Development and validation of an expert system for lubricant based predictive maintenance of machinery

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Abstract. Predictive maintenance is also known as condition monitoring. It is a technique in which systems are monitored at various key points of the operating machinery and data is observed. Analyzing the data is very much useful to assess the health of the machine thereby catastrophic failures can be avoided. This leads to more production and also eliminate to a great extent, the inventory. To make the technique more convenient, the expert system is very much useful. In this paper an attempt has been made to take up a comprehensive review of the literature and emphasis has been given to lubricant condition-based monitoring through an expert system, which will spell out the probable faults along with remedial measures. The expert system embeds the viscosity of lubricant as measurand. It has been developed for different grades of lubricating oils and their industrial utility.

Keywords: Predictive maintenance, Expert System, Lubricant, Fault diagnosis.

1. Introduction
Condition monitoring is a method for finding a machine’s physical condition and performance over time. With condition monitoring, maintenance engineers measure parameters to identify the faults well in advance. It is a management technique using the systematic valuation of the equipment functioning with a view of exploring its health condition data. Such data is used for revealing the faults in the machinery, well in advance.

With the advancements in technology, the functioning of machines and equipment is becoming more and more perfect, integrated, intellectual, and intricate. Even though optimization techniques have been carried out in the machine design and manufacturing process to get better quality of mechanical goods, mechanical failures are still tough to avoid due to the complexity of the apparatus. The condition monitoring and fault diagnosis based on modern science and technology act as an efficient method to predict possible faults and decrease the breakdown of a machine.

Yonghui et al [1] have developed and integrated an online oil monitoring system that combined an inductive transducer with a fiber optic transducer. Hugo Raposo et al [2] in their work predicted a case study and a model to predict maintenance intervention based on condition monitoring of diesel engine oils in urban busses. Artur Wolak et al [3] have focused on determining the content of metals present in lubricating oils using atomic absorption spectrometry. Nicole Dorr et al [4] have taken up a comprehensive chemical assessment of engine oil degradation in a passenger car due to contamination. Charlotte Besser et al [5] developed a novel artificial alteration method to generate altered engine oils with a defined degradation degree in large amounts. Surapol Raadnui et al [6] have developed a low-cost condition monitoring sensor for the analysis of used oils. The performance of the sensor is assessed systematically using the statistical design of the experiment. Xiaoliang Zhu et al [7] have proposed a comprehensive review of the state-of- the art online sensors for measuring lubricant
properties. M.Gopla Krishnan et al [8] in their work have established an knowledge based expert system in C++ for flash point based monitoring of lubricating oils. Ramana K.V. et al [9] established an knowledge based expert system for the investigation of journal bearing faults of rotating apparatus using vibrations. Duduku M.R. et al [10] have established an ES for monitoring the state of submarines using Infrared radiation thermography.

The above literature review that has been taken up, reflects that earlier works on condition monitoring are based on lubricating oil properties and confined to either sensor-based or mathematical models. There is a wide scope to assess the condition of lubricating oil based on changes in their properties using an expert system and also to take up fault diagnosis of machinery which influence the lubricant properties. In this work viscosity , the most significant property has been considered for investigation.

2. Expert System

2.1 Brief Introduction

Expert systems (ES) are a discipline of artificial intelligence (AI). The enhancement of the early expert system in the mid-1970s marked a concept transfer in AI assessment, as a substitute for designing a human-based assessment. In view of the general investigative strategies and heuristic search techniques, the attention moved towards knowledge-based modeling of expertise in a constricted area of study. This part of AI became recognized as an expert system.

Early detection of faults represents an effective method to decrease the chance of equipment failure. Still, a major obstruction to the estimation of component failure modes in industrial machines is the lack of ability to provide industry practitioners with the required knowledge relating to predictive maintenance investigation. One probable resolution to overcome this obstruction is with the help of computer-assisted systems such as Expert systems (ES), which use numerical or non-numerical data to solve problems.

An expert system generally has 3 components: User Interface, Inference Engine, Knowledge Base. Figure 1 shows the main components of the expert system.

![Figure 1. Schematic Block Diagram of Expert System](image)

User Interface-
With the support of a user interface, the expert system will interrelate with the client, takes inputs as queries in a readable format, and send them to the inference engine. After receiving the response from the inference machine, it will exhibit the results to the user. It is an interface that supports a non-expert client to communicate with the expert system to find out a solution.

