Automated Vibration Management Program for the UH60 Blackhawk

Paul Grabill
Diagnostics Engineer
Scientific Atlanta, San Diego CA

Lemuel Grant
CW4
South Carolina Army National Guard.

Abstract

The US Army has initiated a study program to evaluate the feasibility and cost savings associated with vibration management using the UH60 Blackhawk as proof of principal. This two year study program is known as the Vibration Management Enhancement Program (VMEP). Nineteen aircraft are instrumented with an array of accelerometers and tachometers. The data acquisition system uses an enhanced Aviation Vibration Analyzer (AVA) for monitoring the engines, gearboxes, driveshafts, and bearings. The VMEP system incorporates a new PC Ground Station for data storage, display, trending, and analysis. State-of-the-art signal processing algorithms are used to enhance fault signatures and detection sensitivity. A data driven expert system is used with automated fault trees on the PC Ground Station for diagnostic fault recommendations.

Presented at the American Helicopter Society 52nd Annual Forum, Washington, D.C., June 4-6, 1996.

Historical Perspective of Helicopter Vibration Monitoring

Vibration monitoring of helicopters gained prominence during the Vietnam era. Early methods included rotor tracking with a tracking flag and balancing with tape and 45 caliber slugs. Medium and high frequency vibration analysis was done by the "seat of the pants." Trouble shooting procedures consisted of changing parts until the vibration went away. The first generation rotor track and balance analyzer came along in 1971 and with it the first diagnostic tool for vibration analysis.

Mr. Grant, one of the pioneers in using this equipment, began a vibration maintenance program in the early 70's using a vibration analyzer and an accelerometer attached to a broom handle. On the UH-1, he would take measurements from 23 specific locations. The data was recorded to form a historical database and to create a vibration "baseline" for each aircraft. When a pilot would write-up an aircraft for a vibration problem, Mr. Grant would again take all 23 measurements. The new data was compared to the historical information and the "baseline." Useful information was gained from this somewhat crude method. The best example was with a high frequency vibration problem that Mr. Grant analyzed. After taking his 23 measurements and comparing them to the historical data, a hanger bearing indicated a much higher vibration level than the "baseline." When the maintenance officer changed the hanger bearing, Mr. Grant could still feel the high frequency vibration in the aircraft. He replaced the bearing a second time and the high frequency vibration was no longer present. In this case the first replacement hanger bearing was found to be defective. Had they not used this procedure, they would have replaced other items unnecessarily. Mr. Grants early vibration monitoring and maintenance program saved both time and valuable parts.

In April of 1987, Mr. Grant attended a "Joint Government/Industry Conference on Army Helicopter Rotor Systems Track and Balance Requirements." For the first time, a group of hands-on maintenance personnel sat down with the helicopter manufacturers and came to a joint agreement on what technology would be usable in the field. The Aviation Vibration Analyzer (AVA) was the end result.

When the AVA was fielded, the user could take a vibration spectrum of the entire aircraft. This method was useful in troubleshooting vibration write-ups, but there was no convenient way to monitor many different components over long periods of time.

In 1995, Scientific Atlanta, through the direction and funding of the Utility Helicopters (UH-60) Project Managers Office, began the VMEP program to provide the US Army a comprehensive tool for vibration maintenance.

VMEP System Design

Hardwired Aircraft

One of the key elements to a successful vibration monitoring program is that the data gathering task must be very easy and non-intrusive to the day-to-day operation of the aircraft. The VMEP system utilizes a carry-on data acquisition unit with permanently installed accelerometers and tachometers. This allows the user to quickly connect and disconnect the equipment for the vibration survey flights.

Accelerometers are mounted on the following components at strategic locations to optimize gear, bearing, and driveshaft monitoring:

- Cabin
- T700 Engines
- Input Modules
- Accessory Modules
- Main Module
- Oil Cooler
- Hanger Bearings
- Intermediate Gearbox
- Tail Gearbox
- APU

Tachometers are used to measure the speeds of the following components:

- Main Rotor
- Tail Rotor Driveshaft
- Engine Power Turbines
- Engine Gas Generators

A Universal Tracking Device (UTD) is used to measure the track and lag of the main rotor blades.

Upgraded AVA

The standard US Army Aviation Vibration Analyzer (AVA) is upgraded with new data acquisition hardware and software. While retaining the standard form and function of the AVA with regard to the user interface and rotor track and balance, the new vibration measurements for the engine and drivetrain monitoring are automatically acquired during normal aircraft operations. The data is stored on a removable credit card memory unit and is down-loaded to the PC-based ground station.

