VIBRATION ANALYSIS AS A PREVENTIVE MAINTENANCE SYSTEM

BY

ENGINEER LIEUTENANT-COMMANDER L. F. CLARK, M.B.E., R.N., C.ENG., M.I.MAR.E.

This article is a follow-up of the article by Mr. T. Carmody which appeared in Volume 20, No. 2 of this *Journal*. It is aimed at showing how this form of non-destructive testing is being used at present in the Fleet, and explains some of the benefits which may be expected to accrue from a properly planned system.

Preventive Maintenance System

A preventive maintenance system using vibration analysis is an organized effort directed towards obtaining long, trouble-free service life from critical equipment, guarding against costly unwarranted breakdowns and maintaining efficient operation.

The objective is to detect and correct defects that develop during operation before they become serious enough to cause damage or reduce the availability of the equipment. A preventive maintenance system, based on vibration analysis, works to this goal using the following simple facts:—

(*i*) All machines vibrate. They vibrate because of mechanical defects both large and small.

(*ii*) Excessive vibration means that the defects have become mechanical troubles.

(*iii*) Different troubles cause vibration in different ways. Periodic vibration checks are thus used to reveal when troubles are present or impending.

To use these facts effectively, an organized system of periodic vibration measurement on important machines is necessary and this accomplishes the first objective of detecting trouble in its early stages. The procedure is designed to detect those troubles which cause vibration. Not all troubles fall into this category. However, because periodic measurements are being made, changes of reading will indicate to the personnel carrying out the checks the other troubles as they occur.

Organizing the System

There are seven basic steps required to put a preventive maintenance system to work using vibration analysis. They are as follows:—

(*i*) List the critical machines to be included in the programme.

(*ii*) Determine the condition and normal vibration level of each machine.

(*iii*) Select periodic vibration check points.

(*iv*) Select the interval for periodic vibration checks.

(*v*) Establish vibration limits.

(*vi*) Start a simple data recording system.

(*vii*) Train personnel to operate the system.

List the Critical Machines to be included in the Programme

A critical machine is one whose operation is essential to the availability of the ship. It would be impractical to attempt to include every machine in the ship in a preventive maintenance system.

The individual machines to be included are listed, together with their location, on a scheduling sheet similar to the one shown in FIG. 4. This information will be useful later when scheduling periodic vibration checks. The lowest and highest rpm of the rotating parts are also listed on the sheet to provide useful information when carrying out vibration checks on a particular machine.

Determine the Condition and Normal Vibration Level of Each Machine

The next thing to consider is the importance and maintenance record of the machine.

Since the mechanical condition of a machine is not known initially, it is necessary to make a complete vibration analysis to detect any existing troubles. These readings are called the initial vibration measurements. If the machine is trouble free, a generally low vibration level at all measurement points will be found and these measurements can be used for comparison when making periodic vibration checks. Initial vibration measurements are also useful in determining the points at which the periodic vibration checks should be made.

The initial measurements for a machine in good condition, when compared with other similar machines also in good condition, establish the normal vibration pattern. This pattern provides the yardstick with which to compare the periodic measurements that indicate trouble in its early stages.

The initial vibration analysis of a machine may reveal trouble such as unbalance, mis-alignment, bad bearings, electrical vibrations and mechanical looseness. These troubles, if present, should be corrected and a detailed vibration analysis made again.

Thus the initial vibration analysis accomplishes three things: it pin-points any existing troubles for immediate correction; for machines in good condition it establishes the basis for all future periodic checks and vibration analyses; it provides important clues for the selection of the periodic vibration check points.

For an initial vibration analysis to be of any real value, it must be thorough. Each point at which a vibration reading is taken should be clearly identified. A complete pattern of the vibration at each pick-up point should be obtained, i.e., the vibration amount should be listed for each vibration frequency present.

Both for immediate use as well as for future reference, a complete sketch of the machine showing the location of the bearing housings and the points at which vibration readings are to be taken should be made. The sketch should show the rotating speeds of each component, and whether bearings are anti-friction or plain. It is important that the machine sketch uses symbols and a basic layout readily recognizable by others. This sketch forms part of the Diagnostic Vibration Sheet, shown in FIG. 1.

The next step is to make a complete vibration analysis recording, in the space provided on the diagnostic vibration sheet, the amount and frequency of each vibration. The vibration readings should be taken with the machine operating in its normal running condition.

When the vibration analysis is completed and the diagnostic vibration sheet has been filled up, the readings are compared with the values listed on the vibration Identification Chart (FIG. 2) and the General Machinery Vibration Severity Chart (FIG. 3) to see if any trouble is indicated. If suitable vibration tolerances

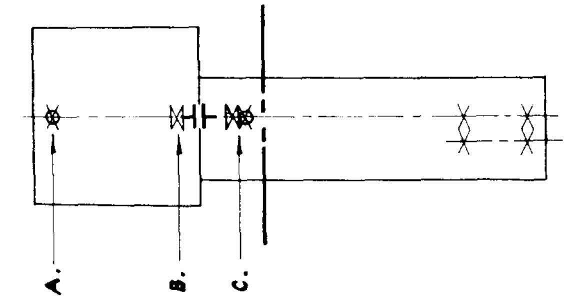
DIAGNOSTIC VIBRATION SHEET.

