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NEW METHODOLOGY FOR HUMS VIBRATORY DATA ANALYSIS

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1 ABSTRACT

Today many aircraft are fitted with vibration-monitoring systems. Eurocopter, for instance, has equipped more than 70 helicopters in this way. These aircraft naturally generate a vast amount of data that is very instructive as it reflects their dynamic behavior. As a manufacturer, Eurocopter has the duty of applying this new data to improve the existing systems and to enhance their performance and sensitivity in the early detection of the various types of mechanical damage. In this paper, we will first review the operation of EuroARMS and EuroHUMS, and then the methodology applied. The part played by this methodology in improving the diagnosis capability will then be explained. Lastly, this new method will be applied to a concrete case of detection in order to demonstrate the validity of the approach.

2 INTRODUCTION

Improving the safety of their helicopters has always been an ongoing priority for helicopter operators. To cater to this need, Eurocopter has fitted its Super Puma helicopters with vibration-monitoring systems known as EuroARMS and EuroHUMS. As of today, 74 of them are flying with these systems, representing more than 100,000 hours of operation. The data recorded by the systems therefore provides an accurate picture of the operation of the Super Puma and a wealth of new information.

First of all, the data contains the image of the scatter in the dynamic characteristics of all the helicopters fitted with EuroHUMS and EuroARMS.

Secondly, this data contains a number of cases of detection (and non-detection) that are extremely valuable in the continuous upgrading of the existing systems, i.e. to further enhance their sensitivity and their capability to detect the various types of mechanical damage at an early stage.

For the manufacturer, this new mass of data calls for the use of new approaches and tools, such as data mining. Moreover, the detection cases in the data help to expand our knowledge of vibration monitoring. However, new methods of analysis, which are explained below, are needed to deal with such a large volume of data. All the data used to illustrate this method comes from EuroARMS or EuroHUMS recordings.

3 OVERVIEW OF EUROARMS AND EUROHUMS

3.1 Source of the data

The measurement principle of these systems is to acquire vibration signatures in flight and on the ground. A vibration signature is a digital time-varying accelerometer signal or the result of a synchronous temporal averaging process. The characteristic values of the statistical or energy properties of each signature are then computed. These values are called indicators.

Helicopter vibration monitoring consists in keeping track - with a slight time delay - of the variations in the indicators. Two methods are used to interpret these variations: thresholding and trend analysis.

3.2 The threshold concept

A limiting value or threshold of the amplitude of an indicator is used to trigger an alarm whenever a significant overshoot is recorded.

Setting this threshold is obviously crucial for the detection capability. If the threshold is too high, it may be of no use at all for diagnosis, since there will never be any overshoots. Conversely, if the threshold is too low, there could be too many false alarms. In this case, the system would be discredited because of the unneeded - and often very expensive - maintenance operations required.

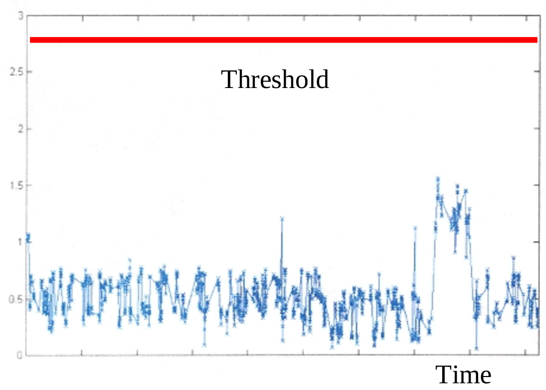


Figure 1: Typical variation of an indicator representing the unbalance of a shaft

3.3 Trend study

The threshold concept is only applied to the absolute value of an indicator's amplitude that exceeds (or not) a set value.

However, it is not always easy to determine the value of a threshold. Sometimes, when it is extremely difficult to define a detection threshold, the value of the absolute amplitude is not utilized but its variations with respect to the amplitude at a given initial time. In other words, a relative baseline value.

In this approach, the trends of the monitored system (in principle, the evolving damage) are therefore interpreted, and not directly the condition of the system (correct or incorrect operation). In other words, only the trend of the system's condition is observed.

