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A Comparison between Model Based and Neural Network Condition Monitoring techniques for the case of Diesel Engine

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Abstract— ***This research work elaborates and compares two different effective condition monitoring techniques: Signal Processing by using Model based first principles and neural networks. The main concern of the paper is on the application of the techniques, not on explaining theory. Each technique is precisely described and then its application to the equipment is discussed. The discussion is finally summarized with the merits and Demerits of techniques. Both techniques are evaluated for condition monitoring of Diesel Engine application taken from marine engineering field by using only the torsional vibration of the crank shaft. The results have shown that both techniques can be used to get high level information about monitored equipment. The main constraint remains the requirement of equipment process knowledge either from measured data or from analysis.***

I. INTRODUCTION

Condition monitoring (CM) is defined as a mechanism to screen the working characteristics of electrical equipment and utilize those behaviors of equipment to recognize the maintenance requirement before a permanent damage is done the equipment [1]. Application of condition monitoring to electrical equipment has been playing an important role in maintaining health and safe operations of electrical equipment in both power stations and industries. As some sudden fault or shot down may result in worst accident and economic loss [2]. Therefore, engineers and scientists have been paying great attention to improve the condition monitoring techniques especially for transformer, engine and induction motor [3,4]. Initially condition monitoring was done by the machine operators as they were physically close to the machines and they can judge the operating condition by their experiences but advancement in technology results in more complex machines and hence difficult to observe the behavior of machine more closely. Therefore, modern CM systems use sensors to acquire data of process variables on the machine and even latest sensors have the ability to screen the equipment at locations where easy access is not possible i-e pressure in cylinder [5]. The whole procedure to perform CM is divided in three steps firstly sensor information is preprocessed to check any defect in sensor and transform only correct information to a suitable format for processing. In processing stage the condition of the equipment id determined by using any of the CM technique i-e Model Based , Neural network based signal processing techniques etc. finally the results are postprocessed to transform them to a clear report to understand the operating condition of equipment [6]. The CM procedural sequence is shown in Fig.1. In this paper preprocessing and signal processing methods are elaborated then two processing techniques Model based and neural network based CM techniques are deeply discussed with their advantages and disadvantages and then these two techniques are tested on real world application ship's diesel engine finally a comparison is provided between these two techniques.

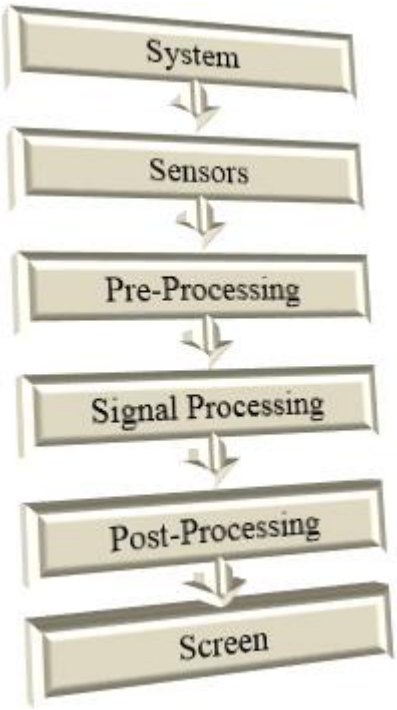

Fig.1. Procedural Sequence of Condition Monitoring

II. PREPROCESSING STAGE

Condition monitoring depends on the information gathered from sensors monitoring different process variables of the machine. Therefore, the accuracy of CM of machine depends on the accuracy of information received from sensors. In preprocessing stage reliability of sensors system is enhanced by monitoring the sensors themselves. Sensor defect detection is done in two ways Direct and Model Based methods [5]. In Direct method sensor signals are analyzed. Some examples are follows

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Sensor Redundancy: In sensor redundancy more than one sensors are used to detect the failure of the sensor. Double redundant sensors can identify the failure of a sensor but cannot recognize which sensor has fault. Triple redundant sensors can locate the defective sensor.

Range Checking: the use of sensors with limited range enables range checking

Model Based methods use information about the monitored equipment to develop an "analytic" sensor redundancy. Instead of redundant sensors the model is used as redundant sensor. This method is used to detect even slight defects in sensors as compared to direct method. One of the effective model based method is shown below

Sensor Fault Analysis [7]: If sensor fails a specific characteristics pattern will be visible in the obtained sensor data to identify a specific fault in the sensor.