HMS. BLACKWOOD.	
MACHINE LOCATION & TYPE. M.D. F.L. PUMP.	
SERIAL No.	
SCHEDULE No.	
DATE INSTALLED.	
OPERATOR.	

SYMBOL.	IDENTIFIES.
——●	PICKUP POINT.
✕	PLAIN BRG.
⊗	ANTI-FRICTION BRG.
⧖	THRUST BRG.
—‖—	COUPLING.

DATE. 20 · 11 · 68	
HOURS RUN.	
MAIN ENG. SHAFT RPM. -	
SUB-ASSEMBLY RPM. 1750	

MACHINE SKETCH.



PICKUP POSITION.		FILTER OUT.	FILTER IN.									
		IN/SEC.	IN/SEC.	CPM.	IN/SEC.	CPM.	IN/SEC.	CPM.	IN/SEC.	CPM.	IN/SEC.	CPM.
A.	H.	0·16	0·12	1,580								
	V.	0·23	0·22	1,580								
	A.	0·25										
B.	H.	0·10										
	V.	0·17										
	A.	0·15										
C.	H.	0·17										
	V.	0·27										
	A.											
D.	H.											
	V.											
	A.											
E.	H.											
	V.											
	A.											
F.	H.											
	V.											
	A.											
G.	H.											
	V.											
	A.											
H.	H.											
	V.											
	A.											

NOTES:

NOTE H. HORIZONTAL. V. VERTICAL. A. AXIAL.

FIG. 1

for the machine are not available, readings may be judged as follows:—

(*a*) Filtered vibration readings which fall in or above the 'rough' region indicate that trouble is present. This should be identified and corrections scheduled.

(*b*) Filtered vibration readings which fall in the 'fair' or 'slightly rough' region of the severity chart call for caution and indicate that trouble is on

VIBRATION IDENTIFICATION

CAUSE	AMPLITUDE	FREQUENCY	PHASE	REMARKS
Unbalance	Proportional to unbalance. Largest in radial direction.	1 x RPM	Single reference mark.	Most common cause of vibration.
Misalignment couplings or bearings and bent shaft	Large in axial direction 50% or more of radial vibration	1 x RPM usual 2 & 3 x RPM sometimes	Single double or triple	Best found by appearance of large axial vibration. Use dial indicators or other method for positive diagnosis. If sleeve bearing machine and no coupling misalignment balance the rotor.
Bad bearings anti-friction type	Unsteady - use velocity measurement if possible	Very high several times RPM	Erratic	Bearing responsible most likely the one nearest point of largest high-frequency vibration.
Eccentric journals	Usually not large	1 x RPM	Single mark	If on gears largest vibration in line with gear centers. If on motor or generator vibration disappears when power is turned off. If on pump or blower attempt to balance.
Bad gears or gear noise	Low - use velocity measure if possible	Very high gear teeth times RPM	Erratic	
Mechanical looseness		2 x RPM	Two reference marks. Slightly erratic.	Usually accompanied by unbalance and/or misalignment.
Bad drive belts	Erratic or pulsing	1, 2, 3 & 4 x RPM of belts	One or two depending on frequency. Usually unsteady.	Strob light best tool to freeze faulty belt.
Electrical	Disappears when power is turned off.	1 x RPM or 1 or 2 x synchronous frequency.	Single or rotating double mark.	If vibration amplitude drops off instantly when power is turned off cause is electrical.
Aerodynamic hydraulic forces		1 x RPM or number of blades on fan or impeller x RPM		Rare as a cause of trouble except in cases of resonance.
Reciprocating forces		1, 2 & higher orders x RPM		Inherent in reciprocating machines can only be reduced by design changes or isolation.

