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A NEW APPROACH TO SHIPS' MAINTENANCE

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INTRODUCTION

In a paper to this Institute in 1957, Mr. W. H. Falconer[1] wrote that "Planned maintenance was the logical conclusion to what has been standard practice for many years with main propelling machinery". Looking over the scene in 1976 it would seem this statement has offered a challenge to some and a soporific to others. Those who have been challenged have looked at their maintenance procedures from the view point of cost effectiveness, reliability and minimum down-time, future development and, above all, personnel involvement. Others, alas, have been content with the knowledge that with planned maintenance reporting they now had records of the condition of practically every nut and bolt in the engine room stacked up in head office — but simply had not the man power to sift through the paper work.

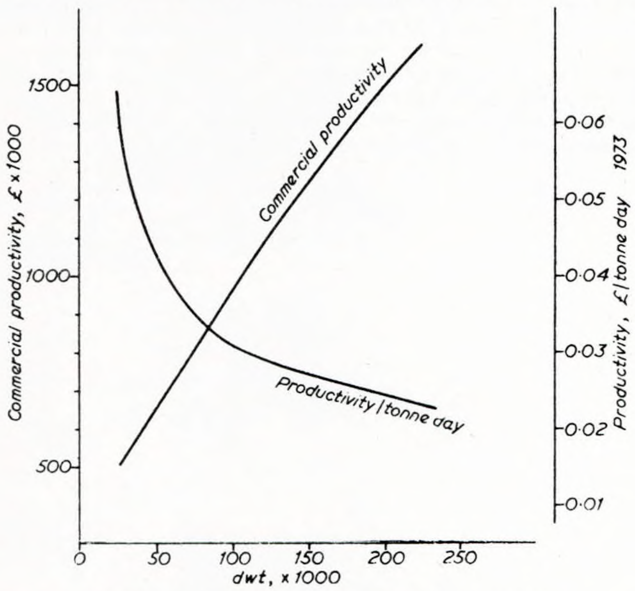


FIG. 1—*Productivity in relation to tanker size*

The principal objective of a planned maintenance scheme should be the progressive elimination of "off-time" caused by unscheduled repairs; and the driving force behind such a scheme should be cost.

Planned maintenance, preventive maintenance, condition monitoring have become household words over the last 18 months, unfortunately too often linked with the phrase "computer controlled". Unfortunately — because this suggests that the computer is the heart of the matter, and that without it, maintenance — planned or unplanned, can be little more than a dream. This is not so, and it must always be borne in mind that the computer is no more than a tool to assist in the performance of a defined function in a better way — and not to initiate it. We are concerned with maintenance. The most sophisticated and expensive piece of equipment is of little use if, after an initial blaze of glory, it spends the rest of its life with more down-time than service time due to inadequate or faulty maintenance or even over-maintenance. Planned maintenance should be concerned not only with keeping the machinery running, but with intelligent feed back to manufacturers and shipyards so that the next generation machine will be better designed for increased reliability and straightforward maintenance. That is; it should become cost-effective over the expected life of the ship.

PRESENT PROBLEMS

The Economics of Maintenance

Figures can be most misleading unless the parameters upon which they are based are most clearly defined. This is particularly true when maintenance costs are examined, as there are arguments for and against including off-hire time, or only unscheduled off-hire time, crew wages, spare gear carried or only unplanned replacements etc, and it becomes exceedingly difficult to make meaningful comparisons.

Figures published in 1973[2,3,4] showed (Fig. 1) that while the commercial productivity of a family of tankers increased with size (the very reason behind their construction) the rate of gain of productivity falls off when the size exceeds 150 000 dwt. Looking at operating costs, (excluding fuel and crew wages and services), in Fig. 2, it can be seen these are escalating with tanker size and that repairs, which include in this graph loss of revenue during docking and repair periods, form a large part of these costs.

FIG. 2—*Operating costs in relation to tanker size*

* Lloyd's Register of Shipping

If estimated fuel, crew and hotel costs, together with a proportion of docking costs are added to these figures, that is approximately the position shown in Fig. 3, from which it may be seen that the repair bill comes to between 10 to 20 per cent of the annual running costs excluding capital repayment[5].

These figures are much the same for bulk carriers where Fig. 4 shows how annual costs were divided. Here the repair and survey costs amount to around 10 per cent of the running costs.

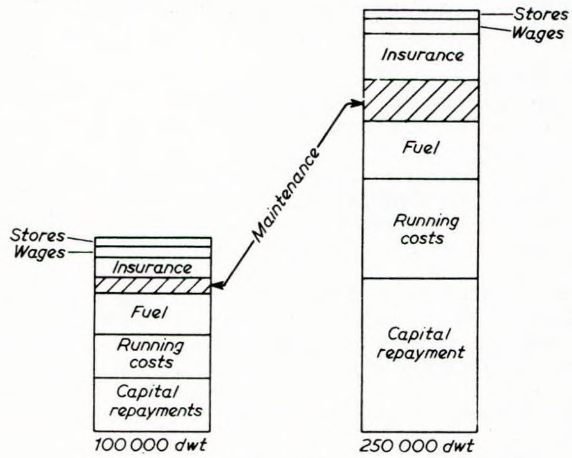


FIG. 3—*Operating cost breakdown—tankers*

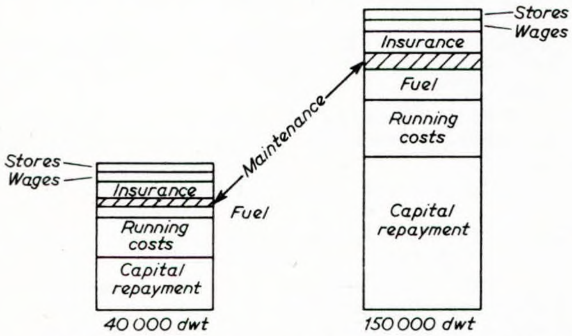


FIG. 4—*Operating cost breakdown—bulk carriers*

Bringing these figures up to date, in 1975, for a bulk carrier, maintenance is running at around 8 per cent of total operating cost including fuel and crew costs (14 per cent excluding fuel). This could rise by as much as 50 per cent for an older ship. For general cargo ships maintenance costs are averaging at about 10 per cent of running costs including fuel and crew, (12 per cent excluding fuel).

These are, of course, no more than general figures as they include a very large divergence in respect of utilization which has an effect on fuel costs as well as crew. They show, however, that maintenance costs still comprise a respectable part of operating costs and they tend to grow larger as the years go by. Looking at the spread of maintenance costs against capital costs culled from various sources, proves the old adage of "swings and roundabouts"; the greater the capital investment, the lesser, usually, the maintenance costs — at least for the first ten years. These costs are high enough, when considering profit margins, and demand serious thought at the initial design stage.

It is also a sobering thought that crew costs now form the largest single figure in annual running costs — and this in a rapidly advancing technological age. Incalculable among these figures is the loss of favourable charters, good-will and even good crew, caused by unscheduled breakdowns, and it is this that should be driving the shipowner to inquire what small savings might be achieved by intelligent maintenance. Considerable sums of money are spent annually in hull design studies aimed at saving just a few more teaspoonfuls of fuel per annum: the same sum spent on designing for good maintenance would produce economies which would startle many owners. Fuel savings of 10 per cent are unrealistic but savings of up to 10 per cent in maintenance costs have been achieved by realistic planning. For example, maintenance cards showing opening-up, overhaul and boxing-up procedures can reduce the chance of carelessness which has often led to breakdowns taking place just after overhaul. These breakdowns have been expensive in terms of both cost of repair and non-availability of the equipment. Good maintenance, intelligent maintenance, is an economy which cannot be neglected in any modern machinery concept.

The Growth of Automation

Fig. 5 illustrates the growth of "automated" ships and ships with the UMS notation in the past ten years. In this context "automated" ships are all fitted with centralized control of the machinery. Many of such ships would qualify for the UMS notation but the notation is not required by the owner. The number of automated ships includes UMS ships.

The basic purpose of this equipment was to ensure the safe and efficient operation of the machinery at all times by introducing automatic control, alarm and safety systems, and there was the additional incentive that a certain number of engine room staff could be released from watchkeeping duties. At one time there were even thoughts of considerable staff reductions until it was remembered that there always needed to be a sufficient number of men available to resume manual control in the event of failure of the automatic system or for periods of operation in confined waters when it is often considered prudent to have watchkeepers below. There also needed to be men available for fire fighting and other emergency procedures. The net result has been to effect only marginal savings in crew numbers, but to release those on board for daywork, a move that has been both popular and productively beneficial.

Not only has the psychological effect of engineers being able to enjoy normal working hours been noticeable, but there have been positive advantages in having a team available on day-work to tackle maintenance problems. This could amount on the larger ships to as much as 1500 man days per annum[6]. Regrettably this has not always been used to full advantage with the result that maintenance has been haphazard and no lasting benefit has been derived from the results. Some companies, however, saw this as the opportunity to regularize maintenance procedures in accordance with

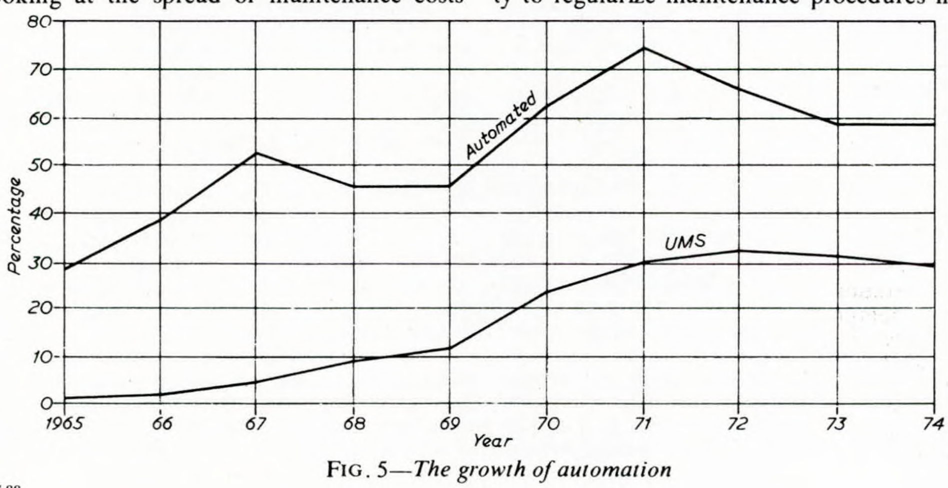


FIG. 5—*The growth of automation*

classification requirements, and introduce forward planning and subsequent analysis of maintenance work from which future operations could benefit.

Engine Room Manning

If automation has reduced the need to some extent to have so many experienced engineers constantly available, it has at the same time created its own problems, in that there are fewer young engineers gaining the necessary basic practical experience of running main and auxiliary machinery to enable them to cope with breakdown and maintenance problems. In the manned situation the "watchkeeper" tends to stay in the control room where the state of the machinery is visually displayed; in the unmanned situation the job is left to run by itself, which is surely the *raison d'être* of automation anyway. To overcome this lack of physical contact many companies have introduced check-lists to take engineers out into the machinery environment and get the feel of the machinery in a running condition. This, together with maintenance programmes during day work will, it is hoped, encourage their engineers to develop an understanding for the machinery they control, its limitations and its performance capabilities so that with this background they are, eventually, able to evaluate the performance of various auxiliary machines to determine whether or not it is necessary to open up for inspection and thereby expose the machine to other environmental hazards.

