1988

Proposed course in planning of maintenance schemes and inventory control of ships

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WORLD MARITIME UNIVERSITY

MALMO, SWEDEN

PROPOSED COURSE

IN PLANNING OF MAINTENANCE SCHEMES AND INVENTORY CONTROL ON SHIPS

BY

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A paper submitted to the Faculty of the WORLD MARITIME UNIVERSITY in partial satisfaction of the requirements for the award of a MASTER OF SCIENCE DEGREE in

MARITIME EDUCATION AND TRAINING

(Marine Engineering)

The contents of this paper reflect my own personal views and are not necessarily endorsed by the UNIVERSITY.

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THESIS ARRANGEMENT PLAN

ACKNOWLEDGEMENTS

First of all, I want to offer my gratitude to my colleques and friends in The Nautical School of Panama, whose support made possible I where here in The W.M.U..

I am also grateful to all those persons who have provided me information and support during the realization of this project, during field trip and lectures, specilly to Prof. C.E. MATHIEU for his willingness to help, Prof. J. Listewnik for the big amount of information given and Prof. A. Howe who together to her collegues in the E.L.P. make a wonderful job with non English speakers.

Finally, it best to say always, my for life thanks to my mother NELLA, my wife LUCIA and my young son RODRIGO ROBERTO whose moral contribution was my principal support.

PROPOSAL COURSE IN PLANNING OF MAINTENANCE SCHEMES AND

INVENTORY CONTROL ON SHIPS

THESIS ABSTRACT

A preventive maintenance method is often focused on: cleaning, lubrication, replacement or reconditioning.

However there are other aspects which must be considered in order to develop a well programmed maintenance plan in keeping with present technological developments.

This project will include as main topics:

- -probabilistic curves used in maintenance,
- -types of maintenance and their advantages and disadvantages,
- -diagnostic systems and methods of monitoring,
- -control of inventory,
- -application of computers as a maintenance planning tool.

The intention of this work is to increase knowledge and be of use as a reference guide for graduated officers and engineering cadets about new techniques and tools frequently used in maintenance plans.

Therefore, the above mentioned objetives will contribute to the improved ability of engine officers from The Nautical School of Panama to meet requirements established by new trends in the shipping industry.

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PROPOSAL COURSE IN PLANNING OF MAINTENANCE SCHEMES AND INVENTORY CONTROL ON SHIPS

CHAPTER I

INTRODUCTION

1.1 "Safety and efficiency always go hand in hand"(D.J. Downward 137).

Efficiency in the engine room will be obtained by applying a well programmed maintenance plan. This plan has to be complemented with the gathering of useful data and updated knowledge of available resources.

In the last ten years the shipping industry has undergone very important changes as a result of the economic crisis worldwide.

The engine room is a department where a great evolution has taken place. Automation has replaced a lot of man-power and computers are more frequently used on board.

Consequently we have to bear in mind that engine staff require the best training in new trends. It is not enough to have the best skilled engineer team on board, if they do not have enough knowledge about parameters which address the good management of spare parts, equipment and other resources on a ship.

1.2 This project has the additional intention of being used as a reference paper in the proposal maintenance course or seminar which will avail to update the knowledge of The Nautical School of Panama students as well as those engineers who have already graduated. This project can have other outcomes, such as increasing their competitiveness and offering the best view of new engineering trends.

Consequently, safety will be increased by this means.

In order to achieve the above mentioned course objectives I recommend use of:

-probabilistic curves which can interpret equipment behaviour;

-the computer and its use in the engine room as an aid to inventory control and maintenance record; and

-new strategies used in planned maintenance policies.

1.3 It is good to mention here, that I neither attempt to create a computer programer nor a maintenance planner. Rather, I am trying to train engineers about how to use available technology and how to make well founded judgments. This does not mean the engineers are wrong; in many academies engineers are not presently trained in management or administrative skills which have recently become so closely related to maintenance policies. Another point is that my basic attempt is to leave the door open to those who are interested in investigating or learning more about various maintenance aspects.

In addition, the aims of efficiency and planned maintenance in this context are very close. According to J.M. Downward, planned maintenance has the following objectives "to maximise the reliability and availability of ship's equipment and to extend its life to the maximum possible" (130).

As we can see, the economic factor is not cited in the above mentioned; however, it will be discussed partially.

1.4 This project consists of eight chapters. The second chapter deals with the construction and interpretation of different useful curves used in maintenance analysis.

The third chapter covers the policies of maintenance; an overall view of traditional maintenance activities and those maintenance systems implemented from few years ago.

The fourth chapter will describe different methods used for monitoring the engine room, including some specific monitoring units created for diagnosis of diesel engines.

Spare parts control system and coding system, useful tools in planned maintenance, are described in the fifth chapter.

The sixth chapter consists of the usefulness of computers onboard and its integration on the different departments; e.g. engine room,deck and management of the ship.

Organization of the course is included in the seventh chapter, which describes course objectives, program, candidates requirements, used resources and duration of the course.

Finally, the last chapter gives conclusions and recommendations.

CHAPTER II

THEORETICAL BACKGROUND OF MAINTENANCE

2.1 GENERAL REMARKS

Graphical representations have always been present in engineering studies and the study of maintenance is no exception.

Graphs are used to represent equipment behavior, time between failures, rate of wearout failures, etc.. Here we are going to see how are they done.

It is relevant to mention that graphical representation has as its main advantage the fast understanding of the facts, therefore engineers if they know the origin of those curves can have a better idea of their meaning and predict in some way equipment performance.

These advantages are going to be utilized more day after day , as we have seen the increased use of computers everywhere.

2.2 DEFINITION OF BASIC TERMS

Before I start to describe the probabilistic curves used in maintenance analysis, there are some terms which we need to know, such as:

-Population: in this case population "refers to all the cases or situations that the statistician wants his inferences or guesses or estimates to apply to" (D.Rowntree 20).

-Sample: it is "a relatively small selection from within the population"(D.Rowntree 20).

-Distribution: the distribution from probabilistic point of view "is a method of describing the various outcomes of some event"(Shields, Spartshott & Cameron 103). It is worth mentioning here that the distribution must have some particulars which identify it.

-Mean value: it is the sum of observations divided by the amount of considered observations.

$$U=\frac{\sum_{i=1}^{N} X_i}{N}$$

-Standard deviation: "it is a way of indicating a kind of average amount by which all the values deviate from the mean"(D. Rowmtree 54).

$$\sigma=\sqrt{\frac{(X_1-U)^2+(X_2-U)^2+(X_3-U)^2+\ldots+(X_n-U)^2}{N}}$$

-Variance: it is the standard deviation squared. Its sign is (Shields, Sparshott & Cameron 105).

2.3 DESCRIPTION AND USES OF PROBABILISTIC CURVES UTILIZED IN MAINTENANCE STUDIES

Having made these terms clear, I would like to start properly by studying the different curves and having a look at their usefulness in maintenance. Most of what is written here is based on the work of S. Shields, K.J. Sparshott and E.A. Cameron.

2.3.1 NORMAL CURVE.

Let me start with the normal curve which is formally called the normal distribution. It has many applications in different fields, however,as we are interested in maintenance, it is going to be used to find the mean useful life of a piece of equipment which fails due to wearout and also the probability of failure before a determined time.

The density function of the normal distribution, in this case the curve height, is defined as:

$$f = \frac{1}{\delta\sqrt{2\pi}} e^{\left[\frac{(t-\mu)^2}{2\delta^2}\right]} \qquad \text{for } -\infty \leq t \leq +\infty$$

where $f_{(t)}$ is the height of the curve,

u is the mean of the distribution,

δ is the standard deviation of the distribution,

e has the value 2.7183,

π is 3.1416

t is the time we are considering (See Figure 1).

The mean and standard deviation of the distribution are values which identify a specific normal curve.

The outcomes from this curve like the expected probability of failure before a determined time are obtained by means of the area under the curve. There is a table already made where we can find that value (See Appendix 1).

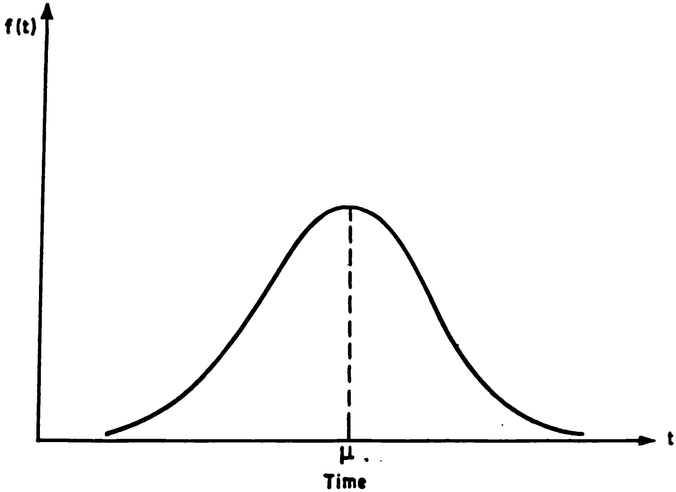
In order to know the value of the area under the curve at a specific time, we must first find the "Z" value which is calculated from the following formula:

$$Z = \frac{T - \mu}{\delta}$$

If Z is a positive value, we have to add the value

Fig. 1

The normal distribution



found from Z value in the table to 0.500, but if it is a negative value we have to subtract that value found in the table from 0.500. It is worth mentioning here that the total area below the curve is equal to the unit.

Failure rate in a normal curve has an increasing characteristic (see Fig.2).

Finally regarding this curve, we can say that it is the curve for wearout failures which can be applied to a large amount of components onboard.

2.3.2 EXPONENTIAL CURVE

The function or height of the exponential curve is defined as:

$$f_{(t)} = \lambda e^{-\lambda t} \qquad \text{for } t \geq 0,$$

This curve has two main uses in maintenance. One of them is related to the "probability of completing a maintenance task at any time t".

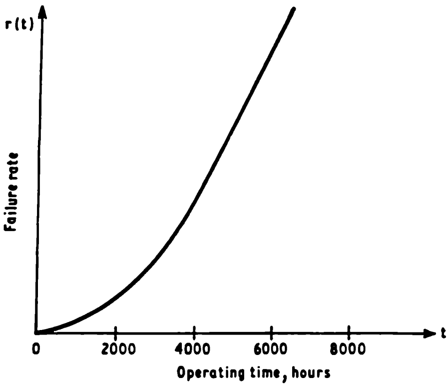
The mean time to complete the maintenance task (MTCMT) is equal to the inverse of the value of λ .

$$MTCMT = \frac{1}{\lambda}$$

As MTCMT is already known from experience, there is no problem finding the value of λ . Having found λ we can solve the function for several values of t, where f is equal to the height of the curve. Shield, Sparshott and Cameron defined it as a "quite good approximation of the time necessary to complete a series of maintenance jobs" (see Fig.3).

