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DIESEL ENGINE DESIGN WITH A VIEW TO REDUCED MAINTENANCE COSTS

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INTRODUCTION

The operational costs of a ship today are relatively high, and with the altered energy policy which has given quite a different picture of the distribution of costs compared with the conditions before October/November 1973, it is still of great importance to reduce the operational costs to a minimum in relation to, for instance, the maintenance costs and the consumption of spare parts, etc.

To obtain a favourable operational result, it is important to be certain what influence the individual units have on the total operational result of the ship. The demands on the manpower on board, the consumption of spare parts and operational means etc, are some of the items represented in the operational budget which make it important that these resources are utilized in the best possible way.

Propulsion machinery must be reliable, and flexible so that it can be adapted for altered operational conditions, as the fuel oil restrictions in 1973 when fuel oil consumption had to be cut down by up to 25 per cent, and when the individual ships had to sail with reduced load and reduced speed where this was possible, or in cases where the propulsion machinery was not operationally flexible, to partially stop the operation. The diesel engine proved, in this case, that it could satisfy such a demand for flexibility.

Up until recently the trend has been to build larger and larger ships (and therefore more complex) to utilize the available operational resources in the best possible way. This has meant that nearly the same size of crew looks after the larger unit. The conversion to the use of heavy fuel oil was a step on the road to a reduction of fuel costs, but resulted in an increase in the maintenance costs owing to the unfavourable operational conditions given by the use of heavy fuel.

The increasing complexity of, such as, the increasing use of electronic systems in connexion with monitoring and operating the plant, make the qualifications of the crew a deciding factor for good or bad operational results. The gradual reduction in working hours which most groups in today's society enjoy, also makes it more difficult to find highly qualified personnel who are satisfied with a job which isolates them from family and friends in periods of over 6 to 12 months. The trend towards irregular calls at ports and the constant change-over of crew is a further obstacle in the co-ordination of operation and maintenance work.

The following aims for K-GF series of two-stroke engines were therefore drawn up:

1) to increase the service reliability;
2) to ease the overhauling work;
3) to improve the operational economy;
4) to reduce the installation costs.

These targets were drawn up before the time of oil restrictions, but are still valid—perhaps, though, listed in a different order of priority.

THE DIESEL ENGINE DEVELOPMENT IN THE LAST DECADE

Through the whole history of the diesel engine, a continuous development of the engine output has taken place measured in kilowatts per kilogrammes weight of the engine, but at the same time the service conditions have changed.

Higher mean pressure combined with the altered service conditions caused by a still increasing use of less refined fuel oils, may result in considerable shortening of the components' lifetime that are in contact with the combustion space.

During the original design in 1957–59 of, for example, the 84VT2BF-180 engines developing 1690 kW (2300 bhp) at 110 rev/min at a mean indicated pressure (mip) of 9·8 bar (mcr), allowance was made for a possible later uprating of the engine.

The engine was uprated to 2020 kW (2750 bhp) at 121 rev/min at a mean effective pressure (mep) of 10·1 bar (mcr) resulting in a reduction of the weight/kilowatt as the dimension of the engine is almost the same.

In the beginning of the 1960s, a demand emerged for a further reduction of service costs. Due to this, initial automatic control of the engines was introduced which enabled the operator to control the engine direct from the bridge.

Long service periods and short idle times are typical for tanker operation. In many cases the service time per year is about 8000h, and in the following this service period is used as a basis.

According to the manufacturers of ship bottom coatings, ships can remain in service without drydocking for more than two years.

However, the docking time has also been used for maintenance work both on the main engine and on the auxiliary machinery, and it is now necessary to increase the length of time between overhauls and this was allowed for in the design of the K-GF engine (Fig. 1).

Objectives for design of K-GF type engines

As previously mentioned, the K90GF engine is a new design with, however, important design points originating from the existing engine types. (Fig. 2).

The cylinder distance is the same as for 84VT2BF-180 and K84EF; however, as compared with K84EF the output is increased to 2507 kW (3410 bhp) at 114 rev/min and mep 11·6 bar.

On basis of service results in practice both with VT2BF and K-EF engines, the design of the K-GF series of engines is developed to counteract unfavourable aspects of the service results.

In close co-operation with a number of Scandinavian shipowners with a representative fleet of ships in service

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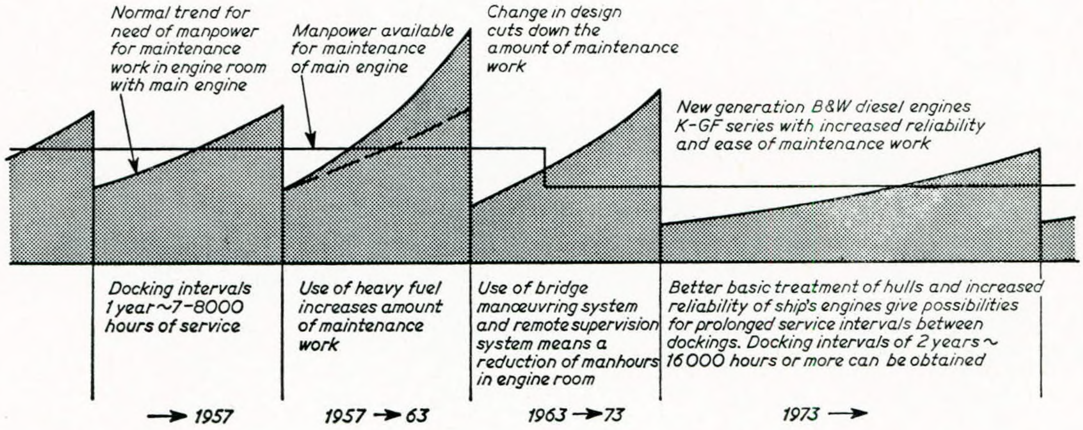

FIG. 1—*Historical sketch of the development of the diesel engine relating to the reduction of operational costs*

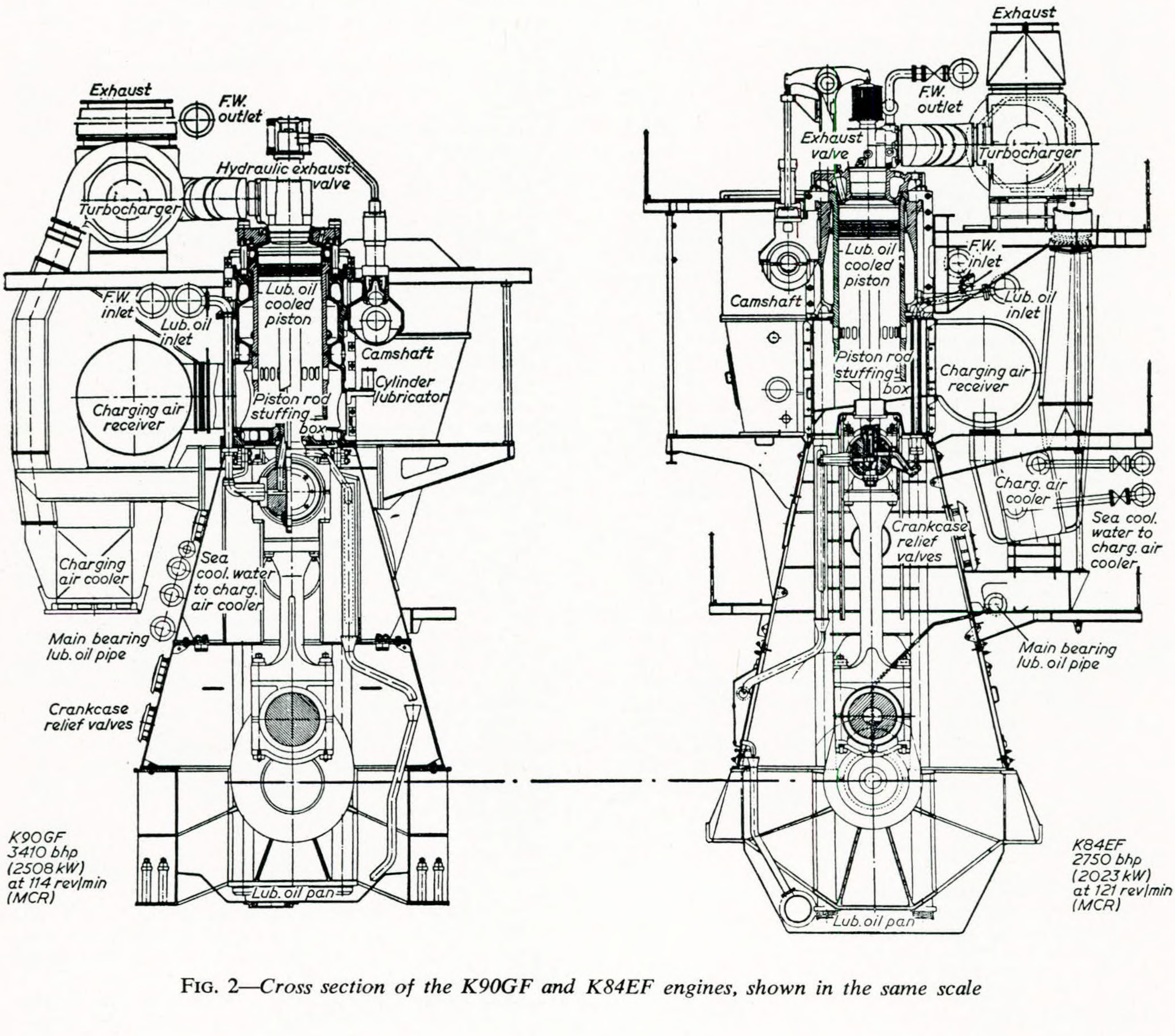

FIG. 2—*Cross section of the K90GF and K84EF engines, shown in the same scale*

under varying forms of operations, which enables a wide spectrum of service experience to be gained, a number of components and systems designed for K-GF engines have been tested on engines in service.

As it appeared from the previously mentioned objectives for the design of the K-GF engines, two of the points relate to the indirect operational economy conditions of the engine. An effort has been made to improve the components and systems so as to achieve longer service periods between the overhaulings.

Further, importance has been attached to designing the engine to be as easily accessible for overhauling as possible so that, the individual overhauling procedures takes a minimum of time and requires the shortest possible stoppage of the engine, which in turn involves a reduction of the labour force. The third objective, to improve the operating economy by means of a higher utilization of the fuel oil at a lower consumption, kilowatts, has been achieved as shown by the curves in Fig. 3 which gives the

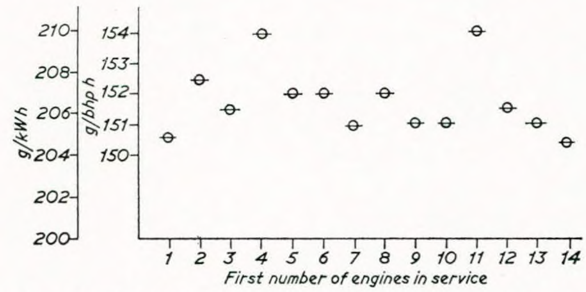

FIG. 3—*K90GF—Fuel consumption test bed result*

fuel consumption of the first 14 engines on the testbed, running on diesel oil at maximum continuous rating (mcr), which gives for the K90GF an output of 2508 kW (3410 bhp) at 114 rev/min.

Improvement of the operating economy also includes an effort to reduce the consumption of wear parts. The objective; to achieve a higher operational safety, involves that individual components and systems that have an influence on whether the engine can operate or not, the degree of reliability is increased, so as to be able to reduce the risk of unintentional interruptions of the operation to an economically justifiable limit.

Testing of new design on engine plants in service

The co-operation with the shipowners has given the possibility of testing components under varying operating conditions, and by only partly rebuilding previous engine types so that new and old components are in operation on the same engine, good comparison material has been obtained.

As appears from Fig. 4, the fuel valve and the exhaust valve with hydraulic movement had, among other things, obtained a relatively long service time before the first engine of K90GF type was put into service in July 1973.

The results show a substantial improvement of the operational results and that these operational improvements are relevant is shown clearly by the fact that the owners involved have started to reconstruct (or already have reconstructed) previous engine types with the new component designs.

By utilizing the service results already obtained as basis for the expected life of parts, i.e. fixing the expected operational life between overhauls, the results for the K90GF components show, for example, that the overhauling intervals for the fuel valve can be increased from about 2000–2500h to about 8000h at a conservative estimate.

Examination of the fuel valve, Fig. 5, and in the first instance of the atomizer which is executed from stellite without separate cooling, shows no signs of burning after 15 500 operational hours (September 1974) and the wear in the atomizer holes was insignificant when checked at 7500h (so the final criteria for discarding the fuel atomizer will probably be based on the life of the holes rather than on the burning of the atomizer tip which has been the case for previous types. The spindle guide of the fuel valve, which in October 1974 had a service result of 16 500 operational hours without overhauling, shows correspondingly good tendencies.

The hydraulic-operated exhaust valve, Fig. 6, where the mechanical movement has been altered to hydraulic transmission of the opening force, shows a satisfactory improvement of the operational results, and it appears in the following results, as guardedly shown, that overhauling intervals of about 8000 operational hours for exhaust valves can be expected.