PC Ground Station

The PC ground station is used for data storage, vibration analysis, and diagnostic solutions. The system features a MS Windows "point and click" user interface. The vibration data is loaded into the ground station and is automatically processed for specific fault Condition Indicator (CI) values. These CI values are checked against preset limits and are used to determine the status of the aircraft. Color coded helicopter icons are used to identify an aircraft in exceedance (red) or caution (yellow) from an acceptable aircraft (green). Figure 1 shows the flow diagram of the data in the ground station.

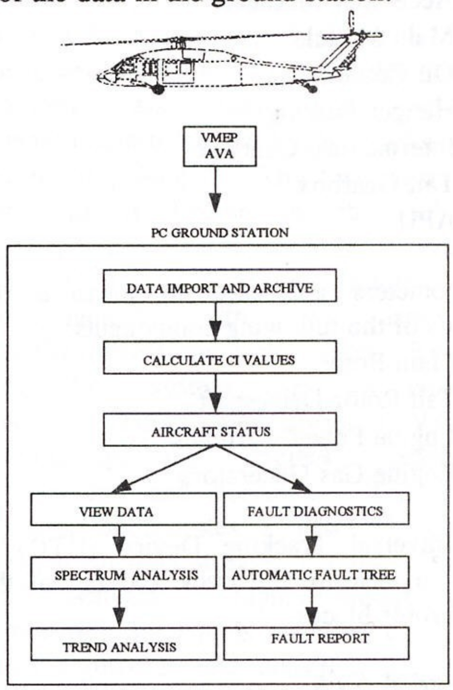

Figure 1 - VMEP Data Flow

Condition Indicator Algorithms

The data that is acquired with the VMEP AVA consists of processed vibration data both in the time and frequency domain. The following data types are acquired during each flight:

- Asynchronous Time Data - processed for bearing fault analysis.
- Asynchronous Frequency Data - processed for general spectrum analysis.
- Synchronous Time Data - processed for gear fault analysis.
- Synchronous Order Data - processed for Rotor Track and Balance.

These four types of data are analyzed on the PC Ground Station for specific fault indicators or Condition Indicators (CI). Each CI is related to a fault and is a single value or combination of values that are compared to pre-defined limits. The current UH-60 setup has over 140 CI values calculated from each flight. Some CI algorithms are relatively simple, such as the 1R vibration from the tail rotor drive shaft. Other CI algorithms involve extensive signal processing, such as a gear wear defect algorithm or a bearing envelope analysis. When the CI exceeds defined limits, the helicopter icon on the PC screen will automatically change colors from green to yellow or red.

Automatic Fault Trees

The key to providing the end user with a meaningful diagnostic tool relies on the ability to not only identify problems or faults, but to render solutions and recommend repairs. The VMEP Ground Station uses a mature fault diagnostics program from Carnegie Group Inc. The automatic fault trees are built upon Fault Hierarchy reasoning. This method uses basic diagnostic objects such as "category," "symptom," "failure," "test," and "repair" to provide a general framework in which knowledge of cause and effect are stored. The unique aspect of the VMEP fault trees resides in the data driven architecture of the system. Instead of the traditional fault trees that start with "Unknown High Frequency Vibration" and then lead down a lengthy path of part swapping and test flights, the data driven fault trees use previously acquired vibration data to identify a specific faulty component such as a generator or hanger bearing. The VMEP fault hierarchy reasoning has the ability to determine past trends and use combinations of exceedances to properly evaluate the fault condition.

Interface with Technical Manual

The "information age" has provided tools and media that allows the technician to access a complete technical manual on a CD ROM. The VMEP PC ground station uses this technology by interfacing with the UH-60 Blackhawk Integrated Electronic Technical Manual (IETM). In contrast to previous vibration monitoring systems where the ground station is designed as an engineering tool for data analysis, the VMEP ground station is designed to provide solutions. The affect of integrating the maintenance manual into the PC ground station completes the process as shown in the maintenance flow in Figure 2.

