Fusion of Oil Debris and Vibration Technology - The Path to Improved H U M S Performance

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Abstract:

Diagnosis of faults in mechanical systems has traditionally involved analysis of vibration data and analysis of oil borne debris captured by magnets placed in the lubricating oil stream and has relied heavily upon trained expert analysis of data. Because the technologies are expert intensive and quite different in practice, they have remained basically separate analytical technologies. Each technology requires specific expert interpretation of data. Generally, neither answers the question " what's failing and how bad is it "? Data in "g's rms. " and " parts per million of iron" will normally be compared to limit values. This usually occasions review by a trained technician to determine the course of action to be followed and may or may not signal the existence of a problem. Optical analysis of oil borne debris by experienced technicians can provide additional information on machine condition well in advance of failure, but the accuracy of the analysis is still highly dependent on the capability of the human expert.

Attempts to automate these analysis processes have mostly been rewarded by a high incidence of false alarms. Operators of early HUMS systems overcame these limitations by employing human expert analysis of data. Sometimes multiple indications were required before a problem was recognized.

Currently HUMS systems must rely almost exclusively upon vibration analysis for detection of most faults, partly because automation of oil debris analysis has fallen behind basic HUMS technology development. While some of the critical HUMS detectable faults do not produce significant levels of oil borne debris, there are many that do. Reliance on prior technology, such as chip detectors and particle sensors / counters, has not allowed development of a truly robust, low false alarm rate, mechanical diagnostic system. New oil debris technology, such as LaserNet, which directly identifies the surface fatigue fault mode(s) from particle shape, can assess severity, and trend growth of significant faults could provide a way forward for integration of vibration and oil debris technologies to produce a superior diagnostic approach. This paper identifies some current technology roadblocks and offers a straw man framework for such an integration process.

Vibration Diagnostic Technology Background :

The characteristics of structure borne vibration signals have been analytically and empirically related to faults in machinery. Analysis packages for vibration frequency spectrum, order domain, broad and narrow band, cepstrum, and others have grown as vibration analysis hardware has become more available and affordable. For most industrial machinery applications the tools are at hand to allow trained vibration technicians to analyze and trend developing faults and plan corrective action before a major machine outage occurs. Again, the capability of the expert largely determines the success of the operation.

These tools and techniques tend to falter in the applications where higher background levels of vibration are present. Such applications as aircraft (especially helicopter) transmissions, where vibration levels reach several hundred "g's" and failures can progress rapidly, have traditionally required entirely new analysis tool sets. Feature vectors and neural nets operating on raw accelerometer signals or signals processed in the frequency domain, or digital signal averages are all part of these tool sets. These tools are often complex and computationally intensive. The time required for these analyses permit only periodic sampling of critical transmissions and often require ground-based computation to define the most important signal features. While this technology has made great progress over the last decade, there remains considerable room for improvement before it can answer the basic question -- " what's failing and how bad is it"? with high reliability and without false alarms.

Oil Debris Monitoring Technology Background:

Vibration analysis is an inferential technology. That is, one can infer the condition of machinery from analysis of data. Oil debris, on the other hand, is generally evidential. Debris on a magnetic plug presents clear evidence of a surface fatigue failure in progress. For applications such as aircraft gear boxes, where failure progression times are short, periodic manual sampling and visual analysis of debris can result in delays and reduced sortie rates. Electric chip detectors are widely applied in critical gearbox applications and can give warning of near term impending failure in many cases. The accompanying penalty is often false alarms caused by non-failure related debris bridging the detector gap. Automated oil debris analysis systems that are designed to monitor debris generation in real time, detect debris size and provide debris count trending data have been developed over the past two decades as replacements for electric chip detectors. Most attempts to deploy these systems have yielded unacceptable false alarm rates caused by the EMI and vibration environment on aircraft (predominantly helicopters). Even if these false alarm issues are resolved through redesign, the current electromagnetic sensing technology systems provide only particle size and count data, but do not differentiate between fault and non- fault sourced debris and do not determine what type of fault exists. In short they still do not address the basic question -- "what's failing and how bad is it"?

A Straw Man Goal:

Most Defense Forces and industrial operations are now committed to the implementation of Condition Based Maintenance to reduce total ownership costs. The success of this effort hinges on the development and improvement of existing enabling technologies in the area of machinery condition monitoring, oil debris analysis, and machinery health prognostics. The goal proposed for an integrated mechanical diagnostic system is to provide machinery fault data directly rather than as a feature of a vibration signal or as numbers of particles. This goal will allow the user to functionally move the determination of machinery fault type and severity to on board and eliminate the need for and delay attendant to remote laboratory analysis and expert data interpretation.