Improvement of the operational conditions

Great importance is placed on improving operational conditions, i.e. extention of the operational periods between overhauls, as well as a reduced working load for inspection

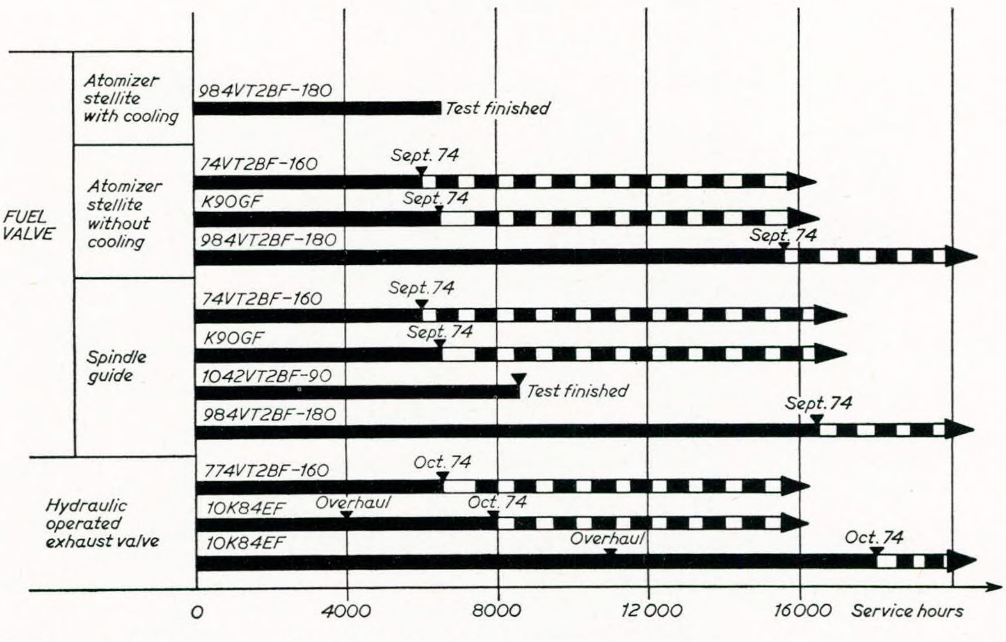

FIG. 4—*Service hours for K90GF components, fuel valve and exhaust valve, tested on previous engines*

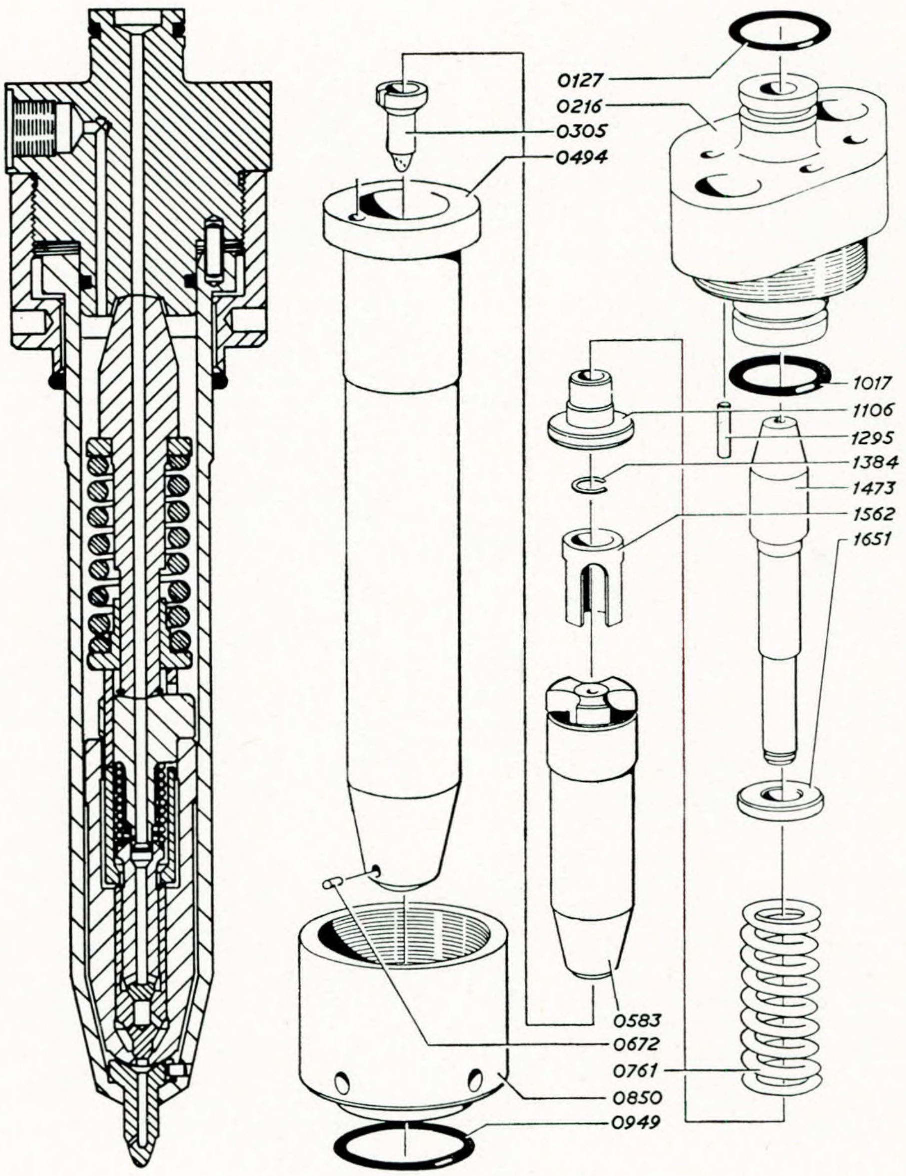

FIG. 5—*Fuel valve for K-GF engines*

and re-conditioning not just for the fuel valves and exhaust valves. But as these two functions put, in most cases, the greatest load on the operational accounts, the most substantial saving will be made with an improvement in this field.

Fig. 7 shows a relative comparison of the stopping time for overhauling between dockings at 24 month intervals between two engines having about the same output effect of approximately 20 227 kW (27 500 bhp) (mcr), namely 8K90GF at 114 rev/min and 10K84EF at 121 rev/min.

When comparing the most important reasons for stopping, it is seen that the stop time for 8K90GF is reduced by about 69 per cent in relation to the stop time necessary for 10K84EF.

In the diagram, stop time is only reckoned to deal with replacements with re-conditioned parts so that the reconditioning and testing of the exchanged parts can be carried out en route.

An analysis of the results obtained shows that the relatively large reduction is due to three main reasons—that there is a smaller number of cylinders with K90GF to reach the desired output, that the life of the components between overhauls is increased and that the replacement time is reduced.

Fig. 8 shows the relative improvements for each of the stated reasons, reckoned in percentage in relation to 10K84EF which is set as 100 per cent. For cleaning the scavenging air coolers, no improvement to facilitate overhauling is reckoned with as no information is yet to hand which can serve as a basis for this, but on the K90GF sections, cooler elements are fitted, which means that a single element can be lowered down for easy cleaning, (Fig. 9), which certainly will decrease the cleaning time and give more efficient cleaning. The smaller share of the stop time by 8K90GF for the fuel valves and the exhaust valves is owed, among other things, to the fact that the overhauling intervals coincide with the piston inspection, so that other desired work with replacement of parts can be carried out within the period taken for the piston replacements.

To look at the total planned maintenance amount, a comparison of the manhours for maintenance within a two year period (16 000 operational hours) for 10K84EF and 8K90GF, shows in Fig. 10 that 8K90GF demands about 50 per cent less work than 10K84EF. In the statement about the amount of work with the main engine stopped, consideration of the fact that a great deal of the work can be done at the same time by the total number of crew is made as the calculation only deals with the total amount

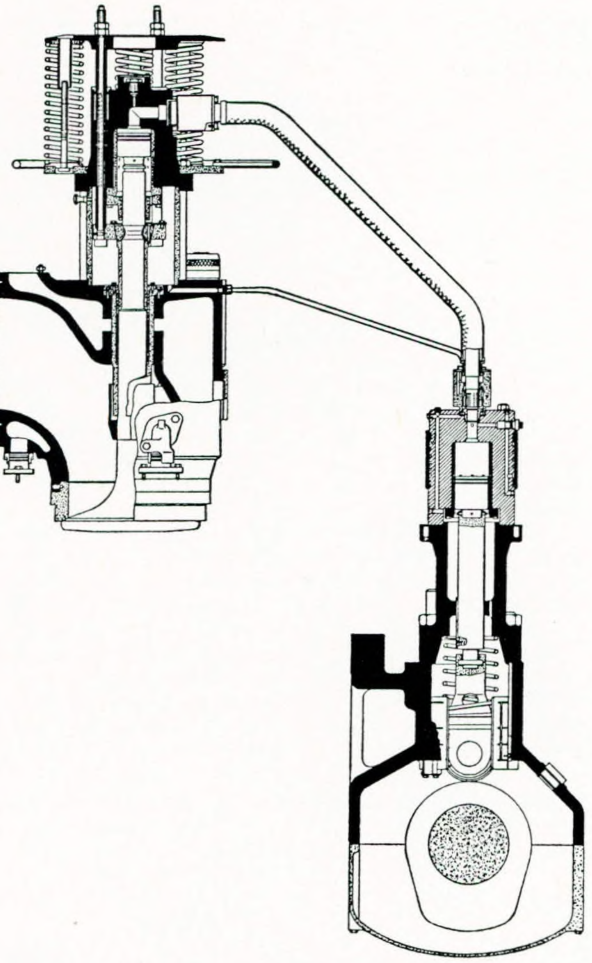

FIG. 6—*Hydraulically operated exhaust valve K-GF engines*

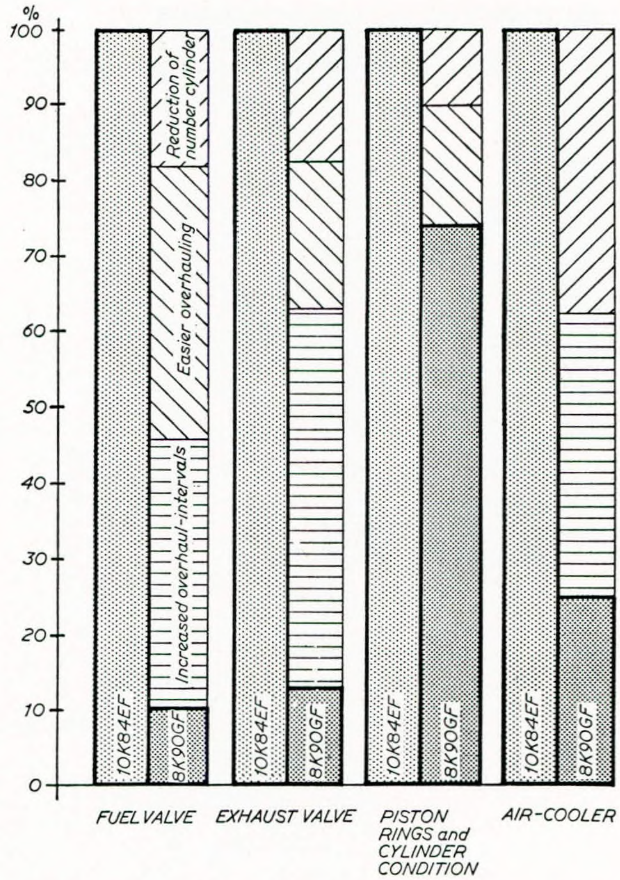

FIG. 8—*Analysis of the reason for the reduction of stop hours for maintenance in the 24 month docking intervals for 10K84EF*

PART OF ENGINE	ENGINE TYPE	HOURS BETWEEN OVERHAULS: Present average	No. of units	Hours stopped engine per unit	No. of overhaul betw. dockings (16.000 hours)	Total hours with stopped engine betw. dockings	Manhours for overhaul by replacememt: Per unit (man x Hours)	Manhours for overhaul by replacememt: Engine per year (manhours)	Manhours for recondition and test: Per unit (man x hours)	Manhours for recondition and test: Engine per year (manhours)
EXHAUST VALVE	K90GF	8000	8	1	1	4	2 × 1	8	2 × 3	48
	K84EF	3000 -4000	10	2	4	40	2 × 2	100	2 × 3	150
FUEL VALVE	K90GF	8000	24	1/2	1	4	1 × 1/2	12	1 × 1	24
	K84EF	2000 -2500	30	1	6	30	1 × 1	105	1 × 3	115
PISTON INCL. CYL. COVER	K90GF	8000	8	4	1	16	4 × 4	128	2 × 1 1/2	24
	K84EF	6000 -8000	10	5	1	25	5 × 5	250	2 × 1 1/2	30
AIR-COOLER	K90GF	Section coolers > 8000	2	1	1	1			Depends on the conditions.	
	K84EF	4000 -8000	4	1	2	4				
TURBO-CHARGER	K90GF	8000	2	8	1	8			3 × 8	48
	K84EF	6000 -12000	4	8	1	8			3 × 8	96

Comparison between 8K90GF (MCR 27300 BHP at 114 RPM) and 10K84EF (MCR 27500 BHP at 121 RPM)

Note: 27300 BHP = 20 079 kW
27500 BHP = 20 226 kW

Hours with stopped engine for selected overhaul procedures (docking intervals 24 month = 16.000 h)

Engine type	Stopped hours betw. dockings	Relative reduction %
8K90GF	33	69 %
10K84EF	107	

FIG. 7—*Relative comparison of hours with stopped engine for main overhaul in docking intervals of 24 months 16 000 service hours*

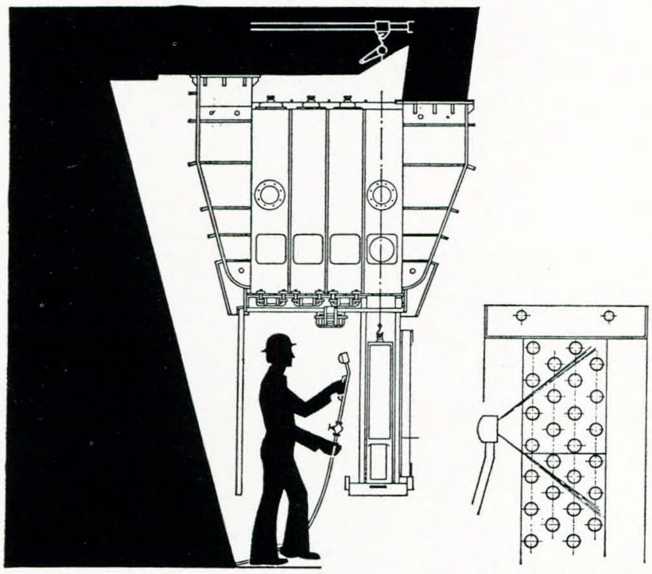

FIG. 9—*Cleaning and scavenging air cooler—K90GF*

of work divided between the stated number of months.

