# MULTIPARAMETRIC DIAGNOSTICS OF GAS TURBINE ENGINES

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## SUMMARY

This article addresses the issue of diagnostics and maintenance of Gas Turbine Engines which are located in high Speed Ferries, Cruisers, Frigates, Corvettes, etc. Assurance of reliable operation can be performed only by using correct diagnostic methods and procedures of monitoring the condition of the devices and by selecting the correct strategy of maintenance. The issue of monitoring the technical condition of Gas Turbine Engines is treated through multiparametric methods of technical diagnostics incorporated into predictive maintenance, which is a part of proactive maintenance. There are methods of vibrodiagnostics, thermography, tribology, borescopy and emissions measurement. Each of these methods has lots of advantages and disadvantages; therefore it is very important to ensure their correct combination for trouble-free operation of those important facilities. Their suitability at work is discussed in the matrix of diagnostic methods application and the PF chart. The output of the work is a proposal of a suitable model of maintenance control which uses multiparametric diagnostic methods for small and big Gas Turbine Engines and optimizes maintenance costs.

## 1. INTRODUCTION

Maintenance plays a very important role in keeping a machine in working order. It is an important part of a machine's operational life. Well-designed maintenance scheme based on the machine's current technical condition guarantees its availability whenever required, which results in increased operating time without downtime. Each downtime causes considerable financial losses to the business. Preventive maintenance helps to prolong the operational life of costly devices by technical diagnostics as a means of preventive and predictive diagnostics.

Technical diagnostics is a scientific discipline that studies and establishes the methods and means used to diagnose the state of objects. The technical condition of equipment is expressed in diagnostic parameters. We must bear in mind that one cause can lead to more than one failure and vice versa – one failure can result from a variety of underlying causes. Inaccurate or incomparable results can considerably decrease the effectiveness of maintenance in comparison with maintenance that is based on checking the actual state of equipment. Securing the operational reliability of machines requires the evaluation of safety, failure-free operation, sustainability and assurance of maintenance, since these aspects influence the availability, operational life, functionality, safety, capacity, quality and effectiveness of the operation [1].

The aim of technical diagnostics is the determination of technical condition of the observed object, its genesis – past operation profile, diagnosis – current state (fault detection) and prognosis – future state (fault prediction); using modern diagnostic procedures and managing the maintenance activities in order to use the maintenance costs efficiently, while considering possible negative consequences of failures. Should the results be used effectively, the feedback principle must be applied. Rotor blades are the key rotating components of Gas Turbine Engines, which play an important role in the task of energy conversion. This includes compressor rotor blades and turbo rotor blades [2].

### 1.1 MULTIPARAMETRIC APPROACH IN TECHNICAL DIAGNOSTICS

Multiparametric diagnostics can be described as employing two or more diagnostic methods in order to increase accuracy and certainty in evaluating the technical condition of the observed object.

Machinery diagnostics is the process of measuring machine's physical properties; it is performed mostly during its operation, however, also offline diagnostics is applied during shutdowns. Changes in the parametric values indicate dynamic changes in the machine's condition [7].

When evaluating the measured values, it is important to consider the typical development stages of failure:

a) initiation of a fault,
b) sign of a fault – symptom,
c) development of a fault,
d) quantitative cumulation of symptoms, especially over the course of time,
e) qualitative fault – irreversible physical changes,
f) substantial changes, increasing problems,
g) failure, damage, or accident [3].

Each stage is manifested by its specific manner and some – especially initial – stages of failure are very difficult to define using non-destructive technical diagnostic methods [11, 12].

Using one diagnostic method does not usually provide a sufficient view of the current technical condition of the observed device. It is often necessary to use other methods of technical diagnostics. Evaluation of the measured data gives a real view of the technical condition of the machine

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in question [10]. Sometimes the failure is revealed when using the first method and other methods serve the purpose of identifying the location and determining the time when repair or substitution of the faulty machine part is necessary. Therefore, the appropriate choice and combination of diagnostic methods and procedures is critical. The assumption that stress fatigue was the main failure mode can be discarded, considering that stress fatigue is not able to produce the strong wall thinning observed close to the rupture [4].