This is the forerunner of condition monitoring, for no matter how much information sensors and other sophisticated devices can give, the ultimate decision must be a human one, and that by someone who knows and understands the machinery in his care.

Techniques

Hand in hand with the demand for more reliable and advanced control systems has been the development of sensors for measuring all those parameters such as pressure, temperature, flow, etc, necessary for setting up control systems. Added to these are velocity and acceleration pick-ups, proximity probes and other devices which will reveal the physical condition and wear rates of machinery, so that it is possible to know a great deal about the health of a machine without stopping and opening it for inspection. Over recent years the sensitivity and, more important, the reliability of these devices has improved — a result of being designed specifically for a marine environment. Environmental testing for type approval has done much to achieve this improvement.

One of the dangers of a proliferation of sensors is the encouragement given to measure everything in sight without due regard how the results are to be used at the end of the day. In particular the sensitivity of the sensor must be compatible with the operating tolerances of the system being monitored: for example, there is little point in measuring exhaust gas temperatures to a tenth of a degree when looking for variations of ± 10 degrees around a mean value. Cost effectiveness must be the keynote in the selection and positioning of sensors if meaningful results are to be obtained, and it is in the interpretation of results that the most expensive mistakes can be made.

Complementary with monitoring comes data logging and, of course, computing. Early data loggers admittedly gave a certain amount of trouble. Their main drawback was the amount of unnecessary paper produced which gave mental indigestion to anyone trying to examine a set of voyage print-outs. The consequence was they fell into disrepute, and their records shelved for posterity.

Computers on shipboard were the subject of a symposium at the Royal Institute of Naval Architects in March 1975, though back in 1968 a paper on the practical applications of computers in marine engineering was presented to this Institute. Computers had found their feet on land, and by 1968 third generation machines were in production. While the potential of computers was realized in land-based installations, acceptance of these on board as a viable proposition has been slow to take effect.

The advantages appeared to lie mainly in the design field, especially with regard to pipe stressing, alignment and steam turbine design, but it soon became clear that if the computer could be used to design a steam system, then it could also be used to control it so as to obtain optimum conditions in the thermal cycle. Cost naturally became of importance in this type of project, and in order to make the inclusion of a computer a viable proposition it would have to perform other work as well. This was appreciated, for instance, at the design stage of *Queen Elizabeth 2*. The original intention had been to install a data logging system alone, but the owners, realizing that most advanced data logging systems were computer based, decided to invest a further 50 per cent over basic data logger cost in order to obtain a more sophisticated control system.

The final system included:

a) data logging;
b) alarm scanning with logging print-out;
c) monitoring and control giving information on fuel economy;
d) continuous automatic control of some machinery;
e) weather routeing estimated to result in 1·5 per cent fuel economy (11 tonnes per day);
f) fresh water requirements.

This type of approach represents an intelligent appraisal of the total situation, and was evidently done with both initial costs and cost savings very much in mind. It is doubtful whether all computer schemes proposed measure up to these standards since it is not just a matter of manufacturers telling a shipowner what computer facilities he can have, as much as the shipowner deciding what he wants to do with the information then at his disposal.

It may be concluded then, that four factors are having an influence on operation of ships today:

i) the escalating costs of maintenance overhauls including drydocking and the off-hire costs in a competitive market;
ii) the steady increase in automation and system control;
iii) the manning problems brought on by a changing society;
iv) the sophisticated monitoring equipment available.

One factor that has not changed, however, is that of manning strength which is governed by the necessity of having get-you-home capability available on board. How shall these "extra" men best be used?

While it is easy to say "all hands to day work" this attitude is not necessarily going to maintain the sense of unity and purpose for which the seafaring community is striving. Indeed, over-maintenance can lead to carelessness and an increase in those very breakdowns the application of maintenance should help to avoid. Planned maintenance, intelligently planned day-work is vital in this situation, yet it is in the very planning that so many worthy schemes go astray.

PLANNED MAINTENANCE

The continuous survey cycles of classification were the fore-runner of the planned maintenance concept, although the time scales involved, four and often five years, were too great to be realistic in terms of the effective maintenance of some components. Practical preventive maintenance had been practiced for years by the good chiefs and seconds who, without rule books, data boards or do-it-yourself cards were able to keep taut engine rooms, notably free from breakdowns, using the minimum outside labour or, indeed, machinery spares. Creditable as this was it failed to produce the sought after end result of reliability, and the self-same piece of machinery in the hands of less than dedicated engineers could soon become a liability.

Thus it was that maintenance became regularized, planned around the five year cycles of classification, and ensuring that all machinery items were overhauled at regular intervals. Schedules were set up either on board, or by the superintending staff, and as long as voyage reports showed maintenance was being maintained, not overmuch attention was paid to the details.

Arising from this, quite naturally, were a number of companies who were willing to undertake the planning work and set up the system for owners whose superintending staff were too small to cope with the extra work. The schemes produced have shown wide variations from simple, functional paper or card index systems, to highly coloured and unnecessarily elaborate work boards that have taken nearly as much time to keep up to date as to do the maintenance recommended.

While the introduction of these schemes has done much to satisfy the "what shall I do now" cry of the engineers, this is not the heart of planned maintenance. The function of a planned maintenance programme is the elimination, as far as humanly possible, of the risks of breakdown during service. The achievement of this ideal is not a paper exercise but one that must start on the designer's drawing board. Planned maintenance requires planning for maintenance from the beginning. It is only too rarely one hears marine engine builders claim their machinery has been designed, not only for maintenance but for *in situ* inspection; though happily this situation is changing. The aircraft industry do just this — and with success. The R.B. 211 engines for the Tri-Star Airbus have viewing ports incorporated with removable plugs through which intrascopes or fibre optic viewing heads can be inserted enabling a visual inspection of all rotor blades to be made. This has reduced overall inspection time on these engines from three days to 20 hours with the minimum of opening up. Their experience has been that the clarity of vision afforded by these techniques enabled them to make reliable judgement whether to allow the engine another hundred and fifty flying hours or to break it down for overhaul and repair.

In other words, while incipient cracks could not be detected through an intrascope, it was equally unlikely they would have been seen by the naked eye without lengthy crack detection, so the level of inspection could be considered to have remained the same. This is a realistic approach to inspection and maintenance procedures, and as such must be based upon the statistical history of failure for each component so that the inspection level is in agreement with the anticipated risk of failure. It would be uneconomic, for example, to provide any level of monitoring on an intermediate shaft coupling bolt where the risk of failure, and equally important, of consequential damage is virtually nil.

Planned maintenance infers the gathering and analysis of all information relative to performance and using this to form a policy of regular inspection and overhaul which also fits into the framework of classification and national authority requirements. But there appear to be five major areas where many schemes fall short of their desired objective; or perhaps it is more true to say they fail because they had no objective in the first place.

1) Schemes which are inflexible are nothing more nor less than "good housekeeping" under a fancy name. For example, because in the past pump "A" has needed a new impeller every "X" months it is scheduled for opening up at that interval — and so is every other pump in the engine room. No regard is paid to extending the life of that impeller, nor querying why other pumps may last longer. This is scheduling, not planning, and the danger in such a system, no matter how attractive the cards on the planning board may look, is that an unscheduled breakdown can so easily throw the whole thing into confusion. If the scheduling is tight it is seldom possible for the ship's staff alone to recover the position and the backlog of overhaul then involves shore labour at the terminal port with considerable additional (unplanned) cost.

The constant aim of the system should be to reduce costs by extending inspection interval times and this can only be achieved by a practical acquisition of an intimate knowledge of the machinery and its idiosyncrasies.

2) Information available from maintenance inspections is not gathered and used. One of the objectives of a maintenance scheme should be to increase the availability of machinery and this can only be achieved if a record is kept of the condition of components examined, and kept in such a way that it can be used for reference at the next inspection and not merely filed away for posterity. These records need not be elaborate, but should give information on running time down-time, condition and spares required to be of value in calculating the cost of maintenance and to anticipate the economic viability of extending the period between overhauls. A measure of the value some shipping companies attach to such data analysis is reflected in their requirement for standardization across their fleet, by installing main and auxiliary machinery whose performance and characteristics are already widely known, and which are easily maintained. For example, the availability of many water tube boilers could be increased were the design such as to eliminate corners and pockets where damp soot can collect, and by a strict control of salinity and alkalinity.

3) To be effective, planned maintenance should be linked with a spares planning policy, and this again springs from knowing more about the machinery performance. Maintenance activities can be curtailed due to the absence of appropriate spares to complete the work. This may be improved by standardization and with a clear idea of how such maintenance is to be carried out by opening up on voyage, and how much by replacement. For example, many electric motors are now produced as sealed units and are maintained by total replacement. There is no reason why the same should not apply for small pumps, provided the manufacturers are prepared to offer a reconditioning scheme at a reasonable cost. Dock side labour is very expensive whether engaged in stripping machines and maintaining them or in servicing equipment on board on a replacement basis, so the more that can be effected by the crew as a self-contained operation, the greater the economies.

4) The fourth area where planned maintenance can fail is in lack of commitment, both of sea staff and management, to making it work. Both attitudes usually arise from "paper indigestion", that is, by sea staff having to fill in unnecessarily elaborate reports, and management not knowing how to use them when they arrive. Involvement is a key word here, and it is the realization by both sides that planned maintenance makes for greater reliability and less unscheduled work in the long run that needs to be appreciated. Reports must be factual, indicating only areas of reduced performance and not sheets of figures showing normal performance. This would involve defining acceptable deviations in key parameters much as in an automatic control system. Overhaul reports, voyage reports should be supplemented by interviews where possible, and constructive appreciation and advice must be apparent at head office level. Above all, the planned maintenance system must be obviously concerned with cost in the short and long term. While the driving force behind planned maintenance is cost saving, the operators do not always have a clear understanding of the magnitude of the financial incentives, particularly those of capital savings achieved by the increased life of major components.

5) Lastly, planned maintenance schemes fail to reach their fulfilment when there is no overall company policy. Briefly, this means that the whole machinery installation is costed, not only for its total price new, but also for its anticipated maintenance costs during the write-down period of the ship's life. Thus plant is bought for reliability, ease of maintenance, accessibility for inspection without major opening-up, and not just because it is the cheapest the company's accountant can see on the market.

What of the cost of planned maintenance? With the rapidly changing economic cut and thrust of ship operating it is hard to quantify, but savings of 20 per cent of normal maintenance cost have been reported due to careful forward planning. These savings in one year equalled the cost of setting up the planning scheme in the first place which immediately made it a sound economic proposition. The real cost saving of planned maintenance in terms of reliability will not be known for a number of years when redesigning of components, of systems, of interfaces has been completed.

CONDITION MONITORING

Condition monitoring is a tool of planning, an extension arm of the aids to determining machinery condition; and is not a science in itself. There must be very clear notions as to what is to be monitored, how to set parameters and, above all, how to use the output, otherwise the value of the exercise is lost.

What, then, is the object of condition monitoring? It is simply to use the sophisticated sensing facilities now available to measure deterioration in performance and it does not require elaborate computing facilities to achieve this end. Clearly, with systems using control loops and microprocessing much will be known about performance, although there is always the danger that a developing fault in one part of the system may be masked for some time by the self compensating properties of the rest of the system. In such cases overall system efficiency becomes the indicator for health monitoring.

