STEAM PLANT ANCILLARY EQUIPMENT

THE CONTRIBUTION OF ANCILLARY MACHINERY TO THE RELIABILITY OF STEAM PLANT

BY

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The following Paper was the opening address presented by the Author at the Convention on Steam Plant Ancillary Equipment arranged by the Steam Plant Group of the Institution of Mechanical Engineers, held in Edinburgh in April, 1967. It is reproduced by permission of the Institution.

Perhaps the inspiration for the title of this Conference came from a sentence in the opening address to the last Conference of the Steam Plant Group in Dublin in 1965. Mr. Booth said 'it is all too easy to forget that in a complex plant availability may be determined as much by what is traditionally called an auxiliary as by the main plant'. Recent experience in the Royal Navy has tended to highlight the role of ancillary equipment in determining availability for various reasons, not the least of which is increasing concentration on how to reduce the maintenance task.

Upkeep to Restore Reliability

Until the Second World War, boilers in the Royal Navy were cleaned after every 21 days' steaming and the period required for this afforded the time to restore the auxiliary machinery to a good state of reliability. With the adoption of boiler water treatment and increased attention to the purity of feed water the need for internal boiler cleaning between major refit periods almost disappeared and so did the periods in harbour allowed for this. For a time the Navy relied on the good sense of its operational staffs to allow intervals in harbour for ships to keep their machinery in a reasonable state. The need for proper planning of maintenance periods quickly became obvious, however, and the whole scheme of scheduled maintenance with a set number of days allowed in harbour in each four-monthly period was instituted. The object was of course to restore the reliability of the machinery during these days so that the operational period would be free of breakdowns. The scheme has proved successful in reducing substantially random defects in most ships, but the maintenance burden is a heavy one. The usage of ships has steadily risen over the past decade and the demands continue for still better availability for operations. The maintenance staff in most of our steam ships are watchkeeping at sea and the result of increased usage is that they have more and more to do in less time in harbour.

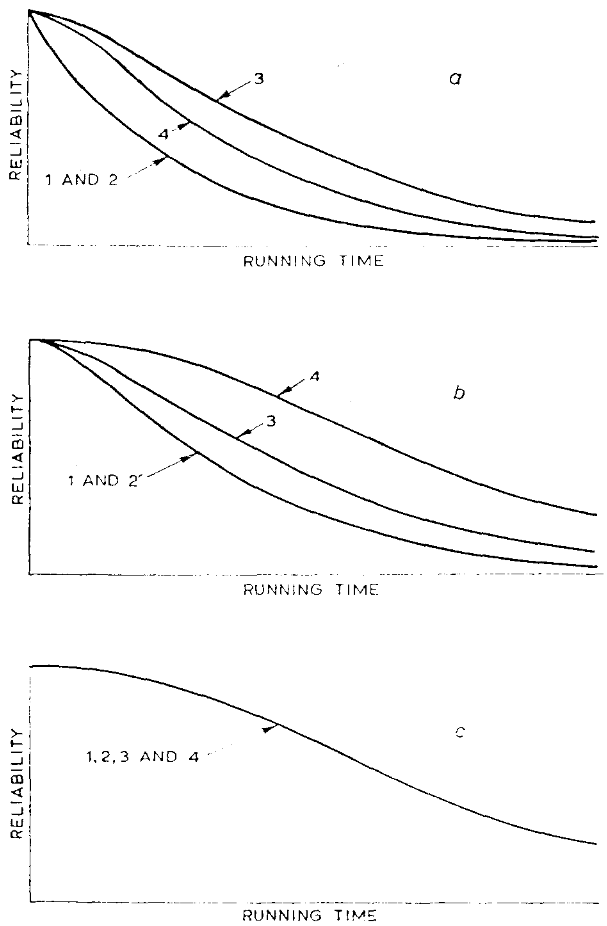
The Pattern of Failures in Steam Plant

The margins for satisfactory upkeep are thus very narrow and it is of interest that during 1965 the number of important defects in auxiliary machinery reported from ships as liable to affect their operational capability was twice the number reported in main engines and boilers. This ratio was curiously consistent with the number of unsolicited reports received from ships on the less important defects from which they suffered.

