A REVIEW OF PERMANENTLY INSTALLED HELICOPTER GEARBOX VIBRATION MONITORING SYSTEMS IN THE AUSTRALIAN DEFENCE FORCE.

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ABSTRACT

The prevention of catastrophic failure of helicopter gearboxes is the primary objective of gearbox vibration monitoring. In the past, gearbox vibration monitoring involved the temporary installation of sensors and cabling followed by dedicated flights to record data. This amounted to an added workload for squadron personnel simply to acquire the vibration data.

The Royal Australian Navy (RAN) recently commenced permanently installing (hard-wiring) the Sea King and Seahawk helicopters with vibration sensors, cabling and junction box. This enables rotor track and balance, airframe vibration survey, engine vibration survey and gearbox vibration analysis to be performed with significant time savings. The gearbox vibration analysis component of this system has been developed by the Defence Science and Technology Organisation (DSTO). The other aspects of vibration analysis are conducted using commercially available equipment.

This paper discusses the DSTO developed gearbox vibration analysis element of the RAN hard-wired system. The system is described in detail and the intended operating procedures outlined. The current status of the RAN hard-wire program is discussed together with proposed systems for other Australian Defence Force (ADF) helicopters.

INTRODUCTION

Historically, the main sources of information about the health of helicopter gearboxes came from either magnetic chip detectors or entrained metallic particle analysis via a spectrometric oil analysis program. Although there are some limitations with these methods, they are generally adequate for wear related failure modes (that generate debris) such as spalling of bearings or gears. Cracking of gear teeth or shaft splines, however, generally does not generate debris and is therefore almost impossible to detect using oil analysis methods.

Analysis of helicopter gearbox vibration is considered to be the best method of detecting non-wear producing faults such as cracks in gear teeth. The sudden and catastrophic nature of this failure mode is the main driver for conducting gearbox vibration analysis [1].

In 1977 the Royal Australian Navy introduced a gearbox vibration monitoring program known as the Recorded Tape Vibration Analysis Program. Initially, commercial spectral analysis equipment was used, however from 1986 onwards a DSTO-designed analysis computer was used. Between 1977 and 1991 the results of the RTVAP were used to initiate 30 investigations of unusual gearbox vibration in Sea King and

Wessex helicopters [2]. One of the main costs associated with this type of program is the time taken to fit sensors, cabling and recording equipment combined with the need for dedicated flights. Unfortunately, the value of this type of program is sometimes questioned by operators, unless defects are being regularly detected. The fatal crash of the RAN Wessex helicopter on the 4th of December 1983 was a sobering reminder that gearbox vibration analysis is a necessary function [3].

In 1996 the (then) Naval Aviation Logistics Office decided that the Sea King and Seahawk helicopters would be hard-wired (permanently installed) with vibration sensors, cabling and junction boxes. Various vibration related maintenance functions could then be conducted with carry on/carry off equipment. This would significantly reduce the down-time associated with fitting sensors and cabling to aircraft in order to perform rotor track and balance, engine vibration survey and airframe vibration survey. Additionally, the inclusion of the gearbox mounted accelerometers in the hard-wire fit enabled gearbox vibration monitoring to be readily conducted. All of these functions apart from the gearbox analysis were to be performed using commercially available equipment (Chadwick Helmuth 8500C analyser and associated equipment). The gearbox vibration element of the hard-wire was specified by DSTO. The data acquisition equipment was developed by DSTO using a combination of commercially available equipment and DSTO-designed equipment. The gearbox vibration analysis software was also developed solely by DSTO.