FIG. 2

MACHINERY VIBRATION SEVERITY CHART

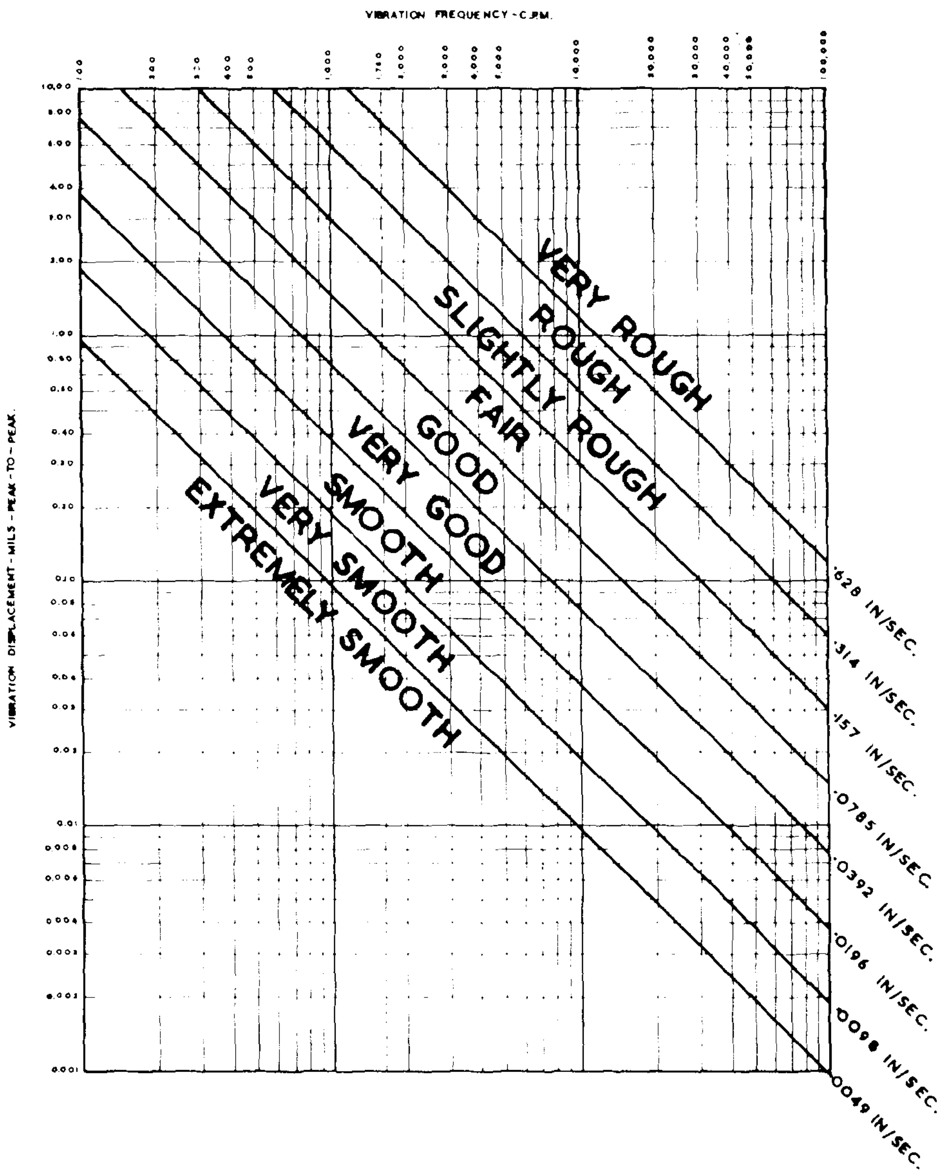


FIG. 3

the way. Immediate corrective action is not necessarily required but periodic vibration measurements should be taken.

(*c*) A trend of increasing vibration indicates that the trouble is becoming worse, and should be identified and scheduled for correction during a planned shut-down period.

Where the vibration levels are acceptable, the completed diagnostic vibration sheet is used to represent the normal condition of the machine. It is also used for this purpose where only one machine of a type is installed and therefore no other yardstick is available. If there is more than one machine of a type, then a comparison of the original readings on the diagnostic vibration sheets for each machine will indicate the normal vibration pattern.

The diagnostic vibration sheet is retained as a permanent record, which not only serves the purpose of establishing the normal vibration pattern for a machine but also provides information for the selection of the critical points on the machine to be used for periodic vibration checks. The readings are also used for selecting vibration tolerances.

In the case of certain reciprocating machinery, such as HP air compressors, readings may exceed the 'rough range' by a fair margin. This does not necessarily indicate that the machine is defective; a comparison with the readings from similar machinery are used to confirm the machine's condition.

Select Periodic Vibration Check Points

The points selected for the periodic vibration checks should be ones which are most likely to show a change in vibration when trouble occurs.

Most machines have their own unique kind of trouble. For instance, fans and blowers are subject to wear from abrasive substances in the air, and machines of this type should be checked for increasing vibration due to unbalance. A pump however is more likely to develop misalignment due to variations in temperature and load during its normal operation. The check points should therefore be selected with close attention to the type of trouble a machine is likely to develop.

The check points should also be selected on or as near as possible to the bearing housings of the machine. Generally at least one radial and one axial vibration measurement should be taken for each separate rotating part of the machine. Axial readings may not always be necessary but are recommended wherever alignment is a problem. Where background vibrations are expected, horizontal readings—which are less likely to be influenced by adjacent machines—are usually preferred to vertical vibration readings. Examination of the diagnostic vibration sheet will reveal the points at which maximum vibration readings occurred. At least one such point for each major component of the machine should be selected. These points will be representative of potential trouble spots.