III. SIGNAL PROCESSING STAGE

Information from sensors connected at different places of machine will only change the point of view unless these values are interpreted by using the process knowledge about the equipment and its behavior. The techniques used in this paper require different amounts of process knowledge as shown in Fig. 2. The quantity of process knowledge determines the strategy required for CM. The two state of the art techniques used in this paper are signal processing using models based on first principles and second is signal processing using neural networks. These two techniques are elaborated below

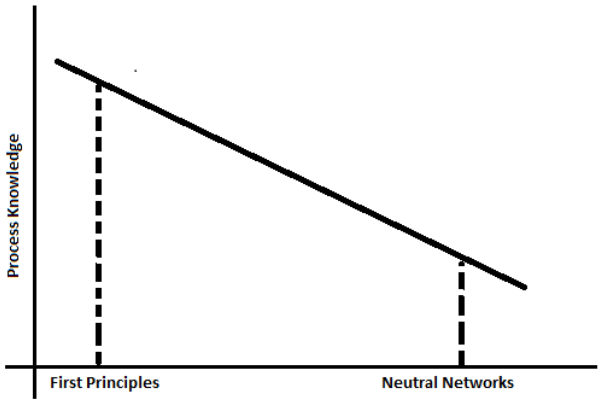

Fig.2 Required Process Knowledge

A. Model Based First Principle Method

As the name suggests first principle method requires large amount knowledge of "First Principles" such as conservation laws and of constitutional laws as the physical properties of matter and some knowledge is required for validation, verification and tuning. This method utilizes the mathematical model of process physics to predict the condition of equipment. The mathematical simulation model requires a large amount of process knowledge of the behavior of equipment and processes. There are two ways to utilize the model based methods for CM of electrical equipment [8]

1) The model based technique can be used to analyze the monitored operational parameters of electrical equipment to establish a healthy status of the equipment so it provides an efficient approach to identify a fault at initial stage before it causes serious damage to the machine. This model based approach provides an insight to the characteristics of equipment which is not only helpful in CM but also used in equipment improvement, understanding equipment and development [8].

2) The models can be used to understand the change in behavior of the machine when fault occurs. The detection of the fault depends on how well the system is modeled and only limited number of faults are available for simulation depending on the number of parameters used in modeling. This technique can be well suited for equipment consisting of large number of components such as pneumatic, hydraulic and electronic systems [8].

The merits of the system are highlighted below:

1) The operator of the CM system does not require the process knowledge to interpret the measured signal.
2) This technique provides an insight to the behavior of the equipment which is not only used for CM but may also used to upgrade the equipment
3) Signal processing only requires a limited amount of knowledge of operating behavior.
4) The knowledge compulsory to detect faults correctly is gained in a organized way and is reproducible.
5) The diagnostic data used in CM is available on startup.

The demerits of the system are highlighted below:

1) A high precision of the measured information is required.
2) The model is always an approximation of the real machinery.
3) A large amount of process knowledge is needed for development of the model.

B. Neural Network

Neural network provides robustness to the system against the noise present in signals and it can identify and categorize the faults without a deep knowledge required about the system and signals as shown in Fig.2. A neural network is an interconnection of neurons with each other as shown in Fig.3.

The behavior of neural network is controlled by adjusting the weights values related with each connection [9]. These weights are calculated during training session. In training session different examples covering all conditions to be detected with specific input and output patterns are presented to neural network. It has advantage over model based technique in terms of minimum process knowledge required but its application to CM requires a large training data set. On the other hand, Neural network ability to train itself results in finding a solution where other methods are not successful [9]. Selecting proper network layout and training sessions for specific tasks is complex task and only little structured

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knowledge is available to chose the best network and training for specific application. The merits of the neural network are given below:

1) Neural networks have less computational burden best suited for real-time CM and can handle large number of signals simultaneously

2) Neural network based signal processing requires a very little process knowledge and it also does not require fault patterns

3) Neural network is robust against noise

The demerits of Neural Network are given below:

1) Knowledge about, and a "feel" for, the training of neural networks is required

2) Managing training sessions for neural network is time consuming

3) A large range of measured data is needed for all categories of conditions, including faults

4) The measured data can be very large

5) Neural Network will only provide suitable solutions inside the trained range

6) Neural network is not flexible as in dynamic scenario it will not give valid solutions

IV. POST PROCESSING STAGE

This stage is also termed as user interface stage at this step after sensor preprocessing and identifying faults by using any of the above method of signal processing the presentation of results are improved significantly by using screens. The process variables and CM status can be displayed on screens. In CM displays are of two types' surveys displays and specific displays [10]. During normal CM operation survey displays are used but when some fault occurs in CM diagnosis and insight displays of fault are required by operator specific display is required. The results that should be presented at postprocessing stage to the user are given below:

1) values of process variables
2) status of the equipment through processed information (e.g., percentage of load, flow of heat, sensor and equipment faults);
3) past, present, and predicted values of condition monitoring (guides for problem solving);
4) Equipment is either in stationary state or not

V. THE DIESEL ENGINE CASE

The purpose of choosing diesel engine for testing model based and neural network signal processing technique is to identify any defect in combustion of any cylinder of medium-sized diesel engine by using torsion signal generated from crankshaft of engine. The processing methods model based and neural network methods are tested by applying to diesel engine. Data is measured and processed to detect the healthy and faulty condition of the diesel.