Another way that we can make use of the exponential distribution, according to Shield, Sparshott and Cameron,

Fig. 2



· ·-- *Typical failure rate of the Normal Curve*

Fig. 3

Exponential PDF of times to complete maintenance tasks

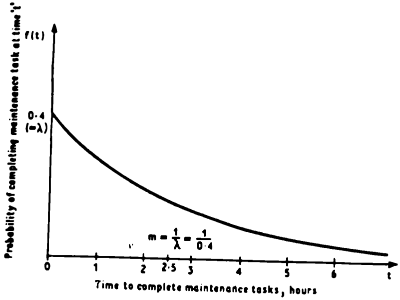
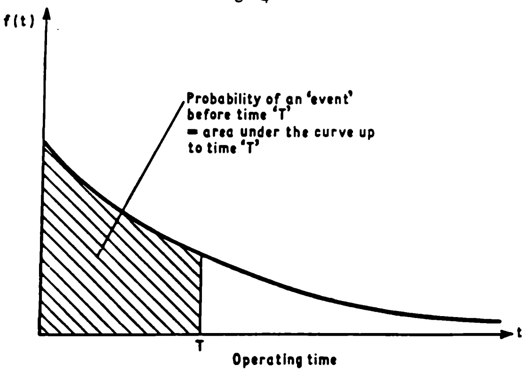


Fig. 4



Area under an exponential curve

is in "the study of machine failures". λ is going to take the value of the failure rate of the equipment which we are concerned about. "If we know the mean time between failures (MTBF) due to chance then we can calculate ".

$$MTBF=\frac{1}{\lambda} \Rightarrow \lambda = \frac{1}{MTBF}$$

After we have found , the curve can be plotted and the area below it is considered as the unit. We could determine the possibilities of having a failure before an estimated time. This can be done by means of the subtraction of the area between t=0 and a fixed time t from the unit, i.e.:

$$T=1-e^{-\lambda t}$$

where T is equal to "the probability of the event occurring before a pre-established time" (see Fig.4).

The exponential distribution is applied to several electronic devices in order to determine their reliability. However, this is only when the failure is a chance failure and not due to wearout. Further, there are other uses for the exponential distribution such as the reliability theory as we can see in structures which have undergone "excessive load from time to time".

"In these cases the failure rate function is given by:

$$r_{(t)}=\frac{\text{N° of Failures During an Interval of Time}}{\text{N° of Components Operative at the End of the Interval}}$$

and the ratio $r_{(t)}$ is always the same throughout the life of the components under consideration. The failure rate will be a constant with value λ at all values of time".

2.3.3 WEIBULL CURVE

The Weibull distribution for which the density function or curve height is given by:

$$f_{(t)} = \frac{\beta (t-t_0)^{\beta-1} \cdot e^{-\left(\frac{t-t_0}{\eta}\right)^{\beta}}}{\eta^{\beta}}$$

where β is the shape of the distribution for $\beta > 0$,
t_0 is the starting point or origin of the distribution,
η is the characteristic life for $\eta > 0$.

It is a versatile curve which may take several shapes depending on the values we fix to η and β. If we make η constant and we have the same starting point, let me say t=0, we can see that the curve will take a bell shape if $\beta > 1$. The specific value of β to get a normal distribution is 3.44. If $\beta = 1$, the curve will take the exponential distribution shape. And if $\beta < 1$, the curve will take a hyper-exponential distribution shape (see Fig.5).

Thus, the above mentioned shows us that the Weibull distribution may be suited to analyze failures due to wearout or chance or a combination of both. In the same way that Weibull distribution is used to obtain the different failure distributions, it may be used to find the different failure rates.

The failure rate function for a Weibull curve is given by:

$$r_{(t)} = \frac{\beta (t-t_0)^{\beta-1}}{\eta^{\beta}}$$

if and only if the time to failure distribution is the Weibull distribution.

Fig.5 *The Weibull Distribution*

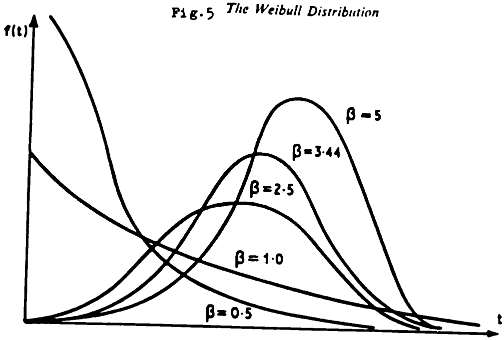
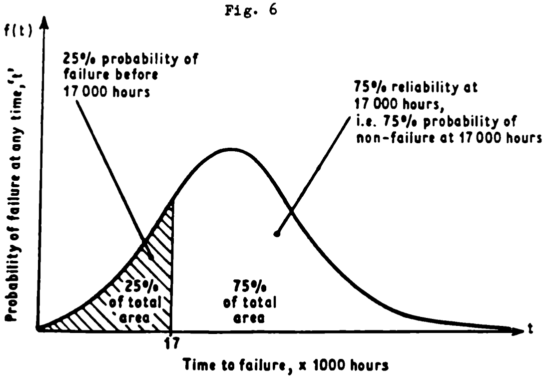


Fig. 6



Probability of failure of C.P. Propeller before 17,000 hours

The parameters have the same meaning as in a Weibull density function.

Taking as reference the above written formula, we see that for $\beta > 1$, the failure rate increases with time. If $\beta < 1$ the failure rate decreases with time and if $\beta = 1$ the failure rate will be constant.

However, there is a very important use of a Weibull distribution which is applied to reliability theory. Before going farther, it is worth defining reliability "It is the probability that a system will not suffer a significant failure in operation during a specified period of time" Shield, Sparshott and Cameron 126.

As we can see, reliability has no meaning if it does not go together with a determined interval of time.

Also reliability may be mathematically defined as:

$$R_{(t)} = 1 - \int_0^t f_{(t)}\, dt \qquad \text{(see Fig.6)}$$

where 'T' is the mission duration or period of interest,

and $$f_{(t)} = \frac{\beta (t-t_0)^{\beta-1} \cdot e^{-\left(\frac{t-t_0}{\eta}\right)^{\beta}}}{\eta^{\beta}}$$

Then R derived from the failure rate Z finally can be written :

$$R_{(t)} = e^{-\alpha t^{\beta}} + c = e^{-\left(\frac{t-t_0}{\eta}\right)^{\beta}} + c$$

from the condition that $R_{(0)} = 1$, we find that c=0 (see Fig.7).

2.3.4 BATH TUB CURVE.

The Bath tub curve is not a single curve showing a

Fig. 7

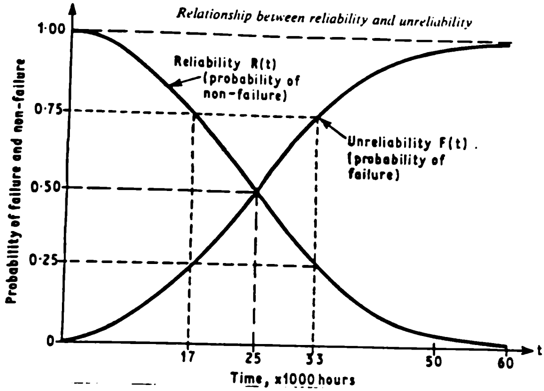
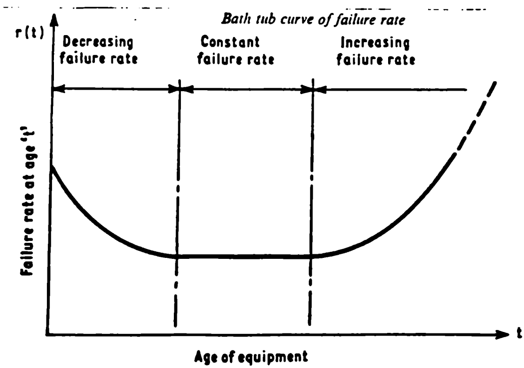

Relationship between reliability and unreliability
1·00
0·75
0·50
0·25
0
Probability of failure and non-failure
Reliability R(t)
(probability of
non-failure)
Unreliability F(t)
(probability of
failure)
17
25
33
50
60
t
Time, x1000 hours

Fig. 8


Bath tub curve of failure rate
r(t)
Decreasing
failure rate
Constant
failure rate
Increasing
failure rate
Failure rate at age 't'
t
Age of equipment

specific density function like those mentioned before. Instead it is formed of three different behaviors of failure rates.

There are faults which may happen to any piece of equipment as the result of a construction or design mistake, or wearout or material fatigue or/and to chance.

The Bath tub curve reflects all the above described failures giving the features of an equipment or engine, from the new stage until it gets old.

The first part of the curve is obtained from the decreasing failure rate represented by a Weibull distribution where 1 (e.g. =0.5). This part reflects the new stage of an engine or equipment when failures occur by defect of bad design or construction.

The second part is done from the constant failure rate obtained from the exponential distribution and this occur when the equipment is still relatively new. Failures here are due to chance.

The last part of this curve is composed of a part of exponential distribution or chance failure and the normal or wearout failure (see Fig. 8).

All those sort of failures are jointed in order to get the Bath tub curve.

Before finishing, I would like to make clear certain pros and cons of the use of probabilistic methods in maintenance.

For instance, probabilistic studies about maintenance require a long time, something that is not generally available most of the time. Such studies also require more paperwork and at the same time more detailed reports. The most difficult is the necesary amount of observations which, if are not enough, will lead us to make an unfair judgment of equipment behavior.

On the other hand, the outcomes from these types of studies are going to reduce significantally the initial cost of a vessel, because they are useful in the detection of reliabity of equipment. They also help us determine an appropiate approach to operating costs.

In addition, I want to emphasize the importance of the data collected in the engine room. This is the basi for interpretion, prognostication and management in good order of any equipment. This means that observations must be carefully collected and well described in order to get good results from probabilistic analysis.

CHAPTER III

STRATEGIES USED IN MAINTENANCE

3.1 MAINTENANCE DEFINITION

Maintenance activities on board can range from the simple action of cleaning a piece of equipment to running a computer program to determine necessary measures to be taken during the next survey of a main part of the propulsion system. Thus, we can see that maintenance activities comprise a large portion of the engineer's work. Even more, related costs of maintenance have obliged personnel ashore, i.e. owners and engine designers, and engineers on board to work with the same objectives in order to optimize maintenance from all points of view.

Therefore, looking at the maintenance functions and people involved in those functions, I think the most suitable definition for maintenanace is that used by the Marine Maintenance Manual that says "Maintenance is any activity of organizational, administrative, technical and economic nature required to effectively plan, execute, record and analyse a technical system" (1.1.2).

Although, all of the above mentioned activities are essential, I would like to point out that recording and analyses are areas where engineers have to be especially careful in order to acheive an effective planned maintenance.

The goals for maintenance activities can be grouped into two main objectives namely the safe operation of the vessel, including the safety of the crew, and the reduction of operating costs. But there are other objectives that are also important, such as obtaining a higher second hand value and increasing the availability of the vessel.

3.2 CORRECTIVE AND PREVENTIVE MAINTENANCE

Although maintenance is a wide field, most of the time it is classified simply as corrective and preventive maintenance. However, this simple classification may create problems, because these terms overlap each other and it is sometime difficult to find differences when they both concern planned maintenance.

Therefore, it is necessary to have a clear idea about the functions and objectives of the different maintenance activities and their sub-divisions. (see Fig.9).

Following in this context, we are going to examine not only the functions and objectives, but also the philosophy behind maintenance based on condition monitoring.