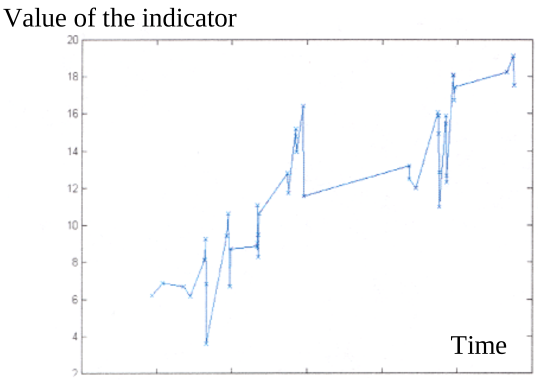


Figure 2: Typical trend of an indicator representing the energy at the gear frequency

This 'system trend' concept is wider than that of threshold overshoots.
Indeed, a threshold can only be exceeded if the value of the indicator increases when a defect occurs.

However, an indicator's value, as defined by its algorithm, may increase for some defects and decrease for others. This means that there are decreasing trends, which also express changes to the system.

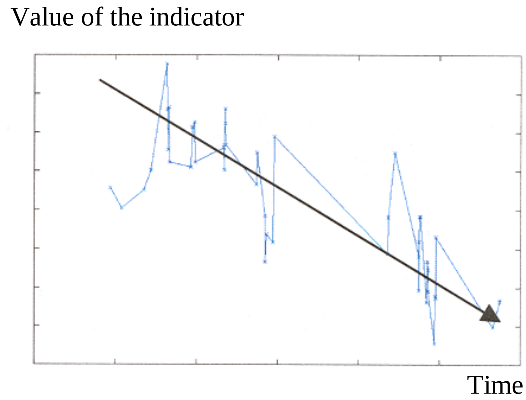


Figure 3: Typical decreasing trend

4 NEW ANALYSIS TECHNIQUES FOR THE MANUFACTURER

4.1 Statistical analysis of the indicators

The values of the indicators have been analyzed for the complete fleet. These studies included a considerable number of aircraft (using the databases provided by various customers). It was therefore possible to build up samples of the indicator values, often containing more than 10,000 points.

Thanks to the large size of this data, the studies conducted were statistically pertinent.

The statistical analysis of the indicators provides an overall picture in which the specific behavior of the indicators can be identified.

Conventional statistical tools are ideally suited to treating this kind of problem.

The distribution histogram identifies the most representative statistical curve (normal, log-normal, etc.).

In addition, the histogram shows the existence of several populations, an assumption that can sometimes be consolidated using Henry's conventional straight line.

Indeed these studies have demonstrated that, for certain indicators, the fleet can be considered as one single statistical population whereas other studies illustrate the existence of different families.

The indicator shown in Figure 4 demonstrates the uniformity of particular statistical properties of a power transmission throughout a fleet.

Number of measurements per class

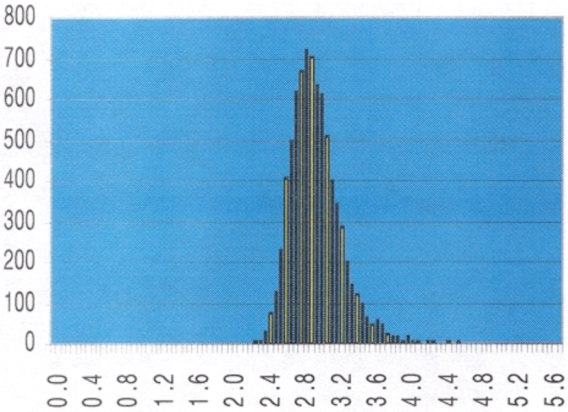
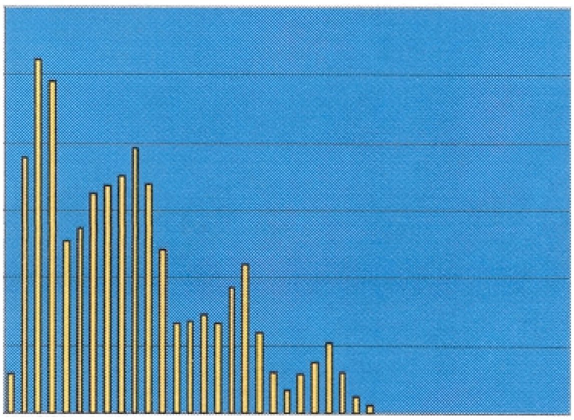


Figure 4: Typical histogram of a Kurtosis indicator

Figure 5 shows several populations. The plotted indicator is particularly sensitive to shaft unbalance. It is seen that the levels are different throughout the fleet.