## 2. DEVICE USED IN THE EXPERIMENT

Gas Turbine Engines performance parameters were observed during the experiment, as described below. Since the transportation of goods is increasing, inspection of Gas Turbine Engines (see Fig.1) is of crucial importance. Diagnostic methods based on the principle of multiparametric approach of technical diagnostics, as specified below, were chosen to inspect the facilities [8].

### 2.1 DESCRIPTION OF GAS TURBINE ENGINE

The set of marine gas turbine consists from a simple-cycle, two-shaft, high-performance engine derived from aircraft engines. The turbine is comprised of two mechanically independent rotors. It serves for the production of hot gas that drives the power turbine, which drives the radial centrifugal compressor through the claw clutch [3].

Table 1: Turbo compressor parameters

| **Turbo compressor parameters** | |
|---|---|
| Gas inlet pressure | 5.25*106Pa |
| Gas discharge pressure | 7.35*106Pa |
| Compression | 1.4 |
| Gas inlet temperature | 23 °C |
| Gas outlet temperature | 47 °C |
| Compressor flow rate | 40,6x106 Nm$^3$/day |
| Clutch power input | 20,440 kW |
| Rotation speed | 6 130 rpm |
| **Combustion turbine parameters** | |
| Ambient air temperature | 15 °C |
| Atmospheric pressure | 10.1325*104Pa |
| Nominal speed of power turbine | 6500 rpm |
| Power output | 22 670 kW |
| Thermal efficiency | 37 % |

The power turbine is a working turbine that uses the energy form hot gas supplied by the gas generator for the torque. It has two speeds and is designed to enable an easy access to parts that require regular checks and maintenance [9].

The gas compressor is a single-cylinder two-speed compressor, driven by the power turbine through the clutch. During its operation, the rotor is exposed to the axial pressure in the suction direction. The rotor of the compressor is located in one thrust bearing and two radial bearings (see Figure 1).

## 3. EXPERIMENTAL MODEL

In order to apply the multiparametric system for observation of the technical condition of the turbo set, the following diagnostic methods were used [9]:

a) vibrodiagnostics:
   - online measurements,
   - offline measurements,
b) tribodiagnostics,
c) thermodiagnostics,
d) borescopic inspection,
e) emission measurements.

Each of the diagnostics uses specific methods and measures different parameters. Selected methods of observation are further specified in the following chapters.

### 3.1 VIBRATION MEASUREMENTS ON ROTATING AND NON-ROTATING PARTS OF GAS TURBINE ENGINE

Mostly online monitoring is utilized on large turbo sets. If one of the monitored values exceeds the preset tolerance, the system provides a warning, verifies the measurement, and checks the sensors and the transmission path between the sensor and the evaluation device. Operation conditions (such as changes in temperature, power, and compression ratio) which can change the machine's behaviour are checked [6]. After confirmation that no operation parameter which could have had an impact on the machine's condition has changed, monitoring devices are searched for errors using mobile measuring device, e.g. data collector; or another technical diagnostic method is used to verify the condition. When monitoring vibrations of the device, absolute values of the vibrations can be measured 0 – Peak (mm/s) as well as relative vibration values – measuring the deviation Peak – Peak (μm) or changes in the courses of vibrations or their peaks in real time.

Offline vibration measurements are conducted on devices which are monitored constantly by fixed detectors (mm/s).