The comparison shows, however, that there is a substantial reduction of the maintenance work with a K90GF engine in relation to a K84EF as the manpower costs totally seen must stand in the approximately same relationship as shown in the figure.

To be able to fully utilize the optimal operational resources of the engine, both regarding the running conditions so that maximum use of the now expensive fuel oil can be obtained, as well as keeping the engine in such a reliable degree of maintenance that unnecessary stops are avoided, it is of utmost importance that the personnel who shall attend and maintain the engine fully know the conditions for which the engine is designed.

Increased facilities for overhauling gives a reduction in the repair and maintenance costs as it is quite certain that the most effective method for reducing these costs is to eliminate the need for carrying out maintenance and the need for costly repairs.

Design of diesel engine for ease of maintenance work

In the development of the K-GF engines, great importance has been attached to the fact that the need for maintenance is reduced to a reasonable level by designing the individual components with the greatest possible reliability in view.

Scale models of plastic have been used to a great extent for simulation of the control of the load distribution of forces, and the deflexion of the frame boxes and bedplate during tensioning of staybolts, as well as the rigidity of the bedplate, and a number of examinations to confirm newly developed calculation methods.

Furthermore, scale models have been used in connexion with investigations of dismounting and mounting work of a more time and work consuming nature such as, for example, dismounting and mounting of complete piston, replacement of bearings in the engine, and replacement of the crosshead.

Thus, it has been already possible at an early stage to make allowance, under three-dimensional conditions, for the location of lifting hooks, platforms, etc, enabling the work to be carried out under the highest degree of safety both for the personnel and the parts which are so handled.

Great importance has been attached to reducing the number of lifting thread sizes in the parts; thus, where it has proved practicable to use only one size of eye bolt, for example; M20 for K90GF and K80GF and M16 for K67GF. An effort has been made, furthermore, to apply only a limited number of screw sizes to limit the number of spanners needed during work on the engine.

Similar to the preceding engine types, all large bolt connexions are tightened and loosened by means of hydraulic tools, which, in addition to easing the manual work, provide the best and most uniform conditions for tightening up the components. For example; the hydraulic ring fitted in the cylinder cover for simultaneous tightening of the studs, as shown in Fig. 11.

The ring is drilled to receive the hydraulic pistons, the bores being linked by integral oil ducts. The four eyebolts which retain the ring permanently on the cylinder cover, also serve as attachments for lifting the complete cover assembly. By connecting an air-driven hydraulic pump to the snap-on coupling on the ring, pressure oil is supplied to all tightening pistons simultaneously via the duct system.

The permanent tightening device results in an exceptionally "clean" cylinder cover and eliminates irritating and easily damaged hydraulic pipe loops, as well as the usual multitude of external connexions at which leakages can occur.

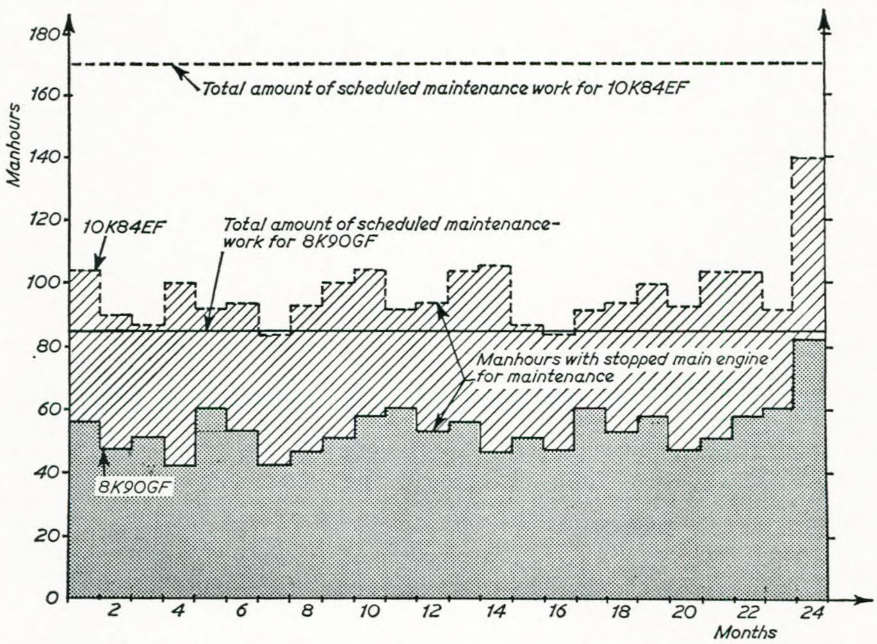

FIG. 10—*Total amount of planned maintenance work for a period of 24 months for 8K90GF compared with 10K84EF*

During the last few years, opinion has gradually won acceptance that to economize on auxiliary equipment which may reduce the overhauling time and contribute to creating a better result in the long run is the wrong way of saving money.

Unfavourable working conditions have a tendency to result in poor profitability of the rather large investments. That part of the operating costs which include labour requirements and the consumable stores such as cleaning

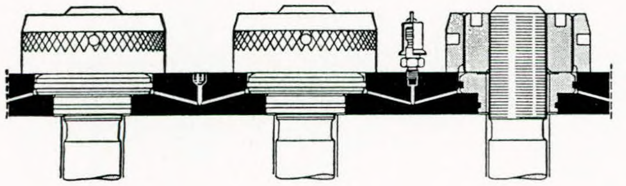

FIG. 11—*Hydraulic ring, fitted on cylinder cover for quick and uniform tightening of studs—K90GF*

preparations, hand tools, workshop equipment etc may seems a considerable expenditure, as they appear constantly on the budget. However, if attempts are made to economize unreasonably on these costs of daily consumable stores, wear of a more serious nature may result on the vital and expensive components.

MAINTENANCE PHILOSOPHY

By increasing the intervals between overhaulings and carrying out only absolutely necessary maintenance work based on estimating the actual condition rather than a fixed schedule, the direct costs can be reduced.

Unplanned maintenance and repairs cannot however be avoided completely as the cost would be prohibitive.

The choice of maintenance system for ship machinery must be based on the actual operational cycle, including the quality of the operating and maintaining staff.

Technical education today has created a group of all-round technical-minded personnel who, to a great extent, can undertake manual maintenance work. This permits the more highly qualified engine room personnel to concentrate on running the machinery and fault finding which in turn avoids machinery being stripped down unnecessarily. This in turn creates a feeling of responsibility on the part of ships' staff as well as job satisfaction.

The tendency towards irregular calls at ports and the constant change-over of crew is a definite obstacle to the co-ordination of running and maintenance work and the provision of spare gear, etc.

The chosen maintenance system must be sufficiently flexible to cope with altered conditions, as otherwise the maintenance costs will become excessive. A too rigid system which does not allow for unforeseen occurrences will break down.

INSTRUCTION MATERIAL

In order to be able to utilize to the greatest possible extent the construction idea lying behind the K-GF series engines, it has been of immense importance that these thoughts and ideas are passed on to the users of the engines.

Great importance has been given to the preparation of easily understandable instruction books which apply to the category of personnel who carries out the individual jobs on the engine.

With due regard to the qualifications of the personnel, the instruction material is built up into two main groups, the one being the basis material for the operational side, which also includes the operational basis for assessment and a description of the construction and function of the engine, and the other dealing with the working procedures which shall be executed to keep the engine in a proper maintenance condition.

For practical reasons, the instructional material is divided into three volumes:

Volume 1 "Operation" which deals with the technical operational conditions of the engine, together with trouble-shooting diagrams and other means of assessment. This volume is, on the whole, for personnel who are directly responsible for looking after the engine, and for operational reliability.

Volume 2 "Maintenance" which besides giving a summary of the recommended overhauling intervals, deals with the most importance maintenance procedures, discriminating between the working operations of the three main types, namely; control procedures, maintenance procedures and overhauling procedures.

Volume 3 "Engine Components" which besides giving a description of the construction and function of the engine, also contains exploded drawings of engine compartments and lists of spare part ordering numbers.

Maintenance

The group divisions of the instruction book correspond with the maintenance work groupings shown in Fig. 12 which take due consideration of an optimal utilization of stop time as well as of the qualifications of the personnel and of the constructional design of the engine.

The maintenance programme can be illustrated by dividing the maintenance into a "plannable" part and into

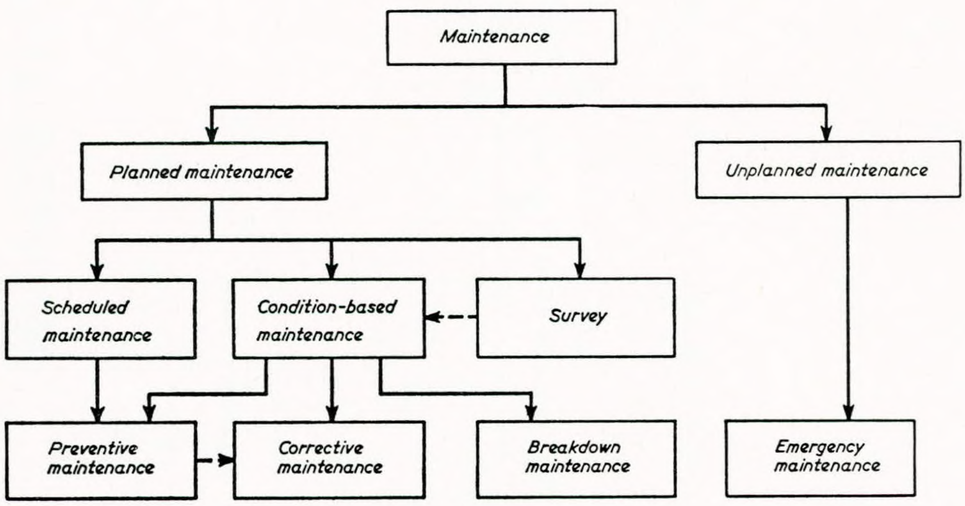

FIG. 12—*Maintenance set-up*

a part lying within economically justifiable limits which cannot be planned. The "plannable" maintenance has a natural division into three main groups:

Scheduled maintenance
Where no actual evaluation of the operational condition is made, and where the control and working procedures are carried through according to a programme based on giving intervals between overhauls.

Condition-based maintenance
Where the operational condition is checked, and on the basis of this checking it is decided whether overhauling should be carried out immediately or done at the same time as the scheduled maintenance programme. This part of the programme can be dealt with manually, by following systematically—via synopsis diagrams—any operational changes in the engine in relation to the condition ascertained on the testbed.

By comparing tendencies in the operational development with model curves, a relatively certain indication of the necessity of making operational changes or carrying out overhauls can be obtained.

A third category of the planned maintenance is the fitting in of the specified control demanded by the classification societies.

It is calculated that the "plannable" part of the maintenance programme represents 50 to 70 per cent of the total maintenance if it concerns an engine without a large degree of automation of the condition control. With an increased degree of instrumentation of continuous condi-

B&W K90GF K80GF K67GF — MAINTENANCE PROGRAM — 900-1, Edition 02, Page 2 (7)

☐c = Check the condition
O = Overhaul to be carried out

No.	OVERHAUL PROCEDURE	Overhaul to be based on procedure no.:	Check before start	Daily rutine	Check new parts after 500-1000 hours	Normal hours of service: 2 000 hours	4 000 hours	8 000 hours	16 000 hours	4 years (survey)	When necessary	With stopped engine	Related procedure
901	CYLINDER COVER												
-1	Dismantling of cylindercover							O				×	902-2
-2	Replacement of valves on cyl. cover Fuel-valve Starting-valve Exhaust-valve										O O O		
-3	Overhaul of cylindercover. Recondition of sealing surfaces. Inspection of cooling-ring.										O		
-4	Mounting of cylindercover.							O					902-3
902	PISTON WITH ROD AND STUFFING BOX												
-1	Inspection of piston and rings through scavenge-ports.				×	☐c						×	903-1
-2	Dismantling of piston compl. with stuffing box.	902-1						O				×	901-1
-3	Mounting of piston compl. with stuffing box.							O				×	901-4
-4	Overhaul of piston and rings.							O					
-5	Replacement of pistontop.	902-4									O		
-6	Replacement of cooling-insert.	902-4 902-5									O		902-5
-7	Testpressure of piston compl..	902-4									O		
-8	Overhaul of stuffing box (outside engine).							O					
-9	Overhaul of stuffing box (inside crank case).	902-1									O	×	

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Fig. 13—*Example of the maintenance programme for K90GF*

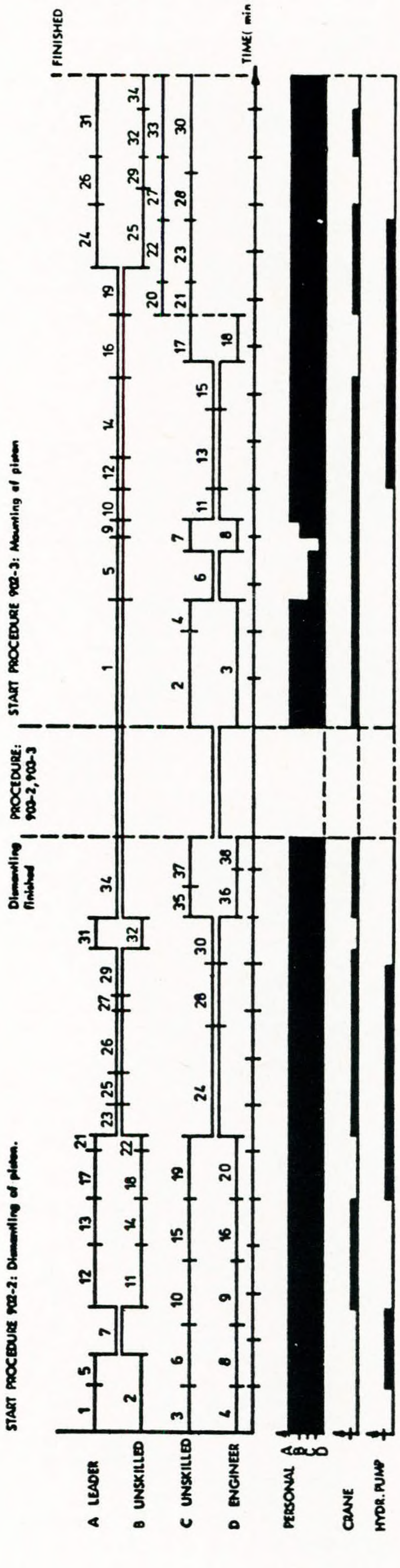


Fig. 14—*Piston overhaul K90GF, procedure 902-2—Network planning*

tion control, greater security against unforeseen occurrences will be obtained, which means an increased possibility for carrying out a more exact planning of the maintenance work whereby the percentage of the "plannable" part of the maintenance will be higher than the manual partial evaluation of the condition control.