A daub of paint on the machine to indicate the check point and a punch mark to provide a handy place in which to put the vibration pick-up ensures that the readings are taken at the same spot each time.

Select the Interval for Periodic Vibration Checks

The interval between checks must be a compromise between ensuring that potential trouble is checked in time and the waste of effort if too frequent checking is carried out. It is also governed by the number of qualified staff available for making the checks and the number of machines and check points concerned.

The type of machine also plays an important role in selecting the interval for periodic vibration checks. As a general rule, monthly checks are sufficient for machinery in regular use. This periodicity may be extended for machines which are less frequently run. Pumps, fans, Diesel engines, turbochargers and similar units may need monthly checks.

However, the best indicator of the interval for periodic vibration checks is the past maintenance record of the machine. Where failures have been frequent then, obviously, frequent checks are called for. Each machine requires individual attention if a wise choice is to be made. When the interval has been selected it should be recorded on the Scheduling Sheet (FIG. 4).

Establish Vibration Limits

Absolute vibration tolerances or limits for any given machine are just not available; only experience can tell what the true vibration limit for a machine

H.M.S. ....

Equipment	*Sched. No.*	*Pick-up point*	*Location*	*Speed range (rpm)*		*Periodic measurement*		*Vibration tolerance*			
				High	*Low*	*Time interval*	*Inst. Model*	*Mils*	*in./sec*	*Accel*	*cpm*

FIG. 4—VIBRATION ANALYSIS SCHEDULING SHEET

H.M.S. ....

	Checked by (Initials)												
	Date				1/6/72	1/7/72							
rpm	*Equipment*	*Sched. No.*	*Vibration tolerance Mils in./sec Accel*	*Pick-up point*	*Vibration levels (Mils, in./sec, Accel)*								
3000	Main Engines	M.111.B.	0·20 Mils	B	0·22	0·20							
	Main Feed Pump	M.411.g.											
	Main Extraction Pump	M.413.n.											

FIG. 5—VIBRATION CHECK CHART

should be. However, it would be impossible to carry out a preventive maintenance system without some guide to establishing vibration tolerances. Those selected as a guide are intended to indicate when a machine is developing trouble, and to warn that further attention is needed.

The General Machinery Vibration Severity Chart (FIG. 3), which applies to machinery such as motors, fans, blowers, pumps and general rotating machinery, can be used in establishing vibration tolerances. The left-hand vertical scale on the chart is graduated in mils, peak-to-peak vibration displacement. The horizontal scale is graduated in cycles per minute. The diagonal lines divide the chart into regions or degrees of vibration severity. These degrees of severity are based upon information and records of vibration readings taken on a large number of machines. A classification of vibration is not however a vibration tolerance and therefore the value for each machine has to be selected. Experience and factors such as safety, ship availability, cost and the importance of a machine's function must be considered. Eventually sufficient vibration measurements will have been accumulated to enable a vibration limit to be established by experience for the purpose of providing a safe warning that trouble is present. It is the author's opinion that in the meantime the limit of vibration should be one and a half to two times the normal vibration level—assuming, of course, that the normal level is acceptable.

The values selected for vibration tolerances using this guide should be used only so long as experience, maintenance records and history proves them to be valid.

Presupposing that an emergency does not exist, an important factor to consider when deciding whether or not to shut down a machine is, 'what is the trouble?' A complete vibration analysis should be made to answer this question, and vibration severity takes on a real meaning.

Start a Simple Recording System

The data recording system selected to provide the information for the decision-maker must be effective without being excessive. The diagnostic vibration sheet completed for each machine is extremely valuable: it identifies a machine, its rotating speed and contains the initial vibration measurements. This data, as already explained, is used to determine the normal vibration level, the periodic check point(s) and vibration tolerances, and serves as a standard of comparison for future vibration analysis work on the machine. The completed sheet should be a permanent part of the recording system. Where overall vibration readings, taken at set periods of time, show little change and fall within the tolerances, discrete analysis is not necessary.

The essential documentary system consists of:—

(*a*) The Diagnostic Vibration Sheet (FIG. 1)
(*b*) The Scheduling Sheet (FIG. 4)
(*c*) The Vibration Check Chart (FIG. 5).

The Scheduling Sheet is a permanent record of all the equipment in the maintenance system in a logical sequence of location, the pick-up points, initial vibration measurements, estimated vibration tolerances, speed range of the equipment and other relevant information.

The Vibration Check Chart is the working check sheet on which periodic checks are recorded.

Training of Personnel

Training and keeping track of experienced personnel is of vital importance. The vibration analyst is the key person in any programme and first class operators pay handsome dividends. A scheme that tries to use part-time operators on essential parts of the system is bound to fail possibly with disastrous results to the ship concerned.

