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FUEL AND WATER DIAGNOSTIC ENHANCEMENTS AT BNSF RAILWAY

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ABSTRACT

In 2005, BNSF Railway upgraded their oil analysis program. With a fleet of over 4000 locomotives, the oil program was processing approximately 1000 samples per day. The objective of the upgrade was to automate data collection from the laboratory instruments and implement automated diagnosis of diesel and compressor failure modes. The upgrade to the program included automating the data retrieval system (LIMS), automating the laboratory process, upgrading the FTIR programs to the ASTM E2412 Practice [1] and automating the oil analysis diagnostics through the implementation of an expert system. The expert system moved the data analysis procedure from an “analysis-by-parameter” process” to an “analysis-by-failure mode” process. The expert system automatically determines and posts maintenance recommendations to the Maintenance Management System for action. This paper will discuss the enhancements to fuel and water diagnostics in medium speed diesel engines achieved under this project, and the associated benefits to the BNSF Condition Based Maintenance Program.

INTRODUCTION

Accurate monitoring and assessment of machinery condition data can significantly reduce the cost of maintenance and improve equipment availability through a combination of improved maintenance scheduling, elimination of unnecessary maintenance actions, prevention of in-service failures and reduced spare parts inventories. Automation of machinery oil analysis methods can be achieved through the use of maintenance management software. GasTOPS has developed a Machinery Condition Assessment System (MCAS) for BNSF that integrates data obtained from laboratory test instruments (and manual data input), and provides comprehensive features to support Condition Based Maintenance including:

a) equipment management;
b) data collection;
c) usage and condition tracking;
d) condition indicator extraction;
e) trending;
f) data analysis and reporting; and,
g) data interpretation and maintenance recommendations.

The key to on-condition maintenance is the timely availability of data describing the condition of the equipment. BNSF sample their diesel engines and compressors every 10 days. The BNSF laboratory uses modern test instruments equipped with auto-samplers. As part of the upgrade, the laboratory instruments were networked together for automated data collection. The automation of the data collection process allowed for the expansion of the set of condition data being collected from the laboratory instruments. In the case of the atomic emission spectrometers, the set of parameters being monitored was expanded from 10 to 20 including the addition of sodium to support diagnosis of water contamination failures. The Fourier transform infrared (FTIR) spectrometers were only being used to predict pentane insolubles, soot and base number (BN) at the beginning of the program. However, during the project they were upgraded to implement the ASTM E2412 Practice providing several additional valuable condition indicators including water and diesel fuel contamination which have proven to be reliable indicators for diagnosing those contamination failure modes.

DATA ANALYSIS:

One of the benefits of the large number of samples handled by the BNSF laboratory is that it provides a significant population of sample data to support statistical analysis of limits for different makes and models of machinery, and for the study of condition indicators. Using the data accumulated in the first year of operation of the system, it was possible to qualify sodium and IR water as valid condition indicators for the water contamination (WC) failure mode and IR diesel fuel for the fuel dilution (FD) failure mode (an example is provided in Fig. 1). Water contamination and fuel dilution comprise approximately 20 % of all diesel engine failure modes at BNSF, and because of their rapid onset and catastrophic effects they are considered shutdown conditions for the more severe cases. As such, more reliable condition indicators save time and money by reducing unnecessary shutdowns and unnecessary failures.

The analysis of the data also showed that there is a high degree of correlation between high sodium and high boron in water contaminated samples (Fig. 2). In some cases, sodium is a better indicator than boron and thus extended the set of condition indicators available to reliably indicate the presence of cooling water inhibitors.