The instruction books

To illustrate the information level found to be realistic, the following summary of the piston inspection procedure can indicate the most important points if manual evaluation of the condition control is used, and the possible maintenance flow.

The maintenance programme, Fig. 13, gives information that the piston inspection is made after previous control of the operational condition by inspecting visually the piston and cylinder condition through the scavenging ports, as stated in procedure 902-1.

The condition of the piston with rings and cylinder liner is noted with regard to ring breakage, sticking of rings, estimated vertical clearance, surface and lubricant condition of piston rings, piston skirt and top, piston rod and cylinder liner, sludge assembly in ports and frame bottom, and finally piston cooling oil leaks.

On the basis of the data collected, it is decided whether overhauling is necessary and, by systematic "follow-up", greater certainty can be obtained for placing available work effort in the best way for the operational economy, as a fixed interval does not in any way mean that components are ready for overhauling.

If, on the basis of the port inspection, it is decided that a piston withdrawal shall be made, this is executed according to procedure 902-2. This procedure of work is built up on the basis of analyses, see Fig. 14, which have been taken as a sequence of operations for planning technique. Partly used so that the manpower as well as time and facilities are most effectively used, and partly tests of the working procedure in practice have been made.

At the practical analyses of the working procedure, a testing of possible special tools is obtained as well as the overhauling facilities of the components regarding ease of dismantling and mounting, at the same time as due consideration of the working reliability can be taken.

The necessary special tools are hung on tool panels, Fig. 15, which are positioned close to the place of working so that time is not wasted in fetching the tools. A drawing showing the tool panel with tools and tool number is found on each panel so that shortage can be seen at a glance.

For the individual working procedures, Fig. 16, the instructional material contains a "data" page on which, besides the necessary tolerances, weights etc, there is also stated the special tools and normal hand tools and tackles etc to be used. Furthermore, the safety precautions are given to be carried out before the work is begun.

The procedure itself is explained in the form of a descriptive picture sequence which shows the varying work cycles in stages. The pictures include sections and perspective drawings to achieve the highest degree of understanding as well as jaw widths, eyebolt sizes, and lifting capacities, etc, enabling the appropriate equipment to be used in each individual situation.

The work instructions proper do not include explanatory text on the drawings, as the action is indicated by easily understood symbols, each of which indicates what is to be done and in which sequence. For those who prefer the written word, a short text explanation is given on the reverse side of the data sheet.

By using pictures to an extensive degree, these instructions can be understood by foreign labourers, who would otherwise be hampered by a language different from their own, and also to some degree by less qualified personnel who are not trained in complicated written explanations, but are more used, as for example through television, to digest a subject in pictures.

After being dismounted, the parts are then controlled. In principle the control procedure is built up on the same lines as the work procedure; however, as control and inspection of the parts are normally carried out by higher qualified engine room personnel, the procedure consists of brief control points and references as well as actual data as a basis for evaluation.

If spare parts or a closer description of the actual components or systems are to be used, the corresponding page in the instruction books is applied as a reference. The drawings are executed as a combination of functional drawings in sections and exploded perspective drawings which, for many, mean a better understanding of the interdependence of the individual components, see Fig. 5 as an example. The drawings specify spare part numbers of the individual parts which correspond with a specified list that also states the designation of the parts.

As a further development of the instruction literature, a number of films are available which show execution of the procedures given in the maintenance programme. The films, which are also obtainable as tv-cassettes, can be applied as a supplement in the training of the personnel and they can also be used to brief new personnel before overhauling is executed.

Training of personnel

The rapid development in marine engineering and shortage of marine engineers, has created a need for training courses in which instruction is given in the operation, maintenance and overhaul of not only new, but also older engine types.

The author's company therefore run one-week training courses for engineers who need a brush-up in their knowledge, and a two-week course for the engineers who have never been in touch with a B and W engine.

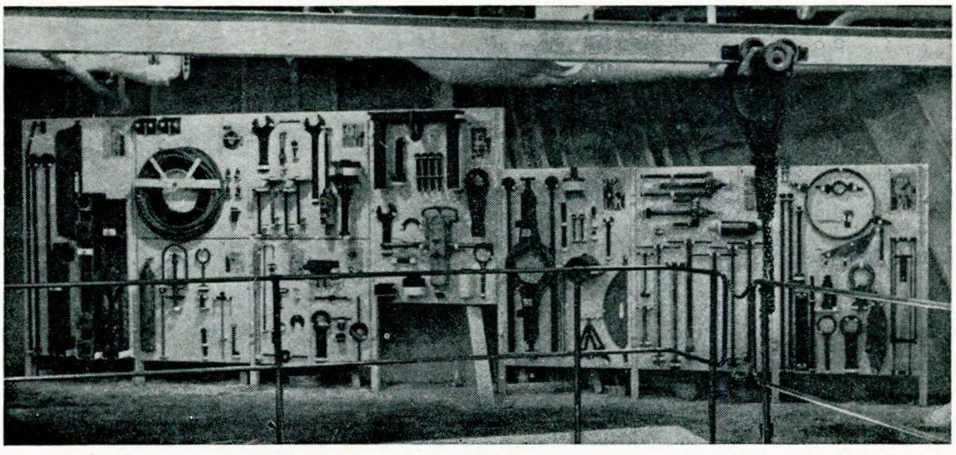
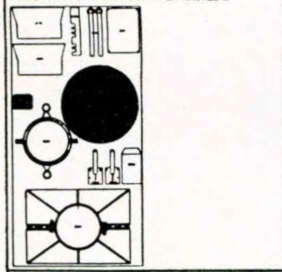


FIG. 15—*Tool panels, with the appropriate tools can be placed near the overhauling work*

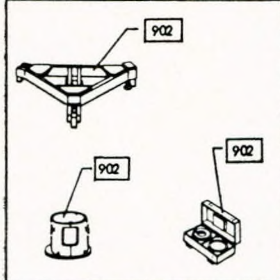
BURMEISTER & WAIN B&W K90GF	DISMANTLING OF PISTON COMPLETE WITH STUFFING BOX Demontering af stempel komplet		902-2
	Related procedure: / Tilhørende procedure: 901-1	Overhaul to be based on procedure no.: / Overhaling baseres på procedure nr.: 902-1	Edition 02 Data 1(1)

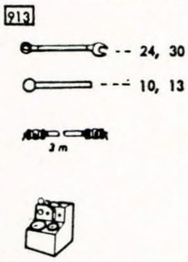
PISTON, PISTON ROD AND STUFFING BOX PANEL PLATE [illegible]



SAFETY PRECAUTIONS
SIKKERHED

- [X] Stopped engine / Stoppet motor
- [X] Block the starting mechanism / Blokere for startemekanismen
- [X] Shut off starting air supply / Luk for starteluft
- [X] Engage turning gear / Indryk tørnegear
- [X] Shut off cooling water / Luk for kølevand
- [X] Shut off fuel oil / Luk for brændselsolie
- [X] Shut off lubrication oil / Luk for smøreolie





Data:

D 1	Piston complete	3000 kg
D 2	Hydraulic tightening-pressure	700 kp/cm²

902-2	DISMANTLING OF PISTON	B&W K90GF
Edition 02 Text 1 (1)		

1. Turn the crosshead down far enough to give access to the piston rod stuffing box.
2. Open the locking devices and remove the innermost screws from the stuffing box flange.
3. Turn the crosshead to TDC, and take off the cylinder cover; see procedure 901-1.
4. Remove the locking strap for piston rod nut.
5. Dismount the piston rod nut using the hydraulic tensioning tool according to the instructions in section 913.
6. Screw the protective nut on to the tool attachment thread of the piston rod.
7. Clean the lifting groove of the piston and attach the lifting tool by screwing up the claws to abut the stop of the tool.
8. Lift out and land the piston in the support placed over the opening arranged for this purpose in the engine platform.
9. Place a cover over the opening for the piston rod stuffing box in the bottom of the cylinder unit.

BURMEISTER & WAIN B&W K90GF	DISMANTLING OF PISTON COMPL. WITH STUFFING BOX	902-2
		Edition 02 ILL. 1(1)

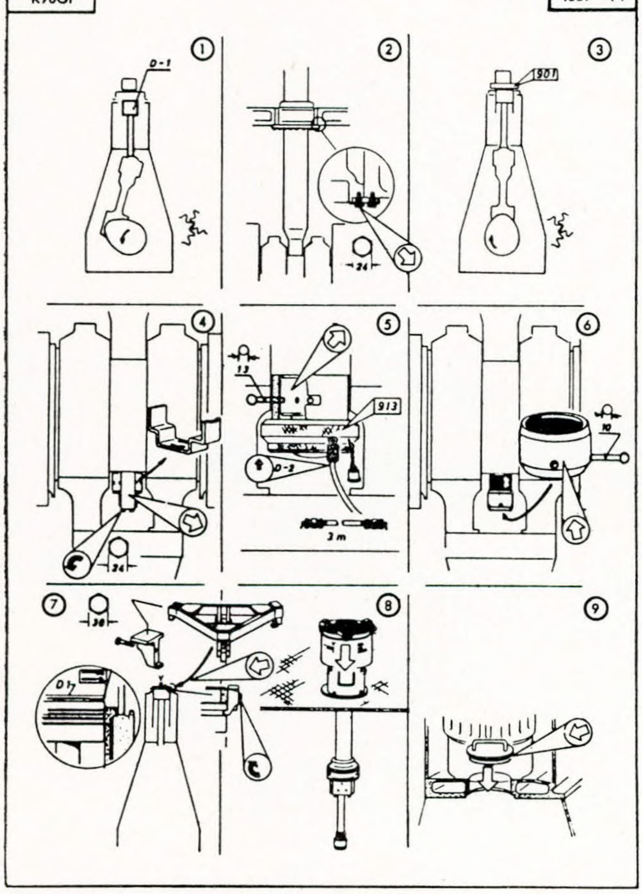


FIG. 16—*Working Procedure 902-2: Dismantling of piston, complete with stuffing box; together with data sheet, text and pictorial sequence instruction*

In the courses, which up to the end of 1974 have been attended by some 1200 engineers from all parts of the world, the instructions are divided between classroom lectures, films and workshop practice.

PERFORMANCE POSSIBILITIES FOR THE ENGINE COMPONENTS

By applying the actual operation conditions as a basis for overhauling, intervention is avoided until the parts reach a criterion that is justifiable with regard to the service as well as the operating costs.

As previously stated, great importance has been attached to extending the service period of the parts and the systems so as to reduce the interruption in service for overhauling to an absolute minimum; however, it is also of great importance for optimum utilization of the inherent operational potential of the individual components that inspection and control are based on a realistic life criterion. Thereby maximum performance of the parts is achieved, however, with so wide a safety margin for unintentional operation conditions that the remaining operating components that are connected to the system are not worn within a shorter period than normally.

Compared to the previous engines, the improved service conditions of the K-GF engines will give extended lifetimes of the wear parts, and Fig. 17 shows a comparison between wear parts of DE 84VT2BF-180 and DE K90GF. The cylinder cover is included despite that this is in fact not a wear part; however, considering the fatigue strength of water-cooled parts, the lifetime will depend on the number of work loads that can be converted into approximate numbers of service hours.

For the parts of K90GF the lifetime is estimated. The solidly-drawn lines show the service experience already gained from parts that are in service in existing engines, see Fig. 4, or parts that are identical with those of the K-EF engines.

The mentioned life of the cylinder liner is based on a liner wear of 0·1 mm/1000h and a maximum allowable wear between 3 and 6 mm on the cylinder diameter depending on the surface condition and correctness of form. As the wear of the cylinder liner mainly depends on the lubrication, the life may vary in accordance with the amount of lubricating oil used.

The design of the crosshead bearings for K-GF differs essentially from the bearings for the 84VT2BF-180 engine. The elastic support of the bearing housing, which was earlier introduced on the K-EF and K-FF engines, provides a more even distribution of the load. The use of bearings shells enables a better binding to be achieved between the white metal and the steel shell, and this means a higher strength; shells are therefore normally supplied as a standard. Bearings of a similar design, but capable of carrying a higher specific load have been in service since 1970. However, the specific bearing loads are lower than for VT2BF engines and on the same level as K-EF engines, which is why 10 per cent replacement only is expected after more than ten years service. The extended life of the exhaust valve spindle and cage is due to the lower temperature of the components of the K90GF as compared with the 84VT2BF-180 engine.

Due to the new configuration of the combustion space with the solid cylinder covers, which provides quite new possibilities of distributing the thermal load with advantage, the fuel jets can be positioned at a higher level in the combustion space which involves a lower wall temperature in the piston top. This means that the burning rate of the crown is—if not eliminated—considerably reduced.

As it appears from the above, the modified designs give reason to believe that the lives are increased, improving the total operating economy.

Increased reliability in service

After many years of experience with diesel engine design the point has been reached where "surprises" are less likely to occur and maintenance work is drastically reduced. The acceptable threshold level for "surprises" and maintenance work has, however, been lowered on account of the improvements achieved in ship management; in this connexion off-hire time is attracting increased attention. The economic consistency as regards the choice of the maintenance system and thereby the degree of planned and unplanned maintenance costs, which is due to unforeseen operating stoppages, are increased in relation to the degree of preventive maintenance, that is, the degree of safety against unforeseen stoppages.

