CONDITION MONITORING

This article is divided into five parts, namely a chronicle of the R.N. development of condition monitoring, condition monitoring of R.N. gas turbines, condition monitoring of diesel engines, fleet experience with vibration analysis, and Canadian Forces experience with gas turbine health monitoring.

CHRONICLE OF DEVELOPMENT

BY

LIEUTENANT-COMMANDER D. G. J. ROGERS, C.ENG., M.R.I.N.A., R.N. (RET)
(Ship Department)

The Carpenter at Sea

REPAIR OF BOATS

The carpenter should constantly examine the boats on the booms, quarters, &c., and report to the senior lieutenant on every occasion that they may appear to him to require repair.

INSPECTION OF SPARE SPARS

He should, from time to time, examine the spare spars, particularly the top-sail and top-gallant-yards, and see that they be always kept in a state of readiness for immediate use; that all their pins, sheaves, and sheave-holes be in order, and that their respective cleats be properly placed.

Naval Officers' Manual
Captain W. Nugent Glascock, R.N.
1836

The Oxford English Dictionary gives several definitions for *maintenance* and also for *upkeep*. *Maintenance* may also be defined as the cost of supporting an ex-wife in the manner to which she may have become accustomed! In the field of Engineering, however, the two words are more clearly defined:

Maintenance: all the activities necessary to keep the *matériel* in, or restore it to, a specified condition.

Upkeep: the various procedures to be followed in order to assure the required material condition and level of performance throughout the life of the specified item.

It is not the purpose here to discuss the whole field of upkeep but to give a brief historical review of planned maintenance in the Fleet and explain the current philosophy, promulgated in DCI(RN) 190/80, as applied to the maintenance of in-service and future design equipments.

Up until the era immediately after the war, Saturday mornings were traditionally given over to upkeep and Captain's rounds with routine maintenance being undertaken very much on an *ad hoc* basis. Maintenance tasks were derived from sundry BRs and allocated by the departmental chief petty officers who filled in the detail from their little black books and their own accumulated ship experience. Planning was on an opportunity basis and the following week's ship programme often dictated what should be done to ensure that equipment was serviceable. No formal recording of these routines was carried out.

The year 1953 heralded the introduction of a formal maintenance system throughout the Fleet. The various categories of ship were allocated to Class

Authorities set up in each of the home base ports (e.g. Devonport C.A. was responsible for all destroyers and frigates) to document by class of ship the structure, machinery, systems, and equipments, and to establish maintenance routines for their regular examination and overhaul, conforming generally to a pattern decided by the usage and refit cycle of the class. These early routines were calendar based and periodicities inevitably erred on the side of caution. There was an understandable trend to overmaintain rather than risk breakdown during operational time, ship availability and operational reliability being the criteria. Paradoxically, instances arose of machinery which had hitherto given good service, developing faults or running roughly after servicing, utterly in keeping with the reliability 'bath tub curve'.

Maintenance planned by class of ship resulted sometimes in the issue of different instructions for the upkeep of essentially similar or even identical equipments. In 1963, the several Class Authorities were amalgamated as the Ship Maintenance Authority, thus bringing together the maintenance of the Fleet under one central organization. This had the advantage of ensuring commonality of maintenance instructions on an equipment basis. It resulted too in the establishment of a central data bank, albeit manual, of upkeep information relating to defective material, design, and logistic support on a scale not previously available. Over subsequent years, the administrative procedures and documentation associated with planned maintenance underwent periodic review and new maintenance systems were introduced, ranging from the original E2 system and a modified system for LEANDER Class frigates via the Ship Upkeep Management System (SUMS) to the current Maintenance Management System (MMS).

The previous maintenance systems were all based on calendar time or running hours, with the cycle of overhaul laid down by the sponsor sections, based as far as possible on the likely ship and maintenance cycles within which the equipments were required to be operated. Theoretically these systems had the advantage of reducing the number of operational defects and permitting a more systematically planned and managed maintenance system. In essence planned maintenance dictated that machinery be either shut down and components replaced on an elapsed operating time basis or calendar basis, regardless of condition; or that inspections be carried out at regular but necessarily arbitrary intervals, replacing components as indicated by their condition.

By 1978 it was all too apparent that this method was wasteful of manpower and material resources in that machinery was being subjected to opening up or exchange of complete assemblies irrespective of condition. This was particularly apparent in the new generation warships of the Types 42 and 21 and later classes. For these the SUMS documentation tended towards an overkill with which neither the ship's much reduced complement (compared with earlier steam-driven vessels) nor dockyard resources could cope.

The way ahead was seen to lie in a mode of condition-based maintenance wherever possible, rather than by plan. The condition of all important components is regularly monitored watching for trends, so as to derive warning of incipient failure in time for corrective action to be taken during planned downtime. To some degree condition-based maintenance has always been with us, e.g. in the form of inspections and surveys where corrective maintenance is carried out as a result of the condition found. The increasing use of Upkeep by Exchange (U × E) permitted individual equipments to be so maintained with a greater degree of flexibility than hitherto. Among other considerations, the wider range of techniques presently available for monitoring purposes prompted a revision of the upkeep documentation for the Types 42/21/22, CAH, MCMV, and ISLAND Class OPVs to accommodate a policy, where applicable, of condition-based maintenance.

