GAS TURBINE HEALTH MONITORING IN THE CANADIAN FORCES

BY

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Introduction

Three types of large gas turbines are fitted in ships of the Canadian Forces Maritime Command, namely the Pratt and Whitney FT4A and FT12A–3 and the International Harvester Solar Saturn. The FT4A is a main propulsion boost engine (dual spool) delivering 26 000 shp. The FT12A–3 is a main propulsion cruise engine (single spool) delivering 3400 shp. The Solar Saturn is a single spool engine delivering 750 kW used as the prime mover for electric power generators.

The following types of gas-turbine health monitoring have been used by the Canadian Forces:

(a) Vibration analysis.
(b) Gas-path analysis.
(c) Macroscopic oil contamination detection including:
  (i) Educated filter checks.
  (ii) Chip detection.
(d) Microscopic oil contamination detection including:
  (i) Millipore patch test.
  (ii) SOAP.
  (iii) Ferrography.
(e) Run-down times.

GTHM Policy

Health monitoring has been adopted as the sole criterion to be used in determining the necessity of engine replacement, and specific engine hours to removal have not been declared. Vibration analysis, SOAP, gas-path analysis, run-down times, and internal inspections are used to determine the health of marine gas turbines in the Canadian Forces. Vibration analysis is carried out hourly on the main engines and as a 250-hour routine on the electric generator prime movers. SOAP samples are returned to the Dockyard Laboratory for analysis each month. Gas-path analysis has been carried out during full-power trials in the past. With new equipment presently being introduced into the Fleet, this analysis will be carried out daily. Gas generator run-down times are recorded on receipt of an engine and subsequently every month. Internal inspections are carried out at 1500-hour intervals.

Although the R.C.N. and, subsequently, the Canadian Forces Naval Arm has used some health monitoring since the early 1960s, there has never been a central headquarters focal point for this subject. However, this has recently been resolved and now one section has taken up the co-ordinating responsibility for all machinery health monitoring which is thus being given more consideration and direction. This is having a spill-over effect on gas turbines with effort being expended to improve techniques and introduce better equipment into the Fleet.

Vibration Analysis

Permanently fitted vibration monitoring systems for propulsion turbines have not been reliable, despite rather extensive modification to this equipment. A manually-operated 'back-up' system was developed by the National Engineering Test Establishment (NETE) and is fitted in all ships, but this too is unsatisfactory.

Hand-held meters are used extensively, particularly with the Solar engines. Unfortunately there tends to be a wide range of 'acceptable' performance with the Solars. Some engines have had a relatively high vibration and yet have lasted thousands of hours. Significant differences have occurred between the suppliers' test-bed VA results and those obtained from engines fitted in ships. These are believed to be related to mounting and alignment problems.

The fitted VA system for the propulsion package may have been too ambitious. A system is required similar to that used in the Royal Navy with peak-to-peak measurement for the purpose of alerting the operator to a problem. In addition to this, a method is needed to allow detailed analysis of problems to be made by ship's maintainers. The complexity of the present fitted system and its poor availability have precluded its use in both these modes. Action is being taken to develop and fit a new fixed system for gas turbines in the DDH280s.

Spectrometric Oil Analysis

Spectrometric oil analysis continues to be applied to all engines. However, the time-delay problem between taking a sample and getting the analysis has not been totally solved. All the monitoring machines planned for the DDH280s and AORs (for use of ship and aircraft gas turbines as well as other machinery) have not yet been installed and set to work. It will take another three years before all ships have been fitted.

A few years ago, SOAP was instrumental in alerting operators to a salt contamination problem of the propulsion lubricating oil caused by a poorly designed breather system. The fault was corrected and since then SOAP has not provided warning of any other failure. SOAP, as an acceptable technique, is challenged by some navies. The Canadian Forces still believe it to be useful, particularly as an aid to analysis when faults occur, while recognizing its limitations.

Gas-path Analysis

Gas-path analysis is not a prominent aspect of the Canadian Forces health-monitoring system. Two main problems contribute to this situation—inaccurate instrumentation and the requirement to perform the necessary calculations by hand. In the past this analysis was only carried out during full-power trials. Very recently, a new method using a hand-held calculator has been introduced into the Fleet. This method determines the change in gas-path conditions that are subsequently plotted to produce a trend. This is a major advance as it does away with the numerous tedious calculations that previously had to be carried out by hand. Also, the operator is now more actively involved in making an assessment of the condition of the engine. The plotting of changes from a base line as opposed to absolute values helps to alleviate the problem of poor accuracy of the instrumentation.

