CONDITION MONITORING OF R.N. GAS TURBINES

BY

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Introduction

For R.N. marine gas turbines, condition monitoring is used to confirm that the condition of an engine is satisfactory for continued running by inspection procedures carried out at routine intervals. These procedures must be able to detect serious incipient defects with a high degree of certainty so that actual breakdown in service is avoided, while on the other hand engines are not removed unnecessarily in anticipation of failure. Engine health monitoring is also used to monitor the progress of deterioration such as cracking and corrosion which could lead to premature removal.

It is recognized that, despite the ingenuity of EHM techniques now available, there are many parts of a gas turbine liable to failure that cannot be monitored by any means in service. The condition of such parts cannot be confirmed except by a degree of stripping that is seldom possible *in situ*. It is therefore R.N. policy to base the upkeep of aero-derived marine gas turbines on a planned life, after which the engine is removed for bulk strip and examination. Planned life is established by a combination of development testing and service experience, and represents a considered maximum safe condition of certain life-limited items. In the gas turbine, small defects can result in expensive and devastating secondary damage; this and other factors favour a conservative approach.

The objectives of engine performance monitoring (EPM) in the R.N. is to enable ship's staff to detect significant deterioration in the performance of an engine, due often to compressor fouling but sometimes caused by incipient defects and control errors. EPM is closely associated with health monitoring. EPM is also needed for accurate setting up and checking engine and propulsion system controls.

Engine Health Monitoring (EHM)

The gas turbine change unit (GTCU) and power turbine are compatible with most available health-monitoring systems. The compact construction of the modern GTCU makes it necessary for EHM facilities and interfaces to be introduced at the design and development stage. The main EHM features and techniques are briefly described below.

Visual Inspection

Regular internal and external inspection is a powerful EHM procedure. Typical examples of external inspection checks are for:

(*a*) system leaks;

(*b*) security of pipes and fastenings;

(*c*) integrity of electrical equipment.

Internal inspection invariably requires the use of rigid or semi-rigid endoscopes. Access points which may penetrate more than one casing skin are positioned to the best advantage in the region of key components and particularly at the 'hot' end of the engine. The newly developed Spey engine which has yet to enter service has 33 inspection positions on the GTCU alone.

Reliable interpretation of the visual image develops with experience. The introduction of the polaroid camera with its 'instant' picture will certainly assist in the communication of this visual information for reference to technical manuals held onboard or to the engine manufacturer for a follow-up assessment.

Chip Detectors and Debris Testing

Magnetic chip detectors are fitted to Rolls-Royce gas turbines in each of the GTCU bearing oil scavenge lines and at the bottom of the auxiliary gearbox. The Olympus has five such detectors. The detector plug has a quick-release bayonet fitting and is situated adjacent to a self-closing valve. The detector is designed such that it will collect not less than 50 per cent. of the magnetic debris carried over.

The most effective inspection period is between twenty-five and fifty hours of engine running. Quantitative evaluation of the debris is done by a 'debris tester'; this is an eddy-current device comparing debris against a calibration piece. A formal record of the results must be kept and these are plotted in the form of a cumulative curve of quantity versus running hours. In cases of high reading or uncertainty, NAML (Naval Aircraft Materials Laboratory) at the RNAY Fleetlands can undertake detailed analysis of the debris.

Vibration

Olympus and Tyne each have two vibration sensors of the seismic mass type. These are externally mounted and are invaluable in the detection of significant out of balance caused by heavy compressor fouling or mechanical damage to the rotating spools. Trend monitoring of vibration, when used in conjunction with other EHM techniques, can give early indication of deteriorating mechanical condition. Used in isolation, vibration measurement can be misleading.

Other EHM Techniques

Power turbine entry temperature spread gives useful insight into the condition of the fuel and combustion system.

Breather and oil system monitoring by pressure and temperature measurement and oil usage is an important indicator of internal cooling system and oil-seal conditions.