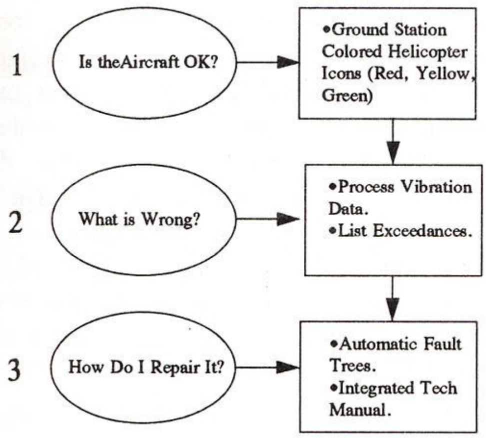

Figure 2 - Integrated System

Results To Date

The VMEP program is designed to run in two phases, the first being system checkout and data collection. Phase I ran from June 1995 to December 1995. At this time the aircraft data was analyzed to set the CI limits on the PC ground station. The second phase of the VMEP program, which started in January 1996, is designed exercise the automatic fault tree recommendations. Cost data is being collected by an independent contractor from both VMEP and non-VMEP aircraft to evaluate the cost savings associated with vibration monitoring and condition based maintenance. Currently the aircraft involved in the VMEP program are as follows:

- 15 VMEP UH-60A aircraft at Fort Rucker Training School
- 15 non-VMEP UH-60A aircraft at Fort Rucker Training School (cost data only)
- 1 VMEP UH-60L aircraft at ATTC, Fort Rucker
- 3 VMEP UH-60L aircraft at SCANG, McEntire Air National Guard Base

The results of the VMEP system are preliminary. The design, development, and installation of the system is complete. Approximately 2000 hours of flight time have been accumulated with the system installed. The cost data analysis will be performed after a significant amount of flight time with the VMEP system has been logged.

Four "significant events" have occurred involving the vibration monitoring of the UH-60 aircraft:

- The VMEP system found a tail rotor fault on the first aircraft tested at South Carolina National Guard. The vibration levels measured on the tail were 3.1 IPS, well above the limit of 0.5 IPS. There were no noticeable or abnormal vibrations felt in the aircraft cabin. The aircraft was 35 hours out of phase, and would have continued to operate with the high vibrations for 465 more hours if the VMEP system had not found this fault. Post flight teardown analysis revealed a faulty tail rotor paddle that had suffered from water intrusion. Testing at Ft. Rucker has shown that tail rotors get out of balance in a fairly short number of flight hours and are undetectable in the cockpit. The Army has experienced a significant rate of tail rotor gearbox mounting flange cracks and this is suspected to be the reason.

- The VMEP system measured high vibrations prior to an engine drive shaft failure on an aircraft at SCNG. This acquisition occurred in Phase I, before the automatic fault trees were fielded, and provided valuable information on the signature and severity of this mode of engine failure.

- A high hanger bearing vibration was detected with the VMEP system on an aircraft at Ft. Rucker. This bearing was running at 2.5 IPS while the typical bearing runs below 0.5 IPS. The bearing is currently scheduled to be replaced.

- A high frequency vibration problem was reported on a VMEP equipped UH-60 at Ft. Rucker. A faulty generator was diagnosed with the VMEP system. The generator was replaced, and the vibration problem was eliminated.

Concluding Remarks

The past 20 years have witnessed helicopter vibration monitoring evolving from roving accelerometers attached to a broomstick to a fully automated vibration maintenance system complete with expert systems and CD-ROM maintenance manuals. The basic idea behind both methods lies in the fact that mechanical failures can be detected with vibration monitoring. This plain and simple fact, as evident as it is, has been clouded with some less obvious pitfalls associated with vibration monitoring.

The first problem lies in the ability to gather meaningful and repeatable data. Problems with the earlier systems resulted in measurement system failures that exceeded mechanical component failures. The sensor and acquisition technology has proven itself in the last 5 years to be capable of providing reliable measurements of aircraft machinery.

The second problem lies in the overload of data. It does not take very long before the sheer volume of vibration spectra will swamp any maintenance officer. Many of the older vibration maintenance programs needed large computers that were not user friendly. PC technology has now reached a level that allows the data processing needed while providing the user friendly Windows interface.

The third and last problem lies in the design of the vibration monitoring tools. Most of the older systems were designed for use by a highly trained expert or a vibration engineer. These systems incorporated specialized tools for data analysis, but the user still had to make the decision on the underlying cause of the vibration problem. The novelty of the VMEP system lies in the integration of the "expert system" automatic fault trees with the data analysis tools needed to help the typical maintenance officer make sense of the vibration data. In addition, the integrated technical manual aids in the end goal of determining how to fix the vibration problem and return the aircraft to service.