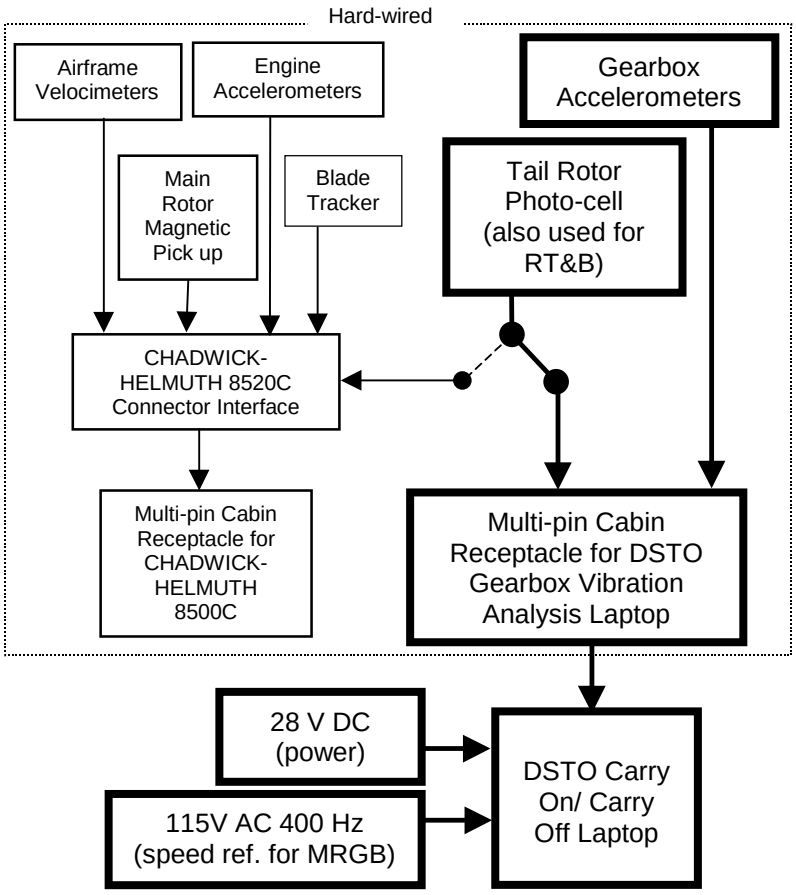

Figure 1: Schematic of RAN Hard-wired Vibration Analysis System

SYSTEM DESCRIPTION

The hard-wired gearbox vibration analysis system constitutes a separate element of the overall hard-wired vibration system fitted to RAN helicopters, as shown in figure 1. The gearbox vibration analysis system consists of a number of high frequency accelerometers permanently installed on the main rotor gearbox (MRGB), intermediate gearbox (IGB) and tail rotor gearbox (TRGB). Permanently installed cables connect the accelerometers to a single multi-pin connector inside the aircraft cabin. A carry on/carry off ruggedised laptop computer is plugged into the multi-pin connector when vibration data is to be recorded. Power for the computer is provided by the aircraft 28V DC system. The 115V 400 Hz AC system is also connected to the laptop for use as a speed reference for the MRGB. A separate photo-cell tachometer is used for the IGB and TRGB.

Endevco 6259M6 constant current accelerometers are used for all gearbox monitoring locations. These accelerometers have a wide frequency response range that enables all gear-meshing vibrations to be measured. Accelerometers used for balancing and structural vibration functions are generally not suitable for gearbox diagnostics as the gear-meshing frequencies are too high. For example, the Sea King high speed input pinion mesh frequency is 12,960 Hz.

The ruggedised portable laptop computer is a Fieldworks FW 7500. It accommodates the three full length ISA expansion cards used to perform data acquisition: a DSTO designed signal conditioning card, an anti-aliasing card and an analogue-to-digital conversion card. Figure 2 shows the portable computer as installed in an aircraft for gearbox data acquisition.

During flight, a program steps through all of the data acquisitions to be made for each type of gearbox. This program has a prompt screen that details information such as the acquisition number, gearbox serial number and flight condition required. Additionally, this program has a basic oscilloscope function that enables the raw data to be viewed. Acquisition time is dependant on gearbox type, however it is in the order of five to seven minutes for each flight condition. Different flight

Figure 2: DSTO Gearbox Data Acquisition Computer

conditions are flown in order to acquire vibration data at different drive system torques. The data files are stored on the laptop hard disk in a directory based on the aircraft tail number and gearbox serial numbers.

The data files are analysed post flight. This includes computing a synchronous signal average for every gearbox shaft. Each signal average represents the vibration of a particular shaft and the associated rotating components. A number of condition indices are calculated from each signal average. These indices measure various characteristics of the signal average and are sensitive to different faults. Indices can be trended over time, and warning and danger limits can be set based on prior experience and fleet statistical averages.