In setting out to plan condition monitoring in all or part of an engine room, the first and most important step is to establish how the individual components might be expected to deteriorate. Ideally, manufacturers should have some idea of the weak points in their products though there may be an understandable reluctance to reveal this information. There are also many manufacturers who bemoan the lack of feed back from users on suspect points of design or operation — points which they could rectify if they were aware of the problem. All too frequently it is only an increase in spares consumption, or the loss of new orders, that indicates all is not well. This is one of the advantages in fleet standardization in that recurrent defects are more quickly shown up and action taken.

Having identified the weak points either from the manufacturer, from personal experience, or from classification society records, the next step is to decide how best to monitor the machinery to identify a developing defect. For example, blade damage on a turbine rotor may show up as vibration if isolated blades are involved or in a change of exhaust steam conditions if complete rows are damaged, whereas erosion on a pump impeller would be shown as an efficiency drop. Plain bearing wear may be monitored by a probe measuring bearing top clearance; thin walled bearings will show marked temperature changes at the moment of deterioration; roller bearings show changes in vibration or "noise" pattern, as they wear. Monitoring must be intelligently placed so that every piece of information gathered shall be used in the assessment of machinery performance. To apply more sensors than strictly necessary is costly, both in terms of the instruments themselves, man hours in maintaining them and logging the results, and time spent subsequently in deciding whether the readings recorded have any significance.

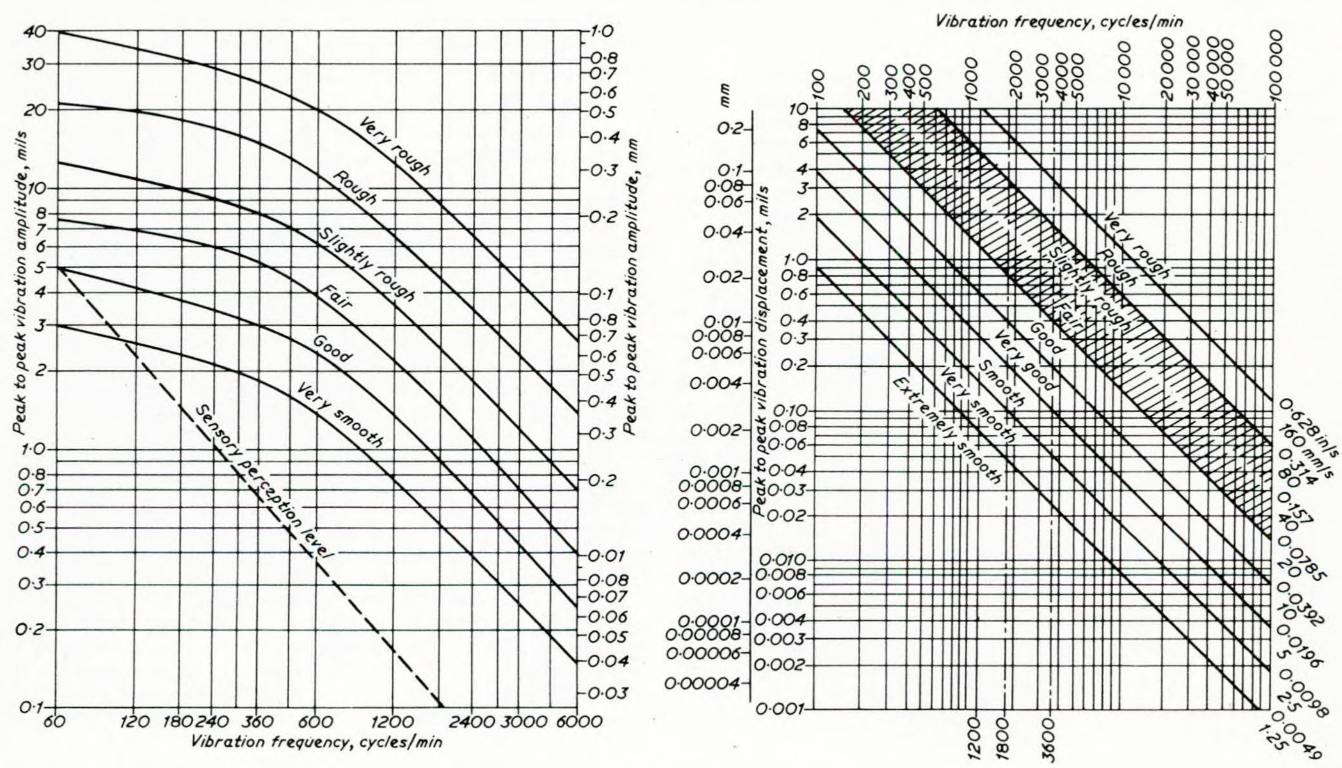
One of the most reliable monitors of machinery performance is vibration. As Figs. 6 and 7 show it is possible to lay down well recognized and accepted limits for vibration, above which the machine must be opened for inspection. Although the chart in Fig. 7 was culled from measurements made on a large number of machines and takes in vibration frequencies up to 1600 Hz, the curves have been based on machines up to 15 years old and take no account of improvements in bearing materials and manufacturing tolerances. They are, however, regarded by many as a fair basis on which to judge machine vibration severity. In monitoring, changes should be looked for from the as new condition, and then co-operating with manufacturers in defining at what stage overhaul or replacement becomes necessary.

With some components such as roller bearings it is not so much a change in vibration level as a change in vibration pattern that indicates deterioration. In such cases it is necessary to compare the complete frequency band analysis with the previous chart in order to detect change.

Generally, however, such is the rate of decline of performance, there is no need to go to continuous monitoring and a twice a voyage vibration signature plotted on a basis of running hours or calendar time is sufficient to show trends in condition change. Where more rapid deterioration is experienced, other parameters are usually affected which cause the normal alarm systems to function. Failing that, the failure must have been catastrophic anyway, and due to a major defect which no amount of monitoring would necessarily detect unless arranged to give a continuous signal. Such is the requirement for turbine rotor vibration monitoring where immediate speed reduction is required for excessive vibration.

In condition monitoring consideration must always be given to the reliability of the sensor. Some temperature sensors are sensitive to high vibration levels and care should be taken to see they are securely fitted. Thermocouples should be annually checked for accuracy. Level alarms have been known to fatigue due to transverse vibration of the float arm and should be mounted so as to minimize these effects. It is not unknown for a heavy mass attached to the wall of a free standing daily service tank to alter the vibration characteristics of the tank wall and give rise to severe vibration conditions.

Some of the early monitoring devices on main engines for liner and ring wear have caused pistons to be drawn more frequently than necessary. But these are, in the main, teething



FIGS. 6 and 7—*Machinery vibration curves* troubles which the selection of proven and environmentally tested sensors should overcome. As with all automatic systems careful thought has to be given to measuring only those variables which are relevant to indicating the performance, choosing a reliable sensor, and then having full confidence in the results put out.

What will it cost? The short answer is that it all depends on how much savings are aimed for, for the only sensible way of approaching condition monitoring is to assess the economies that may be effected by its introduction. That is, in fact, the very *raison d'être* for its being. When an intrascope inspection of an HP turbine rotor can save £8000 in costs for opening up — to say nothing of the time saving — then the cost of the intrascope becomes negligible. The installation costs for sensing on ME pistons however would be much higher and the savings apparently much smaller until one appreciated the hidden savings included in the greater reliability and availability that would be expected.

Much has been written on the subject of data loggers or event recorders in condition monitored systems. The basic rule is that data recording must not become a chore; the moment it does then the level of accuracy inevitably goes down. An event recorder is useful only as long as the reason for each alarm is noted so that a feel for component or instrument reliability can be obtained.

Computers provide an even more emotive point of discussion, and much has been written to extol their virtues. Four points are worth emphasizing:

a) computers have a considerable capacity for work, and it is wasteful if they are not being fully employed;
b) a computer is only as good as its programme;
c) faulty data going in leads to nonsense coming out;
d) there is little merit in analysing in six seconds data it took six months to collect.

This must not be thought of as a negative approach to shipboard computing but a positive one, as it is important to look at the advantages and disadvantages in total, rather than as individual packages. Naturally a computer can cope with many tests, intergrated navigation systems, collision avoidance (bow slamming and hull stressing), cargo pumping and stability, machinery surveillance, steam cycle optimization, as well as condition monitoring and trend prediction, and the more that can be done with a purpose, the greater the efficiency of the overall system. If the computer capacity can be usefully utilized without the necessity of writing special software for individual whims and fancies then there is some justification for considering such an installation. The cost is perhaps not as high as might be imagined, and there is at least one system offering trend analysis of main turbine performance and associated systems together with alarm monitoring of machinery, cargo loading control and an integrated navigation system at an installed cost of around £150 000.

Where a computer is available, the scope of machinery surveillance is extended beyond that of monitoring set parameters, although this function is still required. It enables system effectiveness calculations to be performed on such things as boiler performance, condenser performance, feed pump performance etc, where the set points are not in terms of direct deviation in pressure, temperature or flow, but in terms of the increase in the fuel consumption rate. Furthermore, the effect of various corrective actions may be automatically assessed not only in terms of their effectiveness but also of their influence on the condition of the system as a whole. For example, where impeller wear is leading to a fall-off in pump performance, the flow rate may be restored by running the pump a little faster. This however increases the rate of wear in the pump and there comes a point when to increase pump speed — and therefore rate of wear — becomes uneconomical, and it is better either to look for other corrective measures within the whole system or to stop the pump for maintenance.

A NEW APPROACH

Leaving aside for a moment the descriptive names, the generic term "maintenance" covers a wide spectrum of activity from overhauling by necessity to the advanced systems this paper has been considering. Superimposed on this come the requirements of classification, but it is important to realize that these requirements do not in themselves constitute a programme for maintenance. The classification society's function is to ensure that a recognized standard is being maintained, and the established survey interval of four to five years is the absolute maximum time any component may be allowed to run before thorough inspection and renovation. Classification, as such, is not concerned with plant efficiency or economy, but with safety and reliability and cannot therefore be related to a true maintenance concept.

Why then, is a new approach to maintenance required? It is because there are other economic pressures, forcing a fresh look to be taken at ways of minimizing off-hire time. In the past there has always been the annual docking to provide a breathing space and an opportunity to catch up with overhauls. Now this is becoming a biennial affair, and with recent improvement in hull coatings and underwater survey and repair techniques there seems every reason to expect that the drydocking intervals may be prolonged. The inboard inspection facilities afforded by the patent split bearing sterngear coupled with the promise of increased life from keyless propellers also support an extended interval between major dockings. With the considerable cost of a VLCC docking it is clear that there is a strong argument for accepting alternatives to drydocking, and this will correspondingly reduce the time available for major machinery overhauls. To cope with this change and at the same time maintain machinery in a reliable condition must mean taking a serious look at the ways in which plans are made for the future, and at the way whereby "classification" shall be satisfied.