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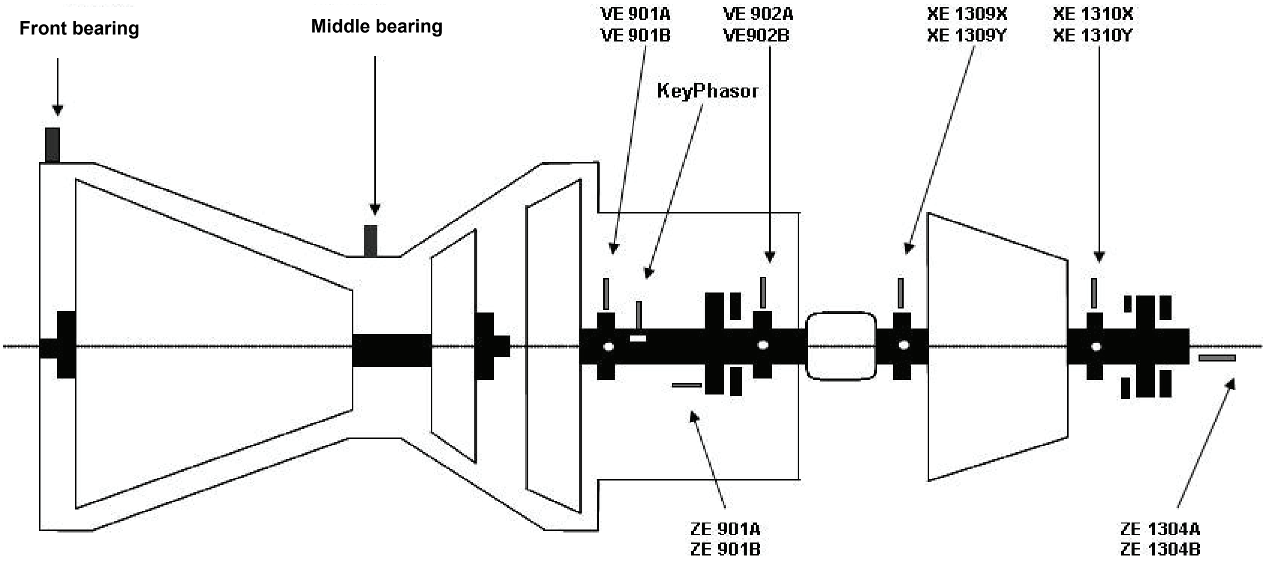
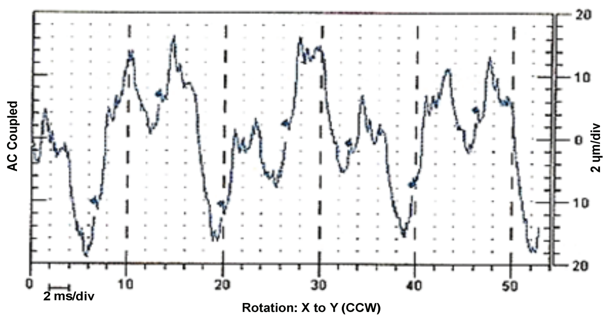
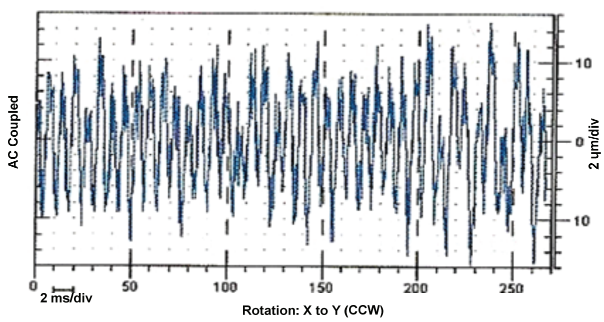



Figure 1: Positions of the vibration detectors on the turbo set

As soon as the diagnostic and maintenance division staff notice a major deviation in the measured vibration values during operation (see Figure 3) and its cause is not obvious enough, it is necessary to carefully monitor the condition. This problem is usually tackled by employing several technical diagnostic methods simultaneously and the conclusions are drawn by evaluating the results of all of the employed methods. For precise determination of the stage before the failure, also the offline diagnostic method can be used (see Figure 2). It is utilized only as a complementary method, often in the walk-through inspection.




a)




b)

Figure 2 Turbo set vibration spectrum

3.2 BORESCOPIC INSPECTION

This type of inspection uses a videoscopic system. Boroscopy facilitates diagnosing the actual technical condition of those parts of the device, which have accessible borescope openings. The advantage of this method is that internal, hardly accessible parts can be monitored through small inspection openings, through which the flexible part of the sensing probe can be inserted inside the device.

This inspection is carried out during regularly scheduled machinery shutdowns. The machinery condition is evaluated using these three grades:

I. – operation is possible without any limitations – no damage was detected or minor faults that do not prevent continual service of the machine,

II. – limited operation is possible – depending on the severity of the damage; shortening the interval between further checks,

III. – further operation is not recommended – due to major damage see Figure 4 and Figure 5.

3.3 TRIBOTECHNICAL DIAGNOSTICS OF MACHINERY

In order to make the technical diagnostics of a machine complete, tribotechnical diagnostics is also employed. Tribotechnical diagnostics monitors the oil level, its wear and deterioration and evaluates its quantitative and qualitative features.