Diesel Engine Case: Model Based First Principle Method

For CM of diesel engine, a model of rotor system of engine is developed. The engine dynamics are presented by a lumped mass model as shown in Fig.3.

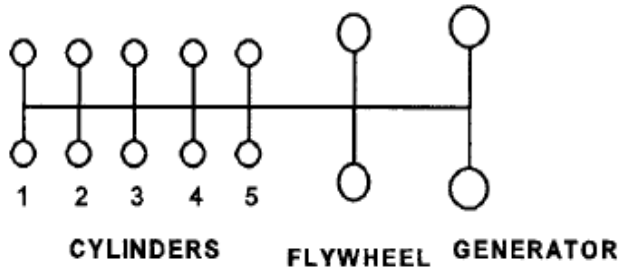

Fig.3 Lumped Mass Model [5]

The lumped model is used to calculate the vibrations of the rotor after first sequence of firing is applied. Furthermore, if gas pressures are known vibrations of engine can be calculated by using this lumped mass model as shown in Fig. 4.

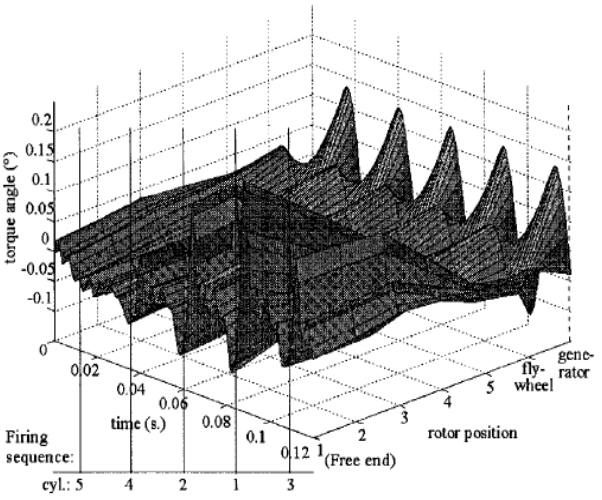

Fig.4 Calculated Vibrations of Diesel Engine [5]

The gas pressures are calculated by "Tangential Effort Curves" developed by Liyod. In Model Based first principle method rotor model is useful for reverse calculations of gas pressures using the calculated vibrations. In real scenario implementation of model based CM technique is limited by large amount of knowledge required about the response of system and additional data can be gained from the specific shape of cylinder gas pressure at varying loads. The gas pressure is generated by two sections one is compression and expansion and other is combustion as shown in Fig. 5.

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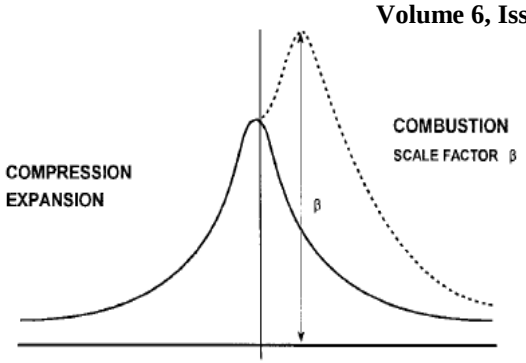

Fig.5 Division of Gas Pressure

Due to scalability of combustion section it is used to develop an invariable standard curve of increase in pressure due to combustion. This is multiplied by a factor to handle variable cylinder load which results in development a simple gas model with one variable load for each cylinder. The little information obtained from the response is quite enough for reverse calculation of each cylinder gas pressure by applying best fit method to measured or calculated vibrations [11]. It is also feasible to calculate power of each cylinder by utilizing a single torsional vibrational signal. The both measured and calculated power contribution of each cylinder is shown in Fig. 6. Faults can be located easily in an early stage to reduce the resulting damage to engine.

