An integrated approach for interoperability of standards, condition monitoring methods, and research models used in the power generation sector

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Abstract. With the rapid growth of modern technology, maintenance contributes significantly vital function in many industries. The objectives of maintenance-related decision-making process will lead to select and use various condition monitoring techniques for different industrial applications. It is evident from the published literature that, effective use of ISO standards in isolation is very well documented, but after knowing the importance of the use of integrated condition-based maintenance (ICBM) strategy, it will be more important to know how interoperability of international standards, company standards, standard guidelines, and recent research models/recommendations will help to implement ICBM strategy more effectively. These paper overview relevant international standards related to condition monitoring & diagnosis of selected machines used in power generation and highlights case of how concept of interoperability of standards defined at different levels helped to select suitable maintenance strategies to improve the availability of the system.

1. Introduction
Condition monitoring is the process of monitoring the parameters of a state of the machine in order to detect major changes, indicating a growing fault [1]. Parameters related to machine performance such as vibration, acoustic emission, thermography, wear, temperature, etc. They are useful indicators of the state of the machine [2]. The successful implementation of the condition monitoring system allows the machine to operate without fail [3]. The state-of-the-art monitoring of energy production mainly consists of three distinct elements (i) monitoring of mechanical properties i.e. pins, bearing, and gear, pump, etc. of the program, (ii) application areas such as rotating machinery, wind turbines, mills, electrical equipment, etc., (iii) application of monitoring measures status for decision-making maintenance plan [4]. In recent years, there have been the developments of various effective surveillance and diagnostic techniques. Vibration Analysis, Acoustic Emission Monitoring, Wear Debris, Temperature Analysis, Ultrasonic Monitoring, Thermography, Non-Destructive Testing, Visual Inspection, Vehicle Monitoring, and Current Signature Analysis [5] various should be developed and published by the International Organization for Standardization (ISO) for rolling element bearings, shaft, pumps, fans, steam turbines, gears, centrifugal compressors, induction motors, screw compressors, large generator, steam turbine generator set, etc.

The published standards viz. ISO/7919 series and ISO/10816 series describe acceptable vibration limits for Evaluation of Vibration Severity explains for Mechanical vibration and evaluation criteria of
non-reciprocating machines and non-rotating parts respectively [6]. As ISO 13373-1:2001 provides general guidelines for the measurement of machinery vibration for condition monitoring and diagnostics of machines. The recommendations are provided for the measurement methods, parameters, selection, location, and attachment of transducer, data collection, machine operating conditions, vibration monitoring systems, signal conditioning systems, interfaces with processing systems, continuous and periodic monitoring[7]. Also, ISO 17359:2003 provides general guidelines for the overall procedures to be considered when fixing a condition monitor program for Condition monitoring and diagnostics of machines. The choice of a maintenance policy features a great influence on the system’s operational cost and its operational availability in thermal power plants (TPP) [8]. The upkeep task is assessed into three groups which are corrective, preventive, and predictive (or condition-based) maintenance [9]. There's a growing impact of standards on global commerce and widely utilized in industries. Therefore this paper reviews the utilization of condition monitoring techniques (CMT) and their application for fault detection, fault identification, and fault classification of machinery through a survey of the literature. This paper reviews and classifies CMT, with reference to the subsequent areas viz. maintenance scheduling, reliability improvement, availability improvement, fault diagnosis alongside their applications in several research and practical domains. This paper overview relevant international standard related to condition monitoring and diagnostics of selected machines used in power generation and represent a case to know how the concept of interoperability of standards defined at different levels that helped to select suitable maintenance strategy to enhance the availability of the system.

2. Review of literature

Relevant publications to date have been reviewed for the purpose of studying CMT strategies used in plant components, to study international standards, company standards, and research models. The CMT practice in industrial use is aimed at the purposes of a) Maintenance Planning b) Reliability improvement c) Availability improvement. Condition monitoring techniques have been used for vibration analysis, wear debris analysis, ultrasonic analysis, and thermography. The practice of monitoring measures used in industrial applications is set out in Table 1.

| Objective               | Vibration Analysis | Acoustic Emission Analysis | Wear Debris Analysis | Ultrasonic Analysis | Thermography |
|-------------------------|--------------------|---------------------------|----------------------|---------------------|--------------|
| Maintenance Scheduling  | [10][11][12][13][14][15][16] | [17][18] | [16] | [19][20][21][22] |
| Reliability Improvement | [23][24][25][26][27][28][29][30][31][32] | [29][30] | [27][13] | [31][32] |
| Availability Improvement| [33][34][35][36][37][38] | [34][35][36][37][38] | [35][37][38] | [38] |

Maintenance, reliability, and availability are important tools for decision-making regarding the estimation and planning of maintenance strategies concerning manufacturing and production systems. The utilization of condition monitoring techniques makes it easier for decision-making. These are a number of the popularly used various monitoring tools allowing the upkeep to be supported the condition instead of equivalent operating hours, thereby extending the periods between overhauls. The reliability also can be increased by employing a mixture of monitoring tools altering the plant operators before faults are fully developed.