What does a new approach involve? Former maintenance schedules where equipment was examined at regular intervals were costly in terms of manpower and materials. The introduction of planning has to some extent reduced these costs, partly by extending the interval between inspections on such items as lubricating oil pumps and coolers, and partly by laying down clear instructions on how overhaul and servicing should be carried out. This has resulted in fewer mistakes being made on reassembly and a more reliable performance of the equipment thereafter. Now a far bigger step is being proposed by introducing flexibility to the intervals between overhauls according to the planning scheme based on the past performance of the equipment. This can only be done provided concise records are kept of performance and of the results of past inspections upon which a fair appraisal of the present situation can be made. This is where condition monitoring will assist to give a much more up-to-date picture of the progress of wear and tear but, overall, this approach should lead to machinery only being overhauled when necessary — not too soon nor, equally important, too late.

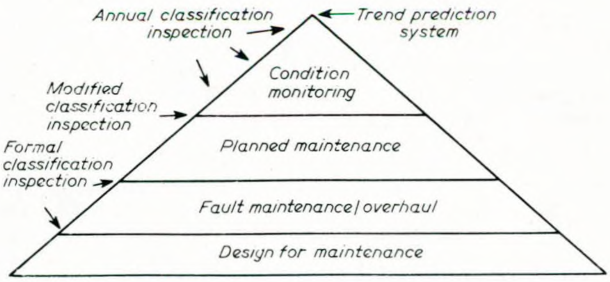


FIG. 8—*The "new approach" to maintenance*

Fig. 8 shows an idealized pyramid of progression from basic maintenance to the ultimate in planning and monitoring, with the intermediate steps leading from one stage to the next. The world's merchant fleet is totally contained within this pyramid, although as sophistication grows one would expect the top of the cone to broaden. There is no reason why classification cannot be satisfied at all levels of the pyramid, relaxation of the full requirements being determined by the level of monitoring and planning at which the owner wishes to operate his ships.

The first steps in this direction were taken when Lloyd's Register of Shipping introduced its Approved Scheme for the survey of machinery by ships' chief engineers. Now it is proposed this may be extended in consultation with each shipowner for the very advanced installations, while for the more straightforward installations where the owner finds it convenient to carry out maintenance at terminal ports the existing requirements for continuous or engine survey would apply.

It is convenient to consider this new approach to maintenance in five steps.

1) Ideally, the approach should start with the shipowner designing for maintenance in any area where he can see realistic cost savings. This implies more than merely selecting machinery for its proven reliability and ease of overhaul, but also considering how such maintenance will be carried out. For example, this could be:

a) in the open engine room — which, as noise legislation becomes effective, would involve providing movable acoustic screening or ear-defenders for the engineers;
b) in a workshop on board — which should be acoustically screened;
c) by replacement either from spares carried on board or at voyage terminal ports.

Thought should be given even at this stage to the organization of watchkeeping and daywork, carriage of spares, overhaul facilities and tools, in fact to everything that can contribute to making maintenance a smooth flowing operation.

2) The owner must decide to what depth his planned maintenance will be supported by condition monitoring if indeed at all. This will depend largely on the length and frequency of voyages, and on terminal port commitments — generally speaking ships which have the highest usage rate — the large tankers, OBOs and bulkers — will benefit most from the monitoring facilities, as will ships where steam systems, central cooling systems are being regarded as a complete entity. Even so, the question is then — what to monitor — as there seems little sense in monitoring pumps where a duplicated stand-by unit is standing by ready to take over. At the same time monitoring one pump of a type can be valuable in giving a guide to the rate of deterioration that might be expected. Over-monitoring is as bad as under-monitoring and invariably leads to a conflict in decision making as to what action to take.

3) Thought must be given to how the acquired data will be handled, whether it is collected mainly by hand or through monitoring sensors. The important point is that data extraction should be straightforward, and should in the main be confined to deviations from the norm.

Naturally a daily set of performance figures are valuable, but unhelpful when presented in bulk at the end of 12 months. This means that data extraction and comparison should be a part of shipboard routine, and forward maintenance planning should be generated from the ship, rather than waiting for head office instructions.

4) Perhaps the most important step of all is the integration of new procedures into the classification requirements. This means that the classification society has to take a hard look at its own procedures, and consider to what extent these are being satisfied by the regular maintenance and monitoring proposed by the shipowner. One point is clear from the outset, that this is very much a "one-off" operation with consideration being given to an individual owner, or ship, rather than laying down a hard and fast set of monitoring requirements. The philosophy the Society is seeking is one where information gathered during the day-to-day running of the ship is being used to provide a sound technical basis on which to take maintenance decisions. It is the Society's function to assess whether the amount of monitoring and the use made of the data collected warrants a relaxation in survey requirements. It should perhaps be stressed that this at no time relieves the Society of its responsibility to carry out surveys nor precludes the inspection of certain major items — boilers, turbine rotors, crankshafts etc, but offers to the owner a means whereby classification surveys shall in themselves become an integral part of maintenance, being equally cost effective.

5) An important final step for the owner to take is to ensure his ship's engineers are made aware of the significance of such a new approach to maintenance, of the economics it offers and, in particular, of their part in the scheme. While automation tends to take people out of the engine room environment, engineers should be encouraged to make physical contact with the machinery and to experience by sight, hearing and touch, the vibrations, flow and temperatures which the sensors are monitoring. Above all, ship's staff must be aware of the importance their company attach to good maintenance and monitoring and the company must be seen to care about the results obtained. This may be done by newsletters on performance, costing, reliability, and as part of an overall integration and education policy, they should not be neglected.

CONCLUSIONS

It had been written, long ago, that "there is nothing new under the sun" and this may undoubtedly be applied to the policy of maintenance. What is new is the approach to the problem, realizing that planning for repairs and breakdowns should be given the same amount of attention as planning for new construction, and dealt with on the same economic level.

Until reliability is 100 per cent over 20 years — repairs and overhauls are inevitable; nevertheless cost saving can be achieved in three areas:

i) less down-time — remembering that time spent on maintenance when the ship is tied up represents money, whereas maintenance at sea does not carry the same penalty;
ii) less shore-labour involvement;
iii) less chance of subsequent damage as a result of opening up in a hostile environment.

When major opening up is unavoidable then use should be made of critical path techniques to ensure that vulnerable items are exposed for the shortest possible time, and that systems can be tested as soon as possible after replacement to give time to iron out any snags.

Where opening up could be avoided or is undesirable due to the extraneous hazards involved, consideration should be given to providing for intrascope inspection, magnetic plugs in L/O systems vibration pick-ups etc, which will contribute to understanding the current condition of the machine.

The owner must formulate his own planning. Manufacturers recommendations form a sound initial guide but they will always contain built in safety margins. The owner, and only he, knows his trading patterns, his preferences for repair ports, his crew costs, and planning should be moulded to his requirements and not to anyone else's if they are going to be cost effective. Furthermore they must be flexible enough to accept change and perhaps more change, if the built in safety margins have been too wide. There is no substitute for experience on top of sound maintenance.

No matter what scheme is produced, classification will always have an overall responsibility to the shipping community and there will therefore always be a limit to the extent of direct survey relaxation permitted. The new approach is not intended to abrogate the role of classification, or to provide an opening for slipshod inspection, but to enhance it, whereby it remains in firm control while taking a broad and long term view of the economic viability of maintaining high standards.

The industry cannot afford to stand still. The reliability of electronic components, of sensors, micro-processors, mini computers is higher than the machinery they safeguard. The industry cannot turn aside from the material benefits that computers will bring, navigational aids, trend analysis, sophisticated system operation etc, all of which relieve part of the burden of management from the ships' officers. The ultimate aim in a new and positive approach to maintenance must be for increased knowledge of performance, of a sound economic appraisal of survey and overhaul which has the flexibility to admit change, but above all for reliability which enables owner, surveyor or sailor to see a ship off to sea with a quiet confidence in her ability to successfully and consistently fulfil her duties.

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Discussion

MR. R. F. THOMAS, F.I.Mar.E., said that the subject of the paper was one of great interest to all sides of the industry. Mr. Batten offered some thought provoking ideas — for after all, maintenance was expensive, and also on occasions had been described as a nuisance.

However, once having accepted the ship, what should management's sole objective be with respect to maintenance? Surely to operate the ship in the most cost effective way possible for the whole of its life.

Fig. 8 showed an idealized pyramid of progression from basic maintenance to the ultimate in planning and monitoring. At the apex was "Trend Prediction System". This, he suggested, was not the ultimate, and more cost effective results could be obtained in the following way.

Deviation from the normal operating or design conditions would cause an alteration in the fuel consumption. More often than not this deviation from normal operating conditions caused an increase in the fuel rate. Deviation which gave an improved fuel rate, might have long term adverse consequences. For example, excessive condenser vacuum might result in turbine blade erosion and tube impingement erosion.

In the case of an economizer, which was a simple heat exchanger, fouling would be indicated by an increase of uptake temperature. This deviation might be plotted against time as shown in Fig. 9.

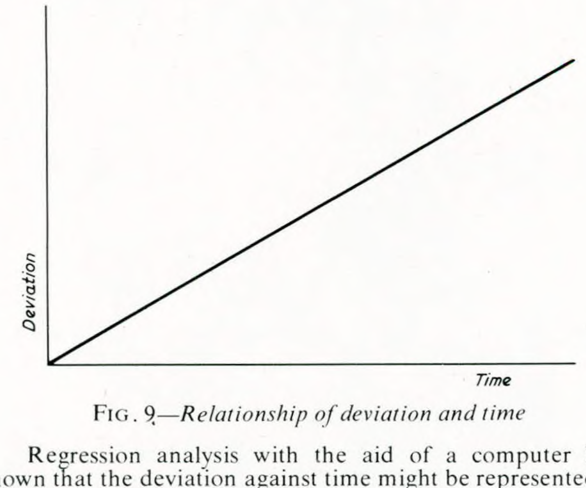


FIG. 9—*Relationship of deviation and time*

Regression analysis with the aid of a computer had shown that the deviation against time might be represented as a straight line curve with a good degree of correlation.

The cost of this deviation might be found using the shipbuilders' correction factors, knowledge of the total fuel consumption and the cost of fuel. This was shown as a straight line in Fig. 10.

However, the area under this line represented the accumulated cost of additional fuel because of this trend, and was shown by the parabola in Fig. 11.

For the developed economizer example, the cost of corrective action could be sub-divided under three headings:

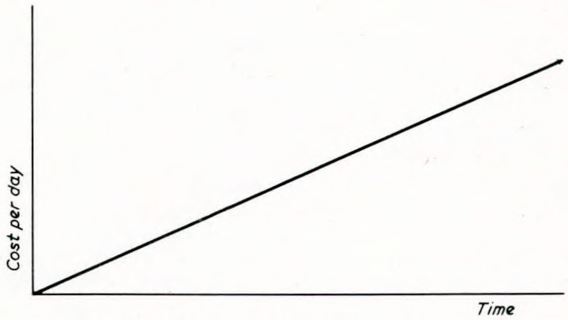


FIG. 10—*Relationship of cost per day and time*

1) time lost due to slow down: since the boiler would have to be out of action while the procedure of water washing took place — this could be costed:
2) manpower — similarly this could be costed:
3) materials: here the water requirement must be included, and fuel used in non-propulsive purposes, namely flashing up.

