed type);
- Proper installation of the sensor and its cable;
- Positions the sensor and its cable.

The above-mentioned points will be investigated below. First, different types of vibration meter sensors are introduced. In general, according to the working mechanism and main parameters of measurements, vibration meter sensors are classified into three groups:
- Accelerometer;
- Speedometer;
- Displacement meter.

Accelerometers

Accelerometers are made in various types and sizes. There are three types of accelerometers that are:
- Piezoelectric accelerometers;
- Piezoresistive accelerometers;
- Capacitive accelerometers.

Piezoelectric accelerometers are more common and are classified in two compression type and shear type in terms of the impact of vibration on them and production of electrical signal. The main element of this type of accelerometers is made of piezoelectric materials such as quartz or certain types of ceramics. These materials produce electrical signals as a result of stimulation. Schematic of the structure of this kind of sensor can be seen in **Figure 4**:

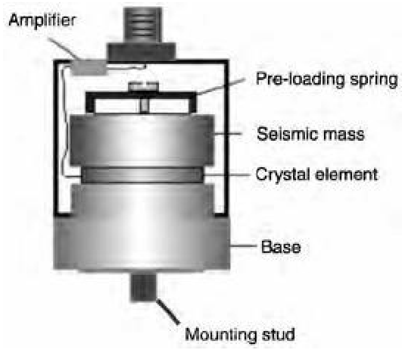

Figure 4. Structure of piezoelectric accelerometer.

As can be seen in the figure, the main components include a mass, crystal material (piezoelectric), a preloading spring, an amplifier, base. This type of configuration is such that the force generated on the piezoelectric material, and thus the electrical signal produced by it is proportional to the acceleration of base. Since the produced signal is usually weak, an internal circuitry is used to amplify the signal. Finally, the sensor output is led toward signal processing devices (data mining devices) through the appropriate cables and can be used for condition monitoring.

Customary vibration analysis methods and techniques for condition monitoring of the machinery. Some of the common techniques of vibration analysis in various applications, especially the issue of condition monitoring and monitoring rotating equipment, include:
- Analysis of the total amount of vibrations;
- Parameters and characteristics of rolling bearings (BCU, BP, Crest factor, *k*-factor, PeakVue, SEE, etc.);
- Analysis of the frequency spectrum (FFT analysis or spectrum);

- Vibration waveform analysis;
- Envelope analysis or vibration signals demodulation;
- Spectrum analysis;
- Analysis of the phase angle;
- Run up and coast down analyses (Bode plot, Nyquist plot, shaft centerline plot, waterfall plot);
- Orbit analysis.

Some of the aforementioned techniques are briefly introduced and then the topic of "detecting common defects in rotating equipment through the frequency analysis of vibration signals and phase angle analysis" is discussed in more detail.

13. Analysis of the total amount of vibrations for condition monitoring

This method is the simplest technique used to assess the condition of rotating machinery. There are different standards for allowable vibration values, including the ISO 10816. It is worth noting that from low to high, normal vibration of the machine occurs in the axial, vertical, and horizontal directions. It is a rule of thumb and may not be true in some cases, but its authenticity has been proven in most cases. However, due to the changes in the pattern, some problems can be easily predicted even without a frequency curve.

13.1. Frequency spectrum analysis (FFT or spectrum analysis) for condition monitoring and troubleshooting

This technique is without doubt one of the most common techniques of vibration signal analysis that is significantly used in condition monitoring and fault diagnosis of rotating machinery (turbines). After some initial processing of vibration signals, the FFT algorithm or fast Fourier transform is used to obtain the frequency spectrum curve. Therefore, the frequency curve is sometimes called FFT curve.

13.2. Vibration waveform analysis and its application for condition monitoring and troubleshooting

Vibration waveform is the vibration signal without almost any processing, which is why it is so important in dynamic analysis of machinery. In fact, some defects such as fractures of gears, defects created by pulses, beat vibrations, and modulation phenomenon are easily detected by analyzing the vibration waveform.