Number of measurements per class



Value of the indicator

Figure 5: Histogram of an indicator showing several families in a given power transmission population

It is not always an easy task to determine the source of these different populations since aircraft of the same type have the same power transmission definition.

However, it is known that certain phenomena are liable to generate such variations, i.e.:

- scatter in the dynamic behavior of the aircraft (variations in weight and stiffness)
- variations in the power input to the transmission during recording (different measuring configurations)
- specificity of the installation conditions.

In fact, when transmission components of the same definition are installed on a given aircraft, the vibration response is sometimes different.

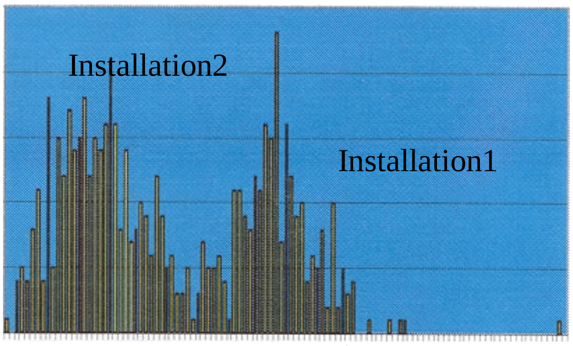


Figure 6: Typical distribution for 2 installations on the same aircraft

The installation conditions can therefore cause the indicator's mean value to vary.
It is thus clear that certain indicators must have specific thresholds for each aircraft, or even for each installation.

This is why, for its EuroHUMS and EuroARMS, Eurocopter utilizes two types of thresholds: fixed and learning ones.

4.2 Fixed thresholds

A threshold is called 'fixed' when it applies to the entire fleet. It can be applied in the following two cases:

- When an indicator is representative of a physical parameter (unbalance, etc.) and when there is a not-to-exceed damage criterion.
- When the indicator's statistical behavior indicates a transmission system whose behavior is uniform throughout the entire fleet.

Figure 7 shows the distribution of the levels for the fleet of an indicator whose behavior permits a fixed threshold to be adopted.

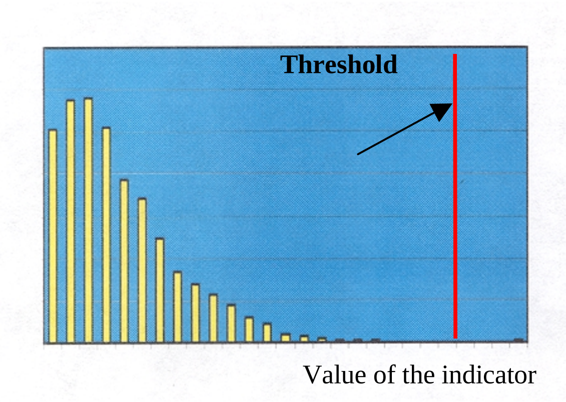


Figure 7: Distribution of the indicator for the fleet, with a fixed threshold

4.3 Learning thresholds

The behavior of certain indicators makes it necessary to determine specific thresholds for each aircraft.

Eurocopter applies the following 'learning' logic: the indicators are computed during the initial operating hours of the power transmission. The mean 'm' and standard deviation 'σ' are then estimated.

The threshold S is given by:

$$S = (m + k \times \sigma) \qquad k \in N$$

This type of computation is well suited when the data is relatively scattered (significant standard deviation). However, very stable data can impose an excessively low threshold liable to generate a high rate of false alarms.
In such cases (very unusual), the threshold has to be reset to a more realistic value.

5 IMPORTANCE OF CUSTOMER FEEDBACK

5.1 A base of wide-ranging, valuable data

This approach is meaningless without regular inputs from the customers of the backups from their ground stations.

The studies conducted by Eurocopter can therefore be sufficiently comprehensive to allow for the many specific features of each customer, such as:

- Aircraft utilization
- Type of missions flown
- Weather conditions, etc.

Various discriminant analyses of this wide range of data can identify some phenomena not perceptible on each aircraft when considered individually.

