LUBRICATING OIL PERFORMANCE ASSESSMENT USING SIGNED DIGRAPH AND MATRIX APPROACH

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ABSTRACT

In this paper, a new approach for lubricating oil performance is assessed as an index by considering its pertinent properties and their interaction, modeled in terms of lubricating oil performance signed digraph (LOPSD). Its equivalent matrix is defined to obtain lubricating oil performance function. Numerical value of the function is called lubricating oil performance index (LOPI) and is a measure of lubricating oil performance and its residual life at a given time. This is obtained by substituting results of the identified oil tests.

KEY WORDS: Lubricating oil performance, Oil analysis, Residual life, Digraph and Matrix approach

1. INTRODUCTION

Performance assessment of lubricating oil is of great concern to plant personnel and this aspect is taken up as oil analysis program under condition monitoring (CM) activity, in which selected physical and chemical properties of the oil for a system are monitored. The oil is changed based on the manufacturer’s recommendation. However, it has not resulted in minimizing failures and optimal use of the oil. Literature [1] shows that the performance assessment of lubricating oil is dominated by experimental, field and standard tests and is based mainly on consideration of limited and individual oil properties to characterize its performance, but has failed to provide the users its estimate as qualitative or quantitative measure.

Graph theory [2] is a well-established systems approach and has proved to be useful in modeling and analyzing system in numerous fields of science and technology. It has potential for performance assessment of the lubricating oil and is extended in this paper. Matrix approach, established in analyzing the graph models, is applied to derive lubricating oil performance function and index to assess the lubricating oil performance.

2. IDENTIFICATION OF LUBRICATING OIL PERFORMANCE PARAMETERS

A lubricating oil performance parameter ($P_i$) is defined as a property or characteristic of the lubricating oil that influences its performance. To identify these parameters, one has to understand what happens to the oil in service [1] and their relative weightage of the specified application. A designer does recommend an oil for the application that is most suitable for its intended functions, and suggests its value or range, including warning limits. Physical and chemical properties such as Viscosity, TAN/TBN, water content, insolubles and contamination are, in general, the considered parameters for the performance assessment. However for the specific application, additional parameters should be identified for realistic assessment.

3. LUBRICATING OIL PERFORMANCE SIGNED DIGRAPH

Lubricating Oil Performance Signed Digraph (LOPSD) is a set of nodes and directed edges and models lube oil performance. Nodes of the digraph represent the oil performance parameters and the interrelations as effect of deviation among these are represented by the directed edges. If a deviation $+$ or $-$ (increase or decrease) of a performance parameter ($P_j$) causes a deviation $+$ or $-$ in other parameter ($P_i$), then a directed edge is drawn from the node ‘$i$’ to the node ‘$j$’. A number is assigned to the edge depending on the direction and magnitude of the deviation. If the moderate deviation in a parameter causes a moderate deviation in the other, a value of 1 is assigned to the edge and for very large, a value of 10 is assigned. If deviation is absent or insignificant, no edge connects the two nodes. The sign of magnitude ($+$ or $-$)
reflects the relative direction of the deviations (increase or decrease).

Signed digraph-models for cases of increase and decrease in viscosity are developed. LOPSD that considers all the possible deviations among the parameters and considering, five performance parameters is also developed and is shown in Fig. 1. This case is considered to develop a general methodology of performance evaluation for lube oil, using the matrix approach.

![Fig. 1: LOPSD with five performance parameters considering all possible interactions](image)

**4. LUBRICATING OIL PERFORMANCE MATRIX**

Matrix representation of the lubricating oil performance signed digraph gives its one to one representation. This matrix is called lubricating oil performance matrix (LOPM). This is an M x M matrix that represents the presence of M lubricating oil performance parameters and their interrelationship, in terms of diagonal and off diagonal elements. This matrix, \( B \), for the LOPSD (Fig. 1) is written as

\[
B = \begin{bmatrix}
P_1 & d_{12} & d_{13} & d_{14} & d_{15}
\end{bmatrix}
\begin{bmatrix}
E_1 & d_{21} & d_{23} & d_{24} & d_{25}
\end{bmatrix}
\begin{bmatrix}
P_2 & P_3 & P_4 & P_5
\end{bmatrix}
\]

(1)

In this matrix, \( E_i \) (\( i = 1, 2, ..., 5 \)) is the value of the \( i^{th} \) performance parameter represented by \( i^{th} \) node in the digraph and \( d_{ij} \) (\( i, j = 1, 2, ..., 5 \)) is the effect of deviation of \( j^{th} \) parameter on \( i^{th} \) parameter, represented by the directed edge \( e_{ij} \).

Lubricating oil performance function (LOPF) i.e. Per (B) for the above matrix is written in sigma form as:

\[
\text{Per (B)} = \prod E_i + \sum E_i \sum E_i \sum E_i \sum E_i \sum E_i (d_{ij} d_{ik} E_k E_l E_m)
\]

The above expression considers all possible interactions among the lubricating oil performance parameters. However in cases, where no interaction exists, that term of the expression is absent as \( d_{ij} \) value for this is assigned value of zero. Expression (2), in sigma form, is a useful expression for lube oil performance analysis, as it contains all possible structural components of the parameters and their deviation. It may be mentioned that permanent is a standard matrix function and is defined and used in combinatorial mathematics [3].

**5. LUBRICATING OIL PERFORMANCE INDEX**

The numerical value of the LOPF i.e. Per (B) is called the lubricating oil performance index (LOPI). As the LOPF contains only positive terms, a higher value of \( E_i \) and \( d_{ij} \) will result in an increased value of the LOPI. The values of \( E_i \)'s are mostly quantitative, and are obtained from the tests but these can have different units. It is therefore desirable to normalize the quantitative values of \( E_i \) on a scale e.g. from 0 to 10.

The value of this index varies from its lowest index value (when all the properties are 100% degraded or 0% residual life) to the highest index value (for fresh oil or 100% residual life). This range of index is divided into five performance intervals. The oil change will be implemented based on the index value for a specified performance level of the system. In addition, its caution and warning limits can also be developed.

**6. EXAMPLE**

Physical and chemical oil tests at different time intervals, by Verma et al. [4], are considered for evaluating the performance of synthetic lubricant for a worm gearbox. However, LOPI value for fresh oil is \( 8.7 \times 10^4 \). The index range is divided into five performance intervals corresponding to rejected, bad, fair, good and excellent performance of the lubricating oil. The value of LOPI after 38 Hrs of working is \( 4.3 \times 10^3 \). This value lies in a performance interval of 50 – 75% and the oil performance corresponding to this is fair.

**7. CONCLUSION**

A new procedure using graph theory and matrix approach is suggested for assessing the performance of lubricating oil based on the lubricating oil performance parameters and their interrelations. The index enables the maintenance personnel to decide planned maintenance action for the oil, based on its performance level or residual life.

**REFERENCES**