13.3. Analysis of phase angle and its application for detecting the problems of rotating equipment of gas turbine

By comparing the values of the phase angle of vibration at different points and directions of measurement on the machinery or any other structure, a representation of how the various components move relative to each other can be achieved. In some cases, frequency specifications of vibration caused by different faults are quite similar; therefore, the distinction between these defects is not possible only through spectrum curve. In such cases, other vibration signal characteristics such as phase angle are used to separate defects, since despite the similarity of frequency curves (spectrum), phase angle pattern is distinctive for different defects. In general, some of the phase angle applications include:

- Shaft crack detection;
- Dynamic balance;
- Resonance and critical velocity detection;
- Obtaining mode shapes;

- Identifying mass unbalance, misalignment, and curved shaft from each other.

14. Troubleshooting with the help of frequency analysis and spectrum curve in gas turbines

As mentioned in the previous sections, different faults that occur in rotary machinery in gas compressor stations each occur with their own dynamic behavior, or in other words, with a special vibrating feature. One important characteristic of vibration is vibration frequency, and in particular, its relationship with working frequency of the machine (its revolution) in many cases determines the type of fault, or at least, its area.

It should be noted that the measured vibration of the machine is usually a complex signal and a combination of several vibration signals with different frequencies. Frequency analysis, also called spectrum analysis or FFT analysis, is a process of signal processing in which frequency content of vibrational frequency is obtained. In FFT curves, the horizontal axis is frequency, and the vertical axis shows amplitude. As mentioned, in many faults and problems, the frequency of the vibrations is related to the revolution, and in fact, harmonics, or in other words, multiples of machine revolution are seen in FFT curve. These multiples are shown as 1 × RPM, 2 × RPM, 3 × RPM, and so on.

There are many different tables expressing the frequency specifications of common problems. A simplified example can be seen in **Table 1**. As can be seen, the first column shows the kind of problem, the second column shows the related frequencies, and the third column shows the direction with the highest vibration.

Table 1. Frequency specification of common problems of machinery.

Type of the problem	Frequency and its relationship with revolution	The dominant direction and behavior of vibration amplitude
Mass unbalance	1 × RPM	Radial vibrations with fixed amplitude
Curved shaft	1 × RPM (and 2 × RPM)	High vibration in the axial direction
Rolling element bearing	Quad frequencies of roller bearings	A subtle effect on the overall amplitude of vibration
Journal bearing	1 × RPM	Radial
Misalignment	1~3 × RPM	High radial vibration for offset misalignment and high axial vibrations for angular misalignment
Belt failure	1~3 × Belt RPM	High vibration in the direction of the connection point of the two pulls
Oil whirl	0.42~0.48 × RPM	Unstable vibrations in the radial direction
Gears' problems	Gear mesh frequency (GMF)	Determined according to the prevailing load of the gear (radial or axial).
Structural mechanical looseness	1 × RPM	
Resonance	Specific frequencies of each system	High amplitude vibrations

15. Vibrations' monitoring in the gas compressor station

15.1. The introduction of gas compressor station

Gas compressor station is selected as an example to investigate the status of CM in the country. During the visit to the gas compressor station, six units with a capacity of 25 MW had been exploited. Gas compressor turbines are Siemens, SGT 600.

15.2. Vibration monitoring system

With a glimpse at stations, it can be seen that a lot of attention has been given to the issue of vibrations in the gas compressor station, so that 16 vibration sensors are installed on each unit and vibration signals are brought to control room. Warning and risk values for vibration amplitude are also specified, and in case of high vibration amplitude, alarm or trip command is issued in the control room. Vibration equipment used mainly consists of sensors, cables, connectors, signal processing, acquisition systems, and software processing.

Two acceleration and displacement sensors are used to measure the absolute vibration of bearing shell and the relative shaft vibration in the gas compressor station. Acceleration sensors are Piezoelectric, version CA201, and have been installed on the bearings in the vertical direction. Two acceleration sensors have been installed on each bearing to raise confidence. The installation location of the acceleration sensors on the bearing housing is shown in **Figure 5**.