The tribotechnical diagnostics of the device is based on monitoring the wear of its parts by inspecting the concentration of wear metals in the analysed oil and the intensity of abrasion. The combination of analytical evaluation of the concentration of wear metals in oil and the particle analysis enables the tribotechnical diagnostics to determine the wear-out regime of machinery and the trend signalling boundary and starting emergency conditions and identify the origin of the products of abrasion.

Since the oil influences the condition of the machine and the quality of oil is influenced by numerous internal and external factors, it is necessary to carry out its regular analysis and evaluation.

The tribotechnical analysis of a machine monitors the following properties of oil (see Figure 6):

- colour, appearance,
- water content in oil,
- kinematic viscosity,
- content of mechanical impurities,
- content of ferromagnetic impurities.

When identifying the presence of undesired foreign matter in oil, it can be treated by electrostatic or mechanical filtration. Appropriate care not only increases the reliability of machines but also lifetime of the oil charge and thus reduces costs. A further improvement in material selection is the choice for a more expensive solution [5].

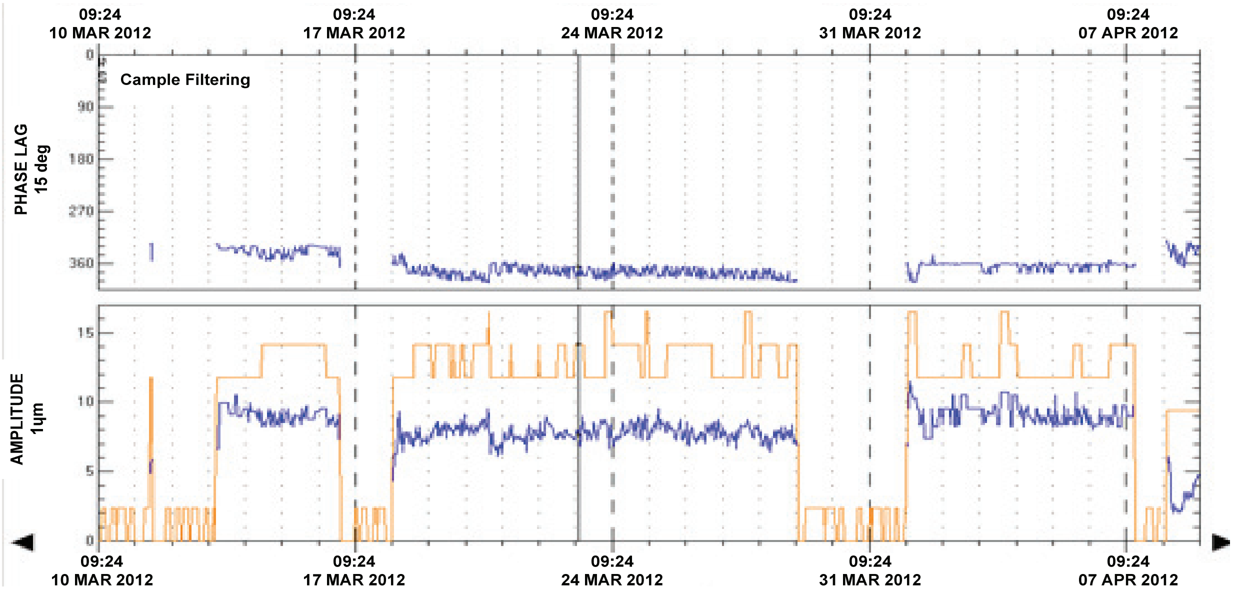



Figure 3: Gas Turbine Engine vibration spectrum monitored over one month

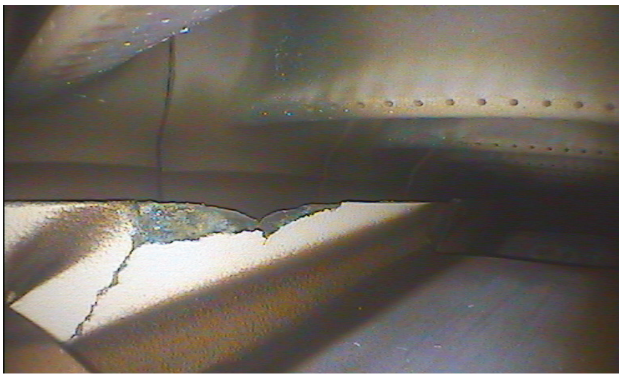


Figure 4: View of damaged thermal protection layer of a rotor blade

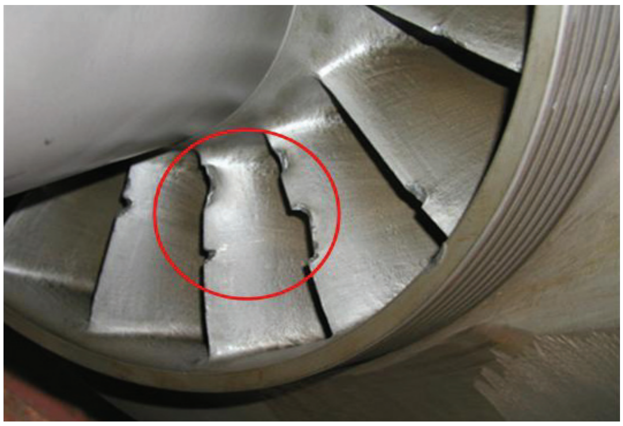


Figure 5: Detailed view of the damaged blades on the first stage of the compressor after disassembly