If, however, a sufficient number of trained survey teams, similar to the one now operated by the Fleet Technical Staff, are made available, then the degree of discrete analysis which a ship may be expected to or would need to achieve for herself would be much reduced.

The results of the trials at sea in many ships have so far been very encouraging and a high degree of confidence has been achieved. These exercises, together with a wealth of experience being built up at the Fleet Headquarters and at the Ship Maintenance Authority, have indicated that the hand held probes involve tedious work, often under adverse conditions, and at the same time require concentration and accurate recording. The development of a simple go/no-go monitor for use in ships is in hand and will affect the pattern of training of naval personnel. However, the portable probe is likely to be used afloat for the foreseeable future. (Hand held probes can, in fact, be screwed to any part of a machine if a suitable stud is provided. Pick-ups would be more accurate if used in this manner.)

For the present, training of naval personnel is given at artificer level: a two-day acquaintance course is followed by practical experience on running machinery in H.M.S. *Diamond*. From then on, actual experience and constant practice is necessary to achieve reliable results. Up to now, this has been shown to be efficient but training and many other aspects of vibration analysis are being currently studied by the Vibration Analysis Sub-Committee, an off-shoot of the MOD(N) Working Party on Non-Destructive Testing Techniques.

Vibration Meters

There are three vibration meters currently in use in H.M. ships: the IRD Model 330, the IRD Model 320 and the IRD Model 306.

IRD Model 330 (FIG. 6)

The IRD Model 330 is the most comprehensive of the three, incorporating a strobe light flashing facility and, with attachments, is suitable for in-place balancing. This model is held by the Fleet Technical Staff, H.M.S. *Dolphin*, H.M.S. *Neptune*, and all the Home Dockyards. It is capable of measuring vibration in units of amplitude (mils) and velocity (in./sec) at all frequencies up to 500 000 cycles per minute.

IRD Model 320 (FIG. 7)

This is similar to Model 330 without the strobe and balancing facility, but is capable of measuring vibration for a discrete analysis. It has a frequency range up to 50 000 cpm filtered and up to 300 000 cpm unfiltered (overall level). It is issued to H.M. ships and is held by the Fleet Technical Staff, H.M.S. *Dolphin*, H.M.S. *Neptune* and the Ship Maintenance Authority.

IRD Model 306 (FIG. 8)

This meter is not capable of measuring for a discrete vibration analysis because it is not fitted with a tunable filter. It does however have the facility of measuring in two units—amplitude (mils) and velocity (in./sec)—from which the predominant frequency can be deduced. The predominant frequency is that frequency at which the greater part of the overall vibration occurs and therefore indicates that part of the machine which needs further investigation. This meter is akin to a go/no-go monitor. It is held and in use in H.M.S. *Dolphin*.