Figure 5. Location of installing acceleration sensors on the bearing housing.

Displacement sensors used in gas compression stations are of the contact type (Bentley Nevada), 330100-90-05 model. Displacement sensors are mounted on the bearing shell and the tip of the probe is in the vicinity of the shaft. The sensors measure relative displacement of shaft and bearings. The sensor needs an oscillator and demodulator that are installed near it. **Figure 6** shows the location of displacement sensors. In the gas compressor stations, two displacement sensors with ±45 angle to the vertical line are installed on each bearing.

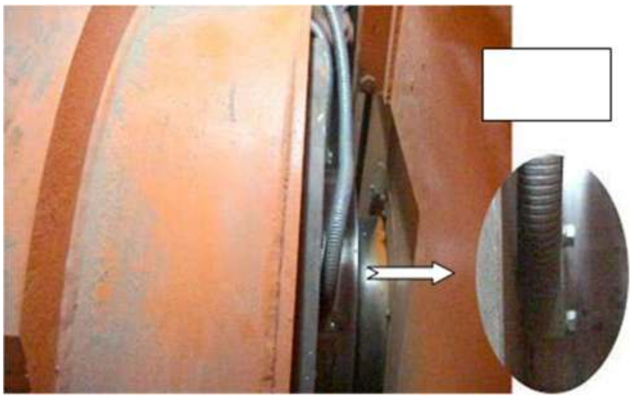

Figure 6. Location of installing displacement sensors on the bearing housing.

15.3. Data acquisition system

To acquire and process the vibration data in gas compressor stations, VM600 system from Vibro-Metr Company is used. VM600 is a complete set used to acquire data, process, protect, and monitor machines. The VM600 system is not fully installed in gas compressor station and only part of it that is related to protection against high vibration is used.

15.4. Software and decision-making system

Vibrating signals and other signals on process are available on the control software in the control room. In the gas compression station, the vibrations are only used for protection. That is, if the vibration signal exceeds a predetermined value, turbine's stop command is issued. Overall amount of vibrations in two-second time intervals is recorded and displayed in the control room. The data is stored in the system for two days and then deleted. Although trend of vibrations is visible within seven days, vibrations are not used for condition monitoring.

Vibratory signals visible in the control room on each gas turbine are as follows:

Two velocity signals (mm/s), which are obtained by integrating the acceleration signal.

A displacement signal (μm peak) equal to the maximum displacement (s).

Vibration protection system of gas compression station is activated with two warnings from the above vibration signals and trip command is issued.

Despite the installation of all required vibration hardware, the vibration spectrum in gas compression station is not available, which is a great problem for this station. In this spectrum, the frequency of the dominant components is seen at frequencies of 50 and 100 Hz. The 50 Hz component corresponds to 1 revolution of shaft (l RPM) and is mainly related to misalignment, and its value (14 μm) is in the allowed limit. The 100 Hz component corresponds to double of the revolution of shaft (2 RPM) and is caused by a lack of alignment, and its value (5 μm) is within the allowed limit. The pattern in the frequency spectrum indicates a healthy condition, and failures will cause a change in it.

16. Summary

A lot of attention has been given to the issue of vibrations in the gas compressor station, so 12 vibration sensors are installed on each turbine. However, vibrations are just seen as protective parameters, and overall, is just taken from among the many pieces of information provided in the vibration spectrum. In the gas compression station, apart from protective system, CM with vibration analysis is not used for high vibrations. Due to the fact that all the vibration sensors are installed in place and the bulk of the hardware required for CM is provided, it seems that the only obstacle to the application of advanced technology for CM in gas compressor station is lack of knowledge rather than the cost of the system. In the gas compressor station, CM systems can be implemented by adding appropriate software and training. The operation is very low cost, and in contrast, it will have a lot of stations. Experience in gas compression station suggests that if they are not aware, benefits of the CM system will not be used despite the high costs and mounting of CM hardware.