By systematically compiling and analysing operation data, reliable statistical material is collected to form the basis of an evaluation of the allowable optimum limits to the utilization of the engine components, so that the maintenance costs can be kept on a reasonable level.

Increased knowledge of the upkeep requirements and possible life of the components will provide a possibility of reducing the costs of spare parts and maintenance work done, and at the same time a greater safety against unfore-

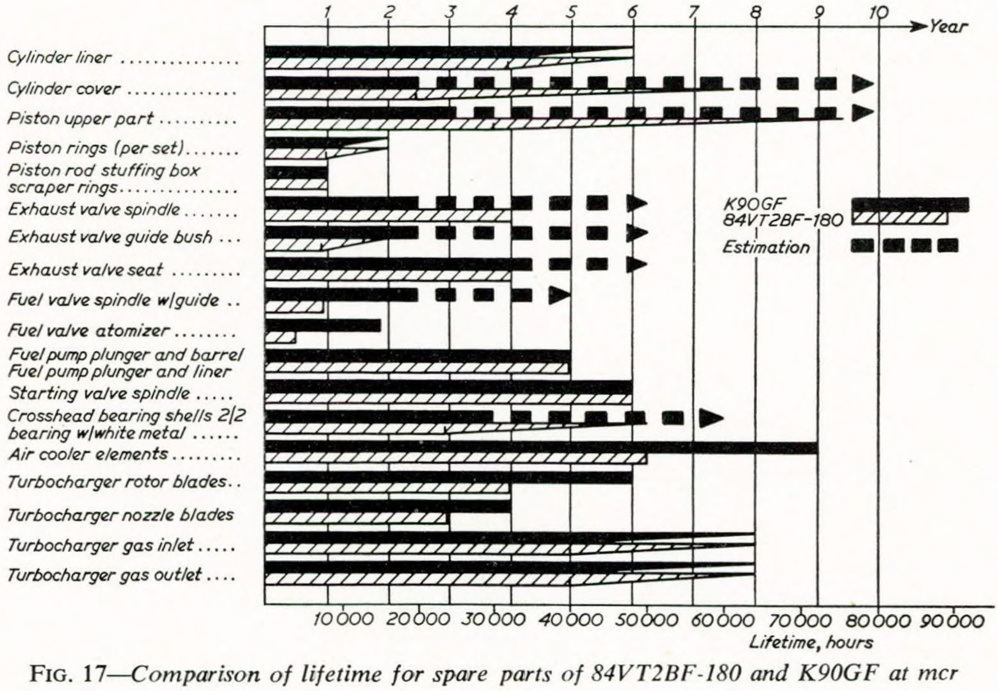


FIG. 17—*Comparison of lifetime for spare parts of 84VT2BF-180 and K90GF at mcr*

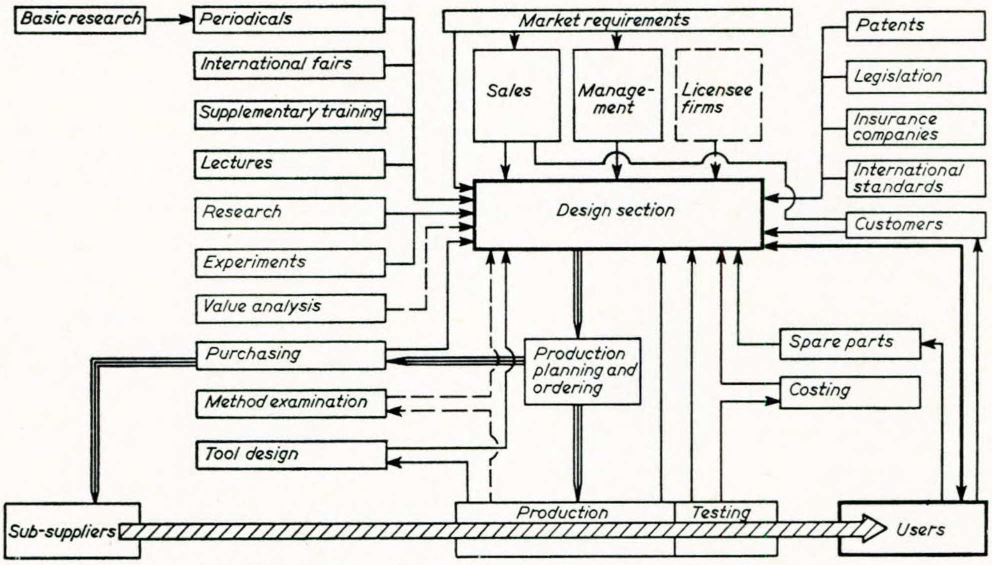


FIG. 18—*Communication flow for diesel engine design*

seen, (unplanned), stoppages can be expected.

The maximum reliability of the specified statistics is achieved by compiling a considerable amount of information from varying operation conditions, enabling overall regard to be paid to all factors both when processing the data and when applying the results.

Standard reporting system for engine performance

In connexion with the introduction of the K-GF engines, it was thought advantageous for all parties to adopt a standard reporting system which will enable off-hire time and inexpedient maintenance works to be minimized through systematic co-operation between shipowner and engine designer.

The engine designers who daily deal with a large amount of service information, Fig. 18, relating to the varying types of engines that are in service, are in the most advantageous positions to indicate which data is relevant for such a reporting system. They will therefore also have the best background for judging the service data of the new engines.

Condition Check System No. 1—CC 1 System

This system, which is called Condition Check System No. 1, (CC 1), consists of three main elements:

a) service programme;
b) component programme;
c) trouble report.

The Trouble Report, which is in the form of a postcard, can also be used in conjunction with, or even instead of, the service programme and the component programme. As, however, the occurrence of Trouble Reports will be quite irregular, they will not primarily be suitable as part of long-term follow-up programmes and the data comprised will not normally be stored systematically.

Fig. 19 shows the flow of information between the ship, the owners and the engine builders. On the ship the data sheets are completed in triplicate, one copy being retained for immediate assessment and filing, and the others being sent to the owners, who forward one copy to the engine builder.

There will normally be some delay between the time of the observations and the receipt of comments back on board. When more rapid action is required, arrangements have therefore been made for certain observations, recorded on performance sheet No. 1, to be sent back to the

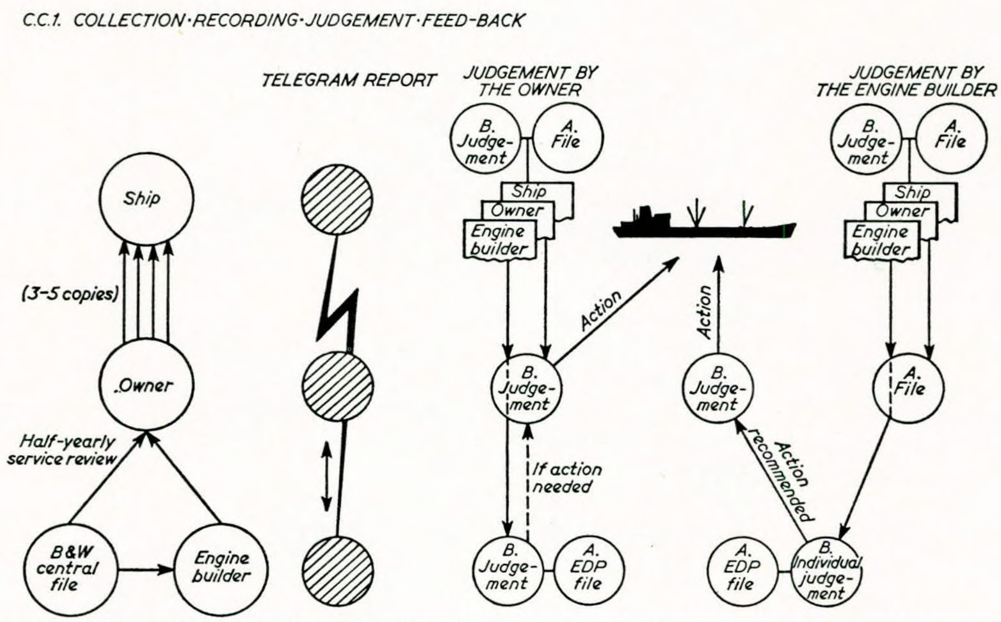
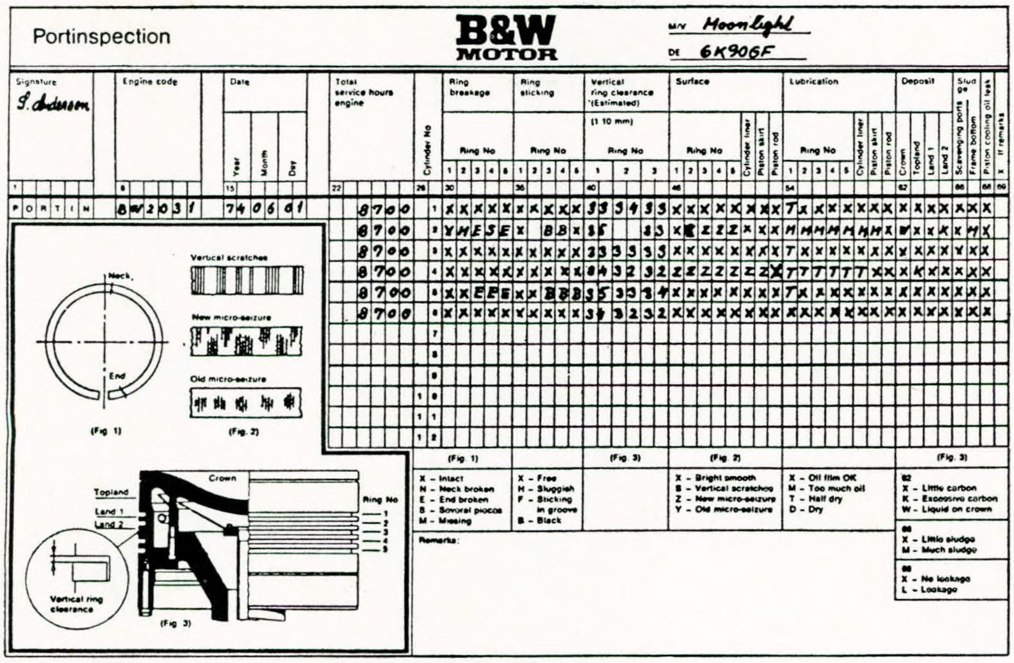
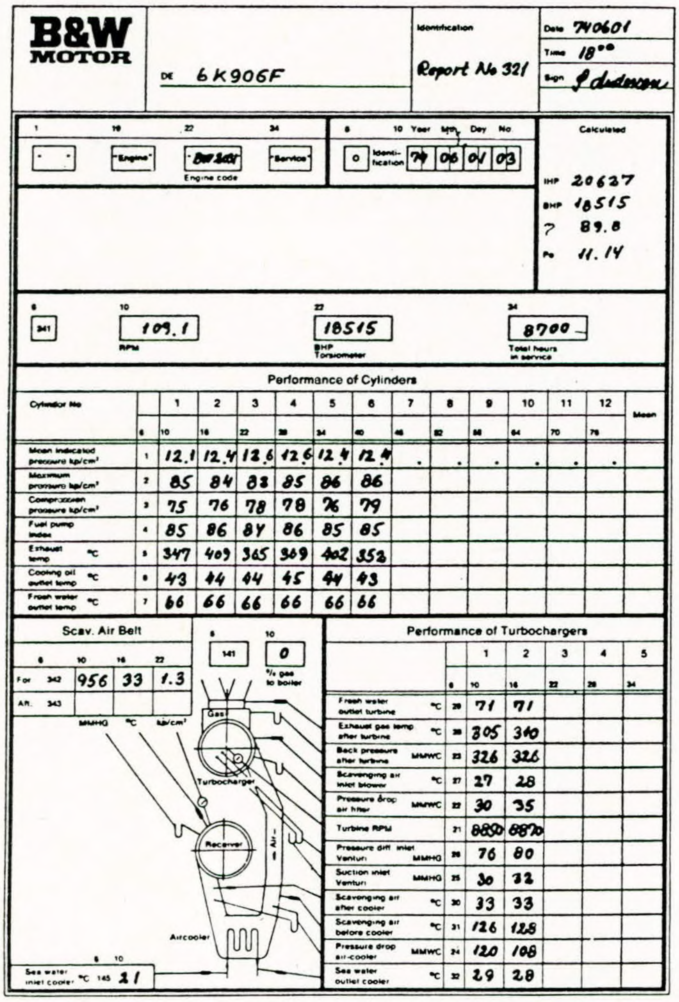
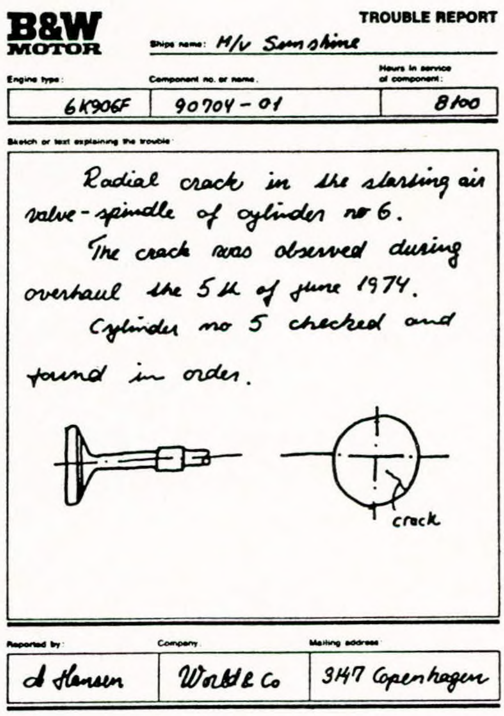


FIG. 19—*Condition Check No. 1—Information flow between ship, owner, and central file, and the engine builder*



COMPONENT CHECK





TROUBLE REPORT

ENGINE PERFORMANCE

FIG. 20—*Observation sheets, used in the Condition Check No. 1 System (CC 1)*

office by radio telegraph. The data involved is sufficient for a decision on first action. When filled in properly, the sheet can be inserted into a special window envelope, the values visible in this window being those to be telegraphed. The observation sheet should subsequently be sent in the normal way. These three elements can be used separately or combined as desired, but of course the use of all three elements will give the best insight into service conditions.