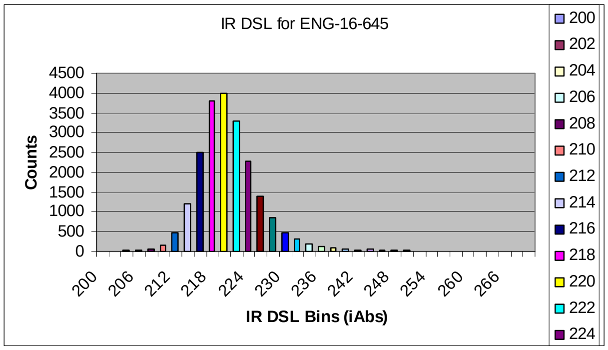

Fig. 1: Distribution plot for FTIR fuel readings

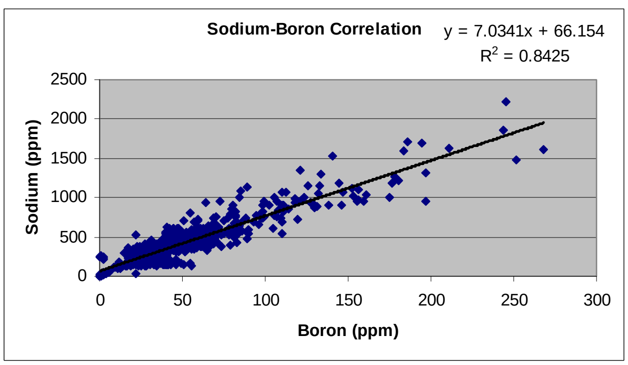

Fig. 2: Sodium and boron correlation.

A similar analysis showed a high correlation between the IR diesel fuel test parameter and the viscosity measurement. IR diesel provides a reliable indication of the presence of fuel in-service crankcase oils.

EXPERT SYSTEM:

The typical diesel engine fleet is made up of many different makes and models, and each one has unique metallurgy and performance characteristics. This means that the fault signatures for each class of machine are unique. Combine this with the fact that condition indicators frequently relate to multiple fault modes and multiple engine component parts. In addition, multiple faults can and do occur at the same time. The resulting fault matrix is extremely complex and human experts are hard pressed to untangle the patterns of indicators to explain which failure modes are at play in a real world situation. In addition, each person tends to have different experience and may make different decisions depending on the data and how it relates to their experience.

The interpretation of condition data is a difficult process that is highly mathematical in nature and is well suited to computerization. Each sample analysis requires the evaluation of the level and trend of 30 to 40 data points, in conjunction with equipment operating data. The expert analysis and data management CBM software introduced at BNSF, provides modules to support statistical analysis and trending. In support of the analysis, test types, lube types, limit data, and expert rules are maintained in a database for the purposes of supporting the analysis of the oil condition data. The oil condition data analysis process is further automated through the use of graphical analysis tools, expert diagnostics, and reports.

The expert system incorporates rules to analyze the various valid combinations of the parametric measurements to resolve the specific failure mode or conditions at play using a variety of physical concepts such as: the molecular ratio of atoms in a compound, the percentage of elements in an alloy, the statistical correlation of elemental ratios or unique elemental patterns with the specific maintenance or repairs. These rules ensure that the expert system will always render the same decision for the same set of conditions. As a result, the expert system can analyze each of the samples passing through the lab to the same level of detail, and with a consistency and accuracy that is impossible for a human expert to achieve. The volume of data and the complexity of the fault matrix are no longer an issue, and the expert system becomes a resource to support and empower the human experts.

Expert system software has completely automated the process of data interpretation. Data reduction routines reduce complex condition data to the simple descriptive terms to define the status of the condition indicator. Typical terms are normal, marginal, high. Each test value is established by comparing the condition indicator to predefined limits. The rate-of-change or trend of various measurements are also reduced to status information (e.g. stable, increasing, moderately increasing) by comparing the current trend to established limits. The expert system captures the decision-making capabilities of expert technicians in expert rules, and utilizes the knowledge to automatically generate maintenance recommendations and condition assessments.

CONCLUSIONS:

The improvement to the condition assessment system; expanding the number of atomic emission and FTIR measured parameters; and the introduction of the expert system have led to the transition from a test parameter based diagnostic system to a machinery failure mode based process. Predictive maintenance recommendations are now raised in the context of the diagnosed failure mode and the associated maintenance action. The introduction of the expert system has reduced the number of locomotive shutdowns and failures thus reducing operational costs and increasing availability. Availability supports the objective of meeting customer delivery times for goods delivered by rail.

REFERENCES

[1] ASTM E2412 Standard Practice for Condition Monitoring of Used Lubricants by Trend Analysis using Fourier Transform Infrared (FT-IR) Spectrometry