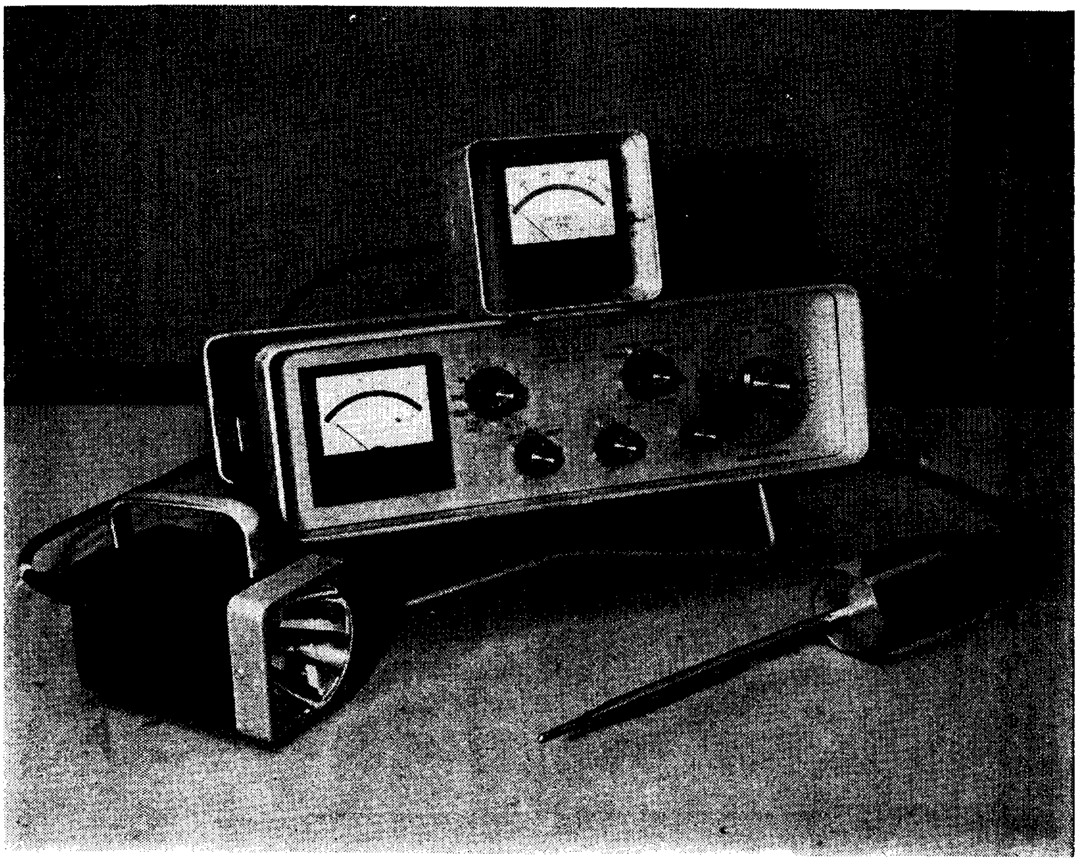


FIG. 6—IRD MODEL 330 VIBRATION METER

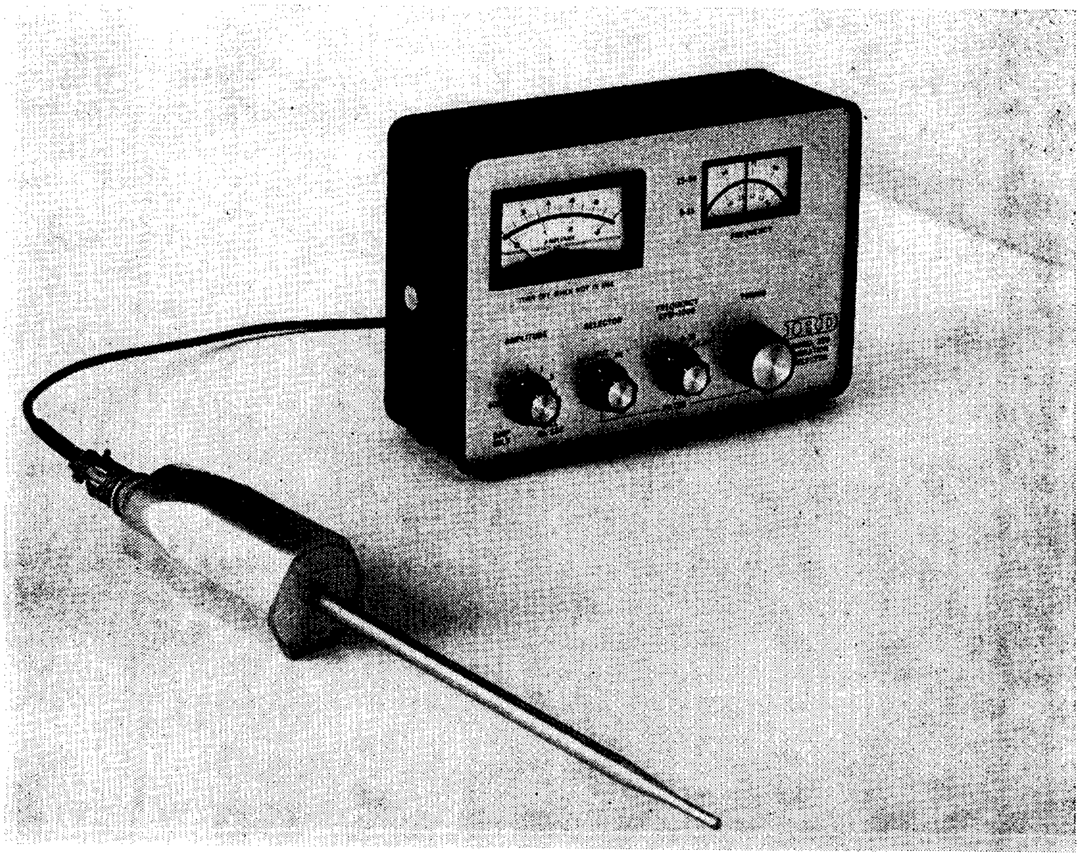


FIG. 7—IRD MODEL 320 VIBRATION METER

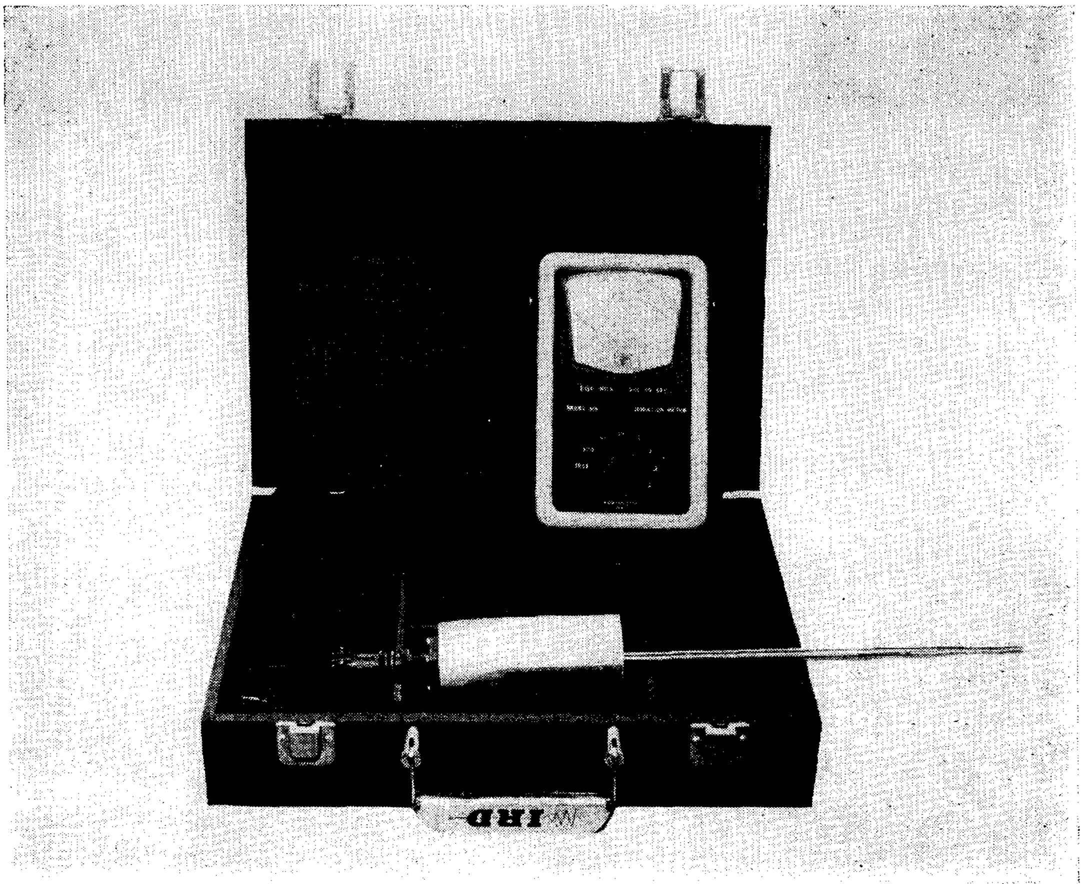


FIG. 8—IRD MODEL 306 VIBRATION METER

The Future

Having set up in a ship the maintenance system as described it must be matched to the upkeep system as a whole. The present planned maintenance which is based on a calendar period would need to be re-appraised, and the current maintenance schedules would need to be re-written in NDT terms omitting dismantling instructions wherever possible.

Before preparing a ship's defect list, a pre-refit vibration analysis survey, together with performance testing of all machinery, would need to be carried out by trained teams as those now administered by the Fleet Technical Staff, and this survey, coupled with the ship's regular monitoring information, can be used to classify the defect list as follows:—

(*i*) Machines that require replacing

(*ii*) Machines that require repair, with details of the repair including the actual parts that need to be disturbed

(*iii*) Machines that require servicing only.

On completion of the refit, all machinery would be checked by the same survey team and irregularities would be investigated and corrected.

Looking even further into the future, the total introduction of maintenance by performance testing and vibration analysis could have a marked effect on upkeep systems, particularly with regard to repair periods, and refits could be greatly curtailed.

On the other hand, something is never achieved for nothing. Fleet bases would have to be set up to undertake some machinery replacements within ships' planned Assisted Maintenance Periods which would otherwise have been done on a calendar basis during a refit. The advent of the Type 21 and 42 frigates