The revised policy was based on the following principles:

(a) Maximum use of condition based maintenance.

(b) Critical examination of maintenance requirements against the operational needs.

(c) Overhaul and repair action to be taken at the lowest sensible level.

Under this policy is emphasized the Engineer Officer's responsibility for the assessment of the condition of the equipments and systems maintained under the revised system of maintenance (condition monitoring), using good engineering judgement based on trends detected by Vibration Analysis (VA), performance figures, equipment history, visual inspections, and other condition-monitoring techniques.

Of the many techniques available with which to monitor condition, the principal ones in use are the primary senses of sight, sound, touch, and smell, suitably aided by:

(a)	Endoscopes, Fibrescopes, Magnifying optics, TV cameras	—	Visual observation of wear, corrosion, erosion, cracks, roughness, pitting.
(b)	Flowmeters	—	Measurement of flow in fluid systems.
(c)	Ultrasonic leak detectors	—	Detection of gas leaks and leaks into vacuum systems, holes and thin spots in tubes, weld seals, and glands.
(d)	Magnetic chip detectors	—	Detection of ferromagnetic contamination in lub.-oil systems.
(e)	Debris testers	—	Quantification, by the eddy current method, of the amount of ferrous debris collected by the magnetic chip detector.
(f)	Acoustic monitor (AMTEAM)	—	Detection of crack growth in pressure vessels under test.
(g)	Shock pulse metering	—	Location of faults in rolling element bearings.
(h)	Vibration analysis	—	Location of defects in anti-friction bearings, gearing, pumps, motors, impellers, and torsional vibrations.

It is very strongly emphasized that the above techniques are in no sense substitutes for experienced engineering judgement. At best, they may be an aid to that judgement; they can never be more.

The gas turbine is a good example of the use of the various techniques in monitoring condition, whereas the reliability of the health-monitoring methods of diesel engines is not sufficiently advanced to justify a change of maintenance from hours run to 'on condition'.

Vibration analysis as a technique for monitoring the condition of rotating elements in machinery was tried out in the 1960s and showed that, when undertaken by operators skilled in the interpretation of results, it represented a valuable diagnostic aid in the detection of incipient failures. The task was, however, time consuming and demanded a high level of skill on the part of the operator. There was little hope that a pool of the necessary skills could be made available in every ship and in the circumstances a Fleet VA Unit was set up under the control of the Commander-in-Chief Fleet to provide advice and assistance to ships' officers in the investigation of problems associated with rotating machinery. The way ahead was seen through the introduction of simple-to-use, hand-held instruments. The shock pulse meter was already available commercially and a small number of instruments was purchased in January 1979 for evaluation in the Fleet. At the same time, trials were instituted with an IRD 306 vibration meter, modified to give a colour-coded readout indicative of the vibration amplitude. This vibration severity indicator (VISIN) together with the shock pulse meter (SPM) were given qualified approval by the Ship Department specialist section. They are currently being introduced into the Fleet coincident with the installation of the new MMS system of maintenance as a standard aid to condition-based maintenance. Both instruments are simple to use and are called for in maintenance schedules (usually monthly) detailed instructions being given on the associated job information card (JIC). Routine monitoring is carried out by semi-skilled mechanic ratings, results being recorded on the appropriate form in order that trends may be observed. It is anticipated that VA prognostications will eventually play a prominent part in the compilation of future defect lists.

The adoption of the revised policy of maintenance by condition has meant the establishment of categories of action of which VA, visual inspections, and trend monitoring play a prominent part:

(a) Maintenance by time and occasion where, for operational or safety reasons, the equipment must have a low risk of failure or for which maintenance must match a specific occasion such as docking.

(b) Monitored wear out which is applicable to equipment that can conveniently be repaired or replaced outside of dockyard programmed upkeep periods (U × E), and for which a marginally increased risk of breakdown is acceptable owing to built-in redundancy in the non-operational nature of the system it serves. Such maintenance is based upon need as perceived by ship's staff with the aid of such condition-monitoring techniques as may be available and appropriate.

(c) Natural wear out of those equipments which affect neither the fighting efficiency nor the safety of the ship or personnel. These equipments are, however, monitored with a view to arranging timely restorative action.

The change from time-based to condition-based assessment for repair should reduce the work load at normal refit periods to defects only. At the same time, a greater responsibility is placed on the ship's Engineer Officer to use his professional judgement in the operation and maintenance of the machinery and systems in his charge. The use of VA, performance figures, trend and other monitoring techniques play an important part in aiding that judgement, such that failure to shoulder that responsibility can negate the positive material and financial gain to be expected from the revised system of maintenance.