2.1 Standards utilized in Condition Monitoring

Standards are documented agreements containing technical specifications or other precise criteria to be used consistently as rules, guidelines, or definitions of characteristics, to make sure that materials, products, processes, and services are fit their purpose. within the field of Condition monitoring and
diagnostics of machines, a spread of relevant standards are developed and published by ISO (International Organization for Standardization) for Vibration Analysis, Acoustic Analysis, Wear Debris Analysis, Ultrasonic Analysis, and Thermography, which is tabulated in Table No.2 as follows.

Table 2. ISO standards used in condition monitoring technique of machines

| Objective | Vibration Analysis | Acoustic Analysis | Wear Debris Analysis | Ultrasonic Analysis | Thermography |
|-----------|-------------------|------------------|---------------------|---------------------|-------------|
| International Standards worldwide | ISO 7919 Series, ISO 10816 Series, ISO 13373-1:2001, ISO 13374-1:2003, ISO 13379:2002, ISO 13381-1:2004, ISO 17359:2003 | ISO 1996, ISO 1999, ISO 2533, ISO 3744, ISO 9614, ISO 12001, ISO 10843, ISO 22096, ISO 16148:2006 | ISO 4406-1999, ISO 4407:2002, ISO 81400, ISO 3722:1976 | ISO12715:2014 | ISO 9712, ISO 18434, ISO 18436 |
| Standards followed by country wise | DIN 4150, JIS D 1601:1995, AS ISO 13381, AS 1359, IS 14817 | DIN 45681, JIS Z 8732, AS 4748-2001, EN 15856:2010, IS 4758-1968 | DIN EN ISO 3104, AS 4002-2001, IS 11083 | AS 1065-1998, JIS Z 2345:2000, IS 11626 | AS 1929-2009, IS 12782 |

Guidelines

a) Mechanical vibration of non-reciprocating machines and machine vibration-measurements on non-rotating parts
b) To predict maintenance on a wide range of rotating machinery
c) Vibration occurs in the 10Hz-10KHz band is considered the best parameters: monitoring structural problems of imbalance, looseness,

- a) Perform route cause failure analysis. Find the source of the problem. Fix it once and fix it right
- b) Coding the level of contamination
- c) Qualifying & controlling cleaning methods

Component / Equipment

- Steam Turbine, Generator, Bearing, Shaft, Gear, Motor, structure
- Cylinder, shaft, bearing, boiler furnace water-cooling wall tube, Induction Motors
- Wind turbines, steam turbine-generator, Gearboxes, Hydraulic fluid power systems
- Boiler furnaces, Bearing, testing of carbon and low alloy steelplate
- Monitoring of bearing, gearboxes, high tension motors.

Models

- Maintenance scheduling model, Availability model (Markov model)
- Maintenance and asset management model
- Life cycle cost management model, Fault
- Maintenanc e Prediction Model
- Fault detection model
Reliability prediction model
Fault prognosis model
Fault prognosis model

The published standards used for vibration analysis defining acceptable vibration limits are the ISO 7919 series (5 parts) and the ISO 10816 series (6 parts). The 7919 series is used for "non-reversing machine vibration i.e. rotating shaft measurements and the testing process" and the ISO / 10816 series is used for "Mechanical vibration testing machines in moderate parts", in condition monitoring and diagnostic equipment, ISO13373-1: 2001 is used to monitor Vibration status. Provides general guidelines for vibration measurement systems. Also, ISO 17359: 2003 provides general guidelines for standard procedures to be considered when establishing a state-of-the-art monitoring and evaluation system.

In the case of acoustic analysis the ISO standards used are ISO 1996, ISO 1999, ISO 2533, ISO 3744, ISO 9614, ISO 12001, and ISO 10843. ISO 1996 describes the basic values that should be used to describe the environment of a noisy society and describes the basics of the testing process [39]. It also clarifies methods for assessing environmental noise and provides a guide to predicting the potential public response to long-term exposure from a variety of environmental sounds. In the case of dress waste analysis, ISO 4406-1999 has been used as basic guidelines for particle size in liquids [40].

The International Organization for Standardization has developed a 4406: 1999 purification code for measuring pollution levels of one milliliter of liquid in three sizes: $4\mu [c]$, $6\mu [c]$, and $14\mu [c]$. This ISO code is displayed with the numbers 3: 19/17/14. Each number represents the defining level code of the corresponding particle size. The code includes all particles of specified and larger size. It is important to note that each time the code increases the number of particles doubled.