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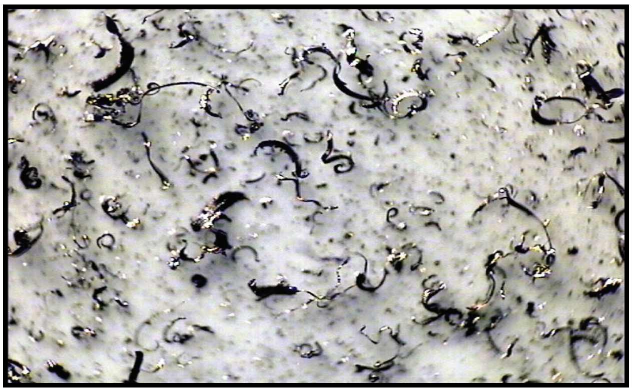
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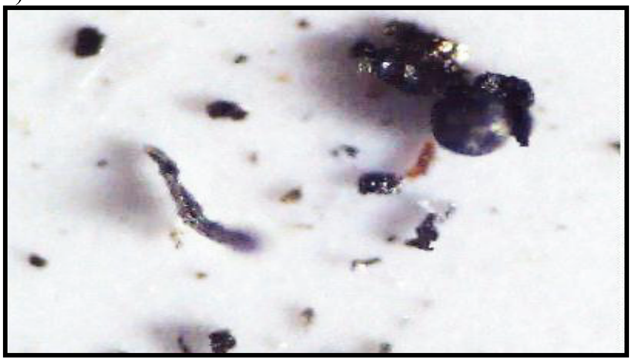
b)
Figure 6: Microscopic view – occurrence of impurities in lubrication oil

## 4. EXPERIMENTAL RESULTS

The underlying philosophy behind the process of maintenance control in various systems is preventing the occurrence of a negative phenomenon i.e. failure, from the viewpoint of the probability of its occurrence or its frequency and resulting consequences. Managing or minimizing the consequences of failures (proactive maintenance) requires fundamental changes in thinking and maintenance planning.

The suitability of utilizing individual types of technical diagnostics for the fastest possible and the most precise identification of problems related to a given turbo set is specified in the following matrix in Table 2.

Table 2: Diagnostic method application matrix for a given Gas Turbine Engine

| Applied diagnostic method | | Gas Turbine Engine |
|---|---|---|
| Vibrodiagnostics | | X |
| Tribodiagnostics | | X |
| Thermodiagnostics | Mechanical parts | ● |
| | Electrical parts | X |
| | Thermal parts | ● |
| Borescopic inspection | | X |
| Measurement of emissions | | X |

Legend of symbols:
X – diagnostics is performed continually or regularly,
● – diagnostics is performed periodically in scheduled intervals,
▬ – not performed.

In order to determine the real condition of the machines, besides the technical diagnostic methods, it is also recommended to monitor the operational parameters listed in Table 3.