Much has been written about reliability in the last few years and if one draws out the components of a steam plant as a mathematical model and considers the reliability of the propulsion system as the product of the reliabilities of all the components, and if the reliabilities of the components themselves are considered in the same way as the products of the reliabilities of each of their parts, the figure of 2 : 1 for Ancillary to Main Machinery is surprisingly low. The reason for this is probably that auxiliaries are often duplicated and the time to rectify minor defects is often quite short. The failures referred to above as being reported are therefore normally in the 'catastrophic' class, such as the bearings of an auxiliary turbine failing and badly scoring the journals so that a new rotor complete had to be fitted. In such cases the defect is fully investigated and measures are taken to prevent a recurrence. One example of this has been a main boiler blower, which in one class of frigates was normally left ready for starting remotely from the control room when the ship was steaming on a cruising blower. The turbine exhaust valve was thus left open and the heat soakage was sufficient, with the turbine stopped, to cause sudden failure of the bearings on starting up. Now a separate motor-driven lubricating oil pump is being provided. This sort of thing is not, however, the major factor in steam plant's reliability. The vast majority of the burden of achieving reliability in ancillary systems is in dealing with an accumulation of minor defects. These are probably mainly due to dirt, water in lubricating oil and corrosion or erosion. Wear, as such, is not often a major problem, in fact the only case met recently in which wear played a major role was the case of the stand-by feed pumps in frigates. Every Petty Officer taking over the watch started up this pump just to make sure it was ready, so that this happened seven times a day. The wear resulting was considerable.

One of the difficulties in reducing the burden of minor defects, is to prove their cause. The Ship Maintenance Authority, which monitors the working of the Planned Maintenance System in the Fleet, now collects the job cards for the actual maintenance and repair work done in ships. This has revealed a substantial discrepancy between the minor defects considered by hard-worked engineer officers worth reporting, and those actually occurring, but which are put right as a matter of course during planned maintenance routine inspections. In one case, concerning the thrust bearing pads of a pump fitted in a large number of ships, it was discovered that in 56 per cent of those pumps examined during one year three pads had been replaced, while in the previous year the replacement of only 15 per cent had been thought worth reporting. There is much food for reflection on the tacit acceptance by some operators of the need to renew as a routine such parts which should not be subject to rapid wear. In this case it may well have arisen from dirt in the systems, combined with sludge formed from an extreme-pressure oil not really suitable for that particular service, but used to simplify storage and logistics.

This example has been chosen as fairly typical of potential failures in which each stage of the process, from early development to the eventual upkeep of the pump, may well have contributed to the trouble. In the design it was obviously not considered necessary to safeguard the pump by fitting a fine lubricating oil filter. The specification did not state that this was likely to be needed due to environmental conditions while refitting. The opportunity for the entry of dirt at the time of manufacture or when installed in the ship, or when refitted on board and so on are almost limitless, but from the designer to the operator, somewhere in the chain there was clearly insufficient recognition of the problem. And yet a corresponding acceptance of the risk of contamination in the main turbines or gearing in a ship would be unthinkable. Everyone is acutely aware of the need for cleanliness in these at every stage. This is perhaps the first hurdle to get over. This rather unsatisfactory example expresses



(*a*) Full power (*b*) Half power (*c*) Quarter power
All pump types assumed to have identical reliability
FIG. 1—RELIABILITY OF COMBINATION OF FEED PUMPS*

the wide scope of the problem of the contribution of ancillary machinery to the reliability of the whole plant and leads to an examination of how to do better.

The Plant Concept

This starts with the statement of the requirement by the user. Perhaps the great virtue of steam plant, its flexibility in layout and in operation, is potentially also one of the most adverse influences on its reliability. Changes in strategy or tactics or in foreign policy can result in naval ships being used in roles for which they were not designed. During the steam plant Conference in 1963 this change of function was also said to occur in the case of generating stations and it would be surprising if it did not apply to quite a wide range of steam plant. In stating his requirements, therefore, the user would be wise to look far ahead and to allow for something more flexible than the performance strictly required in the immediate application. The more closely the requirements are defined the more carefully this factor has to be considered. As an example of how designs may need modifying, TABLE 1 shows the history of combinations of feed pumps in successive classes of generally similar ships. FIG. 1 has been derived on an assumption that all pumps have equal reliability, to show the probability of survival of each of these combinations to continue supplying the output required, with the ship steaming at full, half and quarter power. This probability, which is one way of defining reliability of the system, is plotted against the accumulating time without maintenance. Originally it was expected that these ships would operate for about 80 per cent of their time below 20 per cent of full power.