Chip Detectors

To date magnetic chip detectors have only been used in the Solar gas turbines. These are fitted at the bottom of the lubricating-oil sump tank. This is not satisfactory and so the strategic placing in the lubricating oil system of magnetic plugs to collect debris for testing is being investigated.

Internal Inspections

Internal inspections of all engines are carried out at 1500-hour intervals; these are referred to as hot section inspections (HSI). They include opening of the combustor and turbine areas to allow detailed inspection of hot-section components. This work is done by ship's staff, and in home port a resident dockyard inspector is available to provide some assistance.

It takes three men approximately a day and a half to prepare for a HSI. Defective or damaged burner nozzles, combustion cans, and nozzle guide vanes are replaced or repaired in the ship. The minimum time normally allocated for a HSI is two weeks in home port.

Boroscope inspections are generally not used. Orientation, field of vision, and focusing problems plus inadequate provision of inspection positions have precluded the usefulness of boroscopes by ship's staff. However, boroscopes can be useful when placed in the hands of experienced, highly-trained personnel.

Engine Testing of Health Monitoring at NETE

NETE has been involved in the evaluation of gas-turbine health-monitoring techniques since 1975 using a Solar Saturn engine. This work, the results of which are published in Ref. 2, has run parallel to various other gas-turbine development projects—demister de-icing investigations, evaluation of air atomization combustor systems, and investigations of tar-sand fuels, to name a few. Because it was to be used for this type of development work, the installation was heavily instrumented. NETE has experienced extensive maintenance problems with this engine: a state of constant illness that has proved to be a mixed blessing. While it has afforded ample opportunity to test various GTHM methods, it has also complicated the analysis of results. However, a pattern has emerged through the numerous engine strip-downs and re-builds.

Since 1975, the NETE Solar engine has been rebuilt six times. GTHM was applied during each running period and the validation of results was effected during engine strip-downs. The results of these studies are given in TABLE I.

TABLE I—*Overview of EHM technique effectiveness as applied to NETE Solar gas turbines*

Technique	*Build*				*DCF**	*Conclusions*
	1	2 & 3	4	5		
Vibration analysis	Fair	Fair	Fair	Good	0·5	Good indication of general health but poor diagnostic tool
Boroscopic inspection	Poor	Good	Poor	Poor	0	Not effective
Gas-path analysis	Good	Good	Good	Good	1·0	Effective
Macroscopic oil contaminant detection						Good indication of bearing and gearing general health but less effective as a diagnostic tool
(*i*) Educated filter check	—	Good	Good	Good	1·0	
(*ii*) Chip detectors	—	Poor	—	—	0	
Microscopic oil contaminant detection						
(*i*) Millipore patch test	—	Poor	Poor	Poor	0	Not effective
(*ii*) SOAP	—	Poor	Poor	Poor	0	Not effective
(*iii*) Ferrography	—	Good	Fair	Poor	0·5	Relatively effective

* DCF = Diagnostic confidence factor

The conclusions drawn are as follows:

(*a*) Vibration has proved to be an effective indicator of machinery general health. However, the presence of numerous defects in NETE's Solar installation has prevented conclusive determination of the diagnostic potential of the technique.

(*b*) NETE's employment of the boroscope has strongly suggested that this technique is beyond use by the average maintainer at sea. Furthermore, the complications associated with redesign to retrofit access porting for the boroscope make such action non-effective.

(*c*) Gas-path aerodynamic performance analysis is an effective indicator of compressor and turbine cleanliness and efficiency and has considerable potential as a diagnostic indicator of fault location.

(*d*) With the use of sophisticated filters capable of 13μ or better contaminant removal, macroscopic detection techniques of educated filter checks and rare-earth detectors are very effective as indicators of bearing and gearing general health. However, before these techniques can be used with full diagnostic and prognostic capabilities, much preliminary work must be done on the design location of these monitoring devices and the trend analysis of collected debris quantities. Microscopic contaminant detection schemes, such as SOAP and ferrography, lose most of their effectiveness in proportion to the level of filtration in the system, because there is no regeneration of small contaminant debris particles by successive grinding and regrinding of larger size debris.