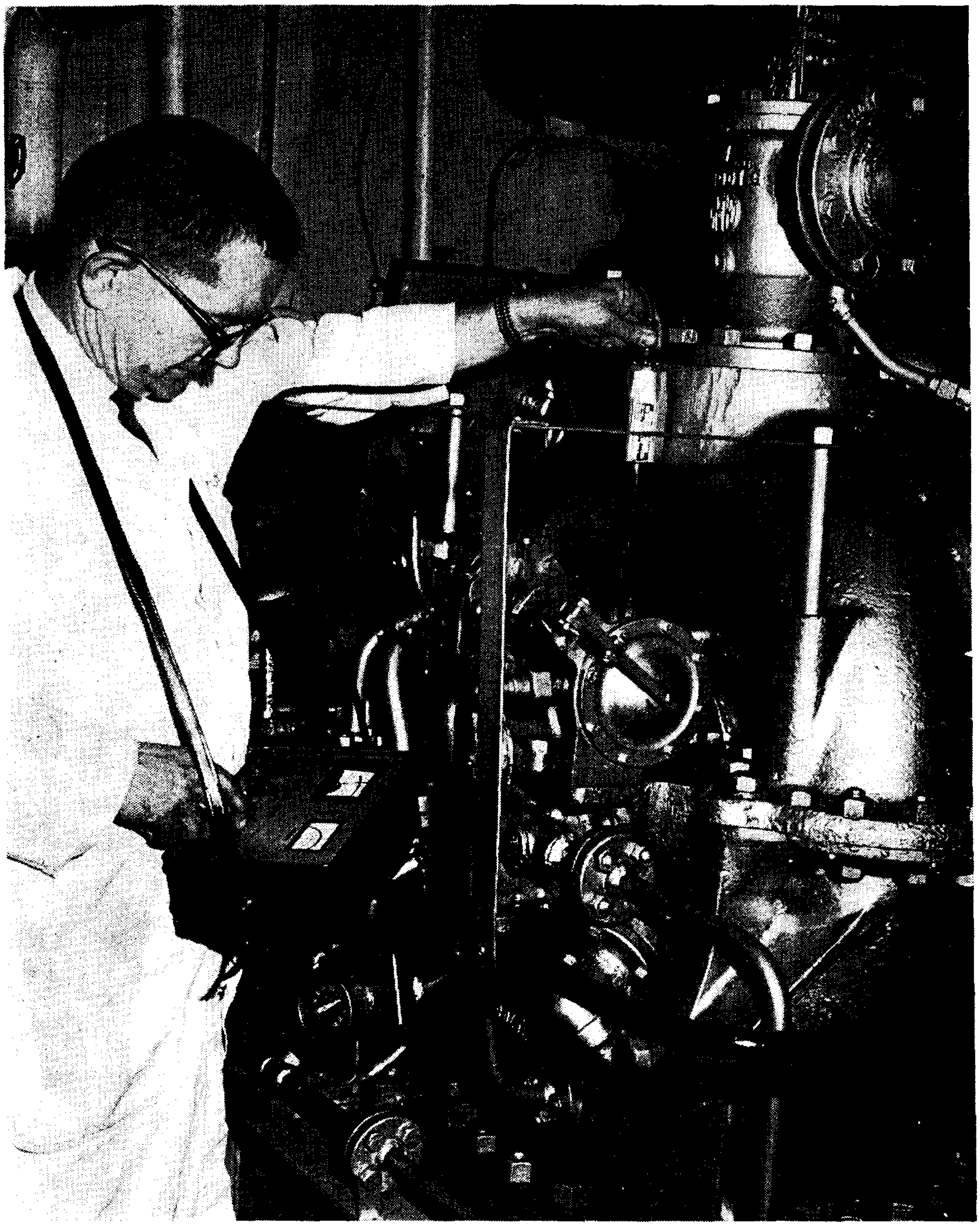


FIG. 9—VIBRATION METER IN USE

opens up new fields where the application of non-destructive techniques will be capable of greater exploitation then hitherto. Indeed, the likely reduction of complements, compared with present-day standards, will necessitate the introduction of all the available labour-saving devices.

It is intended that the Olympus and Tyne modules will be fitted with an installed vibration monitoring system but, in the opinion of the author, the remainder of the critical machinery could be monitored by portable vibration meters of the IRD or similar type as previously described.

Plans are also well in hand to run a $\frac{1}{3}$-octave band vibration monitoring pilot scheme in about five *Leander* Class frigates. This system will make use of tape-recorders in place of the portable meters and process the information at a central point. The scheme is based on comparative vibration levels. It is intended that in future the 'as new' vibration levels of machinery will be measured during contractor's trials, and these initial figures will be compared with readings taken at say four-monthly intervals. Changes in vibration levels would indicate the need to use discrete analysis to determine the cause of the deterioration in the machine's condition.

It is considered that a maintenance system such as defined could well be installed in new ships and, for that matter, in all surface ships with sufficient life remaining to justify the expense and labour. Experience so far has shown that the cost of equipment would be repaid many fold within a reasonable period.

ARTICLES FOR THE JOURNAL

The *Journal of Naval Engineering* is possible only because the Editor receives from Service contributors, and those concerned directly with the Service, a sufficient number of articles and papers for publication. Although he receives most valued co-operation from Authors and Journals unconnected with the Navy in the publication of papers which are of interest to all whose profession is engineering, it remains the organ *of* naval officers rather than an organ *for* them.

The security classification of the *Journal* is 'Restricted' but, within this limit, engineer officers of any sub-specialization can express their personal opinions and ideas on any aspect of their profession. In cases of doubt, the Editor will take the necessary steps to ensure that the classification is not infringed.

Within these limits, papers or letters from any reader, professionally connected or not with the Navy, are equally welcome and their contributions help greatly to broaden the field of view, pose problems and propound ideas not normally within the sphere of Service personnel.

THE EDITOR,
Journal of Naval Engineering,