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*Mathematical formulae used to construct curves shown in FIG. 1:

(1) Reliability (at time t) $= \epsilon^{-\lambda t}$

(2) Parallel system—one working, one stand-by.
When unit reliabilities are identical:

$$R = e^{-\lambda t}(1 + \lambda t)$$

(3) Parallel system—one working, two stand-by all identical reliability:

$$R = e^{-\lambda t}\left(1 + \lambda t + \frac{(\lambda t)^2}{2}\right)$$

TABLE 1. *Combinations of feed pumps. In each case one turbo-driven main feed pump of 100 per cent output plus*

1	2 Steam reciprocating pumps, each 25 per cent output
2	1 Reciprocating plus 1 turbo-driven, each 25 per cent output
3	1 Turbo of 100 per cent output plus 1 reciprocating 25 per cent
4	2 Turbo each of 50 per cent output
	In each case the three pumps are connected in parallel

The speeds at which ships customarily exercise, operate, and deploy have steadily risen, and the emphasis has gradually changed from economy at low power to reliability at higher powers. The change to a second full output pump was governed largely by the availability of a reliable pump of suitable output and the need to enhance the reliability of the system at higher powers. Later on, however, having established that between 25 and 50 per cent had become the predominant range, the latest version of one full—plus two half-duty pumps was selected. FIG. 1 shows that this was justified on grounds of system reliability as well as fuel consumption, since the chances of survival between 25 per cent and 50 per cent full power are substantially better with this combination than the others. (Although the decision was based on logical grounds, rather than on the type of assessment shown in FIG. 1, there is no doubt that although it involves some broad assumptions, this type of presentation of the relative reliabilities of various systems does help in defining the problem and its solution. It also helps to define the advantages of including more flexibility of operation in the initial design.)

Design Margins

Having dealt with the broad pattern of operation perhaps the next major design influence on reliability of the plant is in selecting the performance margins for the various components which make up the systems. The best known pitfall is probably the danger of producing pumps or blowers in which the margins are so large that the characteristic is no longer properly matched to the normal duty. Recently in a new class of warship the rapid failure of small auxiliary heat exchangers was experienced in several ships; in particular in the lubricating oil coolers of turbo-driven auxiliaries. Sea water was circulated to these in an auxiliary cooling system supplied by its own pump. The margin on the pump output was such that the failures were caused by excessive water speeds throughout the system. It was necessary to reduce substantially the impeller diameter of these pumps, thus slowing down the water speeds and obviating the failures.

For years in marine steam plant the designers' interest in margins centred on the heat balance for normal steady steaming conditions and previous experience of deterioration with age. The increasing use of automatic controls has meant paying far more attention to transient conditions and to the reliability with which systems respond dynamically. A typical example is that where an exhaust range accepts steam from auxiliary turbines and provides feed heating steam to a deaerator, the mis-match in a normal heat balance flow diagram may be catered for by automatic supplementing from a suitable steam source, or alternatively by rejection to a condenser. The effects occurring whilst the plant is changing power are shown in FIG. 2. The exhaust range