(*e*) This work would suggest that, for a single-spool gas turbine such as the Solar supported with a repair-by-replacement maintenance policy, the engineer officer at sea can employ vibration analysis, gas-path analysis, and macroscopic oil-detection techniques to monitor the general health of the equipment. The implementation of such a GTHM profile would require various modifications to accommodate chip detector installations at well-chosen points and additional instrumentation not yet fitted on shipboard engines (e.g. compressor mass flowmeter, No. 3 bearing scavenge temperature, and data logging/processing equipment to facilitate trend analysis).

Trend Analysis

In the spring of 1980, Carelton University was contracted to develop a gas-turbine health-monitoring system for application to the FT12A–3 and FT4A engines. The results of their work were published in Ref. 3, and are summarized below. The objective was to provide a low-cost, on-board mechanized system for rapid assessment of main-engine performance. The system does not do anything new, but it permits ready generation of performance data on a regular basis using only that instrumentation presently fitted in the ship. This leads to a better understanding of in-service deterioration and permits maintenance action to be taken in good time. A HP97 calculator was employed for this project simply because it was available and previous experience with this instrument had been favourable.

Data from all four ships, logged during manufacturer's trials, showed that a common baseline could be used for each type of engine, so reducing the risk of using incorrect program cards. Polynomial fits were used to describe these baseline curves. Using fitted instrumentation to obtain input data, spool speeds, exhaust gas temperatures, and compressor pressure ratios are corrected to ISA conditions, and the engine pressure ratio is computed. These are compared against baseline values derived by putting the engine pressure ratio into the second order polynomials describing the baseline curves. The change from baseline values to measured values are printed out for the operator.

To obtain a feel for the usefulness of the systems, data, randomly chosen from daily log sheets for the starboard main engine of H.M.C.S. *Iroquois* and the starboard cruise engine of H.M.C.S. *Algonquin,* was analysed. There is no certainty that this data was taken at a particular stabilized power level, and also there were considerable variations in power settings which can be expected to cause scatter. Notwithstanding the above, the engine parameters varied from baseline values and, when studied in detail, the plots showed some deterioration of performance. Corrected spool speeds and free turbine inlet temperatures proved to be good parameters to trend monitor. It is very clear from this work that the compressor pressure ratio generally remains constant and, therefore, is of little use in trend monitoring.

Gas-path analysis data must be taken at a stabilized operating condition desirably over a period of at least five minutes. Data should be taken at high power levels since deterioration is less likely to be noticed at low powers. As engine pressure ratio is not easily recognizable from the data logger, it has been recommended that LP shaft speed be used as a prime indicator of engine power. A constant setting of LP shaft speed should be used for each gas-path analysis measurement. This system has been sent to H.M.C.S. *Iroquois* for evaluation at sea. To date the Canadian Forces are very happy with this system of gas-turbine health monitoring; however, use at sea will be the proof test. Until this is completed, further comments are only speculative.

Conclusions

In the foreseeable future, gas-turbine health monitoring will be the guide for engine removals in ships of the Canadian Forces Maritime Command. Vibration analysis equipment must be updated to give quick and accurate indication to the operator of engine degradation. In addition to this, more complex instrumentation is required to allow the maintainer to analyse engine problems in detail. SOAP will become more effective as instrumentation is fitted in Fleet operational support ships and DDH280s. Gas-path analysis may prove to be more helpful in the future with the introduction of a simple data manipulation system. Chip detection is an area of which the Canadian Forces have not taken full advantage in the past and, when properly implemented, will provide the maintainer with a better understanding of the problems, particularly bearing degradation. Internal inspections will continue to provide the detailed data on the health of an engine. However, because of the long intervals between HSIs, a good balance of the use of all health-monitoring techniques is a necessity. The work of NETE is an example of the type of research necessary to ensure that a useful gas-turbine health-monitoring programme is implemented into the Fleet. The best techniques and data inputs can only produce accurate predictions when good engineering judgement on the part of the operator is applied to these health-monitoring systems.

References:

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