Table 3: Monitored parameters of Gas Turbine Engine

| Parameter | Combustion turbine | Combustion (aircraft) turbine |
|---|---|---|
| Temperature | X | X |
| Pressure | X | X |
| Compression | X | X |
| Air flow rate | X | X |
| Fuel flow rate | X | X |
| Power output | X | X |
| Torque | X | ▬ |
| Revolutions | X | X |
| Efficiency | X | X |

## 5. CONCLUSION

In each of the abovementioned technical diagnostic methods, it is the outputs that play the decisive role. Their aim is to localize the position of the fault as accurately and objectively as possible in a given node of the machine or the entire machine set. The correct choice and combination of diagnostic methods is of major importance in the multiparametric diagnostics, as it results in so-called synergic effect. Correct determination of intervals listed in Table 4 is not of lesser importance either, similarly to the method used in measurement and correct interpretation of data resulting from the analyses.

Mutual interaction of the combined diagnostic methods should result in the creation of conditions preventing the occurrence of unscheduled shutdown, which causes major financial losses to the company, but especially preventing damage to the device due to faults. The main aim is to prevent loss of control of the technological system, which may result in damage to workers' health, casualties, property losses and/or environmental pollution.

As can be seen from Figure 7 and Figure 8, the probability of identifying the fault increases when employing several diagnostic methods. However, the costs related to the optimization of individual diagnostic methods should also be taken into consideration. At this stage, the decision depends upon the knowledge and experience of diagnostic staff; based on the measured data, they make a decision on whether another diagnostic method should be applied or the data acquired are sufficient to identify the fault and determine subsequent corrective measures.

Table 4: Monitoring of the condition of Gas Turbine Engine

| Applied diagnostic method | Manner, frequency and localization of measurements |
|---|---|
| Vibrodiagnostics | Online measurement, monitoring also t, power output, rotor revolutions |
| | Offline measurement conducted twice a year |
| Thermodiagnostics | Measurement conducted once to twice a year on electric power distribution parts |
| | Measurement conducted once to twice a year on mechanical parts of accessory equipment |
| | Measurement conducted once to twice a year on thermal parts (thermal insulation) |
| Tribodiagnostics | Measurement conducted on mechanical parts of devices twice a year or when suspecting faults |
| Borescopic inspection | Measurement conducted once to twice a year on internal parts of machine |
| Axes alignment | Measurement conducted once in two years and when suspicion arises after vibrodiagnostics |
| Smoke emission measurement | Online measurement or measurement conducted once a year |

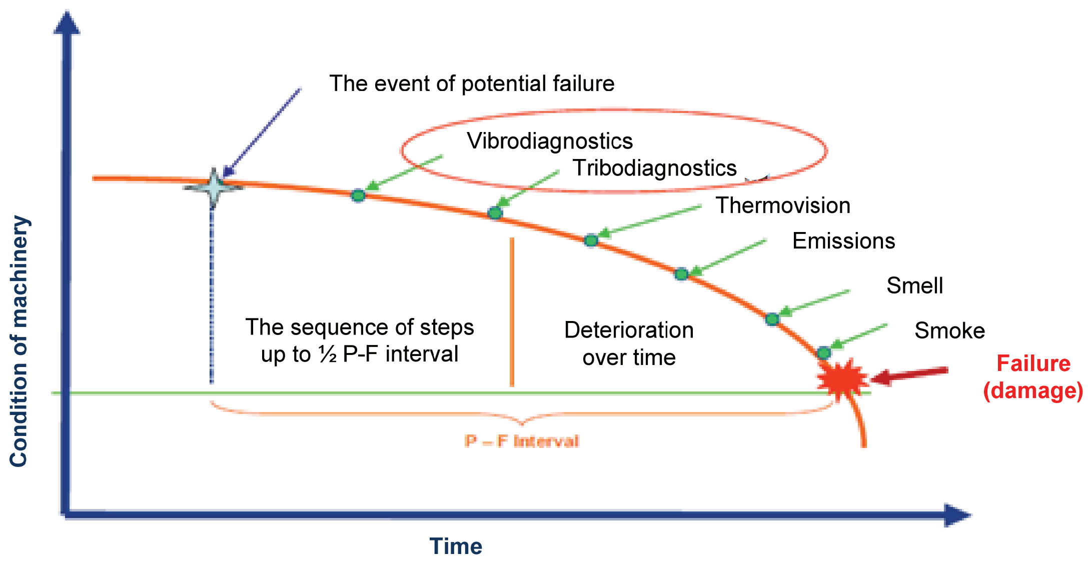


Figure 7: Timely identification of failure and recovery of the device based on application of suitable diagnostic methods [3]