Condition Check System No. 1 is universal in the sense that all the forms are systematically arranged in the natural order of checking procedure and grouped to permit direct assessment of the data, irrespective of the language. Moreover, essential data can be transferred direct from the original form to an EDP store, without rewriting, thus avoiding transcription errors and reducing paperwork.

The service programme is based on parameters normally recorded during the delivery tests and trials and more specifically, on the parameters required to make a service condition trend analysis, see Fig. 20.

The component programme comprises of the examination and check-measurement of main components—not only with regard to the individual component, but also to assess and check interplay between the components with a view to safe and economical operation.

Components and engine sections not included in the above two programmes when they are not considered essential to engine performance and/or because they have not hitherto been identified as troublemakers, can be dealt with in the Trouble Report.

Automatized condition based monitoring system

When the author's company designed the new generation of K-GF engines, it was realized that it would be realistic to expect the preparation of an automatic condition check system for these engines. This system is called Condition Check System No. 10 (CC 10).

Therefore, when designing the engine components, allowance was made for the arrangement of condition check sensors in the measuring points, for example in cylinder cover and cylinder liner. All important information from the prototype tests with K-GF diesel engines as well as relations between the measurements have been recorded and stored in a computer.

Such a system will give information about anomalies in the initial stage and the trend in their development; furthermore it will advise about checking such damage, which means that natural delay in the manual trend analysing can be done quicker and continuously carried out by the micro-computer programme and that most of the condition based maintenance can be taken over by the CC 10 system as indicated on Fig. 21.

Therefore the maintenance work will be reduced to that which is strictly necessary and sufficient to provide safety in service without unforeseen stoppages at sea and stays in ports.

Through the systems information concerning the more slower trends in condition, the overhaul work can be planned on basis of measurements instead of on estimated time intervals, which has been the practice up to now.

The integrated calculation and evaluation programme for areas of related measurements will indicate possible unreliable measurements and exclude these from evaluation, so that erroneous and misleading diagnosis and wrong dispositions can be avoided. The indication of unreliable measurements also simplifies, of course, the maintenance of the system.

Finally, by indicating an anomaly in the initial stage, the condition check will be of invaluable use to the chief engineer in finding new and unknown precautions to prevent anomalies from arising and thereby, among other things, achieve longer intervals between overhauls and repairs.

Such new experience as well as any experience that might be gained can later, at a suitable time in the service, be introduced in the original system simply by recording a new programme in the computer. This quality of the condition check system enables it to be kept up to date and a greater efficiency to be achieved.

Condition Check System No. 10—CC 10 System

The information for the CC 10 System, (Fig. 22), is collected from the engine areas:

1) air and gasways, including turbochargers and air coolers;
2) combustion system, including injection system, fuel consumption, engine output, load distribution between cylinders, and the speed of the ship;
3) cylinder units, including thermal load, wear and piston ring function;
4) auxiliary systems, such as water coolers, lubricating oil coolers and pumps.

The majority of pressure and temperature measurements are carried out by conventional pressure transducers and temperature sensors and a number of more special temperature sensors in the cylinder cover and cylinder liner. The data from the sensors is transmitted to a digital computer programmed to process the results from the individual parts of the system and to evaluate these as an integrated part of the complete system. Fig. 23 shows the system comprising of a diesel engine, micro-computer with

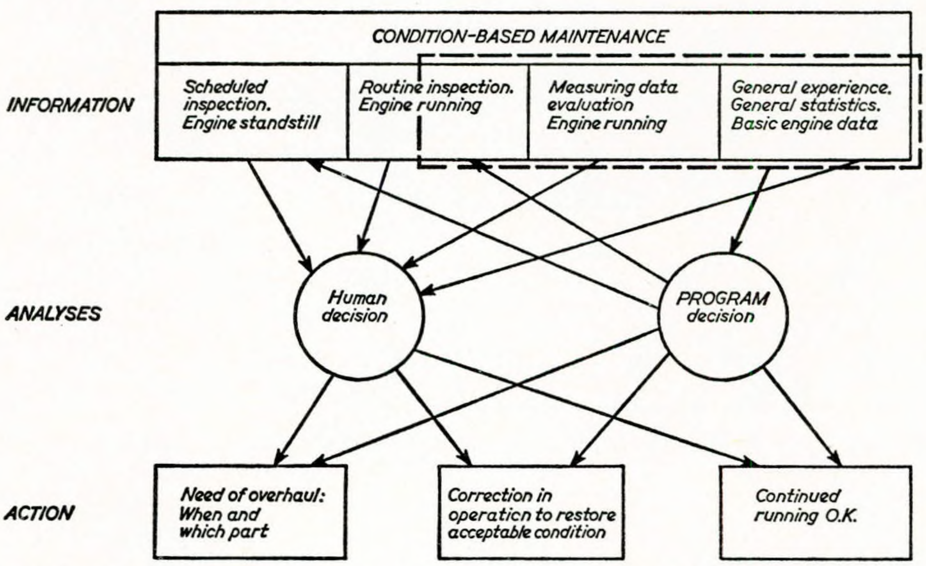


FIG. 21—*Analysis possibilities of the condition based part of the maintenance system*

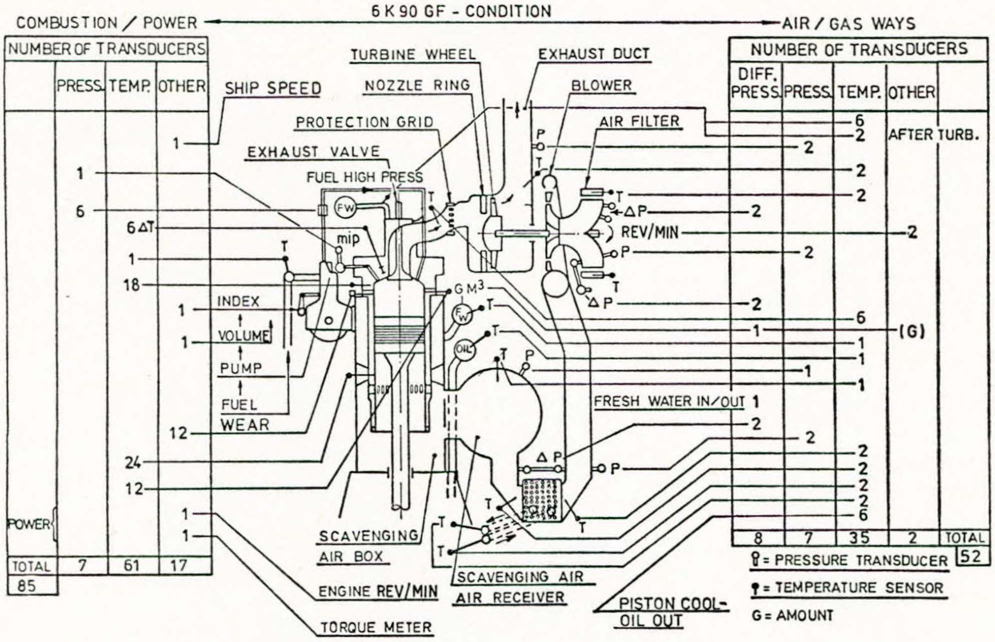


FIG. 22—*Condition Check No. 10 System information from the combustion and power part, and the gas and air ways on the engine*

sensors, and the operator's console which is placed in the control room. The system is new, but the components and principles have already been tested to a considerable extent.

The condition check system is (in principle) based on the manual condition check system thoroughly tested during several years, which is based on comparison of data model curves with service measurement values recorded manually with fixed, rather considerable time intervals.

By recording the deviations in the key diagrams and comparing and evaluating the deviations, a graphic statement of the development in the condition of the actual components is obtained from which diagnosis of the abnormal conditions can be derived.

The automatized system CC 10 comprises of a higher number of components and gives a more thorough indication of the condition on basis of measurements, calculations, and evaluation; in addition to trends and diagnosis, it also gives an alarm by diagnosis if an abnormal condition arises and develops towards a critical limit. Extrapolation of the trend values in future and the statement of limit for maintenance will indicate the time for overhaul work, in other words the required prediction.

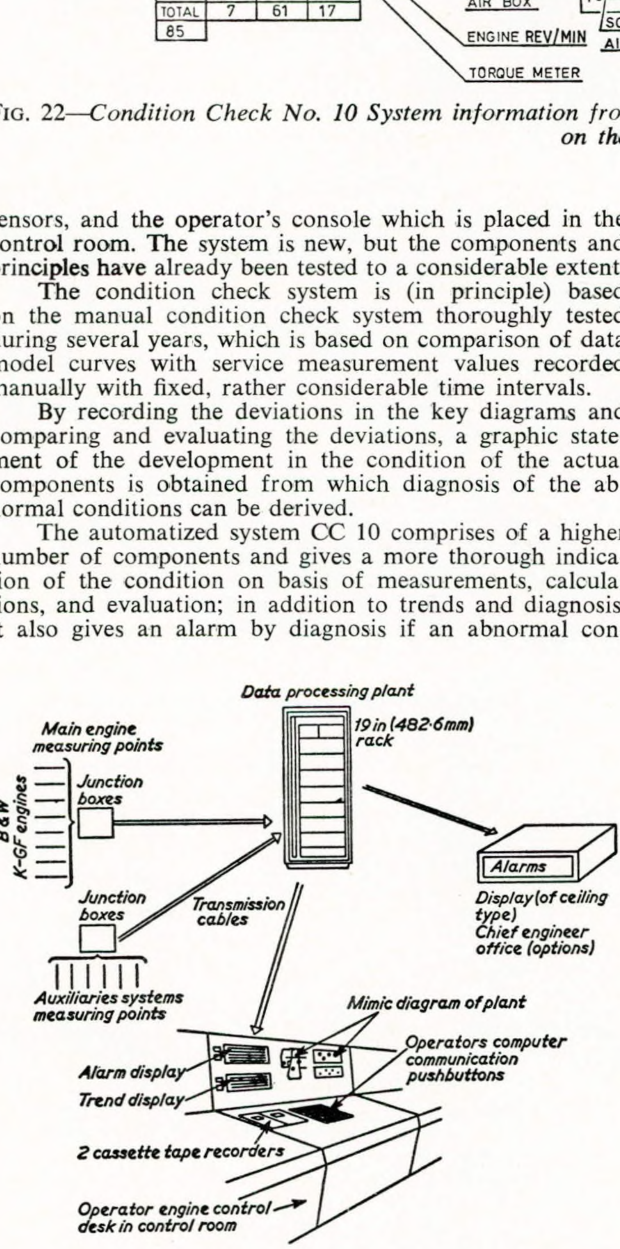


FIG. 23—*System layout, for the automatized Condition Check System, CC 10*

As these trend evaluations goes on constantly, the engine is well-guarded to a degree manual inspections can never do, so that the personnel can take better care of the rest of the maintenance programme, but it should be remembered that the computer only gives answers on what it has been informed about, so that the responsibility is still the engineers', as it has always been.

CONCLUSIONS

With the development of the K-GF series of two-stroke engines, great importance has been given to reduced operational costs by increasing the operational reliability, facilitating the overhauling work and bettering the operational conditions so that the operational economy is improved.

Operational reliability has been obtained by altering the existing construction, by developing a new design, and by increased use of the possible material resources, whereby extended operational periods between overhaulings and longer life of the wearable parts can be obtained.

The increased facilitation of the overhauling work have been obtained by giving importance, from the very first, to a minimum amount of overhauling work being carried out, and during construction, the different dismounting and mounting work has been analysed on the basis of the execution of the existing engines and carried out in accordance with the views put forward by the shipowners, and also by contact with the participants of training courses etc. The built-in overhauling facilitation has been passed on to the user of the engine by means of detailed instructions with reference to the various categories of the engine room personnel. Furthermore, in addition to the instructional material issued, films have been prepared showing various important overhauling jobs, and several more films are under preparation.

Improved operational economy can be obtained by the correct use of the components and systems with which the engine is built up. The altered shape of the combustion chamber and a newly designed fuel valve have, among other things, given the possibility of improved conditions of operation, which means improved operational economy and greater operational reliability.

Increased monitoring of the engine and appropriate positioning of sensors etc which are connected to a system specially developed with relation to the actual construction form, and where the measurement values etc can be harmonized in relation to the total know how of the engine builder, can help the user in case of a difficult situation. By a direct contact, operational problems which arise can furthermore be dealt with quickly and increased prediction obtained.

With the new K-GF engines, propelling machinery has been put at disposal which is based on intimate co-operation with the user and where many good ideas have been combined to a whole which can satisfy the demand for small maintenance costs and thereby satisfy the demand for good operational economy.

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Discussion

MR. J. MCNAUGHT, F.I.Mar.E., said that the author had brought everyone up to date concerning the latest developments in B and W diesel engines and the various maintenance methods.

It was just over 52 years since a former superintendent of his company, at one time his chief, went to Copenhagen, and as a result of this the first motor ship appeared in 1925. This was a twin-screw blast injection eight-cylinder engine, 840 bore, with fairly substantial auxiliary engines as well. When he joined the company himself some years after that many of the operating methods were still in use. This ship came into the mail service with two turbine ships and six reciprocating engine steam ships with scotch boilers. It had to keep going, despite any difficulties, and maintain schedule. The reliability was of a very high order and the stops at sea were negligible. The boast then was how many exhaust valves one could change before breakfast, especially the bottom one. This was a challenge which even with more modern engines would be difficult to beat. There were then 18 engineer officers, two electrical officers and probably about 18 greasers. Another very important factor was that they only had two weeks' leave a year. This also applied when he joined the company himself. The devotion to the overhaul was profound; there was nothing else to do. All the overhaul was done mainly by the ship's staff. The recording was quite wonderful, with information on everything anyone needed to know: for example, when a fuel or exhaust valve was changed in any engine, or a generator, there it all was, on the graph in colour. In contrast, with the sort of engine being described today, they would be lucky to have four engineer officers, and even more so if they all had certificates, (the 18 previously mentioned almost all had certificates), one electrical officer and maybe three mechanics and three or four greaser cleaners. He was a little concerned about how all the the paper work would be done under the system described. Even though the K90GF was shown with a reduced maintenance, would the extra paper work make up for the previous engine work?