There are several "next steps" in the process. One step is to develop the technology to interpret the characteristics of oil borne debris in terms of mechanical fault type identification and severity and translate this to machinery condition and remaining life assessment terms. A second step is to improve the detection, identification and classification ability of vibration analysis technology to permit clear identification of fault type and severity rather than just vibration signal feature and to translate this to machinery condition and remaining life assessment terms. A third step is to combine the condition assessment information from these two technologies on a weighted basis and add corroborating information from other sensors such as temperature, pressure and flow. This can serve to confirm the condition of machinery, provide better fault coverage, earlier fault detection and elimination of the high false alarm rates attendant to current automated machinery condition assessment systems.

One technology that currently has demonstrated the ability to determine wear and fault classification as well as size distribution of debris particles is the optical oil debris monitor, LaserNet, and LaserNet Fines. LaserNet Fines has been developed into an instrument usable at O-level, I-level and on board ship for determining particle sizes down to 5 microns and fault type (surface fatigue failure, sliding wear, and or cutting wear). On line versions of LaserNet and LaserNet Fines are currently being developed for airborne and shipboard applications. Technical operation details are available from the co-author at the U. S. Naval Research Laboratory.

Achieving this fault identifying capability not only with oil debris technology, but also with vibration analysis technology is a key step in providing comprehensive machinery condition monitors for on line operation that will allow continuous autonomous monitoring, supporting reduced manning and reduced maintenance operations and costs.

An Example Approach:

The LaserNet technology identifies debris particles and determines particle type in three major classes in much the same way that a trained debris analysis technician does. The edge roughness, appearance and particle shape aspects of the several classes are reliably (but not perfectly), rapidly and automatically separated. Since, in the early stages of failure, there may be competing failure modes, it is important to determine not only particle count but also particle type and thus type of failure. As an example, surface fatigue spalling may ultimately cause machine failure, but detection of particulate contamination shapes can allow corrective action that will delay the onset of failure.

The reporting of particle characteristics and incipient fault type and severity can also provide a measure of fault severity and, when machine type history is added, provide an indication (not perfect and very dependent upon machine use environment) of probable time to machine failure.

Machine fault type and degree of progression can now be reliably determined by LaserNet technology. Machinery condition determination and prognosis from oil debris particle shape and amount can be substantially improved by considering the relative trends of the major wear fault types as determined by LaserNet. The trends of each particle shape category can identify the fault type and trends in severity. As an example, consider the case where a combined LaserNet / LaserNet Fines on-line unit is monitoring lubricating oil flow in an operating machine. Dr. John Reintjes of NRL has postulated that the fault type progression may be determined from plots of the relative particle shape / fault type particle counts or particle generation rates over time. Further, these characteristics may be represented by a series of numerical feature vectors which might then be matched to patterns of previous machine behavior and provide an automation of the condition assessment process.

Figure 1 is a series of notional plots of particle shape indicators of fault types that might be present in this machine. The vertical axis might be either count or rate data, while the horizontal axis is operating time. While these are just notional they do serve to illustrate the point. Work is in process to automate features vectors for these plots that can be used to develop quantitative representations of machine condition.