For Ultrasonic Analysis ISO 12715:2014 is used as reference blocks and test procedure for characterisation of contact probe sound beams [41]. Also, ISO 9712 is used as personnel certification in non-destructive testing, ISO 18434 gives general procedures of thermography and ISO 18436 is used for requirements for training and certification of personnel [8].

After review of various standards as a reference for condition monitoring techniques, the next section reviews the importance of the term "Interoperability" for the maintenance scheduling and condition monitoring program for industrial applications.

It has been found that interoperability may be a must for the mixing of commercial automation systems with operation and maintenance systems so as to enhance the collaboration and interoperability for systems along the products/assets life cycle. Therefore, interoperability will guide for implementation of a condition monitoring program for systems with reference to a selection of standards, selection of condition monitoring techniques, and finally with the objective to improve availability, reliability, and selection of maintenance strategy.

3. Interoperability of standards for condition monitoring program and maintenance strategy

In the field of mechanical monitoring and analysis, various types of standards have been identified and published by ISO (International Organization for Standardization). The ISO is a global coalition of national standards frameworks from 145 countries and considers itself a bridge between the public and private sectors [42]. ISO standards for monitoring and vibration equipment are regulated by the TC108 technical committee whose SCs (subcommittees) Mechanical vibration and shock. Subcommittees include: SC1 measurement, including measuring instruments, SC2 measurement and vibration and shock testing as used in equipment, vehicles, and components, SC3 measurement and measurement tools, SC4 Personal Identification, SC5 Measurement and diagnostic equipment and - SC6 for Vibration and Shock Generating Systems. The stated scope of TC108 is Standardization in the field of mechanical vibration and shock as well as monitoring and diagnostic equipment. In view of all the basic international standards related to monitoring and diagnostic equipment, compliance standards are studied to apply the monitoring system to systems. The interdependence of standards will help in selecting appropriate remediation strategies, improving accessibility, and evaluating system reliability. The principle of cooperation is regarded as a law, regulation, test vessel, standard, or requirement.
Collaboration is the ability of two or more systems or components to exchange and use data. The principle of interaction can be applied to ISO standards for monitoring and diagnostic equipment. The published standards used for Vibration Analysis defining acceptable vibration limits are the ISO 7919 series (5 parts) and the ISO 10816 series (6 parts). Series 7919 is used for "Mechanical vibration of non-returnable machines i.e. Measurement of rotating shafts and testing process" and series ISO / 10816 is used for "Mechanical vibration by measuring machine vibration by measurement in non-rotating parts". ISO 7919-1 is a basic document that describes the general requirements for measuring and testing vibrator equipment using shaft measurements. Similarly, ISO 10816-1 is a basic document that describes the general requirements for inspecting vibrations using case and / or base measurements. Subsequent sections of each series of documents apply to various categories and types of equipment and include specific testing methods used to assess vibrational complexity.

- ISO / TC108 / SC4 define the standards of Condition Monitoring and Diagnostics of Machines in the various categories discussed below.
- ISO 13372 This standard provides Terminology for Fields of Condition Monitoring and Diagnostics of Machines as a basic guide.
- ISO 13373 This standard provides general guidelines for the measurement of vibration monitoring devices. In conjunction with ISO 13373, recommendations are provided for monitoring the status and diagnostic of equipment through ISO 13373-1: Part 1: as standard procedures and ISO 13373-2: Part 2 Analysis, analysis, and diagnostic of the machine.
- ISO 13374 This standard is used for monitoring and diagnostic equipment for data processing, communication and presentation. It takes a reference to the types of programs, ratings, converters, data presentations, advanced and analytical Annex A - types and areas of ratings, Annex B - material information, Annex C - entertainment, ratings of Annex D.
- ISO 13379: Condition monitoring and diagnostic equipment - General guidelines for data interpretation and diagnostic techniques are 1) condition setting and diagnostic setup, 2) failure mode indicators, 3) diagnostic equipment, 4) diagnostic methods.
- ISO 13380: This standard provides a variety of documents, including indicator standards, suitable for Performance Monitoring and Diagnostics of equipment 1) parameters observed, 2) measurement process, 3) error detection, 4) error chart monitoring.
- μ ISO 17359: The standard level introduces adopted guidelines to be used in the development of a monitoring system. It is used as a standard checklist to make sure there are no big things to miss. General guidelines for setting up a situation monitoring system at various stages consider 1) critical analysis, 2) measurement methods, 3) measurement areas, 4) data collection and analysis, 5) maintenance action
- ISO 18436: This standard defines the certification process for vibration screening personnel who perform monitoring and diagnostic equipment. This standard introduces Guidelines for Training and Certification Staff Requirements to meet the required learning, training, and experience requirements, and successfully completes the qualification assessment and equipment diagnostics described in three sections as 1) Part I - verification requirements, 2) Part II - vibration analysis, 3) Part III - training body requirements.