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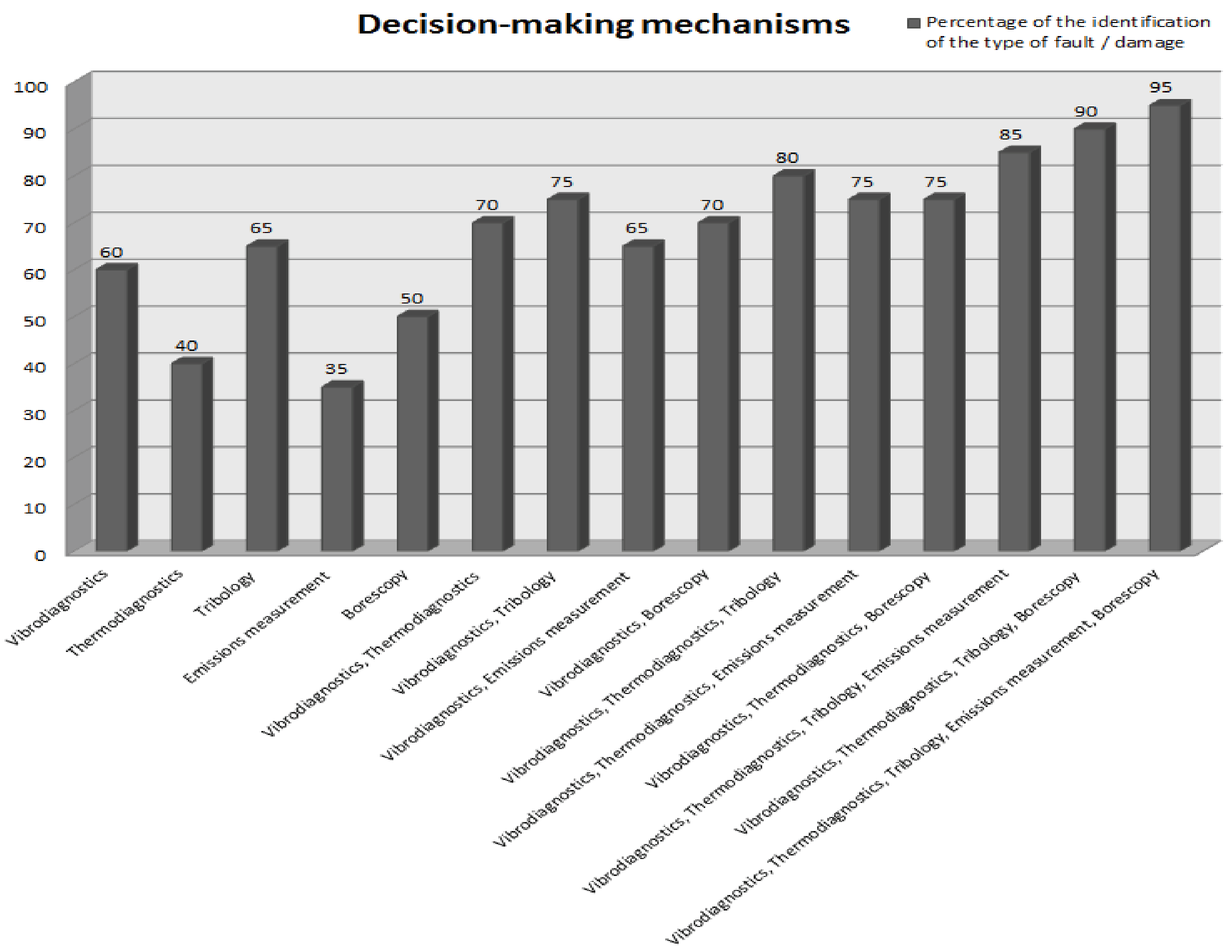


Figure 8: Decision-making mechanisms

## 6. ACKNOWLEDGEMENTS

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