3.2.1 CORRECTIVE MAINTENANCE

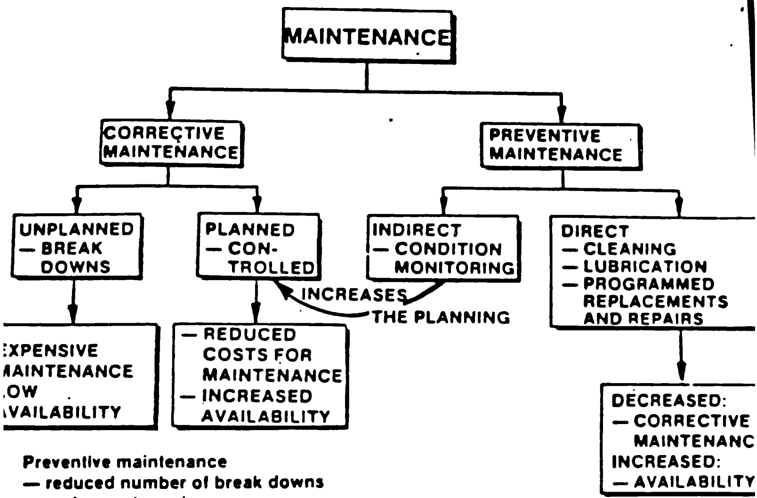
There is a proverb which says "To prevent is better than to cure"; this applies for example to accident prevention. Contrary to what is said in this proverb, however, corrective maintenance is composed of actions such as "repairing, re-conditioning or exchanging" (Marine Maintenance Manual 3.1.1), which are designed to cure or to bring back a piece of equipment to operation.

Corrective maintenance is very often related to an unscheduled breakdown of equipment, which means profit losses, longer downtime and higher repair costs.

This maintenance strategy is sometime deliberately chosen for faults which would neither have expensive repercussions nor extend to vital equipment which could risk the safe operation of the ship.

Nevertheless, corrective maintenance can be performed

Fig. 9



Preventive maintenance
— reduced number of break downs and urgent repairs
— more planning and control of correçtive maintenance

:SULT
INCREASED AVAILABILITY
DECREASED COST FOR MAINTENANCE

during a planned time. Then it will be referred to as planned corrective maintenance. In this matter cost of maintenance will be lower and we will get a shorter down-time.

The economic argument behind a corrective maintenance policy is that it is the best choice when the expenses spent to keep any type of equipment in good order are higher than the expenses caused by its failure. But at the same time it is important to avoid jeopardizing the safety of the ship, crew and cargo.

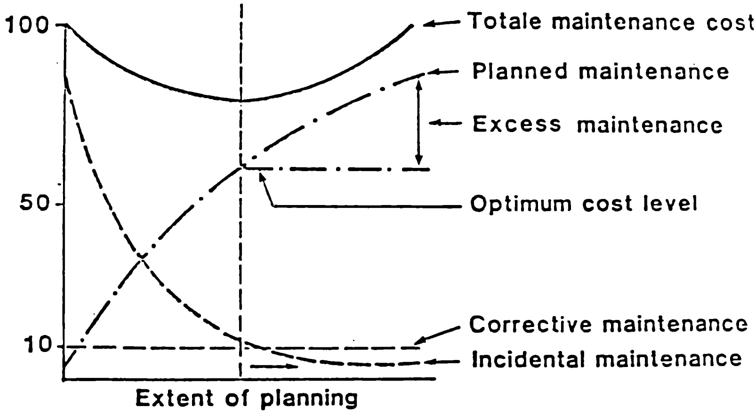
3.2.2 PREVENTIVE MAINTENANCE

Preventive maintenance is the other main type of maintenance. This alternative to corrective maintenance is based on the prevention of breakdowns by means of periodic inspections, adjustments, reconditioning, replacement or condition monitoring. But the critical point in preventive maintenance is to chose the proper time to carry out any of those activities. Because in the best case, if we select a short interval for preventive actions, then the cure will be worse than the sickness. That is to say that it is possible to spend more resources in prevention than correction of failures. (see Fig. 10).

On the other hand, if we are not lucky enough and we have selected a long period, we are going to meet the consequences of an unscheduled corrective maintenance program.

There are several ways to select the time for preventing breakdown failures. The allowed running times are based on builders advice, classification society surveys, governmental regulations and last but not least ship engineer's experience. All these requirements are tailored in such a way that the maintenance is carried

Fig. 10


100
50
10
Totale maintenance cost
Planned maintenance
Excess maintenance
Optimum cost level
Corrective maintenance
Incidental maintenance
Extent of planning

out according to a balanced schedule.

Meanwhile, the other technique more often used in modern installations is based on the equipment state through their constant condition monitoring (part 3.2.2 will deal with condition monitoring). The main advantage of condition monitoring is that the piece can be used until the last moment of satisfactory operation, by means of detecting when it is close to failure.

However, in planned running schedules as well in condition monitoring we have to consider builders, classification societies and governmental requirements in order to perform an economic and unrisky preventive maintenance which must go hand in hand with fullfiling not only the technical but also the safety requirements.

3.2.2.1 PLANNED MAINTENANCE

If we go through the different definitions given to planned maintenance, we find that there are four main elements which are always present. They are planning, execution, recording and analyses or their synonyms. The definition from British Standard for planned maintenance is the following "maintenance work organized and carried out with forethought, control and records". Thus, corrective and preventive maintenance, when they are planned do not present so many differences (we must recall that there are unplanned and planned corrective maintenance schemes).

In planning we have to know what items are going to be maintained and what type of maintenance is required. In order to select the equipment or piece of equipment to be maintained there are some useful questions given by Shield, Sparshott and Cameron in their book called "Ship Maintenance" (28). Some questions are listed below.

"Are items required for continuous survey machinery ?
Would failure through lack of maintenance incur loss of hire of the vessel ?
Would lack of maintenance cause an unacceptable fall in performance standards ?
Would failure due to lack of maintenance incur high spares cost ?
Would failure due to lack of maintenance cause significant loss of safety ?"

If just one such questions is answered positively , it is enough for that item to be included in the planned maintenance.

With respect to what type of maintenance should be made, the jobs can be classified in four main groups which are (again according to Shield, Sparshott and Cameron. 28) :

"Inspection: this comprises visual examination, such as to check levels, pressures, temperatures, etc.
Minor overhaul: this comprises a partial stripdown of a machinery item.
Major overhaul: this comprises a full stripdown of machinery item.
Survey: this comprises a full stripdown of a machinery item and examination by a surveyor".

But maintenance also can be classified according to the following scheme:

1-Long term maintenance which usually spans a period of five years, including classification society requirements.
2-Short term maintenance which frequently comprises

planning for three months or a round voyage period. In this plan, the maintenance due to operational requirements (unplanned), could be done.

In addition to what items and what type of maintenance is required, planning also comprises the study of available resources such as manpower, tools, required time, necessary spare parts. Finally after considering all above mentioned, the job card will be prepared.

The job card must be made for every equipment included in the planned maintenance system. This card shall contain all the necessary information. (see Fig. 11). This instruction must contain answers to :

"What is it ?	The work.
Where is it ?	Location.
How to do it ?	Description of job, number of men, skill level, safety precautions.
When to do it ?	Periodicity, position of the vessel.
What is used ?	Spares, stores, aids, tools.
How long will it take ?	Hours or man/hours." (C.R. Cushing 23).

Execution is the stage of planned maintenance where we will put in practice what has been planned. Here planning is going to be evaluated by the operating personnel onboard and it is also the origin of modifications to the instructions made in planning.

Although execution takes place as a sequence of planning, in this system we can not say that all maintenance activities here are planned. Because, there are other sources, such as routine inspections and condition monitoring, which will inform engine personnel if the eng-

Work Information ..Hampshire...	Motor	System	Equip.	Item
	011	07	02	06.1

Work Source.	De-oiler No.1
Location.	Engine room Platform level, Port. Forward.
Work Description.	Cleaning and examination of float controlled air vents.
SAFETY Precautions.	Inlet and outlet valves shut and lashed.

No. of Men. 1	Skill. K1 EO	Skill	Skill.	Target Time. 8½ Hours.

Tools & Materials.

[illegible]" Whit O.E. Spanner
[illegible]" Whit O.E. Spanner.
Wheelkey
De-greaseant liquid
Rags
Torch.

5 air vessel cover joints.

Method.

1. Shut and lash inlet and outlet valves.
2. Open top drain valves until flow ceases.
3. Remove nuts and cover from air vent vessel.
4. Remove and clean ball float, clean out air vent vessel.
5. Examine vent valve and vent valve seat for wear.
6. Check air escape passage is clear.
7. Check float for leakage (shake float to find out if there is water inside.
8. Check condition of air vessel cover joint, renew if damaged.
9. Replace ball float, air vessel cover joint, cover and nuts.

Work Information Card

ine or equipment requires an unscheduled action different from those established in advance. But, if a failure occurs, we have to look for the most efficient and economic way to solve it.

Recording, as I have mentioned before, is in my opinion one of the most important elements in planned maintenance. By means of recording the important details observed during the maintenance execution, we are able to create our own history of the equipment. Further, the information collected will be used to improve the present plan and to show what could be the features of wea-rout or failure in the equipment.

In one word, we can say that recording, by means of a job report, is the feedback of a planned maintenance system. The job report need not be a complicated one, but must contain relevant information.

Among the objectives which can be achieved by reporting are the following:

- learning from past experiences,
- creating a maintenance history of machinery or a piece of equipment,
- creating operational and control data, and
- creating a basis for the modification of instructions.

Analysis is defined as a "follow-up of maintenance procedures performed" (Marine Maintenance Manual 3.1:3). It is the procces where planned maintenance is going to sense any deviation from parameters already fixed in planned maintenance systems. This is usually the work of the chief engineer or technical department. They can detect from written records the life expectancy, reliability and maintenance costs of the equipment and at the same time evaluate and improve what has been done in planning in order to improve the next planned activity. (See Fig.12).

Therefore, it must be clear that the information collected in the recording phase shall be reliable and concise.

We have seen the main phases of planned maintenance, but coding and spare parts and inventory control schemes (these topics will seen in detail later) are also essential elements which have to go hand in hand with planned maintenance in order to achieve a complete planned maintenance system. (Please see Fig. 13).

Some of the benefits of implementing planned maintenance may be summarized as follows:

-predicting reliable future maintenance requirements,
-reducing ship's expenses,
-increasing ship's availability,
-increasing safety of the ship at sea.

In order to take grater advantage from planned maintenance, the classification societies have developed the continuous maintenance survey, which requires its approval. The documentation to be submitted to classification societies includes the following information:

-numbered index of the machinery items to be included in the scheme,
-time schedules,
-job descriptions,
-adequate reporting and data recording facilities,
-reference data, and
-new building stages.

For more details see Appendix 2.

ANALYSES of MAINTENANCE PROCEDURE – CONSEQUENCE OF FAILURE

OBJECT ______________________________

	A	B	C	D	E
Maintenance Procedure	Failures per year	Direct maintenance cost Repair time + material cost	Cost/year A · B · C	Down time cost/year A · down time cost · D	Maintenance cost/year
A Operate to failure					
Alt 1					
Alt 2					
B Fixed time maintenance					
C Condition Based Maintenance				A · [illegible]	
				B · [illegible]	

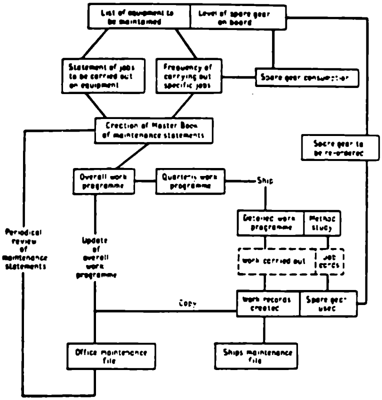
Parallel function investment (Redundancy) ______________________________

Design out maintenance investment ______________________________

Comments ______________________________

Fig. 13

Flow Chart of the complete Planned Maintenance System



Consequently, by making use of the ship's own chief engineers to carry out the class inspections, operational costs can be reduced even more.