Oil analysis leading to identification of the contaminant source, and hence the defect, can be employed in special cases with shore laboratory support. An extensive application of SOAP (spectrometric oil analysis programme) has not been pursued.

Engine Performance Monitoring (EPM)

The techniques that come under the heading of EPM set out to observe changes in engine performance. A fall-off in performance may be linked to a condition observed through EHM. Alternatively it may arise from a control system malfunction which can be overcome by adjustment, recalibration, or component replacement.

The three phases of EPM are:

(a) collection of data from fitted instruments;

(b) numerical manipulation of data including correction to standard day conditions of temperature and pressure;

(c) interpretation of results including comparison against pass-off and installation test results.

The use of EPM in service is limited to regular recording of key engine parameters at specific power levels or spool speed.

Results

Debris testing and endoscope inspection have been the most successful of the EHM techniques. In the case of vibration, the robust and unsophisticated sensor positioned on an external engine casing has limited application. For example, major bearing damage detected by debris testing is seldom picked up on vibration sensors.

EPM and the need for numerical handling of measured parameters has so far not been pursued to its full potential.

Future

In the short term there is a need for a detailed investigation to advance the techniques of vibration monitoring in the gas-turbine environment. Use of more advanced portable equipment which is exposed to the hostile environment for short controlled periods at regular intervals could provide better trend monitoring. Position of sensors on bearing support struts or within the engine itself is likely to improve the validity of data.

In the longer term, a hand-held pre-programmed calculator or installed computer facility opens up EPM opportunities without change to the engine and its instrumentation. Some of the programmes under consideration are:

(a) compressor delivery pressure versus compressor speed;

(b) turbine entry temperature spread;

(c) comparison of HP and LP compressor speed.

These schemes are being investigated by the Gas Turbine Design Section in conjunction with NGTE Pyestock (Marine Gas Turbine Department). In all cases the potential return in terms of engine life and performance must be balanced against the onboard resources, cost of equipment, and logistic support.

Condition monitoring techniques in the areas of engine health monitoring (EHM) and of performance (EPM) will continue to be developed. Development costs in the areas outlined above are not expected to be high and the derived benefits justify an on-going improvement programme.

DIESEL ENGINE HEALTH MONITORING

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Existing Techniques

The techniques currently available for diesel engine health monitoring are fairly basic and great reliance is placed on the engineering expertise of plant operators. Many engines have been saved by experienced engineers looking and listening and it is doubtful whether this expertise can ever be replaced by mechanized systems. The existing techniques currently applied can be summarized as follows:

Engine Instrumentation is probably the most comprehensive facility provided for assessing engine health. Analogue gauges and thermometers have to operate in a hostile environment and sometimes tend to be unreliable and inaccurate. The interpretation of readings at part load is not easy and monthly full load tests are recommended if sufficient ship's load is available for this to be undertaken. Exhaust thermocouples continue to be used as the basis for cylinder health indication but differences between individual engines, the complexity of breathing and fuelling, and the positioning of thermocouple elements make identification of other than major problems difficult.

Crankcase Pressure measurements have in some cases provided early identification of piston failure, and engine damage has been reduced by manual shut down. The pressure measurements are small and manometer readings are significantly affected by machinery space ventilation and long breather pipes venting on the upper deck.

Torsional Vibration readings taken at periodic intervals using the AEL bolt-on unit at the free end of the crankshaft provide information on the overall level of crankshaft torsional vibration and the condition of dampers.

Vibration Analysis has indicated faults, including secondary balance weight failures on 8-cylinder Venturas and bearing failures on ASR1 Godfrey Super-chargers. The vibration pattern from diesel engines is, however, very complex and the majority of problems confirmed by this technique have usually been previously identified to some degree by the experienced engineer.

Spectrographic Oil Analysis was tried experimentally on the HECLA Class Ventura engines and although reasonably successful was considered to be impracticable because of logistic and manpower limitations.