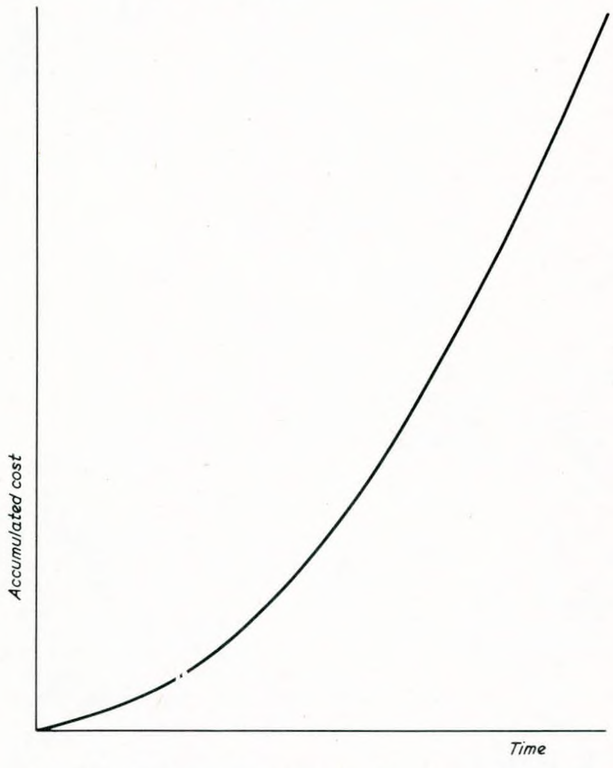


FIG. 11—*Relationship of accumulated cost and time (1)*

The sum of these three figures represented the cost of the corrective action.

When a corrective action was taken this might be represented as a vertical line, and assuming the action was carried out at equal time intervals of t_1, a line could be produced as shown in Fig. 12.

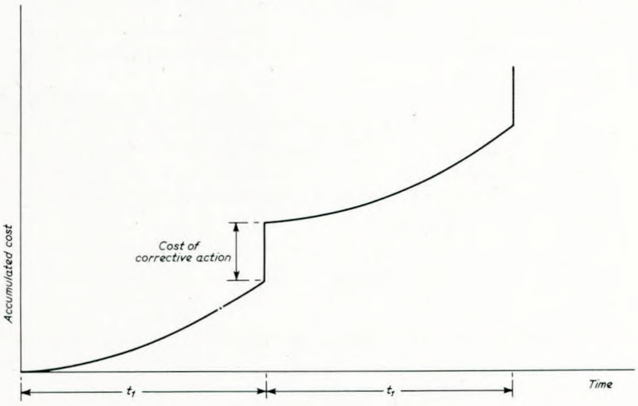


FIG. 12—*Relationship of accumulated cost and time (2)*

The decision to take corrective action might have been made by various rules — calender time, running hours, or pre-set deviation limit.

Fig. 13 showed three conditions:

a) a straight parabola representing the accumulated cost over the time shown with no corrective action taken:
b) a continuous line as developed in Fig. 12:
c) a dashed line which showed a more cost effective result.

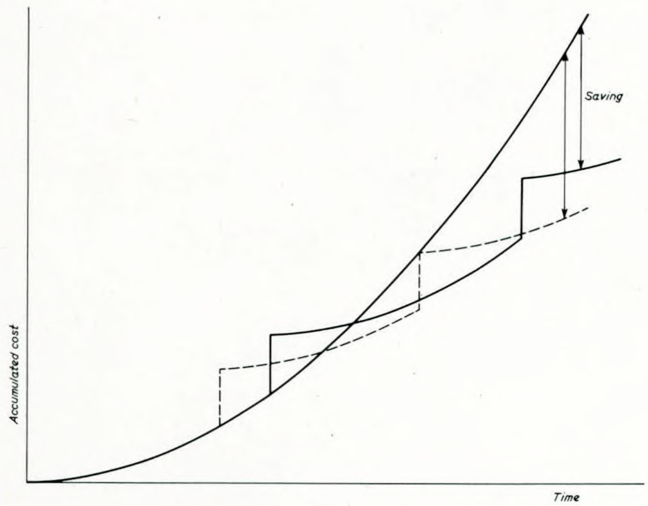


FIG. 13—*Relationship of accumulated cost and time (3)*

. The difference in accumulated cost (saving) from condition a) has been taken as the shown basic.

In the developed example the dashed line showed the most cost effective result, and Mr. Thomas suggested it was the total realization of cost effectiveness in this instance.

The mechanics of operation of such a system of maintenance could be easily carried out on board. The only initial expense being a calculator capable of performing a least square linear regression. This was necessary for the accurate determination of the deviation. Further the system was equally adaptable to part load steaming conditions, with variation of the corrective action cost.

Mr. Thomas summed up by saying for maximum cost effectiveness and economic use of manpower, corrective action should be carried out when the cost of the correction equalled that of the accumulated cost due to the linear deviation.

To prove this mathematically, Mr. Thomas wrote the following after the meeting.

The system of maintenance described in the discussion was applicable when a series of corrective actions were required over the life of a ship when the rate of change of deviation was constant.

Let the cost £/day $= mt$ (Fig. 10). (m being a constant for given trend conditions and incorporated the cost of unit deviation in unit time).

Then the accumulated cost (AC) over time t could be expressed

$$AC = \int_o^t mt.dt = \frac{mt^2}{2} \qquad \text{(Fig. 11)}$$

With reference to Fig. 12, let corrective action take place at t_1 and the cost of this action be k.

Hence AC immediately before correction action taken

$$= \frac{mt_1^2}{2}$$

and AC immediately after corrective action taken

$$= \frac{mt_1^2}{2} + k$$

Let $t_2 = 2t_1$ and further corrective action taken AC immediately after this action at t_2

$$= \frac{2mt_1^2}{2} + 2k$$

In the general case let $T = nt_1$ where n was a number of corrective actions.

AC immediately after action at T

$$= \frac{n.mt_1^2}{2} + nk$$

If no corrective action had been taken T. AC with no corrective action taken

$$= \frac{m\,T^2}{2} = \frac{m\,(nt_1)^2}{2}$$

Difference in $AC = \Delta AC$
= (cost if no corrective action taken) –
(cost of deviations and corrective actions)
Hence at time T

$$\Delta AC = \frac{m}{2}(nt_1)^2 - \left[\frac{n.mt_1^2}{2} + nk\right]$$

$$= \frac{mT^2}{2} - \frac{mT^2}{2n} - nk$$

$$\frac{d\Delta AC}{dn} = -\frac{mT^2}{2n^2} - k = 0$$

$$\therefore n = T\sqrt{\frac{m}{2k}}$$

but $T = nt_1$

$$\therefore t_1 = \sqrt{\frac{2k}{m}}$$

AC at t_1 immediately after corrective action

$$= \frac{mt_1^2}{2} + k = \frac{m2k}{2m} + k = 2k$$

$$\frac{d^2\Delta AC}{dn^2} = \frac{-mT^2}{n^3} \therefore \text{maximum}$$

Hence from the above example the maximum difference in accumulated cost (saving), corrective action should be carried out when the accumulated cost equalled that of the cost of the corrective action.

MR. D. W. SMITH, M.I.Mar.E., contributed to the discussion by saying that regarding classification, was Mr. Batten suggesting that the present system of annual and quadrennial surveys (five-yearly in the case of ships on continuous survey) of hull and machinery, be abandoned, in favour of inspections at staggered intervals? If so, did he feel that such intervals should be determined by analysis of equipment performance — reliability data, mean time between failure, etc. or did he feel that for such a system to be viable, extensive continuous monitoring of plant and perhaps hull would be necessary?

From the computer records at Bureau Veritas of machinery breakdowns, it could be noted that many failures were unfortunately the result of bad workmanship. From this point alone, any means of reducing unnecessary opening up of plant were to be welcomed. It must, however, be borne in mind that the five year continuous survey cycle interval was such that many machines coming within its scope would require opening up for overhaul on more than one occasion during the five year span. There was no requirement to open up such machines especially for survey, but merely to call the surveyor in on one such occasion at no greater than five-yearly intervals.

It was unlikely that any real application of a maintenance inspection procedure based on statistical information could be satisfactorily applied to ships' plant for the following reasons:

1) lack of data on similar plant;
2) rapidly changing technology and variety of plant types made widespread data acquisition difficult;
3) many significant machinery failures were not time dependent.

That an eventual deviation of classic ship survey was a distinct possibility, had been evident for some time. About eight years ago, M. Monceaux, head of Bureau Veritas Electrical and Research Department said at a CIMAC Conference that condition monitoring of ship machinery could lead to a change in the present system of class survey. At that time, however, monitoring equipment suitable for reliable application on ships was not commonplace. As the author said in his paper, reliability and accuracy of monitoring equipment had increased, due not a little to environmental testing carried out for AUT and similar designations, although it had been found that many manufacturers have questioned the stringent test procedure demanded by classification societies. Even now, however, as shown by a recent extensive enquiry by the contributor's Society into this subject, with particular reference to the diesel engine, few of the sensors required for this application demonstrated a reliability high enough to cover, without maintenance, the normal machinery running period. It was interesting to note in connexion with this study — carried out on behalf of a diesel engine builder — that more than 70 sensors would be required to adequately monitor the performance of the engine. These were itemized in the June 1974 issue of *Bulletin Technique* published by the Society.

Apart from the various onstream sensors that could be fitted to a machine and linked up to a computer to assess optimum maintenance intervals, there were a number of useful tools available to help an operator or surveyor to assess the state of a machine while minimizing the amount of strip-down. Mr. Batten had already mentioned vibration analysis and the fibre optics (sometimes known as a borescope or endoscope). While the former might be open to some criticism because the results could be grossly misinterpreted by an inexperienced operator, judicious use of the latter could be extremely beneficial, permitting the eye to see, in good light, internal components with very little strip-down. On some ships, however, the surveyor was hard pressed to find a 0–1 micrometer, never mind an endoscope.

Mr. Smith felt that an area worth closer attention was the analysis of lubricating oil for metal content. This could be performed by spectrometric or ferrographic analysis, both of which were presently receiving some investigation by his Society. One of the big problems of this approach was the frequency of sampling required. He understood, however, that the Admiralty Material Laboratory had had good results from an on-line monitor using x-ray fluorescence and further news of progress in this direction would be most welcome.

Any scheme whereby relaxation might be allowed of survey requirements for ships in service must, however, be approached with caution. Even now the practice of allowing some survey work to be carried out by chief engineers was open to criticism — not that the ability of the chief engineer was in doubt, but the question arose as to whether the additional responsibility incumbent on him was desirable — hence the reluctance to allow chief engineers to carry out boiler special surveys. How much more careful then must the attitude of classification be if asked to rely on data recorded by equipment not under the direct control of the surveyor when trying to assess the condition of hull or machinery.

MR. R. A. LORGE, B.Sc., M.I.Mar.E., said the author's paper raised the question of whether the problem of maintenance in general was not a great deal more intractable than anything so far met with in management. Obviously the single maintenance job presented no problem in itself by the number and variety of jobs, the ramifications of cost and technical control, the lessons to be learnt for choosing future equipment: these were all aspects which worked right through the management structure in an almost insiduous and barely recognized manner.

The result was that many problems at present oscillated like wattless current between ships' engineers, shore managers, suppliers and classification societies, without ever reaching a solution and therefore incurring their costs indefinitely.

Was there perhaps a single, as yet unknown quantity? He believed the author gave the answer under point (4) of his New Approach section, in one sentence. Mr. Lorge quoted:

> "The philosophy the Society is seeking is one where information gathered during the day-to-day running of the ship is being used to provide a sound technical basis on which to take maintenance decisions."