3.2.2.2 MAINTENANCE BASED ON CONDITION MONITORING

Meanwhile, planned maintenance requires periodic inspections which very often include dismantling the equipment. Maintenance based on condition monitoring prevents these practices from being carried out during inspections.

In condition monitoring, the physical properties of a component or machinery are compared with certain parameters of references, allowing their operation up to satisfactory grade of deterioration, at which point the engineer is warned about the part's condition. In this manner, the time closest to failure is detected and chosen to take care of the equipment, so we can make use of the maximum component life.

Condition monitoring may be performed at intervals or continuously, depending on the equipment requirements, in order to watch the trend of wearout, thus we can predict the most appropriate time to carry out maintenance tasks.

To determine if condition monitoring shall be executed at intervals or continuously, we have to consider the component or system rate of deterioration and its consequences. For instance, parts in which deterioration takes place gradually and after being maintained can continue in operation within satisfactory ranges, are suitab le to be followed by intervals according to their estimated failure rate.

With respect to continuous condition monitoring, it is most suitable for supervision of the critical parameters of components or systems which are subject to sudden unnacceptable changes, to continue for a very short time without going through major consequences. These parts require rapid corrective action. Those corrective actions can be obtained by means of connecting those crucial components or systems to a system which will take proper automatic action.

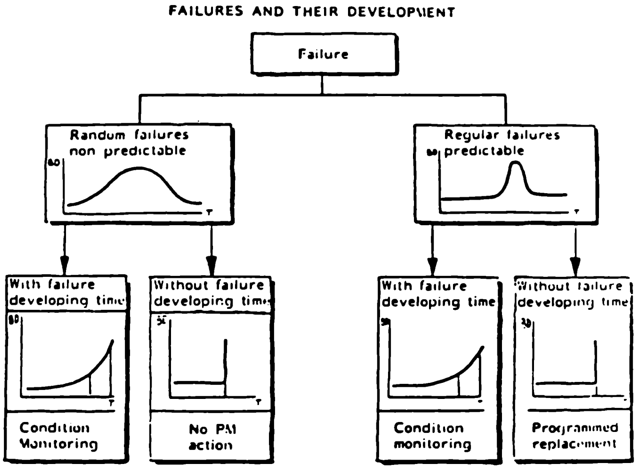
In the phase of choosing either the interval or continuous condition monitoring method, it is neccesary to have a very clear understanding of the different types of failures, their causes as well as how those failures can be forecasted (see Fig. 14).

Although condition monitoring seems only to be used as the core part of condition based maintenance, it has other main uses. From the point of view of running the engine economically, condition monitoring can be utilized to get the following effects:

"to carry out a critical examination of the combus tion process and tune up subsequently the engine so that an acceptable balance is obtained;
to carry out a critical examination of the engine's fuel system, making required adjustments to ensure correct operation;
to establish that the engine is operating within design limits and that the bearings load is safe; and
to determine specific fuel consumption and thus monitor engine performance against a known standard"(J.Listewnik 2).

Those objetives mentioned above can be achieved by means of monitoring the following engine parameters:

Fig. 14


FAILURES AND THEIR DEVELOPMENT
Failure
Random failures
non predictable
T
Regular failures
predictable
T
With failure
developing time
T
Condition
Monitoring
Without failure
developing time
T
No PM
action
With failure
developing time
Condition
monitoring
Without failure
developing time
Programmed
replacement

-shaft horsepower
-engine and shaft rpm
-cylinder pressure-time curves
-oil fuel injection pressure-time curves
-oil fuel temperature and viscosity
-charge air pressure
-exhaust gas temperature
-engine cooling system temperatures and pressures
-engine lubricating oil system temperatures and pressures
-turbocharger rpm and vibration
-lubricating oil analysis data
-crankshaft deflections
-main bearing temperatures
(See fig. 15)

For steam turbine ships, the following parameters are monitored:

-turbine rotor vibration
-turbine rotor axial displacement
-shaft horse power
-shaft and turbine rotor rpm
-plan performance data

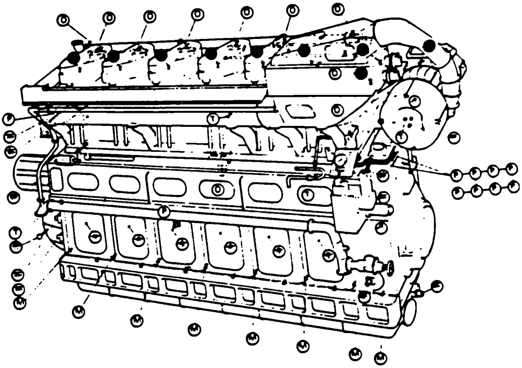
And finally, for auxiliary machinery the following paramaeters:

-cooler efficiencies, inlet and outlet temperatures
-heater temperatures
-pumps and fan vibration and performance
-differential pressure across filters.

As we have seen, condition monitoring is a tool which can play an important role in either maintenance or eco-

Fig. 15

C Cylinder pressures.
● Exhaust gas temperatures (cylinder and turbocharger).
M Main bearing oil temperatures
O Cooling water temperatures (inc. fuel valve
P Various pressures charge air, water, lubricating oil, fuel
T Various temperatures charge air, lubricating oil, fuel
• Crankcase mist detectors
→ Engine and turbocharger speed
◆ Various checks: governor output, low oil level, low water level, low oil pressure, etc.
■ Lubricating oil flow checks.



Measurement points for critical data and automation (six cylinder GMT engine) nomic engine operation, and which increases the safety of the vessel.

CHAPTER IV

METHODS OF MONITORING

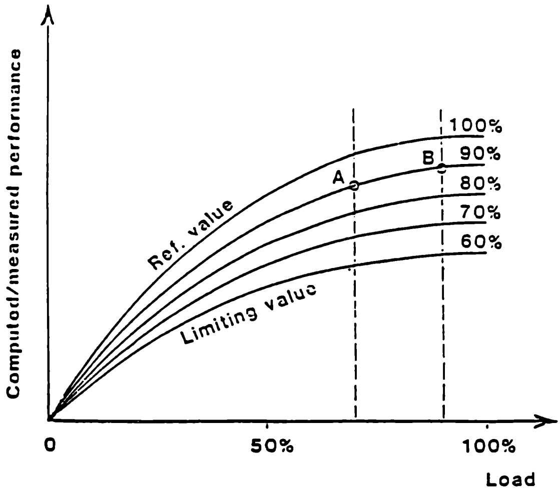
4.1 Performance of machinery

Performance monitoring is mainly based on the comparision between the original output or efficiency values and those values taken during operation of the engine or machinery. The similarities or differences found between these values will reflect the present condition of the equipment, showing proximity to the best performance condition or the necessity to be maintained. Moreover, the comparisions made by means of diagrams or charts will rapidly give a clear picture about maintenance effectivness.

The reference values used in carrying out performance monitoring correlations are usually recorded in diagramatic form. These graphs are provided by engine makers or machinery manufacturers from sea or test bed trials. Based on that information, the model curves are made to have the reference line of optimum performance. Thus, we can do a comparision with the present developed curve and the model curve, and therefore an assesment of the machinery. (See Fig. 16)

Although performance monitoring shows the decay in efficiency or output, this method does not point out what component might cause this decrease in performance. In this state, performance monitoring has to be helped by other methods of condition monitoring to have a better idea of the failing component (units used in condition monitoring will be seen later in this chapter).

Fig. 16



Computed/measured performance
100%
90%
80%
70%
60%
A
B
Ref. value
Limiting value
0
50%
100%
Load

Some of the graphs regarded in performance monitoring, for the same type of diesel engine and hull, are listed below:

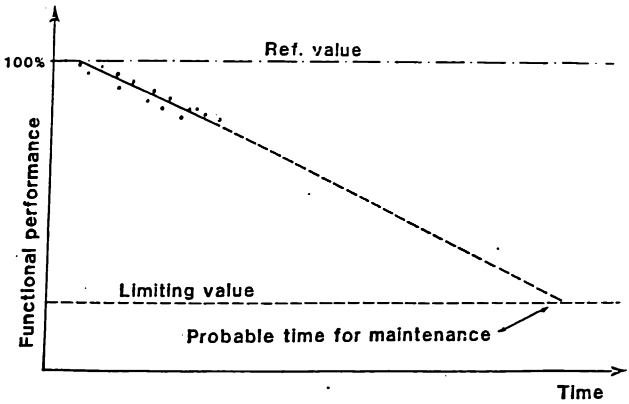
- Absolute compression pressure (P_{ca}) as a function of absolute scavenge pressure (P_{sca})
- Maximum cylinder pressure (P_{max}) as a function of mean indicated pressure (P_{mi})
- Fuel pump index (FPI) as a function of mean indicated pressure (P_{mi})
- Cylinder exhaust temperature (T_{exh}) as a function of shaft kw (Skw)
- Main engine revolutions (N_{ME}) as a function of mean indicated pressure (P_{mi})
- Specific fuel consumption (SFC) as a function of shaft kw (Skw)
- Scavenge pressure (P_{SC}) as a function of mean indicated pressure (P_{mi})

For auxiliary machinery, the following graphs are used:

- Pressure drop across waste heat unit (ΔP_{whu}) as a function of shaft kw (Skw)
- Pressure drop across air filters (ΔP_{AF}) as a function of scavenge pressure (P_{SC})
- Pressure drop across air coolers (ΔP_{AC}) as a function of scavenge pressure (P_{SC})
- Turbocharger revolutions (N_{TB}) as a function of pressure at turbocharger outlet (P_{TB}).

But some of the most useful graphs display from the amount delivered as a function of time. (See Fig. 17) This kind of graph is applied to pumps, compressors,

Fig. 17


Ref. value
100%
Functional performance
Limiting value
Probable time for maintenance
Time

etc.. Monitoring carried out in this way is called functional performance.

It is worth mentioning once again that we must be careful to keep the same parameters used during the building up of reference values.

In addition, in monitoring diesel engines, it is a good practice to have a torque gauge to obtain a fair evaluation of the condition of the engine . Meanwhile, for other equipment, less sophisticated gauges such as thermometers, pressure gauges, flow meters, ampermeters, tachometers and are required.

4.2 Shock pulse analysis

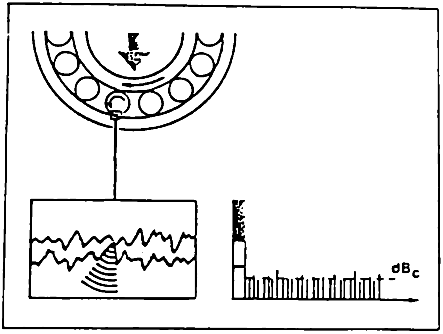
The impact caused between an irregular rotating surface and other surface in normal condition, or both surfaces in irregular condition is the reason a shock pulse signal is produced. This signal can be used to indicate the condition of ball or roller bearings.

By means of a shock pulse meter, the mechanical impact can be recorded due to the high frequency vibrations created and transmitted through the bearing cover. In short, shock pulse analysis can be described as the "measurement of noise of impacts of metal against metal"(R. Cushing 21).