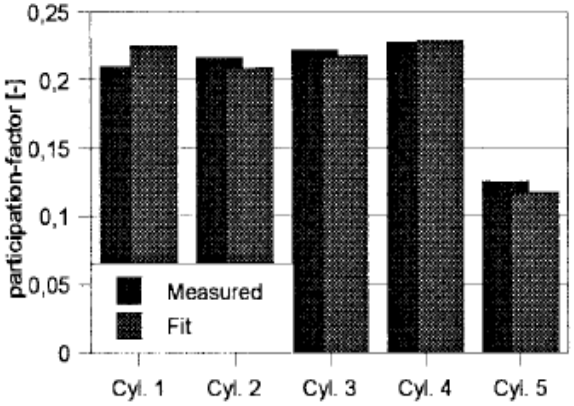

Fig.6 Results of Model Based diagnosis

Diesel Engine Case: Neural Network Method

The torsion vibrational signal is applied as an input pattern to neural network. There are two types of data sets one has conditions to recognize the healthy state of engine and other has conditions to identify one or more defects introduced or simulated. The back propagation method [9] is used to develop training session for various two layer neural networks. Initially a simple network layer is trained to differentiate between healthy and non-healthy condition of engine after that more complicated layers are trained to identify an increasing combination of defects i-e healthy, cylinder-1 defect, cylinder-2, partial power etc [12The available measurement signals limiting the range of data sets. The available data set is of 8 Giga Bytes. In Preprocessing stage measurement signals are effectively preprocessed by following steps resampling (to convert measured signals in bins of 512 samples per combustion cycle), filtering, averaging, peak removal and normalizing. Every neuron of input network layer is mapped with each of the 512 samples. Therefore, every neuron in the output layer identifies a specific class of defects. Postprocessing is only made for accepted classification of neural network based on certain threshold values and classification is only accepted if it repeats itself for a certain minimum number of times in specific time period. The neural networks were trained to identify the defects or faults by follow the training flowchart as shown in Fig.7.

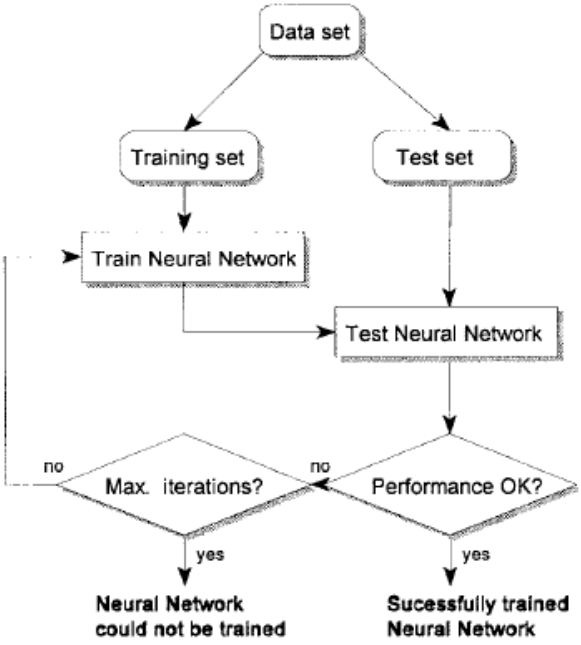

Fig.7 Flow Chart of Training neural Network [5]

The above training session is used to identify the following defects

1) Identify which cylinder is fully off (100%),
2) Identify which cylinder is fully off or partly off (78%)
3) Identify early or late ignition (100% or 75%)
4) Identify low injection pressure (83%)
5) Identify leakage in cylinder

VI. DISCUSSION AND CONCLUSION

By adding smartness to CM by improving signal processing techniques results in reduction of operating personnel and minimization of damage to the equipment by recognizing any changes occurring to the equipment. This research provides a comparison between two signal processing techniques Model based First Principe method and neural network based method for evaluation of diesel engine case. A comparison on key characteristics for these two methods is shown in Table I.

Table I Comparison Table

	Model Based	Neural Networks
RequiredProcess Knowledge	extensive	minimal

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Required Initial data	minimal	extensive
Development effort	extensive	limited
Computer Power during development	limited	extensive
Computer Power On-line	extensive	minimal
Maintainability	good	bad
Adaptability	good	bad
Acquired in-sight	extensive	none

Model-based methods can be useful for recently developed machinery because the design information is already present to be utilized while neural networks majorly based on the availability of measured data and therefore, more appropriate for application to existing machinery. The Table 1 shows that both methods have some merits and demerits so there is a tradeoff exists to select any one of them for particular machine and to achieve best results a combination of these two techniques can be employed together. For future work these two techniques can be evaluated for refrigeration plant case and even feature extraction condition monitoring technique can also be tested

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