So it was in fact information that held the key to virtually all the problems the author outlined. It had already been established beyond reasonable doubt that where reliable data was collected on board ship and was then processed by specialists ashore, a surprisingly clear and comprehensive picture emerged of each piece of equipment on each ship, at remarkably small effort and expense. Equally clearly emerged the correct maintenance policy, its costs, and its financial viability.

What was the alternative? With the present lack of cost numeracy in maintenance, many of the problems remained entirely hidden whilst for others the cost of an improvement could not be properly justified, and even if an improvement *was* achieved, no-one could prove its financial success as it receded into the mists of time and crew changes.

It followed that no amount of exhortation would lead to maintenance improvements unless there was first the discipline of financial case and second, the means of measuring the financial success finally achieved. In fact there was a strong argument for not attempting maintenance improvements at all until these conditions were met.

The impact of such an information system on shipowners and classification societies alike could well be enormous. The author's Society might be well-placed to take a lead in this matter as a valuable addition to their surveillance techniques or services to shipowners.

The author's comments would be very welcome, particularly if he could give his view on how much a shipowner would be justified in spending on such a system annually.

MR. R. S. SYMON, F.I.Mar.E., said the author had presented a paper which contained some candid, but welcome, comments concerning ship maintenance systems. Colleagues from the ship operations sector of the industry would, no doubt, recognize many of the problems Mr. Batten had pinpointed and perhaps if there were some not recognized, this paper had given warning.

The author opened his paper by recalling a challenge he recognized in a paper on planned maintenance (P.M.) presented nearly two decades ago. Mr. Symon's own experience of P.M. began in 1967 with a simple calendar based system. In retrospect the system might be criticized for containing some of the faults Mr. Batten outlined. However, he would emphasize that, of necessity, it fulfilled the need of the day. The major problem then was the loss of continuity of shipboard maintenance due to reduced periods of service between leave of engineer officers. This first P.M. system, and he suspected it to be true of others, replaced the lost continuity by a comprehensive system of maintenance scheduling, which was — he dared say it — printed out quarterly by computer.

However, the shortcomings of a purely calendar system were recognized from the outset and with the advent of reliable condition monitoring equipment the opportunity was taken to revise the system. Development work took place during 1972 and to date he had been associated with the equipping of 26 ships to operate a preventive maintenance system, based on condition monitoring, for auxiliary machinery.

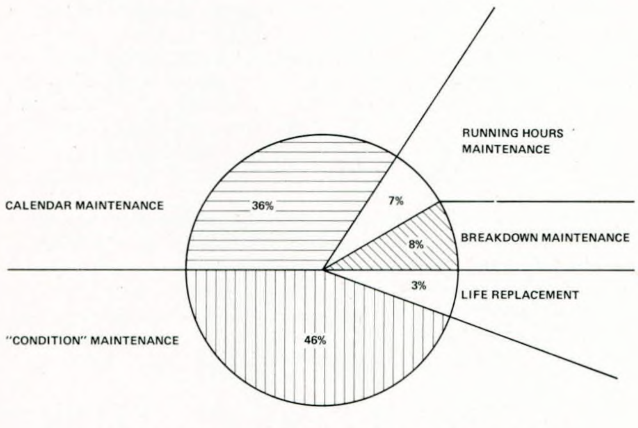


FIG. 14—*Preventative maintenance categories*

Several categories of maintenance were involved, the proportions of which were illustrated in Fig. 14. Briefly, examples of the content of each category were:

Revised Maintenance Categories	Examples
Calendar maintenance	Deck machinery, fire fighting equipment, safety equipment, etc.
Running hours maintenance	Diesel generators, cargo pumps.
Breakdown maintenance	Minor non vital services such as domestic S.W. pumps.
Life replacement	Cabinet refrigerators, iced water dispensers, washing machines.
Condition monitoring	All machinery which could be satisfactorily maintained by this method.

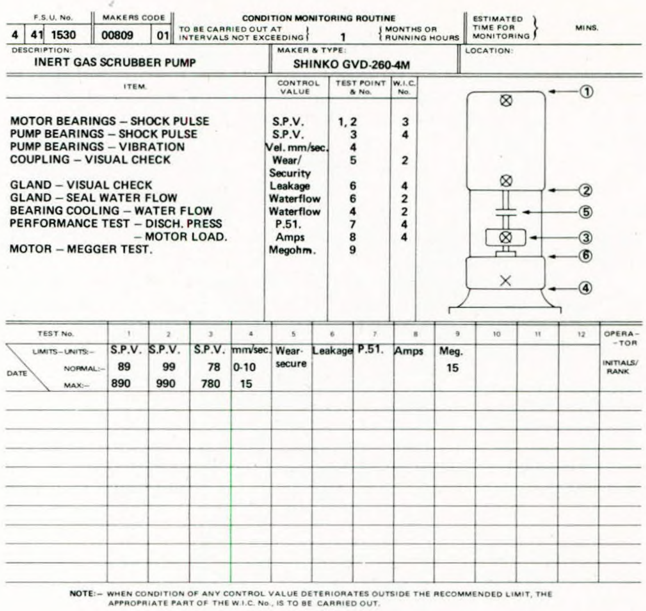
The condition monitoring sector utilizes several techniques which included:

1) visual inspections:
2) physical performance checks:
3) insulation tests:
4) ultrasonic tests:
5) vibration analysis:
6) shock pulse measurement (S.P.M.)

It was the last two techniques which were perhaps more relevant to the paper. Vibration analysis had been described by the author, and he would add that in his experience there was convincing evidence to support the extensive use of selective vibration analysis. However, he would draw the author's attention to another equally valuable tool in the diagnostic techniques toolbox — the shock pulse meter.

Shock pulse meters were used extensively in this preventive maintenance system to monitor the condition of ball and roller bearings. The meter sensed impact velocity indirectly through an acceleration sensing transducer which, after signal processing provided an analogous reading. Deteriorating ball and roller bearings caused mechanical impacts which were readily measured by the S.P.M. technique.

Fig. 15 showed a condition monitoring record card which included S.P.M. tests. In this example an inert gas scrubbing



F.S.U. No.	MAKERS CODE	CONDITION MONITORING ROUTINE	ESTIMATED TIME FOR MONITORING
4 41 1530	00809 01	TO BE CARRIED OUT AT INTERVALS NOT EXCEEDING 1 MONTHS OR RUNNING HOURS	MINS.
DESCRIPTION: INERT GAS SCRUBBER PUMP		MAKER & TYPE: SHINKO GVD-260-4M	LOCATION:

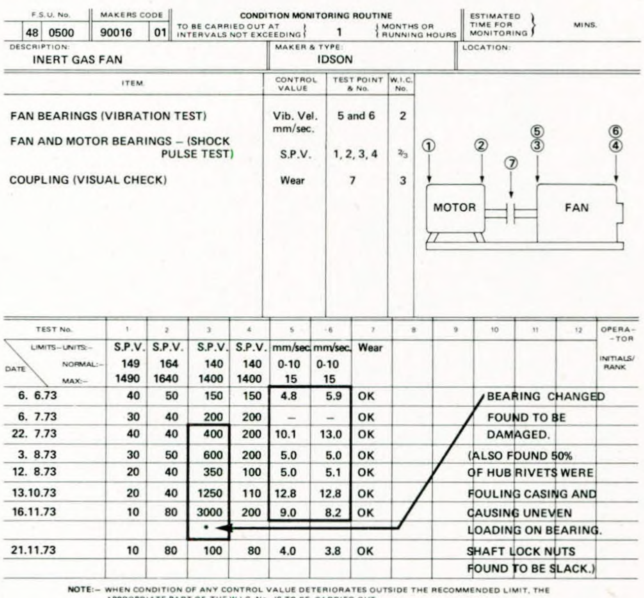
ITEM.	CONTROL VALUE	TEST POINT & No.	W.I.C. No.
MOTOR BEARINGS – SHOCK PULSE	S.P.V.	1, 2	3
PUMP BEARINGS – SHOCK PULSE	S.P.V.	3	4
PUMP BEARINGS – VIBRATION	Vel. mm/sec.	4	
COUPLING – VISUAL CHECK	Wear/ Security	5	2
GLAND – VISUAL CHECK	Leakage	6	4
GLAND – SEAL WATER FLOW	Waterflow	6	2
BEARING COOLING – WATER FLOW	Waterflow	4	2
PERFORMANCE TEST – DISCH. PRESS	P.51.	7	4
– MOTOR LOAD.	Amps	8	4
MOTOR – MEGGER TEST.	Megohm.	9	

TEST No.	1	2	3	4	5	6	7	8	9	10	11	12	OPERA-TOR
LIMITS–UNITS:–	S.P.V.	S.P.V.	S.P.V.	mm/sec.	Wear-secure	Leakage	P.51.	Amps	Meg.				INITIALS/ RANK
DATE NORMAL:–	89	99	78	0-10					15				
MAX:–	890	990	780	15									

NOTE:– WHEN CONDITION OF ANY CONTROL VALUE DETERIORATES OUTSIDE THE RECOMMENDED LIMIT, THE APPROPRIATE PART OF THE W.I.C. No., IS TO BE CARRIED OUT.

FIG. 15—*Condition monitoring record card*

tower sea water supply pump was subjected to nine checks at regular intervals. On the top left section of the card the checks were delineated and the check position identified on the right hand side. The numbered columns below were for recording the check values, each column number corresponding to the unique check point and check description number.



F.S.U. No.	MAKERS CODE	CONDITION MONITORING ROUTINE	ESTIMATED TIME FOR MONITORING
48 0500	90016 01	TO BE CARRIED OUT AT INTERVALS NOT EXCEEDING 1 MONTHS OR RUNNING HOURS	MINS.
DESCRIPTION: INERT GAS FAN		MAKER & TYPE: IDSON	LOCATION:

ITEM.	CONTROL VALUE	TEST POINT & No.	W.I.C. No.
FAN BEARINGS (VIBRATION TEST)	Vib. Vel. mm/sec.	5 and 6	2
FAN AND MOTOR BEARINGS – (SHOCK PULSE TEST)	S.P.V.	1, 2, 3, 4	2/3
COUPLING (VISUAL CHECK)	Wear	7	3

TEST No.	1	2	3	4	5	6	7	8	9	10	11	12	OPERA-TOR
LIMITS–UNITS:–	S.P.V.	S.P.V.	S.P.V.	S.P.V.	mm/sec.	mm/sec.	Wear						INITIALS/ RANK
DATE NORMAL:–	149	164	140	140	0-10	0-10							
MAX:–	1490	1640	1400	1400	15	15							
6. 6.73	40	50	150	150	4.8	5.9	OK			BEARING CHANGED			
6. 7.73	30	40	200	200	–	–	OK			FOUND TO BE			
22. 7.73	40	40	400	200	10.1	13.0	OK			DAMAGED.			
3. 8.73	30	50	600	200	5.0	5.0	OK			(ALSO FOUND 50%			
12. 8.73	20	40	350	100	5.0	5.1	OK			OF HUB RIVETS WERE			
13.10.73	20	40	1250	110	12.8	12.8	OK			FOULING CASING AND			
16.11.73	10	80	3000	200	9.0	8.2	OK			CAUSING UNEVEN			
			•							LOADING ON BEARING.			
21.11.73	10	80	100	80	4.0	3.8	OK			SHAFT LOCK NUTS			
										FOUND TO BE SLACK.)			