However, we must have reference values as in other comparisions. Under normal conditions, bearings will behave with almost no difference between the decibel carpet value (dB_C) and the decibel maximum value (dB_M), as the oil film is kept normal between the metals.(See Fig. 18)

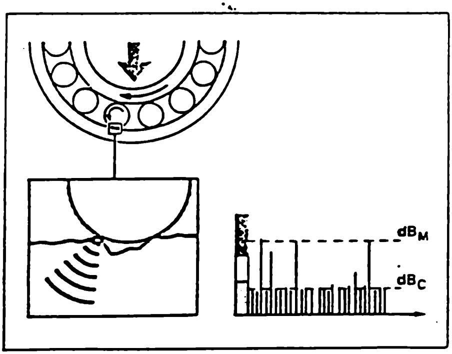
As the bearing is kept in operation, it will develop some irregularities on its surfaces, which will produce "single shock pulses with higher magnitudes at random

Fig. 18



Shock carpet value.

Fig. 19



Bearing damage.

intervals" (Marine Maintenance Manual 6.10:2). At this stage, the decibel values with the highest magnitude will show a difference with the carpet values and this gap will be analyzed to detect the bearing condition. (See Fig. 19)

Carpet and maximum values will show a better picture of the bearing condition if these values are shown in a shock pulse diagram in function of lifetime. (See Fig.20)

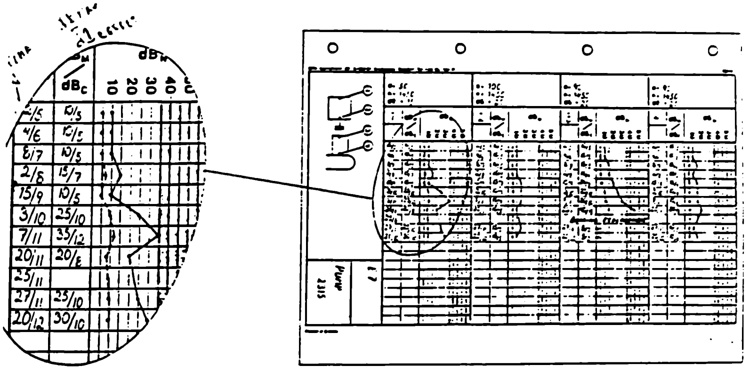
We have to take care to pick up the right shock pulse signal from the machinery that is monitored, as shock pulse can come from other sources. For instance, mistaken signals can be obtained from the following origins:

"-abrasion between shaft and other machine parts;
-loose parts striking the machine frame and/or the bearing housing;
-shocks between a badly fastened machine and its foundation;
-excessive play and misalignment of couplings;
-vibration in connection with loose parts and excessive bearing play (vibration alone does not affect shock pulse values);
-gear tooth damage, particles in the lubricant;
-cavitation in pumps; and
-load and pressure shocks arising during the normal working cycle in certain machines " (Marine Maintenance Manual 6.10:2)

Also according to the Marine Maintenance Manual, there are some recommendations for picking up the shock pulses, including the following:

1-"The signal path must contain only one mechanical interface, that between the bearing and the bearing

Fig. 20



Follow-up forms.

housing

2- The signal path between bearing and pick up point shall be as straight and short as possible

3- The pick up point shall be located in the load zone of the bearing".

The reason for these suggestions is that shock pulses are dampened during their propagation. Shock pulses travel in spherical waves (sound is a kind of vibration) and also are produced most of the time in the load zones of the bearing.

4.3 Vibration analysis

Vibration in machinery is something usual, but it can be generated by many different causes. Among them, we can mention the following:

-reciprocating forces,
-unbalance,
-misalignment,
-bad antifriction bearing,
-mechanical looseness,
-torque vibration,
-bad drive belts,
-tooth impact,
-resonance, and others.

In vibration analysis, the vibration characteristics of the machinery are going to be measured and compared with previous data for determining its source.

In order to detect where the origin of the vibration is, we can make use of a vibration analyzer which will provide us with valuable information which can be represented in the form of graphs for a quick examination. These graphs are made from values of amplitude and frequency of the vibration and are referred to as "vibration signature". (See Fig. 21)

A general mechanical condition of the equipment is obtained by means of interpreting the vibration amplitude measurements. By mean of the frequency analysis, however we can pinpoint the origin of the vibration and thereby find the failing component. The vibration identification chart is a useful tool to look for the causes of different amplitudes, frequencies, or phases. (See Fig.22)

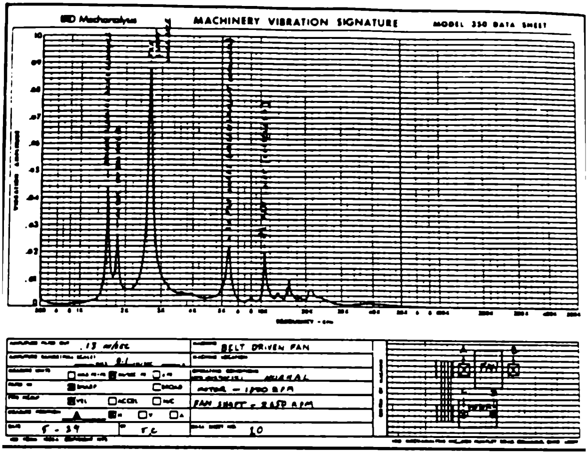
4.4 Periodic oil analysis

As part of monitoring engine performance, the periodically used oil analysis contributes as well to the economic operation and prediction of potential sources of trouble.

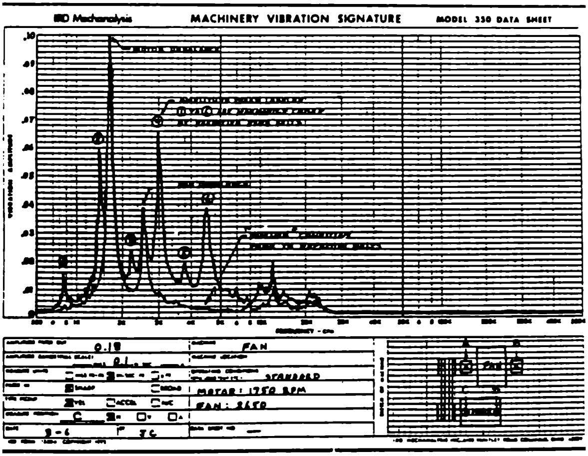
For medium speed engines, oil analysis is carried out mainly to determine the Total Base Number (TBN) which has a great influence during wearout process in the event it has a great influence decreased below its border line . However, oil analysis is also used to determine the present properties of the used lube oil to know whether it is accepted for further service in medium speed as well as slow speed engines.

The introduction of spectographic examination of used oil samples in detecting wear metals can represent the effects of changes of fuel properties and thereby assess wear as it occurs in order to take due actions. With this system, it is not necessary to have an internal inspection of the engine to know the results of using different fuels.

Fig. 21



Graphic Recording of
Vibration Measurements



Graphic Comparison of
Machine with and without Defective
Drive Belts

Fig. 22

VIBRATION IDENTIFICATION

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

Before starting with the description of the next equipment, I would like to make clear that the only reason I have chosen them is to show the new trend of technology used presently in the engine room and not to promote their use. These descriptions are taken from the manufacturer's papers.

4.5 Diagnostic systems for diesel engines

4.5.1 SEDS (Sulzer Engine Diagnostic System)

This system has been designed for the monitoring of essential machinery parts with the aim to detect anomalies at an early stage to avoid consequential damage. The system is subdivided into data acquisition, data analysis and man-machine communication. (See Fig. 23)

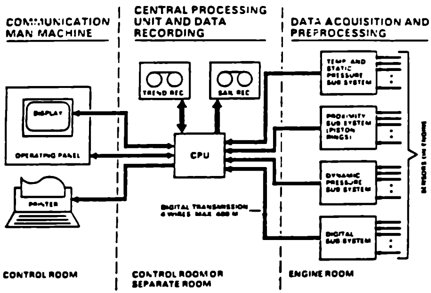
By means of sub-systems, the data acquisition part of the system pre-processes the reading from temperatures, statics and dynamic pressures (combustion and injection pressures), piston ring monitoring sensors and pulse or digital signals coming from engine speed, engine torque, fuel flow and turbocharger speed.

The data analysis and man-machine communication part is composed of a central processing unit (cpu), operator's console including pre-programmed keys, control lamps, an alphanumerical display which presents any measured or calculated value and also any built in parameter, on request. Parameters such as alarm levels can be adjusted at any time through the panel.

Also the system includes a printer, a tape cassette unit with the following tasks: load new programs, load the self diagnostic program "help" and external memory for trend analysis. Further, a tv screen type display is

Fig. 23

THE ENGINE DIAGNOSTIC SYSTEM



Hardware block-diagram of SEDS

optional and can be installed at any distance from the computer.

4.5.2 SIPWA (Sulzer Integrated Piston ring Wear Arrangement)

This unit continuously measures and records the wear rate of the top piston ring which consists of a particular cross-section and which is filled with a material with different magnetic properties. A sensor installed in the inspection hole of the cylinder liner detects the wear element on the piston ring and from this reading calculates the wear rate. This information is plotted at regular intervals for every cylinder, giving the engineers an early warning to check in particular the fuel treatment.

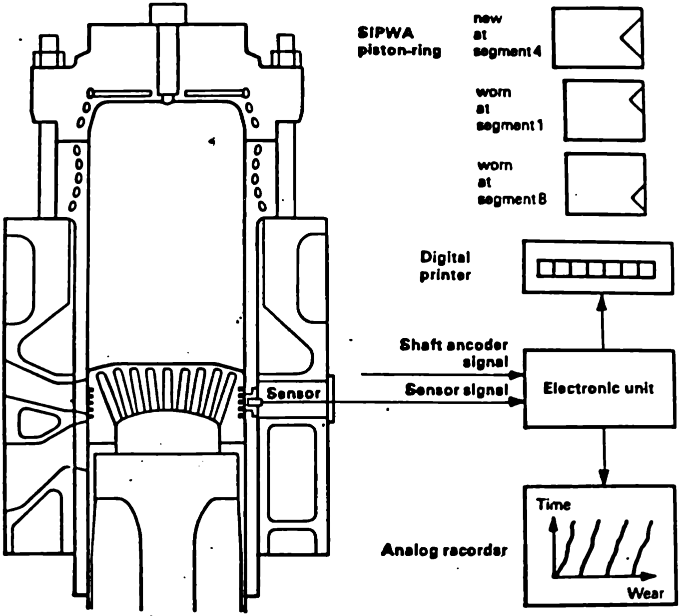
In this manner, we can optimize the piston running condition, and increase the liner and piston rings life. Further, superfluous maintenance is eliminated thereby reducing the operational costs. (See Fig. 24)

4.5.3 MIP

The MIP-calculator NK-5 is a diesel monitoring control unit for presentation of pressure time curves and data from the following sensors:

A-Cylinder pressure sensor

- -MIP, mean indicated pressure
- -P_{max}, maximum combustion pressure
- -P_{comp}, compression pressure
- -P_{exp}, pressure on the expansion curve,36° deg. afte T.D.C.
- -αP_{max}, the angle where P_{max} occurs, referred to


SIPWA
piston-ring
new
at
segment 4
worn
at
segment 1
worn
at
segment 8
Digital
printer
Shaft encoder
signal
Sensor signal
Sensor
Electronic unit
Analog recorder
Time
Wear

0779 7006-1

T.D.C.

-Load, cylinder load in kw

B-Fuel pressure sensor

-FP ,maximum fuel injection pressure

-FP ,fuel injection pressure when the valve opens

- P ,the angle FP open occurs referred to T.D.C.