After a critical review of ISO standards, it was found that ISO 17359 describes the methods used to create monitoring systems and the selection of equipment to repair equipment. The methods used to monitor the condition of the equipment are i) vibration analysis ii) acoustic analysis iii) wear waste analysis iv) Thermography. Defined definitions of ISO standards for monitoring systems are already described in section 2.1. The importance of the interaction of standards in choosing a remediation strategy is discussed as follows.

As "Interoperability" has great importance for implementing condition monitoring programs and selecting maintenance strategy for systems. The upkeep activities on critical equipment and systems have traditionally employed one among two maintenance philosophies which are preventative maintenance or corrective maintenance but, condition-based maintenance (CBM) or predictive maintenance represents a replacement maintenance philosophy, whereby maintenance activities are
only performed when there's objective evidence of an impending fault or failure condition. The CBM approach is used to optimize the supply of high-value critical assets, whilst also reducing overall maintenance and logistics costs. Condition-based maintenance entails continuous monitoring of system data to supply an accurate assessment of the health, or status, of a component/system and performing maintenance supported its observed health. It involves using real-time system monitoring and processing. There are three levels of the CBM process viz. data acquisition, processing, and maintenance decision making.

In order to achieve improved maintenance decision-making, it is required to use condition monitoring for the execution of condition-based maintenance strategy. Recommendation of published literature and fields experience advocates the use of more than two CBM methods for correct diagnosis and condition predictions. But, it demands the use of different standards to monitor the condition of the same component/system and in such situations interoperability of such standards could be a challenging issue to tackle with. One such case of coordinated condition monitoring approach implementation is discussed in brief with a case study.

3.1 Case study
The growing requirement for electricity has indicated that it is crucial to keep the power generation resources in India with a higher preference. With several sources, TPP is principal source of power production. It’s crucial to retain TPP in running condition. Providentially, this is not the case, because breakdown is inevitable, although it can be reduced through execution of accurate maintenance policy. The earlier researchers have conducted the study for the improvement of the reliability and availability analysis for subsystems of thermal power such as boiler-furnace subsystem [52], turbine-generator subsystem [53], condenser subsystem [54], coal-supply subsystem [55], and water-circulation subsystem [56].

Jagtap, et al. [38] presented a case of induced draft fan of TPP. In their study, a coordinated condition monitoring approach is proposed by the mixing of 4 techniques, namely, vibration analysis, noise analysis, wear analysis, and ultrasound analysis techniques for diagnosis and validated through a case study of induced draft fan utilized in a TPP. At the initial stage, the methodology focused on selection criteria of critical equipment of TPP using multi-criteria decision making techniques viz. analytic hierarchy process [56]. State of the ID fan is monitored by measuring various parameters measured such as vibration level, noise level, and size of wear particle. Then, ISO standards were followed for finding the deviation from a reference level of these parameters for vibration level [ISO 10816], noise level [ISO 1996], ultrasound level [ISO12715:2014], and particulates in oil sample [ISO 4407:2002]. At the initial stage of fault detection, the trends of vibration parameters are analyzed, and a comparison is formed between measured vibration parameters level with ISO-10816 standard. The measured vibration characteristics of the ID fan have provided quick and accurate information that hydraulic coupling is during a deteriorated state. At the final stage of methodology, through detailed study, the fault of the bearing of the hydraulic coupling (HC) of the induced draft fan is detected and it was recommended to remove the old HC bearing and suggested to install a new pack of HC bearing well in advance to avoid the failure of ID fan of TPP. An ISO 9712:2012 recommends and defines conditions for principles for the qualification and certification of employees who could perform industrial non-destructive testing at the plant to confirm the effectiveness of solution implementation. The result obtained from a case study helped the plant engineer to optimizethe maintenance plan and resource allocation at the nearest available opportunity without generation loss.

4. Summary
This study presents an overview of relevant published literature which deals with interoperability of international standards and therefore the models for condition monitoring-based maintenance strategy. The Paper also highlights the challenging area for implementing simultaneous use of ISO standards and company standards for condition monitoring, fault diagnosis, reliability improvement, availability improvement, maintenance modelling of the system used in various process industries such as TPPs. A case study reported in this paper presented guidelines for use of ISO standards, the recommendation for maintenance planning, and general guidelines for the skills required for the
personnel at end-user. For precise fault finding and diagnosis and diagnosis, it is recommended that field operators/engineers must understand relevant ISO standards, company standards/guidelines, research models, and best practices followed in the field to define optimum maintenance strategy for subsystems/components of system/subsystem/component under consideration.

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