SYSTEM DEVELOPMENT

In 1993, the initial prototype of this gearbox vibration system was successfully demonstrated by DSTO on an Australian Army S-70A-9 Black Hawk helicopter attached to the Royal Australian Air Force Aircraft Research and Development Unit. This system consisted of off-the-shelf laboratory equipment that was mounted in racks fixed to the aircraft. As this system was only intended to be a concept demonstrator, the equipment was cumbersome and bulky.

A new lightweight system consisting of the carry on/carry off ruggedised laptop computer, as described above, was then developed and demonstrated [4]. It was at this stage that the (then) Naval Aviation Logistics Office showed considerable interest in the system. Following further trials of the lightweight system in 1995, the RAN decided that the gearbox vibration analysis system would be included in the hard-wire outfit for the RAN Seahawk and Sea King aircraft.

A significant re-organisation of the RAN aircraft logistic management organisation, combined with key personnel being reassigned or resigning, meant that this project languished for a number of months. It has only been relatively recently that the program has regained momentum.

SYSTEM INSTALLATIONS

SK-50 Sea King

The RAN Sea King helicopter MRGB is fitted with three externally mounted accelerometers – one adjacent to the ring gear of the epicyclic train and one on each of the input housings. The 115V 400 Hz AC generator is one of the gear-driven accessories attached to the MRGB and provides a convenient speed reference signal for the MRGB vibration analysis. A single accelerometer is fitted to both the IGB and TRGB. A photocell is fitted to the TRGB to provide a tachometer signal for vibration analysis of the IGB and TRGB. Figure 3 shows the hard-wired accelerometer locations for gearbox vibration analysis of the Sea King helicopter.

At present three Sea King helicopters are hard-wired and the remaining four are due to be completed in the first half of 2001.

S-70B-2 Seahawk

The RAN Seahawk helicopter MRGB is fitted with five externally mounted accelerometers – one on each input module

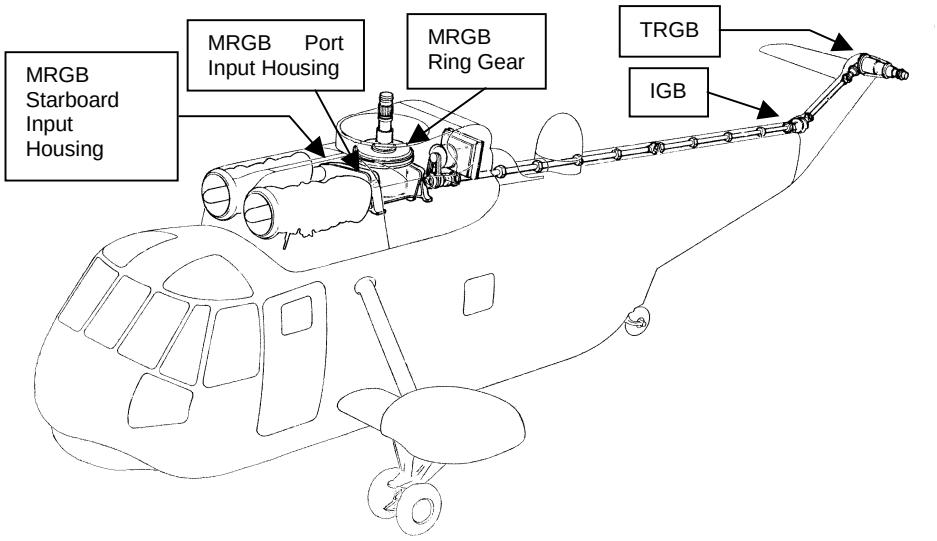

Figure 3: Accelerometer Locations for Sea King Gearbox Vibration Analysis

(total of two), one adjacent to the main bevel gear at each input (total of two) and one adjacent to the ring gear. A single accelerometer is fitted to both the IGB and TRGB. A photocell is fitted to the TRGB in order to provide a tachometer signal for analysis of IGB and TRGB vibration data. The locations sensed by the various accelerometers, for gearbox vibration analysis, are shown in figure 4 (for clarity, only the rotating components of the transmission system are shown).

Hard-wiring of the Seahawk has commenced, however since the process is considerably more involved (compared with the Sea King) and involves a fleet of 16 aircraft, it is not clear when all of the Seahawks will be completed.