-G, fuel oil delivery in crank angle degrees

C-Scavenge air pressure sensor

-P ,scavenge air pressure

D-Crank angle information sensor

-RPM, revolution per minute

-Piston position

(See Fig. 25)

This unit is provided with a screen for presentation and a floppy-disc for storage of curves and data regarding the combustion and injection process of the diesel engine.

From the screen, we can obtain the following combination of curves/data:

-Cylinder pressure curve/data

-Injection pressure curve/data

-Cylinder pressure curve/data together with injection pressure curve/data

-Cylinder pressure curve/data together with stored cylinder pressure curve/data

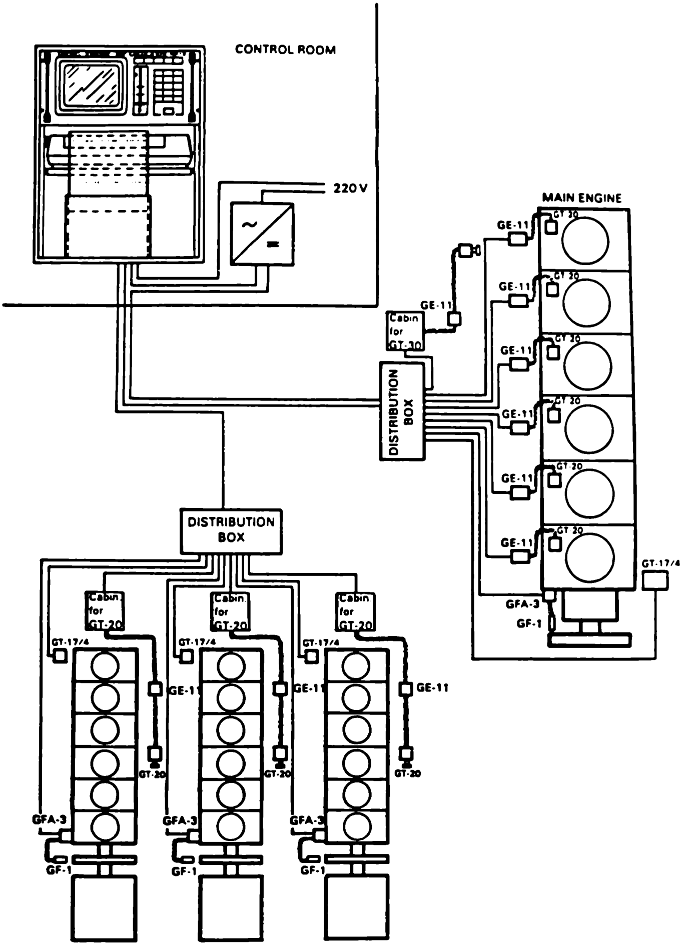
-Injection pressure curve/data together with stored injection pressure curve/data

-Stored curves/data

-Bar graphs

Fig. 25

NK - 5. Example of installation on main- and aux. engines



-Engine total state

-Piston ring pulses

The values coming from the cylinder pressure sensor, scavenge air pressure sensor, and the RPM can be updated and transferred to local value storage, while the oldest values are skipped.

The operation of this unit is made by use of menus and soft keys. The main menu presents the following choices:

1-Select cylinder measuring

2-Engine state analysis

3-Set up adjustments

4-Piston ring indication

5-Disc operation

By pressing the soft keys numbered from 1 to 5 the different sub-menus will be presented on the screen. (See Fig. 26)

The MIP in combination with a engine fixed with Variable Injection Timing (VIT) would represent a great advantage from fuel saving point of view.

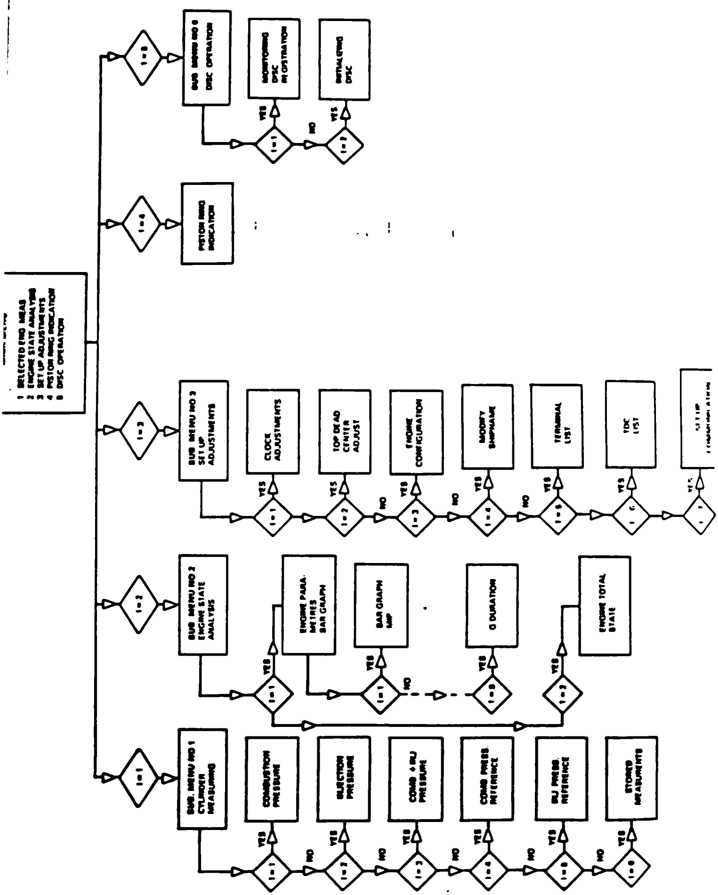
During 1985, the MIP system was ordered for more than 117 ships.

4.5.4 Combustion Pressure Monitoring System CPS 360 (Soren T. Lyngso)

The CPS is a measuring system which can give the operator a great deal of information necessary to be able to determine the general state of the engine combustion.

This system may be used for all two stroke engines as well as for four stroke medium speed engines with a maxi-

Fig. 26


1 SELECTED ENG MEAS
2 ENGINE STATE ANALYSIS
3 SET UP ADJUSTMENTS
4 PISTON RING INDICATION
8 DISC OPERATION
DISC OPERATION
MONITORING DISC REGISTRATION
PISTON RING INDICATION
SUB MENU NO 3 SET UP ADJUSTMENTS
CLOCK ADJUSTMENTS
TOP DEAD CENTER ADJUST
ENGINE CONFIGURATION
MODIFY SHIPNAME
TERMINAL LIST
TDC LIST
SUB MENU NO 2 ENGINE STATE ANALYSIS
ENGINE PARAMETRES BAR GRAPH
BAR GRAPH MIP
ENGINE TOTAL STATE
SUB. MENU NO 1 CYLINDER MEASURING
COMBUSTION PRESSURE
INJECTION PRESSURE
COMB + INJ PRESSURE
COMB PRESS. REFERENCE
INJ PRESS. REFERENCE
STORED MEASUREMENTS
YES
NO

mum speed of 1000 revolutions per minute. And the same CPS trunk unit can be utilized for up to eight individual engines.

The CPS 360 receives information from the cylinder pressure through a piezo electric crystal sensor mounted at the indicator cock which takes measurements on one revolution starting from the bottom dead centre. This information is measured and calculated when one of the different function modes is selected. After being calculated, the result is shown on a 4-digit led display and/or plotted if the CPS is connected to the optional plotter.

This unit is able to take and calculate the following measures:

1-PMI (bar)
2-Pmax (bar)
3-Pcomp (bar)
4-Pexp (bar)
5- Pmax (degrees)
6-RPM
7-Plot P, (with plotter)
8-Plot P,V (with plotter)
9-Numbers of teeth. (N. of continuous teeth counted for each revolution).

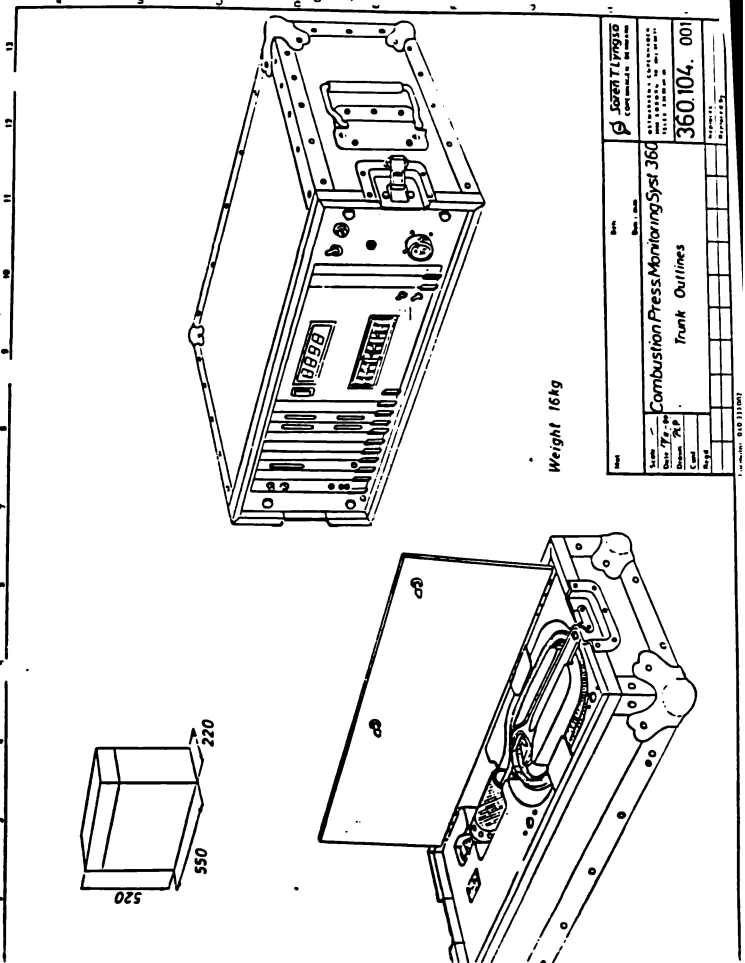
For all types of engines, the position of the piston can be detected from teeth/holes on the flywheel or an impulse band on the output shaft. Meanwhile, on cross-head engines, the position can also be detected from teeth on the telescopic pipes.

The CPS monitoring system has a built-in diagnostic test programme which can check the most important parts of the hardware and a battery back up unit in order to keep the information when the main power is disconnected.

As we have seen, this system provides engineers with valuable information which contributes to the diagnosis of cylinder combustion. In addition, the CPS 360 has the characteristic of being a portable unit, although it can be fixed as well. (See Fig. 27)

To conclude this chapter, I would like to mention that the main idea behind the description of these items of equipment in particular is to show a general view of the development in condition's monitoring systems. This is not to say that there is no other equipment which might be better and more complex than those mentioned. In general these units have more or less the same functions and same principles of operation.

Fig. 27


520
550
220
Weight 16kg
Søren T. Lyngsø
Combustion Press Monitoring Syst 360
Trunk Outlines
360.104. 001

CHAPTER V

SPARE CONTROL AND CODING SYSTEM

5.1 Spare control system

Planned maintenance can not succeed without the co-operation of an adequate spare control system. Both of them are complementary and required in a good management plan of a fleet or vessel in order to avoid unnecessary shut down time which result in higher operation costs as well as fewer ship benefits.

However, the first question that comes to our minds could be "what amount of spares is the right one?". The answer to this question is going to depend on many factors which have to be settled all together in order to determine the necessary level of spares. Further, commonly theoretical patterns used in spare consumption are applicable only for those components which have a normal wearout rate and are frequently used.