NOTE:– WHEN CONDITION OF ANY CONTROL VALUE DETERIORATES OUTSIDE THE RECOMMENDED LIMIT, THE APPROPRIATE PART OF THE W.I.C. No., IS TO BE CARRIED OUT.

FIG. 16

Fig. 16 showed a result from this part of the monitoring system which demonstrated S.P.M. technique. In this case an inert gas fan. Column three showed the record of S.P. measurement at bearing three over a number of months. The reading continued to rise yet there was no evidence of deterioration detectable to the human senses. In fact even when the bearing was removed from the machine, ship's personnel could not detect any fault until the bearing had been degreased.

Readings obtained after bearing renewal contrasted sharply with those before, and illustrated a further important advantage of these techniques: that was the provision of the facility to quickly confirm bearings had been replaced properly and were functioning correctly. He would, therefore, disagree with the author's implication that only vibration equipment should be used for ball bearing monitoring. He would emphasize that the system thus briefly described depended upon portable equipment costing only a few thousand pounds and in no way required sophisticated computer back up. A 15 per cent reduction in spare gear usage would quickly pay off the investment.

Mr. Symon wished to make one further point which concerned the terminology used by Mr. Batten. He preferred to see these modern techniques described under two headings rather than one. They were condition monitoring and performance monitoring.

Condition monitoring was the technique which enabled the physical and material condition of machinery to be measured without dismantling for the purpose of deciding when, to avoid breakdown, preventive maintenance should be done.

Performance monitoring was the technique which enabled the efficiency of machinery and systems to be measured while in use for the purpose of deciding, by comparing the cost of doing work with the incremental higher fuel cost of reduced efficiency, when tuning, adjusting, and maintenance should be done to restore efficiency.

Mr. Symon considered this division desirable and would recommend these definitions because a condition monitoring system could be developed and installed quite independently from performance monitoring. The latter was also likely to require a higher degree of sophistication.

Mr. G. Taylor, F.I.Mar.E., in his contribution said: planned maintenance systems were many and varied, with the more complex ones involving the exchange of an immense number of cards or forms between head office and ship, whereas what was required was a simple flexible system, with the minimum exchange of paper between ship and office, and run by the minimum of staff.

Having said this, the simplest system he had seen so far, involved a planned maintenance programme stored in a computer: the facility of the massive memory bank available in the computer allowed overhaul and maintenance schedules to be varied as required and provided great flexibility.

The author's mention of avoiding the term "computer controlled" was heartily endorsed — one must avoid any connotation of "big brother was watching" for any measure of success in operating an ocean-going fleet of ships must be a co-operative effort dependent on intelligent inter-flow of information of all sorts between the ship's staff and shore.

Due to the present day conditions of short tours of duty, it was no longer possible to ensure continuity of ship maintenance by the individual chief and/or second engineers, they seldom returned to the same ship at the conclusion of their leave. However, the necessary continuity and progression of various maintenance jobs at their planned frequency was readily and accurately produced by the computer in the form of a "print-out" and the work load spread evenly. It was important to record the computer never forgot a schedule — provided it had been correctly programmed by the planning team.

Mr. Taylor went on to describe the programme in more detail. Prior to joining his ship, a chief engineer visited head office for the usual briefing on his coming tour of duty, at the same time receiving and discussing a copy of the print-out of maintenance schedule — which was personal to him, even to bearing his name — and covered only his particular tour of duty: precisely what times were due for maintenance and/or survey during that tour, and detailing the amount of work involved in each schedule.

On joining his ship, the chief engineer was able to refer to the schedule and ensure all necessary spares and materials were on board prior to sailing, and plan with his engineering staff how they would progress with the maintenance schedule through the voyage: reasonable tolerances were allowed within the schedule to give the chief ample flexibility to satisfy cargo and charter requirements.

As the voyage and the work progressed, a single preprinted sheet was filled in (a carbon copy being filed on board) noting the maintenance items completed, the spare gear used and recording essential calibrations and where necessary, spares or special attention required at the next scheduled planned maintenance on any particular unit.

Each sheet was mailed to head office where it was carefully analysed by the fleet superintendent and by the maintenance superintendent and then transferred to the machine for use in the next print-out or enquiry report.

Mr. Taylor believed the above scheme had the essence of simplicity. It was most satisfying to note the acceptance of the scheme by fleet chief engineers, as was shown by the fact that originally, some 30 sheets per year were sent from ship to office, now with increasing demand from chief engineers for more knowledge and a greater involvement in ship management procedures, which his company welcomed, about 52 sheets per year were received from each ship.

Furthermore, Mr. Taylor's company have found when chief engineers reported personally, they described how they were able to involve all their engineering staff in planning discussions and how junior engineers showed greater enthusiasm and interest in completing the practical work content involved, recording and documenting spares used and required, which, he said, surely brought a dividend of one sort or another.

To assist the office based management team there was an added bonus, for it was possible to obtain very quickly from the computer helpful summarized reports whenever required on subjects such as:

1) warnings of overdue maintenance:
2) comparisons of breakdown of a unit or units across a class of ships:
3) analysis of breakdowns:
4) warnings of repetitive breakdowns:
5) complete history of any particular unit across a class of ships:
6) the situation of survey cycle:
7) index of machinery units with details of maker, type, number, etc.

As this type of information built up in the computer memory bank, so the usefulness of this facility would increase and would be available for new design in the future.

As experience increased in the operation of this simple planned maintenance system it was hoped to expand in very much the manner Mr. Batten suggested, with individual job description cards for major essential schedules — and, perhaps — the ultimate provision of complete voyage budgets for chief engineers.

Referring now to Mr. Batten's concluding paragraph, Mr. Taylor agreed it was essential that classification societies should take a look at planned maintenance systems being developed by shipping companies, for these were often more comprehensive and stringent than class requirements.

For example, in operating the simple system briefly outlined above, Mr. Taylor's own company:

a) calibrated main engine crankshaft deflexions ten times during a five year cycle although this in itself was not a class requirement:
b) took main bearing readings (by poker gauge) five times more frequently than required by class:
c) overhauled fuel injectors ten times more frequently:
d) opened up for inspection main engine pistons and liners three times more frequently:
e) took megger readings of all electric circuits 12 times as frequently:
f) opened for inspection sea pumps five times as frequently:
g) opened for inspection boiler feed pumps ten times as frequently.

It was suggested that in the case of a shipping company operating an approved planned maintenance system and with closer liaison between the company and classification local office, would be progress towards safer operation, safer maintenance — safer, surely, than the present irregular visits by different surveyors in many different world ports.

Such closer liaison could include perusal of chief engineer's reports and logs, and would enable classification to gain a more intimate knowledge of the owner's operations which surely would be of advantage to the marine insurers.

Mr. J. L. Buxton, said Mr. Batten drew attention to the role of the classification society when he stated:

> "Classification, as such, is not concerned with plant efficiency or economy, but with safety and reliability . . ."

Reliability could mean different things to different people but in the context of classification a reasonable definition would be:

> "Reliability was the probability that equipment would perform its purpose adequately for the period of time intended under the operating conditions encountered."

Reliability could be quantified in mathematical terms with a high degree of accuracy but usually a great deal of data was required in order that the statistics of probability were truly meaningful. It was worth mentioning that 100 per cent reliability could only be achieved if a component operated satisfactorily for an infinite time. Since a ship's life was expected to be, for example, in the order of 25 years it could not be expected for any equipment on board to be 100 per cent reliable. That was not to say a particular item of equipment would fail during that time period, but there was always a definite probability that it might fail.

Before any attempt could be made to determine the level of maintenance an item of equipment would require, it was necessary to be aware of the failure pattern that equipment might experience.

If a typical failure distribution was considered for any piece of equipment or system, it would fall into three fairly obvious groupings:

1) early failures:
2) chance failures:
3) wear out failures.

Conditions of health monitoring of that equipment or system would not predict early failure or chance failure. It could, however, be of tremendous benefit in predicting wear out failure. Fortunately it was the prediction of wear out failure which had the most significance on any maintenance routine and the continuing reliability, at a given level, of the equipment.

Early failure could generally be attributed to faulty manufacturing or poor workmanship and became apparent during trials or the "burn-in" period. While these failures might be high they did not affect the reliability of the equipment since they were ironed out or debugged before the ship went into service. Occasionally they might be carried over into a maiden voyage but thereafter were not a factor in reliability considerations.

Chance failures occurred suddenly without preceding deterioration symptoms. The physical mechanism of such failure was debatable but was usually attributed to a sudden accumulation of stresses acting on and within the component. From a routine maintenance and scheduling point of view it was important to appreciate that while chance failures occurred at random time intervals, over a sufficiently long period of time they would be constant. If sufficient data was available, the constant could be predicted and accordingly the level of machinery down time and corrective maintenance required could then also be predicted.

Wear out failures began to appear at the end of a component's useful life and the longer equipment was operated after its useful life the greater the failure rate. In the past, wear out of components had been assessed by manual inspection, necessitating opening up of machinery. Very often the crucial mistake of replacing components with new ones was made simply because they had run to a given number of hours even though the useful life of these components had not been reached. This did not increase reliability but decreased it since early failure symptoms were introduced once again. It was also a fallacy to believe that chance failures might be eliminated or reduced by regular replacement of components which were still in their useful time domain.

Condition monitoring could be a valuable aid in predicting the onset of wear out failure and it was only at this time that components should be replaced or overhauled, unless, of course, corrective maintenance for chance failure was necessary.

Used intelligently with results and trends interpreted correctly, condition monitoring would increase reliability as defined for classification purposes and should lead to considerable economies.

Correspondence

Dr. R. A. Collacott, F.I.Mar.E., in his written contribution, said the paper was especially valuable in the introduction of a pyramid concept by which activities escalated from the initial concept of "Design for Maintenance" to the pinnacle of "Condition Monitoring" and "Trend Prediction Systems". As a person intimately involved in the training of engineers, the author's pyramid indicated the interdependence of all classes of engineer in the maintenance function — and this ranged from shore based design engineers to technical ship board engineers to laboratory based engineers — scientists.

It was in this more advanced phase concerned with condition monitoring and trend prediction that much of the future of ship maintenance was likely to lie: despite the author's comments concerning computers, these were developing to a high state of reliability and were becoming so familiar to engineers, particularly in the mini-computer forms — that considerable use could be made of their facilities for multiple-scanning numerous sensors and in using their memory for data comparison purposes.

It was interesting to note that the UK Mechanical Health Monitoring Group, which Dr. Collacott formed as a means of providing a forum for persons interested in monitoring to meet and discuss progress had developed rapidly during its twelve months existence with several hundred registered members and an attendance at the last meeting in excess of 140 delegates. The next meeting would be dealing with developments in performance monitoring, which had gone a long way since the days of the old manually written engine room log, but which still provided an adequate data basis for experienced and knowledgeable engineers to be able to interpret what was going on.

Possibly the use of the phrase "experienced and knowledgeable engineers" was the nub of the problem. With the complexity of modern installations and the pressures of shipboard life on frequently changing crews the ability to get to know a machinery installation was missing. Getting to know such an installation was in effect learning the "signature" of the installation, whether it be the sound, the feel (vibration), the smell (leaks), or the look, all could be sensed and appropriate signatures used in a condition monitoring and trend extrapolation system.