Inference machine
The inference tools are well-known as the intelligence of the expert system. It supports in obtaining a faultless solution of queries given by the client. With the support of an inference machine, the system finds out the information from the data acquisition.

Knowledge Base
• A knowledge base is a category of storage space to store the knowledge gathered from different experts of the specific domain. It is considered as a huge storage space of knowledge.
• It is the same as a database that contains data and rules of a specific area or topic.

2.2 The Approach

Figure 2 shows the Data storage and Data retrieve process in the Expert System:

![Figure 2. Data Storage and Data Retrieve of Expert System](image)

Figure 3 shows block diagram of Development of Expert system by using Python code, Flask app deploying through GitHub repository under Heroku server

![Figure 3. Block Diagram of Development of Expert System](image)
Figure 4 shows the expert system without inputs.

**Figure 4. Expert System without inputs**

### 3. Validation

#### 3.1 Case Study:

This case study is on SAE 10W40 gasoline engine oil. It can be recommended for commercial automobiles, work machinery, or manufacturing units as well as passenger automobiles, manufacture it the idyllic gasoline diesel-powered oil for an assorted fleet of automobiles.

Table 1 shows the specifications of SAE 10W40

| SAE Grade | 10W 40 |
|-----------|--------|
| Viscosity @ 100°C (cSt) | 13.0 |
| Viscosity @ 40°C (cSt) | 93.274 |
| Viscosity Index | 155 |
| Density g/ml @ 15.6°C | 0.86 |
| Flash Point ºC | 212 |
| Pour Point ºC | 45 |

**Table. 1 Technical Specifications**

#### 3.2 Data Acquisition

Generally, a gasoline engine consists of a fixed cylinder and moving piston. Due to combustion of fuel, gases will expands and push piston, it will further roates the crankshaft. This mechanical power transmitted to wheels over a system of gears, this drives the vechie. Therefore, there are many parameters such as engine temperature, lubricant oil properties will come into the picture. In this work lubricant viscosity sample wise data have been collected for further process.

#### 3.3 Data Pre-processing

Data pre-processing is a data mining technique that is used to transform the raw data into a useful and efficient format. The error extracted from the sample data is stored in the database, which will store the data of all types of oils grades. New data stored for training the model will be recognized to
record if any error in every grade of oil from the selection of the database. An average value was taken to select the samples and eliminate outliers for further design of the model.

Figure 5 shows the relation between SAE Grade and Viscosity Test set model data.

![Figure 5. SAE Grade vs Viscosity (Test set)](image)

Figure 6 shows the relation between SAE Grade and Viscosity Training set model data.

![Figure 6. SAE Grade vs Viscosity (Training set)](image)

3.4 Data processing

Once after training the model, the collected sample data from the present state can be used as inputs to find out the facts and then predict the possible faults. In this case study, the data has been collected for SAE 10W 40 that was under usage normally and steadily without any maintenance for a period of time.

Fig. 7 shows the safe condition based on the input value which is less than the limiting value.
Figure 7. SAE 10W-40 Safe condition

Fig. 8 shows the normal condition based on the input value which is equal to the limiting value.

Figure 8. SAE 10W-40 Normal condition

Fig. 9 shows the Unsafe condition based on the input value which is greater than the limiting value.

Figure 9. SAE 10W-40 Unsafe condition
4. Fault Diagnosis and Remedial Measures
Since the expert system output reflects “Unsafe”, the following are the probable faults in the engine that influence the viscosity of the lubricant-
Friction between the piston rings and cylindrical bore, Dislocation of the piston rings in their grooves, Dislocation of cylinder liner, Non-collinearity of longitudinal axes of cylinder and piston, Wear and tear of cylinder liner.
It is suggested to the service person to check for the root causes for fault. It has been diagnosed that oil rings got a misalignment in their grooves.
After rectifying the fault and the engine kept running for 2 hours, a fresh sample has been taken and measured its viscosity. The value has been entered as input to the expert system and the output is observed to be “Safe” condition and shown in Fig.10. The expert system has been developed to store and print the inputs and outputs.

Figure 10 shows the after rectifying the fault a fresh sample result

5. Conclusion
In this paper, an attempt has been made to develop and validate an expert system using python, to monitor the condition of the machine, through a change in the viscosity of lubricating oil. The expert system diagnoses the faults for unsafe condition and also suggest remedial measures to bring down the viscosity to the safe limit by attending the faults in the machinery. The recorded data can be used for further failure analysis and prevention.

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