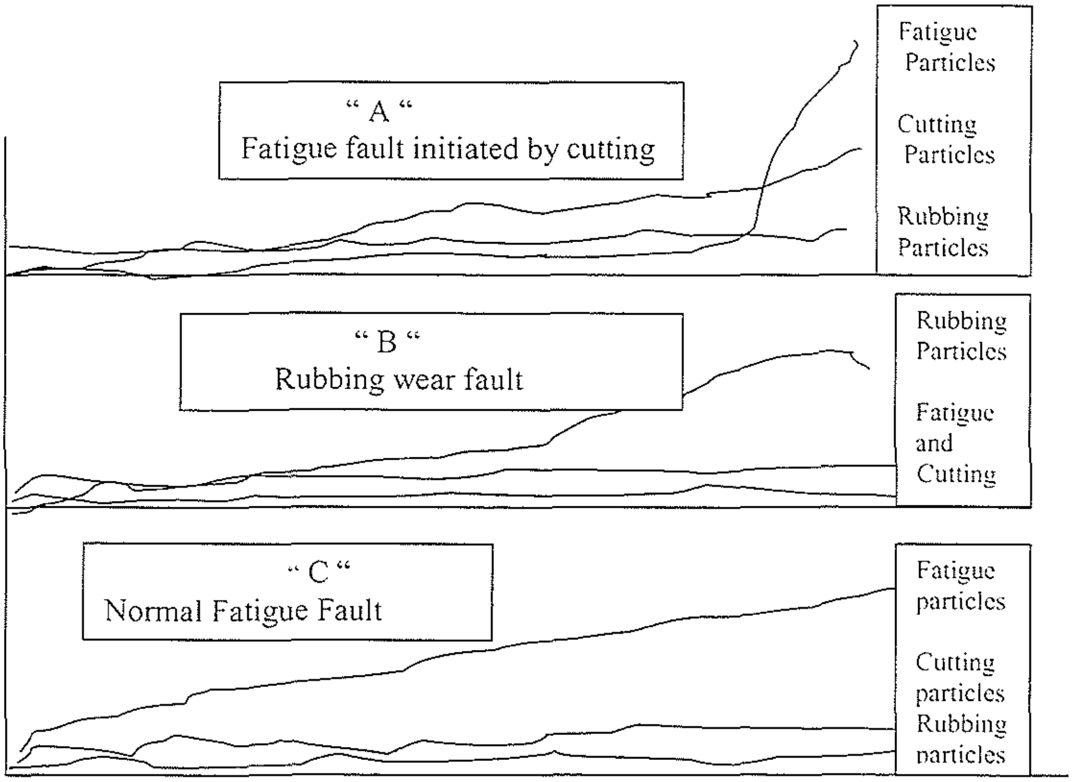

Figure 1.
LaserNet Fault Type Notional Plots

The translation of this approach or a similar one to the vibration technology regime is needed to accomplish the integration of technologies. The translation is by no means an easy task, but the reward is commensurate with the effort. While the present vibration systems can provide some measure of fault detection, the end result lacks the value of an integrated low false alarm machinery diagnostic system

The Issues and Tasks:

The main issues in the oil debris diagnostic area are automation of the curve analyses shown in numerical terms and setting pattern recognition masks to automate the alarm function.

The tasks in the vibration area involve improving the feature vector clarity and linking features (or feature pairs) to specific faults, such as fatigue crack, surface fatigue, etc.

It may be that the newer Neural Net technology developing within the diagnostic community may provide a shorter route to the goal even though the financial investment to date in the feature vector approach will provide high inertia against change.

Figure 2. Illustrates a notional flow chart to update the current vibration feature vector sets, advance the LaserNet technology and integrate the resultant technologies into an integrated machinery diagnostic system that meets the needs of current and future applications.

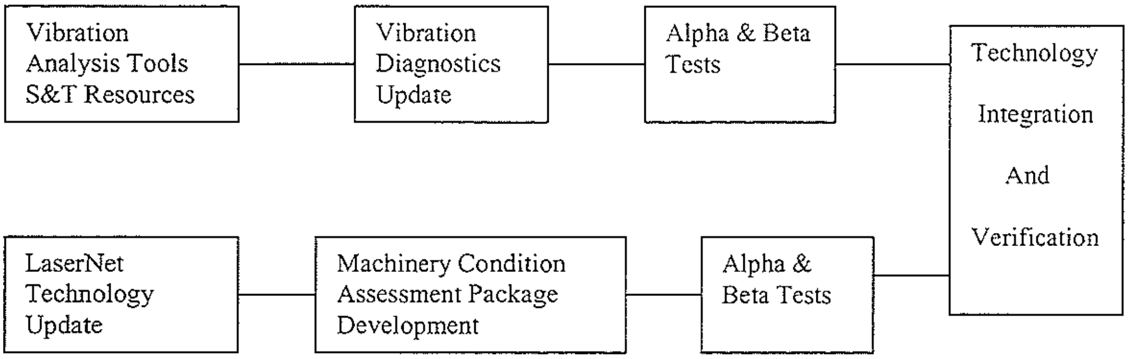

Figure 2.
Straw Man Technology Development and Integration Road Map

A key ingredient to the success of the program is development and application of both alpha and beta test beds. The goal will almost certainly not be achieved by mathematical analysis alone. These test beds need to be highly representative of actual conditions that will be encountered in the application set that the system is designed for. Many of the past failures to meet diagnostic performance can be directly traced to the failure to adequately test in realistic operational environments while the technology was being developed.

With reductions in real terms of 15 to 30% per year in defense department operation and maintenance budgets, and maintenance becoming the only remaining source of cost savings to maintain a competitive posture in industry, the urgency of this effort is self-evident.

Within the past year, the U.S. Navy has initiated programs to explore and demonstrate the integration of oil debris and vibration technology. These programs are two to three years in length and include cooperative efforts with the U.K. MoD and universities on both sides of the Atlantic. Program scope will include test and evaluation of feature vector and fault information level integration for shipboard machinery, marine gearboxes, and eventually aircraft propulsion and power train equipment. The results of these efforts will provide the foundation for future systems with improved early fault detection and lower false alarm rates. This can provide the enabling technology base for accurate machinery condition prognostics and it is here that the key to future maintenance savings and effective asset management resides.