Lubricating Oil Condition monitoring using the Diesel Engine Lubricating Oil Test Kit is a practice which will be continued to define oil change periods.

Endoscopes can be used to evaluate possible problems, in particular to assist in the examination of cylinder components. This technique has not been generally adopted as a routine procedure mainly because the cylinder-head injector aperture provides only a very limited view of components and the angle makes interpretation difficult.

Fuel Injectors are removed as a routine procedure and tested for pressure characteristics and spray pattern.

Top and Major Overhauls provide an excellent opportunity to assess engine condition provided comprehensive data is collected and properly processed. Trend analysis of such information can lead to increased running hours between top and major overhaul activities and this whole area is currently being reviewed.

Improvements to Existing Techniques

As previously stated the most comprehensive facility available for engine health monitoring is the recording and analysis of engine instrument readings. Ricardo Consulting Engineers were recently employed by MOD(N) to undertake an independent study on the performance checking routines currently being used for the Ventura diesel generator engines fitted in Type 42 destroyers and a report has been produced[1]. In their report Ricardo concluded that, although a large number of readings are taken at frequent intervals, the performance information currently provided is insufficient to enable ship's staff to assess easily the acceptability of load-dependent parameters. Key load-dependent parameters of air manifold temperature and

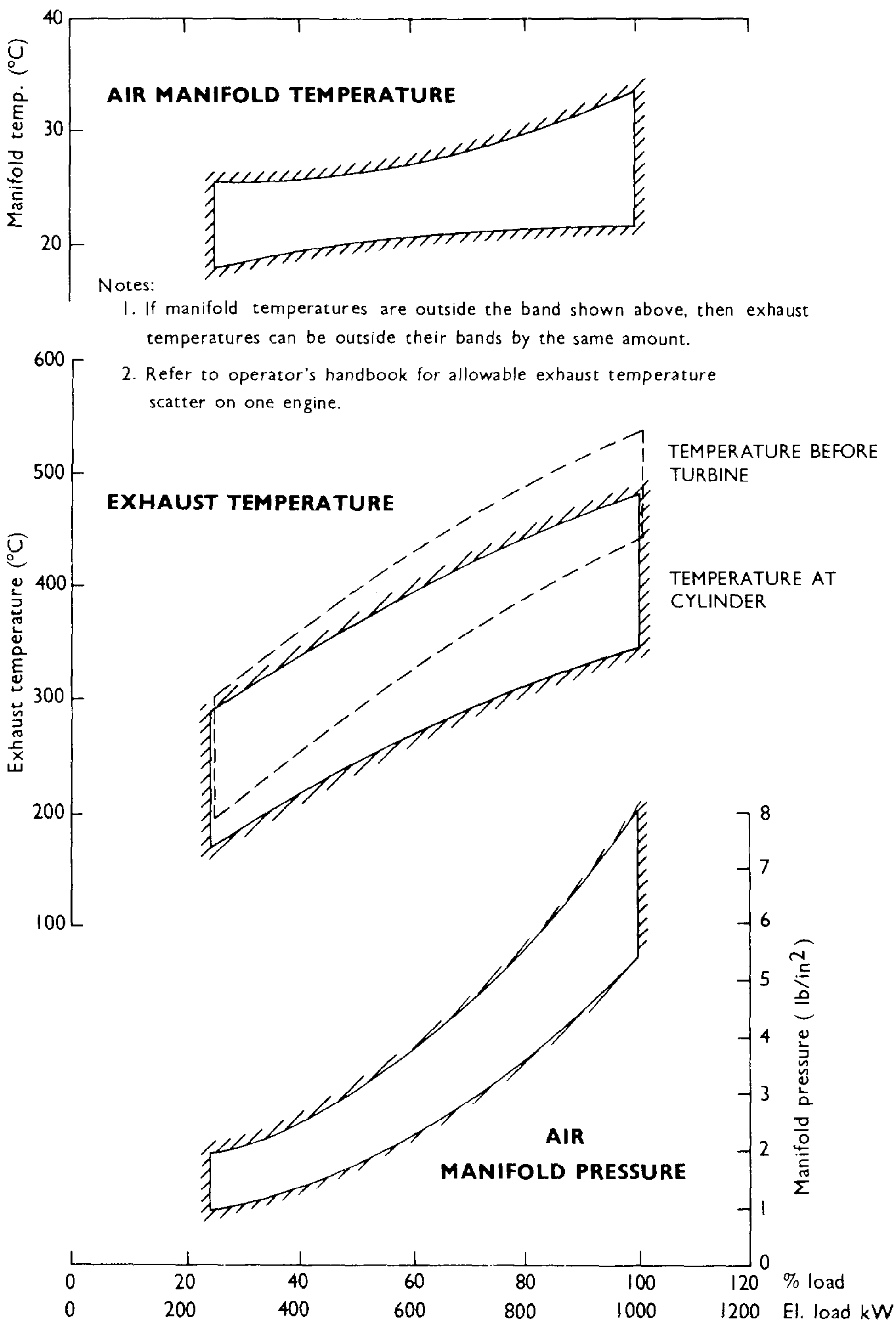

FIG. 1—16YJCAZ DIESEL GENERATOR—TYPICAL PROPOSED STANDARD ENGINE PERFORMANCE CHARTS

pressure and exhaust temperature could be checked on a standard performance chart derived from shipbuilder's load trials of a number of diesel generator installations and a sample is shown in FIG. 1. The system would provide greater flexibility to match performance data with operating load but requires the introduction of additional permanent instruments to measure air manifold boost pressure and temperature. The improvements suggested in the Ricardo report are currently being considered in conjunction with longer term trend analysis recommendations.

Future Trends