With regard to design, what extent the new engine had been built for allowing flexibility in power downwards? They had all been moving upwards to get higher power per cylinder and per engine, but lately they were being asked if they could run the engine on 50 or 60 per cent power without difficulty. Was this engine capable of running indefinitely in this mode, or down to what power could it be run indefinitely without having to disconnect the turbochargers or lift fuel pumps or something like that. The figure of 8000 hours for the running time was quite high. Their own bulk carriers were just over 6000 hours and some of the refrigerated ships 4000 per year.

As usual, fuel consumption was given in diesel. Why could the figure not be given in heavy fuel? This was the one on which they had to work out consumption. The 205 g/kW h (151·8 g/bhp h) was quite a good figure. Could the author put alongside that a figure for 1500 seconds upwards of fuel?

With regard to service life and fuel valves, they had no K90GF and had changed from flat to conical seated valves, and the valve life was still only 1500 hours. If this new fuel valve could beat the previous one they would be pleased with it.

They kept a very close record of running hours of exhaust valves on the smaller ships and had an average of 800 hours between overhauls. Could they do better than this? They always used heavy fuel. Would they get 8000 on diesel fuel? Other ships did manoeuvring on diesel oil because they were not suited to manoeuvring on heavy, but the figures obtained were not as good as those mentioned by the author.

With regard to personnel, they would all like to have the staff. There were not many left from 1925, though he could think of some who would have liked to be present tonight. They had not the staff who knew the conditions for which the engine was designed, and with the present system in Britain it was rather difficult to have hand-picked men, so the engine had to be designed to suit those available.

With regard to the bedplate, even with the deeper bedplates built by British licensees they were still not sufficiently good, and they had just had to re-check one ship after something like ten years. On the K90GF they had gone to a deep bedplate from the continental bedplate. Were they doing anything about the chocking area? This was one of the difficulties, and it was quite frightening to see the cost of correcting it, even with the modern resin chocks.

Hydraulics were mentioned. Not long ago on a new vessel the shipyard used the hydraulic jack intended for service use for all the erections, so that by the time the ship was taken over the jacks were rather battered. This made the first claim under guarantee.

The B and W jacks were probably all right but there had been a lot of trouble with those bought in various countries. The later ones were much better. If the hydraulics were not good. It was not possible to put an ordinary spanner on any more.

With regard to piston overhaul, it was very nice having all these things but when the recorder said "pull pistons one, two, three, four, five and six" at one stop it was rather difficult, so they still preferred something that was time-based, enabling them to plan.

Perhaps there were not any scavenge fires in the new engine. If there were they would have to be dealt with fairly quickly.

With regard to liner wear, they ranged from 0·04 to 0·2. The 0·2 had been associated with bad alignment in the building and he did not know to what extent this was taken care of first of all in design and secondly in the workshops, but they had had one or two unsatisfactory experiences with this and had to scrap one liner within the year on a rather new ship. On that one he would not like to say it was alignment entirely because it was still under investigation. It was a question of some water being involved as well.

Who was the user? Was it just the man who bought an engine from Copenhagen? They had only one ship from a licenser. What about the licensee engines? Were the customers there included as users or not?

If the sensor told a lie they would have to open up the unit unnecessarily. This could be seen with aircraft coming back with a supposed fire due to a bad sensor. This was a suspect area and unless there were very good sensors and very good wiring it could be very difficult.

Burmeister and Wain had done a lot to make the equipment right and get the tools to do the overhaul. This was fine so long as the time was not greater than with the old-fashioned methods. He had seen some engines where this tended to be the case. This had to be avoided.

It was certainly very pleasing to see that the shipowners existed in the eyes of the engine builders and that some attempt was made to see their needs in present-day conditions.

MR. A. N. S. BURNETT, F.I.Mar.E., said that the paper was extremely interesting and rewarding to read, in that it dealt with a number of the wishes of the average user in looking forward to better practices in maintenance management. He disliked the term "planned maintenance", much preferring the overall term "management of maintenance", of which planned maintenance was just a part.

There were four criteria set out on the first page of the paper. According to the author, these came about after discussions with the user, the shipowner. Had the author taken into consideration ship repairers and ship builders as a minor or as a major issue in regard to these four criteria?

At various places in the paper records from users were mentioned. The accuracy and collection of data were both terribly difficult tasks. How was it possible to know when one had enough of the right sort and the right quality? In his experience to get the kind of data needed for the advancement of design, it usually had to be obtained by specific data teams who knew exactly what they were doing. If the ship's staff reporting system was used, often data would be omitted, especially that which people did not want to disclose. The author's comments on this very important area of data would be of interest.

Were the new engine designs going to take into consideration the use of easy to obtain materials, in view of the fact that acoustic materials were going to get even more expensive, some of them already being on the short supply list? Would they be looking more towards the use of easy to obtain materials, rather than just progressing the design to do what they wanted it to do and then finding ten years later that they were unable to get the titanium, or whatever the unobtainable material happened to be?

He had not seen anywhere in the paper any remarks referring to licensed manufacture, although it was raised by the previous speaker. Did all their licensees manufacture the same engine or were there variations throughout the world in this respect, raising design problems in regard to usage and maintenance?

He had been very pleased to hear the word "guidance" in relation to maintenance, as opposed to mandatory instructions. There must be many people who would wish that those above them had the same view, that a maintenance policy was there for guidance and not as a mandatory instruction. One owner might use a ship on a different route or at a different interval of time, so instructions ought to be for guidance rather than being specific or related to an exact amount of running hours.

In trying to reduce manhours it was important to remember also to take into consideration the better use of the kinds of trades available on board, as opposed merely to designing for fewer manhours and then finding that the right quality of man was not available to do the job.

In the aircraft industry, there was the problem of space, with two or three jobs often having to be done in the same area. Obviously two men could not be in the same place at the same time, and designers had to take account of the fact that one job was being done from one side and one from the other, as opposed to both together. There was no mention of this aspect in the paper.

As to training, was it not time that the average ship owner gave more thought about career structure for people who went to sea, rather than merely enlightening the crews as to what to do? If shipowners would create a career structure for their shipborne personnel there would be a better understanding. There did exist some people in ship management who had gone through a career structure with the shipping line and were aware of how things were controlled from bottom to top, as opposed to the normal practice of injecting people from various sources at various levels in the process. What would the author, as representing an engine builder, like to see shipowners doing in this direction?

What the author had said about "pictures" was very close to his own views about showing the maintenance people what to do in the form of pictures. To take it one step further, microfilm could be used with projectors, so that from small cassettes pictures could be blown up into larger pictures for easy viewing. The extension of this idea was to carry the microfilm pus the apparatus to the maintenance area, so that a man wanting to do a job could see it in life size and know what to do and what not to do. It could also show him what would happen if he did a particular thing or if he did not do a particular thing, and would save him having to go and ask somebody else. Each maintenance task would be visible in picture form at his side.

Then there was the question of languages. It was all very well having these superb maintenance manuals and instructions but there was the problem of language and of interpretation by people of different nationality. There were some words which were rather difficult to translate into all languages in such a way that they meant the same thing to everyone concerned. He had discussed this problem with one or two engine manufacturers in the past.

Perhaps the author would care to say a little more concerning tv cassettes. It would appear that the crew off duty could be amusing themselves from time to time by running through the maintenance cassettes on the ship's tv system.

The previous speaker had mentioned sensors and transducers. Was the search for reliable transducers still a problem?

It was extremely interesting to note that there was now a system where the chief engineer was used more in his proper function, which was to assess the efficiency of the various machinery sectors of the ship while going from place to place. In some instances in Scandinavia, the arrangement was that the shipowner had to plan, arrange and negotiate his own operating and overhauling programme and the home-based superintending engineers etc were there only to be called upon if the ship needed them. It was not the other way round, where the home-based engineers went to the ships and told people they ought to be or not to be doing. This was already in operation. Could the author comment further on the details of the monitoring system they had on board for the chief engineer and others to use to assess the efficiency of the mailing systems?

MR. P. J. ADOLPH, F.I.Mar.E., said that one item in the paper that had received very little mention was the crosshead bearing. It was true that in recent years there had been improvements in the reliability of this particular bearing, but it was still the case that an unscheduled stoppage due to crosshead bearing problems was extremely expensive to the shipowner.

In a recent paper Mr. Østergaard* had said that "The admissible specific bearing load may be further increased through the application of stronger bearing materials such as tin-aluminium. In this case, however, there is a risk of an increase in the sensitivity of the bearing to dirt."

Some years ago on Burmeister and Wain engines one of their licensees went over to this type of bearing, including the use of a lead overlay. One of the things they did immediately, being well aware of the problem of dirt scratching the bearing surface, was to specify the use of an alkaline type crankcase oil. Their argument was that the type of additives used to obtain the alkalinity gave mild detergent dispersant properties, and they considered that

* "Adapting Burmeister and Wain Diesels for Future Ships", A. Østergaard (Burmeister and Wain).

the dispersant properties would aid in breaking down dirt particles and thereby provided a useful insurance against the scratching of the bearing surface by these dirt particles. These alkaline oils were a little more expensive, and also there had been problems with water separation, although this latter point was being improved. But on the benefit side there were the dispersant properties referred to, there was very considerable protection against corrosion in the crankcase, there was improved cleanliness in the internal piston cooling spaces, and from the point of view of maintenance environment there was a much cleaner crankcase. Did the author consider that the use of tin-aluminium bearings would improve the reliability of this particular item, and did he foresee the specifying of an alkaline crankcase oil, rather than the present position where the choice whether or not to use an alkaline oil was left to the shipowner?

MR. A. A. J. COUCHMAN, B.Sc., M.I.Mar.E., said his contribution would basically consist of a few questions associated with some of the diagrams.

With regard to Fig. 3, could the author give some figures concerning the kilowatt loading for the essential main engine support auxiliaries, so that the propulsion fuel rate could be evaluated?

Going on to Fig. 4, the author gave the expected life of fuel and exhaust valves at about 8000 hours. Would he indicate whether he had experienced any difficulties coupled with this life—for example, problems in removing these components from pockets?

Considering Fig. 17, the life of some of the components indicated seemed to be shorter than might be expected in reality, while other indicated lives were considerably lower than might be expected. For the older designs of engine major components such as turbocharger elements, air coolers, cylinder heads, were given a life cycle in which these components were replaced about three times in the life of the ship. This was an extremely expensive basis of maintenance and it was not very good advertising to the shipowner. Would the author care to comment?

The life of piston rod scraper rings was given as one year. Would the author care to give the procedure and time to renew a set of rings and the cost per set for one cylinder?

The question of shipboard personnel had been raised by a previous speaker in the context of the calibre perhaps at times not being as high as might have been expected a few years ago. It could not be stressed enough that the engine designer must take account of this not only in his design, with the object of simplifying design as much as possible, but also to remove the possibilities of human error.

For education purposes, tv cassettes would be of extreme value. In the ships with which he was particularly concerned there were tv monitoring systems, and it would be an easy matter to put cassettes straight on the tv and use them as an instruction environment.

He was particularly pleased to note that the main engine air coolers had finally been designed to permit easy cleaning by ship staff. Recent costs for shore labour for cleaning just one cooler ran out at about £500 to £600. With a fleet of ships this was quite a considerable figure when added up. Was it the engine builder's intention to supply the cleaning tools as standard parts of the engine?

With regard to Fig. 7, unless he was interpreting the figures incorrectly there seemed to be some arithmetic error in the engine per year (manhours). Perhaps the author could elucidate on them a little. With respect to the engine stoppages themselves, what proportion of them were planned or involuntary?

In connexion with Fig. 18, one of the most annoying things when trying to do maintenance was obtaining spare gear throughout the world. There were, he felt sure, many present with the same experience as himself. When wishing to get a piston or a part for a particular engine, on many occasions the answer was to go back to the licensees. Was this because of differences in the manufacture of the engines by the different licensees? It was necessary for Burmeister and Wain to apply controls and safeguards against these differences so that at any time the necessary parts could be obtained from any licensee throughout the world in terms of accuracy, tolerances, etc.

Also in regard to Fig. 18, it was indicated in the diagram that there was direct access from the user to the design section. Was it also intended that the design section should communicate straight back to the person requesting information?

Finally, concerning crosshead bearings, he had been discussing this problem with someone in his organization very recently, again endeavouring to see what the general opinion of crosshead bearings was, and the problems associated with them. In his company they tended to run crosshead bearings for something like 20 000 hours now, and it was found that, even though they were cracked, opening up at shorter intervals was a sheer waste of time.

MR. A. D. RUSCOE, F.I.Mar.E., said that he would like to enlarge on the remarks of the second speaker about taking the measurements on which much of this work must be based—things like rates of wear. It was expecting a lot to get ships' staff to do this successfully. They were mostly concerned with boxing up and getting the engine back on line before there was excessive loss of hire. It was even more unreasonable to ask them to analyse the measurements before they had boxed up again. It was very desirable to have a specialist to do this. Often, in the absence of this, there was a very great scatter when measurements were plotted against running hours. One could draw a line through them in almost any direction one cared to choose. He did not think that anyone used any method to distinguish between a good and a bad series of observations. Some years ago he had devised a method which would distinguish objectively between results upon which some reliance might be placed and those where it could not. There was one element of subjective judgement which had to be made at the outset in fixing the significant parameter in this method, but once having made that, all elements of judgement were eliminated and all situations were treated alike. Had the author's company devised some such method for distinguishing between a good series of wear measurements and a series on which little reliance could be placed?