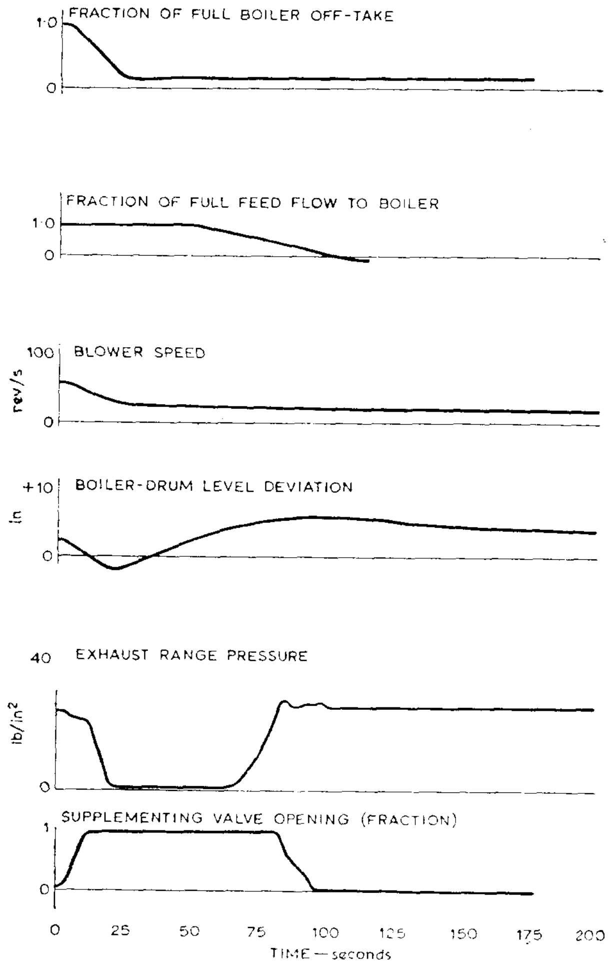

FIG. 2—INTERACTION OF BOILER, DEAERATOR AND EXHAUST RANGE

pressure falls drastically for a period of a minute or so, due to the feed water flow to the deaerator continuing at its initial value for some time, before the boiler level control system and deaerator level controller sense the power change. The blower exhaust steam reduces quite rapidly. In this case the supplementary valve based on steady state requirements was quite inadequately sized to arrest the pressure fall.

There is then clearly a need to consider the interaction of all the systems involved, in matching the components within each one. But perhaps the lesson which this illustrates above all is the need for thorough understanding and co-operation between the user, the system designer, and the component suppliers. If any of these fail to make a proper contribution, the reliability of the whole plant can be jeopardized. However, even if such understanding exists, there is the problem of design checking.

Design Checking

The complexity of modern engineering and design techniques makes it increasingly difficult for designers or draughtsmen, however experienced, to check intuitively that the specification has been met and that their system and component designs are basically reliable. In revising the specifications for machinery for warships, attention is now being paid to clarifying the requirements by including chapters on systems in which all relevant material, component, and test specifications are referred to. At the same time an experiment is being carried out, with the help of two firms, in the use of design check lists, on which are included every relevant requirement from all the applicable specifications. Like so many modern attempts to relieve the more highly trained engineers of routine work, the result tends to drown his subordinates and eventually himself in a sea of paper, but the experiment is based on the conviction that reliability can only be achieved if every man involved in design, manufacture, testing and operation knows precisely what is required of him. The second objective is to try to avoid the proliferation of design reviews by individuals or specialist teams and to allow people to apply the necessary checks to their own work.

From across the Atlantic comes a stream of techniques, such as value engineering, reliability engineering, cost effectiveness estimating, and zero defect programming. In each there is obviously much virtue and it would clearly be to the advantage of the user if the designer had people to carry out design reviews for reliability, maintainability, produceability, durability, and so on, but the shortage of skilled manpower and the comparatively small size of the design organizations in this country clearly make it necessary to try to find some other way of achieving the same end.

Standard Ranges of Machinery and Refitting Procedures

Two ways are now being developed to try to contain rather than solve the problem for naval machinery in establishing standard ranges of not more than three or four sizes for each auxiliary and in classifying each one for either refit by replacement or refit in place. The suppliers should then have a better understanding of how their products will be maintained in service. It is also to be hoped that the reduction of variety would justify further refinement of each design to achieve reliability and maintainability—and perhaps 'cleanability' inside and out. The refit by replacement policy will necessitate thorough integration of the ship design and the machinery layout to ensure that routes are kept clear for removal and replacement of the machinery so earmarked and that adequate access is provided to refit the rest in place. This is nothing new, of course, but the recognition of the real need for the space and facilities for such measures, if availability is to be improved by reduced refitting times, has given new impetus to the policy.

Manufacture, Installation and Testing

Having tackled the design problems in this way perhaps the best contribution which the operator can make towards manufacture, installation, and testing is to make his requirements clear and easy to interpret. The ultimate objective must be to enable the manufacturer or installation management to put in the hands of the man actually carrying out the work, clear and comprehensive instructions on what is actually required of him. In the past the reliability of steam plant depended upon the diligence of the craftsman who knew his machinery and had been brought up to meet certain standards. The pace of development in technology now makes this virtually impossible and reliability can now probably be assured only by great attention to planning the work and issuing clear instructions on what has to be done at each step. For naval ships substantial help has been afforded by two firms who have written out from naval specifications each of the operations required for the installation and testing of various systems. This has helped not only to check the completeness and consistency of specifications, but will allow them to be re-shaped to make it easier for anyone to issue similar instructions in future.