5.2 Utilizing the cases of detection

The other very valuable mechanism for improving EuroARMS and EuroHUMS is obviously the feedback of the detection and/or non-detection cases. Eurocopter has implemented a series of procedures with the customers in order to centralize and exploit all these isolated cases.

It then becomes possible to look for the similarities in the various cases of mechanical failure and ultimately pass the findings on to all the customers.

6 ENHANCING THE DIAGNOSIS CAPABILITY

6.1 Comparison of indicator values with the remainder of the fleet

Thanks to the fleet-wide studies, the levels experienced by the aircraft can be correctly estimated. Consequently, the value of an indicator can be compared with the remainder of the fleet: any value significantly differing from the fleet value can then be interpreted as a preliminary symptom.

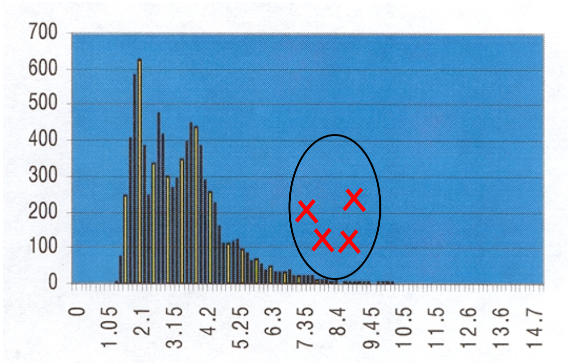


Figure 8: Typical values recorded on a system with a mechanical problem

However, comparing an indicator with the remainder of the fleet may not always be informative, even when the system has a mechanic problem. In such cases, it is concluded that the indicator is insensitive to this damage.

In Figure 9, the plot shows the values of another indicator representing the failed power transmission in figure 8.

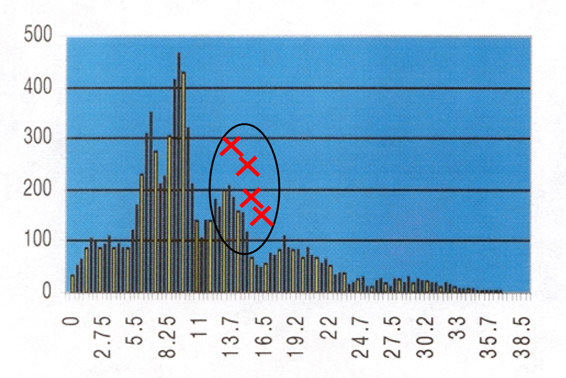


Figure 9: Example of an unproductive comparison with the remainder of the fleet

This indicator is sensitive to the energy at the gear frequency but not to the defect experienced.

6.2 Comparison of spectra

The EuroARMS and EuroHUMS databases not only contain indicators but also power spectra. These power spectra are an abundant source of instructive information for making or confirming a diagnosis.

The example in figure 10 shows a spectrum representative of a correctly operating system (obtained by averaging the spectra of several healthy transmissions systems), and the spectrum of a power transmission with a defect.

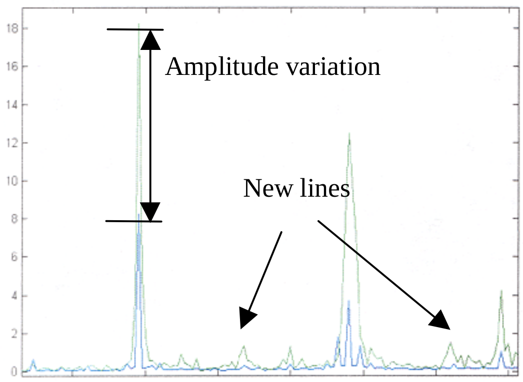


Figure 10: Comparison of two power spectra

This technique involves two types of observations:

- Visualizing amplitude variations
- Identifying the appearance of new energy lines

However, care must be exercised when interpreting the amplitude variations of the lines as they are also strongly dependent on the power input to the transmission.

7 UTILITY OF THIS METHOD FOR AN ACTUAL CASE OF DETECTION

This method will now be applied to a case of detection of a defective gear, by successively using the available capabilities (comparison of indicator values and spectra).

7.1 Trend evolution

This defect was originally detected by the trend of an indicator sensitive to changes in the signal 'noise' level.