Dr. Collacott felt the author could have included in this section of the paper reference to many other forms of sensing, not least that of contaminant monitoring and not forgetting the ubiquitous magnetic plug inspection technique.

Mr. E. F. Kirton, F.I.Mar.E., wrote after the meeting, that as the author was no doubt aware, there was interest in the concept of condition monitoring at government level through the Committee for Terotechnology. This interest had led to certain investigations aimed at determining potential economic benefits of the wider adoption of condition monitoring techniques to the nation. Predictably the investigators' findings had postulated that a significant part of the nation's £500 million annual industrial maintenance bill could be saved by the widespread use of condition monitoring techniques. It would be interesting to learn whether the background of the paper related to these facts or was the result of an independent marine initiative born as a result of totally independent observations regarding recent advances made in the field of marine automation by certain foreign manufacturers. Either way the author's views, assembled as they were from an intimate knowledge of recent automation and maintenance trends were an important extension in a detailed sense to the automation symposium referred to in the paper.

The contributor would be grateful, however, if the author would go into even greater detail by suggesting specific items of marine machinery which, on evidence, appeared particularly amenable to a condition monitoring technique or would appear to warrant development effort. Clearly a priority requirement should be based upon safety or economic considerations. On this assumption it was suggested that the development of a device for use in medium speed trunk piston engines, which could herald early warning of lubricating oil contamination or deterioration would be a particularly valuable asset, more urgently needed in a marine environment perhaps than vibration orientated devices. A further suggestion was that the creation of a few simple searching questions concerning basic requirements might prevent a re-occurrence of the over-zealous application which had accompanied some automation equipment in the past. For example, justification might well derive from the following questions:

1) Were the consequences of undetected machinery failure with regard to cost, danger to life or the environment likely to be:

a) catastrophic:
b) serious:
c) minor.

2) Justification to proceed with condition monitoring should then query the proposal by asking: Was the proposed technique superior or equivalent to manual detection abilities:

i) because of the continuous nature of the surveillance:
ii) because of the sensitivity of the proposed technique:
iii) because of the unacceptable disturbance necessary for manual detection:
iv) or was the proposal a supplementary deterioration detection technique?

An unsatisfactory reply to these queries might well encourage development effort. The author's comments on these suggestions would be appreciated. His definition of condition monitoring would also be welcome since some would argue that condition monitoring had been with us, to some extent, for years. A tell-tale hole, for instance, often used in machinery to reveal a seal failure was surely monitoring the seal condition. The inference of a necessary association with complex electronic devices did not therefore appear valid.

Author's Reply

Mr. Batten was grateful to those members who had taken part in the discussion, both formally at the meeting and informally after the meeting, and to those who had taken the trouble to write. Maintenance and monitoring concepts were, after all, in their infancy and it was important that views should be freely interchanged at this stage.

Mr. Thomas was quite right when he said that a "Trend Prediction System" was not in itself the apex of the idealized pyramid (Fig. 8). The inference however, behind such a system was that at this stage of development sufficient information was being gathered and could be analysed to show not only the trends, but also the consequences of such a trend against time and cost. Regression analysis of function deviation then became an integral part of trend prediction, and this was what Mr. Thomas was seeking. There were already a number of "package" systems on the market which had this approach.

While agreeing with Mr. Smith that much marine machinery was opened up more frequently than once during the five years continuous survey cycle, the advantages of a planned maintenance scheme were such that some of this could be done carefully on passage rather than of necessity, having to fit it in during a rapid turn-round at a port where a surveyor was available. This in itself constituted a hazard, particularly with smaller items, where there was always considerable risk of wrong re-assembly. On the other hand the author never intended that maintenance inspection should be based entirely on statistical information. It was the use of all available information as a basis for technical appraisal that was important. It was true that to attempt to gather statistical data on ship's plant could be a thankless task with the constant minor variations introduced by manufacturers. Nevertheless, many shipowners tried to introduce some standardization within their fleet, as not only did the information they were able to gather provide a useful basis for dialogue with manufacturers, but also the capital tied-up in spares could be reduced.

The urge for statistical information was always dangerous as it could so easily lead to a discouragement of new or possibly adventuresome development.

The author was glad Mr. Smith had raised the question of the reliability of sensors. So often the need to carry out maintenance and checking on the sensors themselves was ignored. In many cases this was due to the rather optimistic claims to accuracy made by sensor manufacturers without any reference to possible deterioration during their working life. Although environmental testing had aided the ironing out of bugs in most sensors and other monitoring equipment it was reasonable to conclude they would then require the same amount of care and attention as the machines they monitored. The major danger, in the author's view, of using too many sensors to monitor engine performance was that of being lulled into a false sense of security and relying on the monitoring to "stop the job" if disaster threatened, rather than using deviations from the norm as an early warning system against increasing deterioration. Though there were computer programs available which would do this both in terms of performance deterioration and optimum maintenance costs as suggested by Mr. Thomas, there was, in the end, no substitute for practical interpretation and experience. No matter that borescopes were liable to be misused or the results from vibration plots or shock pulse meters misinterpreted — the same accusations were levelled at crack detection and ultrasonics when first introduced. We must make ourselves adept at interpretation and analysis with whatever new instruments were developed if knowledge of the machinery used was to be increased. It was too easy to stifle progress under the name of caution.

Mr. Lorge had made a very useful contribution to the discussion in relating the concept of maintenance to the management aspect. Costing the value of maintenance was a very difficult task — in fact practically impossible to do from the outside, as each individual company had its own financial disciplines and methods of measuring financial success. Unfortunately the time scale was a long one, and it was usually not until a ship had passed out of the fleet was one able to analyse its lifetime maintenance costs against the cost of planning or monitoring, and even then one had to guess what those costs might have been had no planned maintenance been carried out. On the single ship basis, where a good planned maintenance scheme might cost some £30 000 to £40 000 it was reasonable to assume this was recoverable in reduced outside costs and spares in about 18 months. Where a sophisticated automatic monitoring and data analysis system costing some £150 000 was introduced, the write down period would obviously be longer, but if Mr. Thomas's philosophy was being followed the annual savings could be greater. Clearly, the moment standardization was introduced by building two or more sister ships the cost of basic planning was reduced drastically (by nearly 50 per cent) while the cost of system monitoring remained high. The hidden savings in the latter case however were going to be in terms of fuel, plant economy and crew "wear and tear" and these would be much greater as the complexity of the plant increased.

In the author's private opinion, a good general rule for guidance was:

1) Where a one-off ship was involved, or two or three sister ships having well proven diesel machinery, the first move should be to introduce a planned maintenance system supported by vibration, shock pulse, temperature monitoring or interval recording where a change in parameter would give a good indication of the onset of bearing wear or other troubles.
2) Where highly sophisticated and tender systems were involved in steam plant, etc: where every variation in performance could be related to increase in fuel and other running costs, then an equally sophisticated monitoring system could be justified over the life of the ship.

The author was grateful to Mr. Symon for giving some of his own company's experience in planned maintenance as this sort of information from a user was extremely valuable. The breakdown of preventive maintenance categories in Fig. 14 was especially interesting including, as it did, the idea of life replacement. The author believed this percentage would rise in time, particularly more packaged units were introduced in the electrical field. Mr. Batten was also pleased Mr. Symon had referred to shock pulse measurement — an important tool, mention of which had somehow been omitted from the paper. There was no longer any doubt that there were monitoring techniques which were extremely reliable and functional, but which were still regarded by some as being "black box magic". Maintenance, condition and performance monitoring demanded re-education of many seagoing and company staff. The sooner these techniques were recognized as being the inevitable price of progress, the sooner the value of these powerful tools would be appreciated.

Mr. Taylor had brought some useful practical experiences in his contribution and it was encouraging to hear an owner speak of the effectiveness of planning. It would have been interesting to know how far the spares planning was integrated into the scheme, and whether the chief engineer could be certain all spares were already on board to enable him to cover his voyage maintenance. It appeared that Mr. Taylor's company had assimilated and were applying all the precepts of good planning and personnel involvement with promising results.

Mr. Buxton had dealt with a most important aspect of planning in his contribution, namely, component reliability, and it was probably on this very subject that there was the least amount of knowledge available. Early failures and chance failures were a natural hazard of all equipment and were either built-in in the former case, or the result of external changes in the latter case. In any event they were unpredictable but not incurable. Wear out failures, however, were inherently a function of design and as such could eventually be predicted with some accuracy, although it was usually the case that by the time sufficient data had been collected to establish a norm the component was on its way to becoming obsolete.

Early replacement, as Mr. Buxton had said, was not the path to increasing reliability. Condition monitoring was certainly going to improve the reliability factor by pushing the essential replacement zone further towards the limit of the component life but maintenance was surely the key factor which would lead to an improvement in component life itself, and in this way to an increase in the reliability factor.

The author was grateful to Dr. Collacott for highlighting two important points in his contribution. Firstly, that involvement with maintenance covered the whole spectrum of engineers right from the designer, through the drawing office and installation team, and on to the last greaser in the engine room. There were many instances in the author's experience as a surveyor where effective maintenance was thwarted by thoughtless design or installation, and equipment was neglected because of the extra and unnecessary effort involved in getting at the job through a mesh of badly run pipework. Secondly, Dr. Collacott had written about getting to know the machinery — the "signature" of the installation. This was a very difficult thing to do in the face of rapidly changing crews, and it was particularly interesting that some large shipowners who were fully committed to maintenance found it worth their while to keep their senior engineers to one ship, or to one class of ship, as long as possible. This was another argument for fleet standardization as the changes could be rung so as to alleviate monotony, either of ship or companions, without losing the advantages of knowing the machinery.

To Mr. Kirton's comments the author would reply that this paper was initiated as a result of personal experience both in the practical surveying and survey record field and, more recently, with developments in control engineering. It was only during the writing of the paper the author became aware of governmental concern over the national maintenance bill.

Mr. Kirton had posed some very searching and most relevant questions concerning what to monitor and how best to do it. The author agreed wholeheartedly that once condition monitoring was contemplated there was a dreadful tendency to measure everything in sight. Questions needed to be asked and frankly answered as to the cost and danger of undetected failure, both with regard to the component and to the system of which it was a part. Also the degree of monitoring needed to be questioned, and it was here perhaps that the division between condition and performance monitoring as discussed by Mr. Symon became apparent.

Basically, the object of monitoring was to detect deterioration by either change in condition or performance so as to take action before complete failure occurred. In some cases a change in system performance (i.e., in a cooling system) would be sufficient to draw attention to the fact that trouble was developing in one of the individual components of the system, and these could then be individually checked. This could be sufficiently determined by interval monitoring. On the other hand cylinder lubricant failure on a medium speed diesel would not be detected quickly enough by a change in cooling water conditions to avert disaster, and some other method would need to be used.

It was the author's personal opinion that for performance monitoring it was in the field of medium and high speed diesels and high pressure temperature steam systems that research would be most rewarding, while for condition monitoring *in situ* inspection of turbines and gearing and contamination monitoring would be worthwhile projects for investigation. The author felt it would be wrong to attempt to lay down suggestions for specific component monitoring at this stage until everyone had a clearer picture of why monitor and what could possibly happen if it was not bothered with. In the main the answers to those questions would come from experience gained in planned maintenance, and the author believed that it was better for companies to approach this in the light of their own operation policy, than have requirements imposed on them from outside.