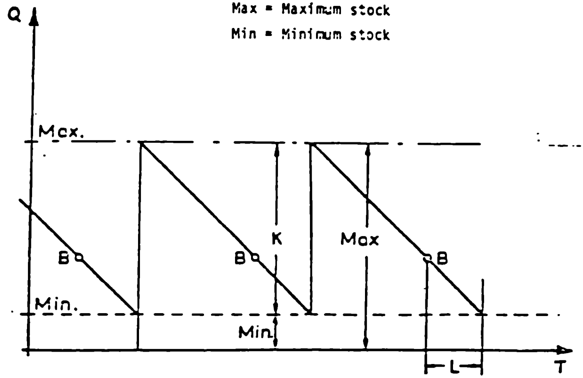
Although demand of a component is the main factor in choosing the correct level of spare, there are other factors which also have to be considered. Among these factors are the following:

1-the spares which must be onboard for safety reasons
2-the amount of spares required by classification societies
3-the delivery time of parts
4-the vessel trade route
5-the cost of shut down
6-the competence of the crew.

Fig. 28

Q = Quantity
T = Time

K = Quantity ordered each period
B = Placing of order
L = Delivery time
Max = Maximum stock
Min = Minimum stock



Ordering stores and standard parts.

-main index, equipment index, spare parts issue/in stock, ordered/received, recondition of spare parts sent to shore, additions/corrections in spare part forms

-label for spare parts.

Information about the location of the item, ordering data, e.g. re-order level, quantity, normal stock, etc.,specification and name of the spare part is also found in the spare part form.

By means of the issue/in stock form, the path of a component can be followed up.

In addition, all the equipment is identified by means of a code number to which can be added the manufactur's code number in order to facilitate ordering transactions of spare parts or even signals which will indicate a specific maintenance activities.

The system using cabinets is composed of the following main parts:

-cabinets with drawers

-miscellaneous cards for technical data, consumption and stock card

-ordered/received cards

-labels for identification of spare parts

-store issue notes

-signals for noticing of spare parts to be ordered, etc..

The technical data, maker/supplier, agent, drawing number, location, all this information is contained in the data card. Other cards such as consumption and stock card contains information about the spare when it is received or issued, the stock for each item and ordering data which includes re-order point, quantity and prices.

The ordered/received card contain dates of when the part has been ordered or received.

In order to ease the handling, drawers and cards can be identified with different colours.

By implementing any of the aforesaid systems, we are advancing in the way to facilitate the management of work on board. Further, in case computerization takes place in the engine room, we have advanced some work providing some organized data to feed any maintenance programme integrated with spare part system.

5.2 Coding system

In this part, I am going to refer just to the decimal code system as it is one of the most suitable for put all together management, maintenance and spare control systems. Moreover, presently the decimal code is being promoted for use for the different groups in the shipping industry.

The system is based on eleven digits, where the first and second digits represent the ship number code, assuming that this system is developed for a fleet which can be composed of up to one hundred ships. If this is not the case, these figures can be ommited. The third digit is

used to identify the main groups. All the ship's equipment is divided according to function. According to the Marine Maintenance Manual, an example of the nine main groups can be the following:

1-hull structure

2-cargo handling and deck equipment
3-accommodation
4-propulsion machinery and steering
5-auxiliary and other diesel engines
6-auxiliary systems
7-electrical plant
8-automation
9-administration

Systems and sub-systems are a more detailed breakdown of the main groups and are identified by the fourth and fifth digits in this coding system. With these two digits, it is obvious that up to one hundred sub-headings might be represented.

The sixth and seventh digits are used for components: specific pieces of machinery within the system and sub-system.

The eighth digit is for sub-components; it will indicate a part of the main component, e.g. electrical motor, pump, etc.. When this digit is a "zero", it describes the complete component.

The ninth and tenth digits describe spare parts of the sub-components. If we have more than one hundred items, an alpha numeric indexing allows the amplification of the amount of data for spare parts.

Finally, the eleventh digit describes maintenance tasks which migth allow up to ten different activities, with the alternative of being increased by means of using the alpha-numeric indexing.

In addition, the decimal coding system with respect to maintenance can be complemented with different colours to indicate periods of maintenance.

An example of the aforesaid coding system can be seen as follow:

Major overhaul of driven unit of sea service pump

```
   Code nunmber: 03/6/82/02/2/--/1
                 |  |  |  | |  | |
1&2 Ship No.------  |  |  | |  | |
3   Main Group-------  |  | |  | |
4&5 System and----------  | |  | |
    Sub-system            | |  | |
6&7 Component-------------- |  | |
8   Sub-component-----------   | |
9&10Spare of-------------------- |
    Sub-component                |
11  Maintenance Task-------------|
```

CHAPTER VI

6.1 COMPUTER APPLICATION IN MAINTENANCE.

For some years, computers have being used onboard because of the need of the shipping industry to optimize the general performance of the ship operation.

In the engine room, computers are utilized to develop calculations related with the following systems:

- -alarm system
- -remote control of main engine and generators
- -electric power management system
- -diesel engines monitoring and tuning-up
- -automatic combustion system for boilers
- -diagnosis and failure analysis system
- -planned maintenance
- -stock control, etc..

Some of these systems have been seen in part devoted to condition monitoring or mentioned in their manual form. But something interesting to mention is that most of them operate separately without any connection among each other, although these units contribute a large amount of data by themself. Data obtained from this unit offers useful knowledge to engineers about the operated system.

The collection of data that in early years represented workload and higher operation cost, in form of paperwork and consumption of time of technical staff, now can be carried out through computers with limited intervention by engineers onboard.

With respect to planned maintenance, we can find various firms which are able to offer hardware and software with integrated maintenance management systems that include functions for planned maintenance, spare parts control and analysis of the diesel engines.

The extensive potential of the use of computers in planned maintenance give us the opportunity to have a very versatile amount of functions which are displayed in form of main function and sub-functions.

According with the last programme release from Transtema Kockumation "Chiefplan" , we can obtain functions regarding to planned maintenance such as:

-overview pictures (it is presented as the wallboard maintenance plan in the monitor screen)
-list of jobs
-work discriptions and hints
-manual and/or automatic calculations of future works
-history per component
-user instructions per picture
-yearly spare parts consumption per component
-list of docking jobs
-list of Classed marked jobs
-spare parts per component
-full integration between meters and due jobs
-list of routine jobs
-work reports
-piston overhaul reports.

The same programme offers also functions regarding spare parts control, such as:

-alphanumeric search of spare parts
-position in stock per spare part

-ordering level per spare part
-handling of spare parts sent ashore for repair
-number of spare parts in stock
-handling and print-outs of requisitions and follow-up procedures
-inventory list and spare parts listed in locations
-code based search for spare parts.

Usually computer programmes for planned maintenance covers scheduled routines for five years period with the flexibility to be modified.

Computerisation of planned maintenance will depend on the needs to integrate the propulsion plant to the whole management plan in order to optimize the total vessel performance. In addition to saving operation costs, factors such as reduction of workload and its unsatisfaction for the personnel,(because they have to do reports and statics by manual procedures), are also considered prior to deciding to computerise the maintenance plan. Further, something very important that we must bear in mind is that computers require the necessity to train personnel in both sides onboard and ashore. Without proper training the system will represent a big investment that is not fully utilized.

Here, is where academies play a very important roll in offering short postgraduated courses such as the one that I propose.

Computerised planned maintenance as manual systems have to be kept updated to be functional.

Finally, the proccess to change from the manual system to the computerised one could require up to three months of technician work. But at the end, the vessel in general will have an improved system to purshase, a better organization of spare parts control, reduced operation costs, better performance and last but not least higher second hand value.

CHAPTER VII

PLANNING OF THE MAINTENANCE COURSE

7.1 OBJECTIVES

The skill of a merchant marine engineer is not only determined by knowing how to correctly operate the thousands of horse power in the engine room, but also to know how to diagnose in advance failures and organize the maintenance activities.

Based on previous experiences, new equipment and strategies have been developed in order to improve the total vessel performance.

Consequently, the intention of this course is to give to marine engineering senior students and experienced engineers good knowledge about the trends in planned maintenance to be able to:

-analyze data making use of probabilstic methods,
-assess the different maintenance strategies,
-identify the different methods of monitoring and recognize the usefulness of some units used for diagnosing diesel engines,
-organize and codify a spare control system, and
-be aware of the utility given to computers in the engine room.

Although, this course is designed for The Panama Nautical School's students, it can also be suitable for marine engineers already graduated.

7.2 PROGRAM

Modules Plan Notes:

Session	: the period of time used to describe common subject matters. Usually, this period will be considered as forty five minutes.
Total time	: it is the time required to deliver a set of topics during a session.
Topic	: it is the title or reference to the subject to be discussed.
Time	: time included in each module is intended to be a guide as to the depth of treatment of the appropite subjet. It can vary according to circunstances.
Objectives	: they represent what the students will be able to do after the topic(s) have been covered.
Teaching aids	: this part comprises the audio-visual aids, tranparencies, projector, printed documents, computer, cross-section equipment, black-board, method of teaching, etc.; which are used in the different lessons.

Session : One

General subject : Introduction to Planned Maintenance and Inventory Control, and Theoretical Background of Maintenance.

Total time : The time for this course will be fixed after considering the circumstances in situ.

Topic	Time	Objectives	Teaching aids
General introduction to Planned Maintenance and Inventory Control		At the end of the lesson, the student will be able to: -have a general visual of aspects that will be seen in the course of planned maintenance and inventory control, -present suggestions their expectancies about the course.	Transparency, overhead projector, black board, printed documents Method to be used: -lecture and asking questions.

Topic	Time	Objectives	Teaching aids
Theoretical bacground of maintenance.		At the end of the lesson the students will be able to: -define terms used in the study of probabilistic curves, -mathematically define the Normal curve, -construct and apply the Normal curve, -make use of necessary table to find the "Z" value.	Transparency: 1,2 overhead projector, blackboard, printed documents. Method to be used -lecture and demonstrative.

Session : Two

General subject: Description and Uses of Probabilistic curves

Total time :

Topic	Time	Objectives	Teaching aids
Description and uses of: Expnonential curve.		At the end of the lesson the students will be able to: -mathematically define the Exponential curve, -construct and apply the Exponential curve, -recognize the use of this curve in the reliability theory.	Transparency: 3,4 overhead projector, blackboard, printed documents. Method to be used: -lecture and demonstrative.
Description and use of: Weibull curve.		At the end of the lesson the students will be able to: -mathematically define the Weibull curve, -construct and apply the Weibull curve, -identify the uses for	Transparency: 5,6,7, overhead projector, blackboard, printed documents. Method to be

		the different shapes of this curve	used: -lecture and demonstrative.
Description and use of: Bath tub curve.		At the end of the lesson the students will be able to: -identify the different parts which compose this curve, -construct and apply the Bath tub curve, -be aware of pros and cons of probabilistic practices.	Transparency: 1, overhead projector, blackboard, printed documents. Method to be used: -lecture and demonstrative.