Operation

Reliability in service depends on the proper operation and maintenance of the plant. Following the same line of thought, that the man on the job must know exactly what is required of him, the need for a timely supply of instruction books, drawings and spare gear, is obvious. In a number of trite observations, perhaps this will seem the winner as the king of platitudes and yet how often the operators fail to get the best out of machinery for lack of these very things!

Maintenance

Experience eventually persuades most engineers that to take machinery apart when there is nothing obviously at fault, although it may be done in order to check or enhance its reliability, does in fact constitute a hazard. Much theory has been propounded on optimum times for dismantling or renewal, but ultimately some form of assurance is usually required that to continue operation is safe. The employment of endoscopes can help considerably, also poker gauges fitted from outside to measure wear down of bearings; but instrumentation and diagnostic tools need much development before dismantling for preventive maintenance is only carried out when there is something to be done. This leaves planned maintenance scheduling dependent on statistical probabilities and the feedback from operating ships.

Feedback

There is perhaps no more difficult activity than devising a reporting system to give the right balance of detail and scope and still to retain the interest and co-operation of the reporters, who have many more urgent tasks on their hands. The naval S.M.A. system is no exception. There are dangers in accepting incomplete statistical analysis as proof of design shortcomings. On the other hand much useful collation of information has been achieved and the system has revealed various cases in which design investigation is required. Two examples serve to illustrate this. First, the case of distiller pumps which continually failed in one class of ship. This led to a cure by repositioning the pumps away from particularly bad conditions of water and steam leaks. Secondly, the widespread reporting of unreliability of overspeed trip gear has led to a redesign to protect these devices from the effects of dirt, lacquering of oil and high temperature. Other results of this organization have been the dissemination to all ships of the experience of a particular defect in one or two ships which has enabled many others to take preventive action.

A refinement of the reporting system is now being studied to see whether a concentration of reporting on a few rather narrower areas and insistence on 100 per cent reports in these fields will lead to quicker elimination of weaknesses. It is hoped that by reducing the reporting and processing task the feedback to firms may be more meaningful and concentrated. Ultimately, the aim must be to provide the sort of information on performance in service which will enable quantitative statements on reliability to be made and to improve the knowledge of designers and operators alike on the failure characteristics of every system used or projected. But experience seems to indicate that no statistical system is likely to be good enough to produce the answer as well as the complaint. The user, having told the designer that his product breaks down, will no doubt continue to be invited to operate and maintain it better and investigation will still be needed to establish the real cause of failure.

Testing of Systems and Components

This may require testing under controlled conditions, at least to eliminate some of the possible causes of failure. An Auxiliary Machinery Test House is now ready to start operating at the Admiralty Marine Engineering Establishment at Haslar. It has been put up specifically for the purpose of improving the reliability and maintainability of ancillary machinery used in the Navy and is a demonstration of the importance attached to this subject. It is not, however, intended to do the initial development testing, which should rightly be done by the designer, nor the production testing of the manufacturer. Its existence is really an indication that neither of these is at present producing the complete answer. Perhaps it may be shown that not only the auxiliary machinery but the various ancillary systems as a whole require more careful development testing.

Conclusion

Having seen the enormous advantages in the making of decisions on future plant, which the presentation of numerical assessments of reliability can offer, there was a great temptation to spend some time in discussing these techniques for assessing reliability. They are now in use in various fields of engineering and there is no doubt that the demand for their use in steam plant will grow louder every year. So far the lack of standardization of components and the corresponding lack of statistical validity in terms of reported experience of breakdown make it a difficult and slow business to introduce such assessments, for naval steam plant anyway. But it would be a mistake to underestimate the importance now attached to what is called reliability engineering.

However, the objective is to achieve reliability, rather than to assess it. The examples used in this Paper to illustrate the parts played by ancillary equipment in reliability of the whole plant have been perhaps prosaic and even trivial. This has been done deliberately, because the whole method of achieving reliability is one of taking care of the prosaic and the trivial at every stage, from specifying requirements to operating and maintaining the installed steam plant. The golden thread which runs through the whole process is the need for the man on the job, whether draughtsman, fitter, or operating mechanic, to understand thoroughly what is required of him to achieve reliability. If every clause of specifications, every drawing issued from the office, and every instruction book were constructed with this in mind more than half the battle would be won.