INTENDED OPERATING PROCEDURES

Recently, the RAN and DSTO have agreed to commence gearbox vibration analysis of hard-wired Sea King aircraft. As an intermediate step, DSTO will be performing gearbox vibration data acquisition and analysis for the hard-wired Sea King helicopters. Ultimately it is intended to transfer the data acquisition function to squadron personnel and the analysis function to a cross-platform vibration analysis cell within the Naval Aviation Logistic Management Squadron (NALMS). This intermediate step is seen as an essential phase in the transfer of this technology to field use.

At present it is anticipated that gearbox vibration data will be acquired from each Sea King helicopter every 50 flying hours and post gearbox replacement. When an aircraft is due for gearbox vibration analysis, the following procedure will be followed:

1. Carry on / carry off laptop will be connected to the aircraft.
2. During the flight the data will be acquired for the various flight conditions. It should be noted that the acquisition can take place during any flight that can accommodate the various flight conditions required.
3. Post flight, the data will be analysed and a concise report issued to the squadron engineer and NALMS.
4. All vibration data will be archived.

FURTHER DEVELOPMENTS

Existing system

DSTO are currently further developing the Windows-based ground analysis software that will be used to analyse the data obtained from the Sea King and Seahawk helicopters. Other minor refinements will also be made to the hardware associated with the data acquisition.

SH-2G Super Seasprite

The SH-2G Super Seasprite is being delivered to the RAN with hard-wired vibration transducers fitted. It is unclear exactly how this system will be utilised at present however there appears to be scope to incorporate the DSTO-designed system for gearbox vibration analysis should the RAN request it.

CH-47D Chinook

Another ADF helicopter that could benefit from a hard-wired gearbox vibration analysis system is the CH-47D Chinook operated by the Australian Army. The Chinook has a significantly more complicated transmission system than either of the RAN helicopters mentioned above. The Chinook helicopter has a limited hard-wired system that is intended to monitor certain elements of the transmission cooling system (fans, shafts etc), however the gearbox vibration is not analysed. At the Australian Army's request, DSTO is currently investigating the feasibility of installing a gearbox monitoring system in the Chinook.

CONCLUDING REMARKS

This paper has described the DSTO-developed gearbox vibration analysis system that is currently being installed on RAN Sea King and Seahawk helicopters. It is expected that gearbox vibration analysis will commence on RAN Sea King helicopters early in 2001. An overview of the intended operating procedures and transfer of the technology to field use have also been discussed. Finally, further developments of this system and other potential recipient ADF helicopters have been identified.

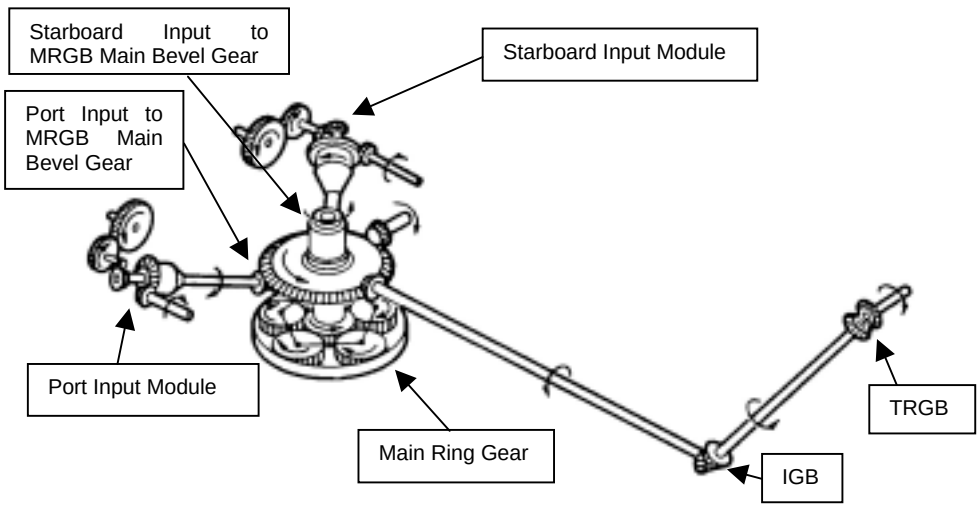

Figure 4: Locations sensed for Seahawk Gearbox vibration Analysis

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