Session : Three

General subject: Strategies Used In Maintenance

Total time :

Topic	Time	Objectives	Teaching aids
Corrective and preventive maintenance.		At the end of the lesson, the students will be able to: -define corrective and preventive maintenance, -recognize the goals behind corrective and preventive policies, -identify factors which control the appropiate running time of a specific engine.	Transparency: 9,10, overhead projector,blackboard. Method to be used: -lecture.
Planned maintenance.		At the end of the lesson, the students will be able to: -understand the four essential elements in any good E.R. management e.g. planning,execution,	Transparency: 11,12,13, overhead projector,blackboard,printed documents.

	recording and analysing; -list the documents which are required for conti- nuos maintenance survey.	Method to be used: -lecture and demonstrati- ve.
Maintenace based on condition manitoring.	At the end of the lesson, the students will be able to: -comprehend the philoso- phy behind maintenance based on condition moni- toring, -identify equipment which are suitable for conti- nuous or at intervals monitoring, -describe the different uses of condition moni- toring for the good per- formance of diesel engi- nes, -identify the parameters which usually are moni- tored for engines,steam turbines and auxilliary machinery.	Transparency: 14,15, overhead pro- jector,black- board,printed documents. Method to be used: -lecture and demonstrati- ve.

Session : Four

General subject: Methods of Monitoring

Total time :

Topic	Time	Objectives	Teaching aids
Performance of machinery.		At the end of the lesson, the students will be able to: -construct graphs to be used in performance monitoring of M.E. and auxiliary machinery, -be aware of parameters which are required to be fixed during the building-up of reference values, -list necessary equipment to evaluate condition.	Transparency: 16,17, overhead projector, blackboard, printed documents. Method to be used: -lecture and demonstrative.
Shock pulse and vibration analysis.		At the end of the lesson, the students will be able to: -identify the different shock signals, -identify sources of mis-	Transparency: 18,19,20,21, 22, overhead projector, blackboard, printed

	taken signals, -recognize good measures to pick up shock pulses, -state different sources of vibration, -analyze vibration signatures.	documents. Method to be used: -lecture, demonstrative and working in groups.
Periodical oil analysis	At the end of the lesson, the students will be able to: -recognize the importance of oil analysis, -identify factors affecting the state of lubricating oil.	Printed documents. Method to be used: -working in groups.

Session : Five

General subject: Diagnostic Systems For Diesel Engines

Total time :

Topic	Time	Objectives	Teaching aids
SEDS, SIPWA, MIP,CPS-360		At the end of the lesson, the students will be able to: -know the particularities and posibilities of SEDS SIPWA, MIP NK-5, CPS-360	Transparency: 23,24,25,26, 27, overhead projector,printed document. Method to be used: -demonstrative, lecture and working in groups.

Session : Six

General subject: Spare Control System

Total time :

Topic	Time	Objectives	Teaching aids
Spare control system.		At the end of the lesson, the students will be able to: -know the factors considered in choosing the the correct level of spares, -identify necessary documents with respect to the handling of spares, -identify the different components of the two main manual systems of spare control, -elaborate a spare control system.	Transparency: 28, overhead projector, printed document, black-board. Method to be used: -lecture and demonstrative.

Session : Seven

General subject: Coding System

Total time :

Topic	Time	Objectives	Teaching aids
Coding system		At the end of the lesson, the students will be able to: -comprehend the functional oriented decimal code system, -organize a decimal code system.	Printed documents and black-board. Method to be used: -lecture and working in groups.

Session : Eight

General subject: Computer Application In Maintenance

Total time :

Topic	Time	Objectives	Teaching aids
Computer application.		At the end of the lesson, the students will be able to: -recognize the areas where computers are presently used in the E.R., -recognize the advantages and disadvantages of the use of computers on board, -identify the functions of programmes for planned maintenance and spare control integrated system.	Printed documents, black-board and computers. Method to be used: -lectured and demonstrative.

Session : Nine

General subject: Final Evaluation

Total time :

Topic	Time	Objectives	Teaching aids
Participants and course evaluation.		To: -obtain feedback from students in order to know their assimilation of the subject, -obtain feedback to ensure objectives have been achieved, -obtain feedback to ensure the course can be improved.	Open question and questionnaires.

7.3 Aspirants Requirements

This course will be given to marine engineering students who have had experience on board and those experienced engineers who need to brush-up on their knowledge on maintenance developments.

7.4 Resources

The course is projected to be delivered in the facilities of The Nautical School of Panama where the following equipment is readily available :

- -computers,
- -diesel laboratory,
- -overhead projector,
- -audio-visual equipment,
- -class rooms,
- -copy machines and other equipment necessary to issue this course.

In addition, visit to vessels which make use of those units described in this course will be accomplished.

7.5 Limitations

This course is programmed to last not more than ten class room hours, but, this does not includ the time spent in visiting ships.

7.6 Participants and course evaluation

Evaluation will take place in the last session. It will be carried out in order to receive information about assimilation of students, methods used and objectives achieved.

The questions will be presented in the form of open questions, and also a questionnaire will be delivered to receive opinions about the attainment of participants expectancies.

CHAPTER VIII

CONCLUSIONS AND RECOMMENDATIONS

It is essential that merchant marine academies look to not only fulfill the minimum requirements in the S.T.C.W. 78 convention, but also offer to their students the opportunity to have enough knowledge to tackle situations on board as well as ashore related to the shipping industry.

This proposed course has the intention to offer origin to the thinking that engineers also require education that is not traditional in the marine engineering field, but that day after day is required for shipping industry "management knowledge".

It be that some engineers do not agree with the subjects that comprise this course, an example might be the inclusion of the topic of probabilistics to which I have devoted one chapter. I think, however, that the person who is interested in investigations shall exhaust all the possibilities to find a good solution. In addition, the career of marine engineer does not have as the final goal that engineers remain all their life sailing. In our particular case, they are also welcome to work ashore.

Consequently, we as lecturers in M.M.A.(s) have to provide our students with as much knowledge as possible which will also help them in the investigation and administration without forgeting our main objectives.

Other reasons which had a major contribution in the production of this paper was my wish to contribute the present path of The Nautical School of Panama in developing courses for post-graduated engineers in addtion to those which are running, such as:

-radar operator,

-automatic controls,
-survival at sea,
-radio telephony operator, and
-handling of dangerous goods.

In the engineering department, we must implement some new courses, in view of the international conventions and the development of the maritime industry. Among such courses that have to be implemented in the near future are the following:

-up-grading course for Chief Engineers,
-up-grading course for First Engineers,
-course for safety marine inspectors,
-operation of oil, chemical and gas tankers and
-course in prevention of pollution.

The aforesaid will require more personnel and the cooperation of institutions involved in the maritime field; in order to attain the development all together and to make it more useful for the merchant marine personnel and those working in the maritime administration.

In this matter, I want to point out that the support of the I.M.O. through the courses given in the W.M.U. are a good help in the world wide maritime development. And it is my most firm recommendation to advocate to continue sending Panamanian staff involved in the maritime education and maritime administration to the W.M.U..

APPENDIX 1

AREA UNDER THE NORMAL CURVE

The area A is measured from the mean "μ" to any ordinate "x".
The table gives values of A $\times$ 10^4 for values of "z" at intervals of 0·01.

z	0·00	0·01	0·02	0·03	0·04	0·05	0·06	0·07	0·08	0·09
0·0	0000	0040	0080	0120	0159	0199	0239	0279	0319	0359
0·1	0398	0438	0478	0517	0557	0596	0636	0675	0714	0753
0·2	0793	0832	0871	0910	0948	0987	1026	1064	1103	1141
0·3	1179	1217	1255	1293	1331	1368	1406	1443	1480	1517
0·4	1554	1591	1628	1664	1700	1736	1772	1808	1844	1879
0·5	1915	1950	1985	2019	2054	2088	2123	2157	2190	2224
0·6	2257	2291	2324	2357	2389	2422	2454	2486	2518	2549
0·7	2580	2611	2642	2673	2704	2734	2764	2794	2823	2852
0·8	2881	2910	2939	2967	2995	3023	3051	3078	3106	3133
0·9	3159	3186	3212	3238	3264	3289	3315	3340	3365	3389
1·0	3413	3438	3461	3485	3508	3531	3554	3577	3599	3621
1·1	3643	3665	3686	3708	3729	3749	3770	3790	3810	3830
1·2	3849	3869	3888	3907	3925	3944	3962	3980	3997	4015
1·3	4032	4049	4066	4082	4099	4115	4131	4147	4162	4177
1·4	4192	4207	4222	4236	4251	4265	4279	4292	4306	4319
1·5	4332	4345	4357	4370	4382	4394	4406	4418	4430	4441
1·6	4452	4463	4474	4485	4495	4505	4515	4525	4535	4545
1·7	4554	4564	4573	4582	4591	4599	4608	4616	4625	4633
1·8	4641	4649	4656	4664	4671	4678	4686	4693	4699	4706
1·9	4713	4719	4726	4732	4738	4744	4750	4756	4762	4767
2·0	4772	4778	4783	4788	4793	4798	4803	4808	4812	4817
2·1	4821	4826	4830	4834	4838	4842	4846	4850	4854	4857
2·2	4861	4865	4868	4871	4875	4878	4881	4884	4887	4890
2·3	4893	4896	4898	4901	4904	4906	4909	4911	4913	4916
2·4	4918	4920	4922	4925	4927	4929	4931	4932	4934	4936
2·5	4938	4940	4941	4943	4945	4946	4948	4949	4951	4952
2·6	4953	4955	4956	4957	4959	4960	4961	4962	4963	4964
2·7	4965	4966	4967	4968	4969	4970	4971	4972	4973	4974
2·8	4974	4975	4976	4977	4977	4978	4979	4980	4980	4981
2·9	4981	4982	4983	4983	4984	4984	4985	4985	4986	4986
3·0	4986	4987	4987	4988	4988	4989	4989	4989	4990	4990
3·1	4990	4991	4991	4991	4992	4992	4992	4992	4993	4993

If "z" is positive:
Probability = 0·5000 *plus* value in table:

If "z" is negative:
Probability = 0·5000 *minus* value in table:

APPENDIX 2

APPROVED PLANNED MAINTENANCE SCHEMES - AN ALTERNATIVE TO CSM

What then are LR's requirements for approval of a planned maintenance scheme? Not surprisingly the scheme should be based on preventative maintenance or condition based maintenance or a combination of the two.

The following information is required to be submitted:-

1. A numbered index of the machinery items to be included in the scheme.

   The index will no doubt cover many items which are not required for classification, it should however at least include all items which appear on the "Master List of Surveyable Items". The indexing system should be such that immediate cross-reference to LR machinery survey codes can be made. The index should indicate these items to be maintained on preventative maintenance and those on condition based maintenance.

2. Maintenance and monitoring methods. Time schedules and limits of acceptability.

   Maintenance descriptions should at least cover the minimum opening up necessary to enable a satisfactory examination to be carried out.

   The extent of work to be carried out should also be indicated but it is not necessary for approval purposes to include all detailed job descriptions. A few sample job descriptions to demonstrate how the system works is sufficient.

   Where machinery items are maintained on a condition basis the monitoring technique to be used should be described and details of the equipment should be stated. Also the parameter limits must be clearly defined. These should be derived from manufacturers recommendations, applicable severity criteria or the Owners required limits, which may be more severe.

   Machinery on preventative maintenance obviously must be examined completely for survey purposes at intervals not exceeding 5 years, although in practice maintenance will usually be carried out more frequently. Machinery on condition based maintenance may be accepted for survey on the basis of the monitoring records or after examination when opened up for deteriorating conditions.

3. Adequate reporting and data recording facilities.

   The recording system is to be sufficiently comprehensive to enable the surveyor to satisfy himself that the scheme is being operated correctly and is up-to-date.

   Lloyd's Register have no wish to dictate to Owners the form the planned maintenance scheme should take provided it meets the three basic conditions described above. It follows therefore that widely varying schemes can and will be acceptable from basic planning charts to the more complex computer based systems.

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