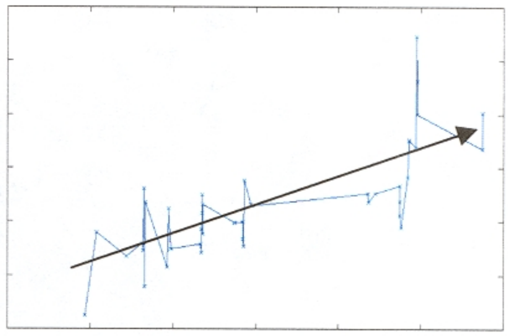


Figure 11: Trend that permits the detection of a defect

The various tools presented above will now be applied to confirm this detection.

7.2 Comparison with the fleet statistics

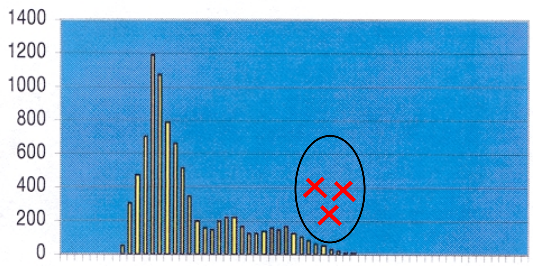


Figure 12: Comparison of the values recorded for the defective gear with the remainder of the fleet

In Figure 12, the values at the end of the trends are seen to be relatively far from the remainder of the fleet. The monitored gear therefore appears to have an abnormal behavior.

7.3 Comparison with a baseline spectrum

The presence of a defect is clearly identified by a baseline spectrum (figure 13). First of all, there are large swings in amplitude at the first two harmonics (***MF and 2*Fe***) of the meshing frequency.

Secondly, there are bands on both sides of the meshing line.

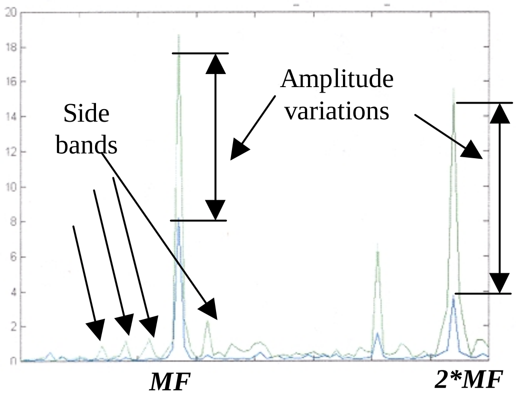


Figure 13: Comparison of the spectrum recorded for the defective gear with the baseline spectrum

In fact, these side bands are the result of a modulation phenomena.

7.4 Comparison with the spectrum of a spalled gear

Thanks to the experience gained with EuroARMS and EuroHUMS, it has been possible to make use of some of the cases of detection. A case of spalling on this gear had already been detected and archived.

When the spectra representative of the two defects are compared (figure 14), both similarities and differences are evident:

- the difference in energy at the gear frequency is much lower than with a healthy transmission system
- at twice the gear frequency, the level is similar
- the side bands present appear to be specific to the defect encountered.

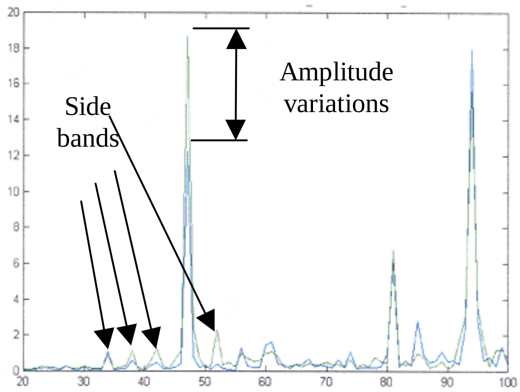


Figure 14: Comparison of the spectrum recorded for a defective gear with the spectrum of a spalled gear

An investigation of the suspect power transmission indicated that the gear was spalled and its mount had loosened.

8 CONCLUSIONS

The data recorded by EuroARMS and EuroHUMS forms a very valuable and instructive source of information.

The data plays a fundamental role in enhancing and expanding the detection capabilities of vibration monitoring systems.

The manufacturer plays a pivotal part in this process because he possesses an overall picture of the fleet and is, at the same time, fully conversant with the mechanical characteristics of the aircraft.

Eurocopter therefore has the ongoing task of extracting as much useful information as possible from this data so that the company can constantly update the performance of the proposed systems.

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