Vibration is one of the important parameters to evaluate the status of gas turbine in operation. Manufacturers of gas turbines have monitored this parameter with a view to protecting this system, which is not sufficient for the purposes of maintenance and repairs. For monitoring vibrations in gas turbines, measuring relative and absolute vibration is required. The vibration values of the two measurement models and the relevant locations are provided in ISO standards. Vibrations and vibration status of each machine are often expressed in terms of its overall amplitude that involves all frequencies. The overall amplitude of vibration should be continuously monitored and the status of the machine should be first determined based on it. The maximum amplitude of vibration in turbines and most of the rotary machines happens during the operation revolution. Also, almost all the vibration imperfections have a component in the frequency of operation revolution. In some cases, double function component also contributes to the vibration response. Especially if the measurements are taken in the direction toward generator, these parameters will be observed with a greater amplitude. Amplitude monitoring and the phase of these two components help to determine the exact vibration condition and the type of defects. Gas turbine vibrations are often produced at different frequencies with different amplitudes. Vibration amplitudes bypass the lower blade, and it is necessary to measure them during the process.

One of the most important parameters in determining the status of vibration and type of defects of turbines in journal bearings is measuring air gap from the inner part of the bearing to shaft and also tracing the path of the shaft within the bearing. Due to the installation of two non-contact sensors or motion detectors inside the bearing, movement of the shaft and the air gap can be monitored. Roller bearings are sometimes used in the driver parts. In this case, the software should be capable of processing high signals resulting from the failure of this type of bearing.

Another important issue in monitoring vibrations as well as their processing is a choice of filters. The software should have a variety of different filters to determine the vibration frequency bands. In measuring the vibrations, it should be possible to compare different vibration sensors together. The most important part of the vibration software is Fourier transform. The number of lines in Fourier transform is another important parameter in determining the value of software. With more lines in a fixed band, it is possible to obtain high accuracy in magnification. In measuring the vibrations of gas turbines, different signals are received from different parts with different amplitudes. To realize the importance of the amplitude of the signal, it is required to use signal envelope (envelope spectrum) in some cases, such as signals received from the gearbox or roller bearings. To view the amplitude of all signals with different frequencies and amplitudes, the software must be capable of dividing a Fourier transform diagram into several different frequency bands. This will be done with the use of CPB (constant percentage bandwidth).

17. Conclusion

In this paper, vibration monitoring was studied as a protective and troubleshooting tool and vibration monitoring systems in gas compressor station in region 3 were compared. Vibration monitoring in stations has improved in terms of both the number of sensors and protection. However, the software and decision-making approach based on vibration data have not changed much at stations, and maintenance and repair based on the status of the stations has not found its place yet. Therefore, it seems that there is a need for more education and culture-building in this regard.

In this research, by implementing this method, we were able to reach the following results:

1) By implementing this method, we can reduce various costs, including repair costs.
2) According to the investigations, there are favorable conditions and conditions for the implementation of this system in the region of three gas transmission operations in Iran.
3) There is a significant relationship between the maintenance and repair system and the productivity of the production line employees, and it leads to the productivity and satisfaction of the employees.
4) To improve the system, we should focus and pay more attention on the mechanics group.

Author contributions

All authors contribute to this research.

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Conflict of interest

The authors declare no conflict of interest.