Because current diesel engine health monitoring is in a primitive state, recent emphasis has been placed on improving current facilities and defining the areas to which research should be directed[2]. The way ahead based on current obsolescence of equipment, the unreliability of certain components, and the unmanned machinery space philosophy has indicated a requirement to undertake development work in the following areas:

Improved Torsional Vibration Analysis. Investigations are being made by NGTE, West Drayton, to adopt current in-service vibration meters to measure torsional vibration as a replacement for the AEL Damper Tester.

Fuel Injection Performance. A portable meter that can be attached to or fitted in the injector or on its fuel pipe to indicate the health and timing of the fuel system is being considered.

Cylinder Pressure Indication is another facility which is currently being successfully utilized mainly on experimental and large merchant ship slow speed engines. The possibility of developing a single unit based on either pressure transducers, strain gauge studs, or load cell washers is a requirement.

Crankcase Breather Flow as an alternative to the rather sensitive pressure manometers would be beneficial. A permanently fitted meter to measure crankcase breather flow interconnected with an efficient oil coalescer could enable breathers to be led to turbo-charger air inlets.

General Instrumentation is being re-examined leading to a rationalized fit for future engine applications. Improved gas thermocouples, smoke meters, and pressure transducers are particular areas that need early consideration.

Data Processing to improve performance checks and assist in trend analysis will be pursued in conjunction with Ricardo Consulting Engineers.

Spectrographic Oil Analysis is being used by British Rail to determine when to overhaul the Valenta prime mover of High Speed Trains, as most wear particles wash into the oil. The system used by BR is considered by them to be cost effective and needs to be re-examined on the basis of condition monitoring rather than the identification of incipient failure.

Initially the future Diesel Engine Health Monitoring programme will be aimed at assisting operators to identify problems earlier thereby reducing the risk of major damage. Secondly, there is a need to shift diesel engine maintenance from a rigid system to a condition monitoring base to take full advantage of engine potential. A major requirement is to reduce the number of strips that a diesel engine experiences in its working life.

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