References

1. Taghipour M, Seraj F, Hassani MA, Farahani Kheirabad S. Risk analysis in the management of urban construction projects from the perspective of the employer and the contractor. *International Journal of Organization Leadership* 2015; 4(4): 356–373. doi: 10.33844/ijol.2015.60284
2. Mahboobi M, Taghipour M, Ali Azadeh M. Assessing ergonomic risk factors using combined data envelopment analysis and conventional methods for an auto parts manufacturer. *Work* 2020; 67(1): 113–128. doi: 10.3233/WOR-203257
3. Taghipour M, Mahboobi M, Gharagozlou H. The impact of ICT on knowledge sharing obstacles in knowledge management process (including case-study). *Iranian Journal of Information Processing and Management* 2016; 31(4): 1049–1074. doi: 10.35050/JIPM010.2016.003
4. Khalilpour M, Kamyabi Y, Nabavi Chshmi SA, Taghipour M. The impact of accountant's ethical approaches on the disclosure quality of corporate social responsibility information an Islamic perspective in Iran. *National Academy of Managerial Staff of Culture and Arts Herald* 2018; 1: 1173–1181. doi: 10.32461/2226-3209.1.2018.178689
5. Mirzaie F, Nazari AA, Zargham BH, Taghipour M. The relationship between social bearing capacities with conflict as a result, in the perception of the visiting historical sites. *Journal of Investment and Management* 2015; 4(6): 403–408.
6. Alamdar Khoolaki M, Naami A, Taghipour M. Effect of integrated marketing communication on brand value with the role of agencys reputation (including case study). *Journal of Process Engineering* 2019; 5(11): 30–44.
7. Taghipour M, Safari M, Bagheri H. A survey of BPL technology and feasibility of its application in Iran (Gilan Province). *Science Journal of Circuites, Systems and Signal Processing* 2015; 4(5): 30–40. doi: 10.11648/j.cssp.20150405.11
8. Seddigh Marvasti SMA, Beheshti B, Chegini H, Taghipour M. Assessing the effect of FRP system on compressive and shear bending strength of concrete elements. *International Journal of Innovative Research in Science, Engineering and Technology* 2015; 4(11): 11511–11524. doi: 10.15680/IJIRSET.2015.0411119
9. Jalili L, Ghafourian M, Toopal T, Taghipour M. Comparative study of Khaje Rashid al-Din views on Rab-e Rashidi Islamic Utopia and Kevin Lynch ideas. *International Journal of Archaeology* 2015; 3(5): 39–47. doi: 10.11648/j.ija.20150305.11
10. Taghipour M, Vosough A, Azizi D, Abdi J. Insurance performance evaluation using BSC-AHP combined technique. *National Academy of Managerial Staff of Culture and Arts Herald* 2018; 1: 1158–1166. doi: 10.32461/2226-3209.1.2018.178687
11. Rezvani BA, Ghobadian V, Taghipour D. The design of high-rise building with ecological approach in Iran (Alborz Province). *International Journal of Modern Trends in Engineering and Research* 2015; 2(10): 455–464.
12. Taghipour D, Ganji F, Zolfagharijoo A, et al. The identification and prioritization of effective indices on optimal implementation of customer relationship management using TOPSIS, AHP methods (case study: Pasargad bank). *Management* 2020; 3(4): 43–60. doi: 10.31058/j.mana.2020.34004
13. Taghipour M, Yazdi H. Seismic analysis (non-linear static analysis (pushover) and nonlinear dynamic) on cable-stayed bridge. *American Journal of Civil Engineering* 2015; 3(5): 129–139. doi: 10.11648/j.ajce.20150305.11
14. Taghipour M, Barzegar P, Mahboobi M, Mohammadi S. Investigating the relationship between competitive strategies and corporates performance—Case study: Parsian Banks of Tehran. *Management* 2020; 3(4): 13–28. doi: 10.31058/j.mana.2020.34002
15. Taghipour M, Moosavi SA. A look at gas turbine vibration condition monitoring in region 3 of gas transmission operation. *Journal of Environmental Science, Computer Science and Engineering & Technology* 2020; 9(3): 423–432. doi: 10.24214/jecet.C.9.3.42332

16. Rahamni M, Vaziri Shams S, Abedi V, Taghipour M. Providing health, safety and environmental management (HSE) program in metal mining industry (including case study). *Management* 2021; 4(3): 14–35. doi: 10.31058/j.mana.2021.43002
17. Taghipour M, Vaezi M. Safe power outlet. *Electrical Science & Engineering* 2020; 2(2): 5–10. doi: 10.30564/ese.v2i2.2464
18. Azarian R, Taghipour M. The impact of implementing inclusive quality management on organizational trust (case study: Education). *Journal of Multidisciplinary Engineering Science Studies* 2020; 6(7): 3376–3383.
19. Mohammadi S, Taghipour M, Mahboobi M. Investigating the role and impact of using ICT tools on evaluating the performance of service organizations. *Iranian Journal of Information Processing and Management* 2021; 37(1): 1–26. doi: 10.52547/JIPM.37.1.1
20. Abdi J, Safarian S, Usefi R, Taghipour M. Predicting entrepreneurial marketing through strategic planning (including case study). *Educational Administration Research Quarterly* 2019; 10(39): 127–146.
21. Khorasani Z, Taghipour M. The location of industrial complex using combined model of fuzzy multiple criteria decision making (including case study). *International Journal of Innovation Scientific Research and Review* 2020; 2(7): 268–280.
22. Taghipour M, Sharifzadeh S, Seraj F. Risk assessment and analysis of the state DAM construction projects using FMEA technique. *Trends in Life Sciences an International Peer-Reviewed Journal* 2015; 4(2).
23. Hoseinpour Z, Taghipour M, Beigi JH, Mahboobi M. The problem solving of bi-objective hybrid production with the possibility of production outsourcing through imperialist algorithm, NSGA-II, GAPSO hybrid algorithms. *Turkish Journal of Computer and Mathematics Education* 2021; 12(13): 8090–8111.
24. Taghipour M, Sarchoghaei JA. Evalation of tourist attractions in Bourujerd County with emphasis on development of new markets by using Topsis model. *Science Journal of Business and Management* 2015; 3(5): 175–189. doi: 10.11648/j.sjbm.20150305.16
25. Safdarpour S, Pourkhosravani P, Taghipour M. The effect of government support on innovation ability (including a case study). *Journal of Multidisciplinary Engineering Science and Research* 2023; 2(6): 233–237.
26. Ganjali R, Negaresh Z, Taghipour M. Strategic analysis of household hazardous waste reduction. *International Journal of Educational Foundations and Management* 2023; 11(4): 1–10.
27. Taghipour M, Safdarpour S, Taherian P, et al. The impact of managerial factors on increasing the productivity of low-level employees (including case study). *Management* 2022; 5(2): 16–21. doi: 10.31058/j.mana.2022.52001
28. Ganjali R, Ohadi Digesaraei D, Taghipour M. Investigating the relationship between environmental awareness and the level of education and occupation of people. *International Journal of Educational Foundations and Management* 2023; 11(4): 11–15.
29. Baghipour Sarami F, Bozorgiamiri A, Mououdi MA, Taghipour M. Modeling of nurses' shift work schedules according to ergonomics: A case study in Imam Sajjad (AS) Hospital of Ramsar. *Iranian Journal of Ergonomics* 2016; 4(1): 1–12. doi: 10.20286/joe-04011
30. Taghipour M, Habibi MH, Amin M. The impact of working capital management on the performance of firms listed in Tehran Stock Exchange (TSE). *Journal of Multidisciplinary Engineering Science and Technology* 2018; 7(6): 12146–12154.
31. Molavi A, Taghipour M. A survey on electrical cars advantages. *Progress in Energy & Fuels* 2023; 12(1): 1–14. doi: 10.18282/pef.v12i1.3351
32. Safdarpour S, Pourkhosravani P, Rooholamini V, Taghipour M. The effect of communication on learning ability (including a case study). *Management* 2022; 5(4): 46–54. doi: 10.31058/j.mana.2022.54006
33. Akbarnezhadbaei K, Mohammadi M, Kouloubandi A, Taghipour M. Modeling the application of knowledge management system in order to improve the technology governance in the automotive industry of Iran using the data mining environment. *Journal of Educational Administration Research Quarterly* 2023; 14(55).
34. Molavi A, Taghipour M. An overview of electric vehicle concepts and its features. *International Journal of Educational Foundations and Management* 2022; 11(4).