With regard to the opening speaker's remarks on fuel valves, his early experience was based largely on free piston machinery for which the outward stroke of the piston was not restrained by a crank and flywheel to anything like the same extent as in an ordinary engine, therefore the acceleration from combustion would be very great indeed, and it was essential for injection to be very short and sweet. The indications had been that, if the fuel valves were right to start with then their lives would be satisfactorily long; otherwise they would be very short indeed. The idea was to set them up on the test bench and not crack them by short sharp jerks of the hand pump but to do it very slowly indeed, checking that the atomization was really satisfactory by watching it develop over quite a distance from the fuel valve. He did not think he had ever seen a test rig on a ship which did not have a drip tray much more than a few inches from the nozzle, so one could not see whether it was "raining" or not. This seemed to be so sometimes even with the diesel engine and fuel valve manufacturers. He doubted whether the superintendents were always aware of what was done on board. It could be argued that injection took place much more rapidly in the engine itself, therefore a short sharp jerk on the hand pump was neither here nor there, and that the greater air density at the end of compression would ensure good atomization. But at idling there was a rather slower rate of injection. If they were not going to place some value on the atomization how could they judge the quality of the fuel valve at all? They could only judge cracking pressure and the position of impingement of the spray. Valves which chattered during atomization were not always necessarily satisfactory.

Some years ago he had seen a pneumatic rig and this gave a series of short, sharp jerks which could be slowed down in infrequency but even so the injection strokes were so rapid that one could not follow what was happening. They could see more or less where the jets were impinging on the transparent housing but could not see whether they were atomizing properly. One should only give a preliminary short, sharp pump on the test bench to make sure that the valve was properly seated and then immediately after this do the slow cracking process to check the atomization. This would go some way to eliminate poor injection. The fuel valve in the author's new engine had a very long nozzle well away from the cooling arrangements, although some of his competitors found it essential to cool up as close to the jets as possible but without over-cooling and causing corrosion. In the latter engines the fuel valve was, however, symmetrically located in the combustion chamber and this could be one reason why the fuel sack in the nozzle could be shorter.

Correspondence

Mr. N. K. Bowers, F.I.Mar.E., in a written contribution commented that it was refreshing to see a leading engine builder put so much deliberate initial design effort and ingenuity into reducing total maintenance costs on a new engine. In particular the Condition Check System was most detailed and thorough and should provide valuable feedback. However, the system involved yet more paperwork and appeared to take away some responsibility from the chief engineer. From the ship managers' point of view there were strong arguments in favour of treating ships as autonomous, self-sustaining and profit-conscious entities, particularly for ships trading world-wide. Under this broad concept the chief engineer must have total responsibility for the efficient running and maintenance of the machinery under his care. He must also be able to plan and execute all maintenance, and survery work efficiently and with the minimum of assistance from the engine manufacturer or from Head Office.

Performance surveillance or data feedback was nevertheless essential and the Condition Check System mentioned by the author was one possible method of achieving this. In Mr. Bowers' company it had been found that the most effective routine surveillance method was through a weekly feedback of data to Head Office by telex or by cable. The telexed data was in a highly condensed numerical form but nevertheless provided effective monitoring of the ship's main machinery. In addition, an independent check on the condition of the engine was carried out by the superintendent engineer during his routine ship visits.

Referring to Fig. 7, Mr. Bowers thought that the required man hours and total ship stop time quoted for overhauling the K-GF section air coolers were on the low side. Perhaps the figures quoted related to a partial dismantling and overhauling only. Would the author comment on this and also whether *in situ* cleaning of the K-GF coolers by high pressure water jets or by circulating chemicals would be a viable alternative to conventional cleaning by dismantling and water washing.

With regard to the K-GF liner wear rate, the author stated that this mainly depended upon the amount of lubricating oil used. However, it was generally recognized that certain combinations of sulphur in the fuel and the TBN of the lubricating oil used for the cylinder liners could also influence the liner wear rate. In some cases this had led to very high liner wear in a relatively short time.

Ships trading world-wide might have to burn fuels of either a low or high sulphur content at comparatively short notice. Could the author comment on the value of shipboard monitoring of sulphur content and the subsequent action required to counter the effects of sulphur on liner wear rate.

Mr. J. Allen, F. I. Mar. E., wrote that the author drew attention to operating conditions which were of some significance to the shipowners though perhaps they were not readily appreciated at this time when he forecasted that the combined effect of increasing mean effective pressures and declining fuel qualities—which would bring fuels of higher sulphur content into the bunker market—would have the net effect of shortening combustion space component life.

Higher cylinder pressures and higher fuel sulphur contents both pushed the combustion vapour dew point upwards thus exposing larger areas of cylinder surface to sulphuric acid attack. But solutions to these problems, because they were predictable some years in advance by farsighted research, would be readily available for both shipowner and engine builder to take advantage of when time and place required them.

It was of interest to note that in Fig. 8 the author showed that the reduction by 25 per cent in maintenance hours required by the piston rings and cylinder conditions of an 8K90GF compared with a 10K84EF had been only achieved by a configuration of fewer cylinders and easier overhauling. However, much could be achieved in this area by extending the piston overall periods, and here the life of the piston rings became the controlling factor.

In Fig. 17 the author indicated piston ring life of what appeared to vary between one and two years or 15 000 hours maximum. Would the author state the piston ring wear of the first and second rings in mm/1000 hours that he considered an average obtainable figure for the two engine types quoted?

Regarding liner life the observation was made that this might vary in accordance with the amount of lubricating oil used and this was supportable, but he had not pinpointed the marginal consumptions that were found in service and were so often the result of false economies and inhibitions about scavenge fires and top land deposits. But to take the quoted figures of maximum allowable wear of between 3 mm and 6 mm depending on surface condition and correctness of form suggested a variation of some 30 000 hours in liner life at a progressive wear rate of 0·1 mm/1000 hours, and since lower figures of 0·10 mm/1000 hours could often be achieved, the variation became 60 000 hours if a progressive wear rate of 0·05 mm/1000 hours was taken.

Perhaps the author could expand his reference to surface condition and correctness of form as criteria and also say to what extent operational statistics suggested that liners were changed for other reasons than the wear having reached the maximum control limit.

Commander W. P. Noble, F.I.Mar.E., in his written contribution said his first comments were to bring attention to ship bottom coatings as mentioned in the paper. Paint manufacturers might quote that a ship's bottom, providing it was coated with a particular product, could remain in service without drydocking for more than two years. Of course it could; indeed, it could stay at sea indefinitely, providing the hull remained water-tight. But normal conventional hull coatings did not remain free from marine growth for more than two years. Free from corrosion perhaps, but in two years the ship's performance falls off.

A further interest to shipowners, in view of increased fuel costs, was "economical steaming". Would Mr. Bakke inform us as to the safe minimum revolutions of the GF engine without resorting to major engine adjustments.

Mr. Burnett mentioned "management planning" as against "planned maintenance". This was a subject worthy of further lengthy discussions. He also asked, did licensees build the same engine? Cdr. Noble wrote they did not, and this was a subject also worthy of further discussion.

Many shipowners have engines built in different countries by official B and W licensees. Methods of construction by individual licensees vary. This was not particularly important unless one method proved to result in an improved engine, i.e. overcame a stress peak problem on the bedplate, or improved alignment in way of "A" frames and guides, for instance, resulting in improved liner wear. Another example had a particular British licensee's ideas on bedplate construction. Yet a further example was a licensee's ideas on monitoring piston rod gland leakage.

All these ideas were ideas introduced by licensees, or shipowners to improve an engine of their choice.

Commander Noble put to Mr. Bakke, why did B and W not implement all these improvements on their engines? Why not make this part of the development of an engine type? If there was something good about an idea submitted by a licensee or a shipowner why did not B and W make this a standard modification? Surely this was what this paper was all about: savings on maintenance costs, marine engineers working together on development of a particular engine type.

It was suggested that alkaline type crankcase oils offer improved running. Should not B and W insist on this in their lubrication oil specifications.

Air cooler cleaning tools were mentioned in connexion with the B and W improved type air coolers. Could Mr. Bakke tell us if these tools are supplied in kit form with the engine.

It was the Commander's privilege to witness the shop testing of a licensee's first GF type engine; it was a 7K67GF. It was a beautifully constructed engine.

Generally, the running gear was no problem. The fuel valves were smaller, lighter and function without cooling. A big step towards less maintenance costs. However, he was sorry to see the design of the fuel valves change from the old type of flat seats at the bottom of the valve pockets. The Commander felt the new type of taper seat would provide problems with regard to withdrawing the valves. It was significant to note that stellite atomizers results in running hours of 8000. Mr. Bakke quoted 16 500 hours for fuel valve spindle and guide. He assumed this was life span.

With regard to exhaust valves he believed Mr. Bakke to be rather optimistic. 8000 hours was quoted in the paper.

The contributor's only experience with the GF engine was at the shop test of the above mentioned licensee, where he learnt a lot, as indeed the licensee did too.

They found that the exhaust valves must be made with extreme care. It was important to fit the piston rings, in both the pump assembly and the exhaust valve actuating cylinder very carefuly indeed, otherwise such problems as partial seizure and leak past would develop effecting the correct operation of the valve with resultant engine unbalance and (on the engine the Commander observed on test) the lifting of cylinder relief arrangements, which on this engine was the cylinder cover.

The contributor added that when he turned to point out this malfunction to the test squad, they had quite suddenly disappeared. However, improper fitting of piston rings within the exhaust value assembly also resulted in the passing of the hydraulic oil (camshaft lubricating oil) down the exhaust valve spindle, filling the flame cup and draining out of the drain holes situated at the base of the cup and eventually down to the lid of the valve itself, to be burnt in the engine. One could easily imagine the cost of lubricating oil consumption if this was allowed to continue unchecked. Therefore the fitting of piston rings within the exhaust valve assembly was most important and he would like to see closer tolerances on the drawings for these valves to attempt to overcome this problem.

The other problem with regard to these valves was the form of the contours at the end of the valve spindles together with the matching split retaining collars. The total running time of the engine on test was 30 hours, yet on inspection of parts on completion of test exposed fretting between the spindle contour and the split collars on every cylinder. Further communication between the contributor and the licensees suggested this problem had been, they hoped, overcome by stricter machining routine to finer tolerances. Perhaps Mr. Bakke could elaborate on this. However, these problems were minor and could be overcome—no doubt they had been overcome already—but they were points to watch and these comments were respectfully submitted as constructive criticisms from an impartial observer, but nevertheless an observer intensely interested in the development of a very fine engine; an engine, if the Commander might be permitted to say, the ship owners had been long awaiting, an engine more sturdy, certainly more cleaner than past engines produced by this very famous "stable".

A further point Commander Noble would like to raise was the possibility of fitting the non-return valves, in the hydraulic transmitter of the exhaust valves, the wrong way round. Perhaps an etched mark on the barrel of the valve would overcome this possibility. Spring failures of these valves still persisted, but no doubt the choice of manufacturer had something to do with this.

The Commander was impressed with the standardization of thread sizes, as far as possible, with regards to overhauling gear in an effort to limit the number of spanners and eye bolts etc. Any advance in this direction was most welcome and a good practical approach.

The hydraulic equipment for fastenings was good, but he agreed with Mr. McNaught that after erecting the engine on the test bed, dismantling it and erecting it again on the ship, using the jacks supplied with the engine, these most important tools were sometimes not in perfect condition when the vessel was handed over.

The Condition Check System No. 10 (CC 10) was a most welcome data reporting system. He was pleased to see engine builders were putting this idea across more forcefully. In the past it was often left to owners' Superintendent Departments, but the work load of most such departments were usually so heavily involved that time necessary to implement such data reporting etc, was insufficient to operate a scheme successfully.

The point often missed here was they were marine engineers, and as such they practiced, in the same way as doctors. They could never know everything about everything developed in the marine field, and were often guilty of not sharing problems and knowledge.

The reporting systems implemented by engine builders was a good step forward because it was to the builders' advantage as well as the owners' to pool as much knowledge as possible regarding engines with the result that operators could have the benefit of feed back from all others participating in the scheme.

Mr. A. C. Brotherston, F.I.Mar.E., wrote asking, could Mr. Bakke give an opinion on the following queries?

1) Improvements have been made in the gear for hydraulically tightening the cylinder cover nuts. Could similar methods be adopted for the main tie bolts and holding down bolts, which also required to be checked regularly, or was it considered that the time now required for these jobs was satisfactory?

2) Observation of piston rings of large bore diesels when they were opened up for inspection indicated that after a comparatively short running period the radius (chamfer) was worn off the top and bottom of the ring running surface leaving a sharp edge which scraped the oil film off the liner wall with a bad effect on both liner and ring wear. Was it considered that a heavily chromed top ring wear surface would prevent this effect?

Author's reply

Mr. T. Bakke was very pleased with the interest for the paper. Mr. J. McNaught commented on the previous engine types, but the author was very glad that the progress which the latest engine types showed regarding the objectives stated for the development of the K-GF engines could, to a large extent, win the interest of the shipowners and direct users, as well as that of the engine room personnel and the technical staff of the shipping companies who, at first, did not have any direct influence on the final design of the engines.

Indirect influence on the design of the engine, however, was had by all who in their daily work looked after the engines, who used the engines as part of the equipment which was necessary to transport cargo from one port to another, and where the operational conditions, problems and the experience gained came back to the constructors who got the opportunity of taking all this experience, good and bad, into consideration at a very early date.

One of the ways in which experience could be collected was through a standard reporting system, such as the CCI system mentioned in the paper.

Mr. McNaught, and also Mr. Bowers in his written contribution, were afraid that such a system would demand more paper work than previously, but one of the basic ideas of a standardized reporting system was that the number of papers and the amount of desired information were limited to the absolute necessity, and therefore long reports containing a lot of irrelevant data, which, in the end, was not of value for the owner or anyone else, had been done away with.

The individual pages of the report forms were issued in different colours and the necessary number of copies could be filled in at the same time by means of carbon paper.

The forms were, to a certain extent, self-explanatory as each form contained sketches etc, which showed where the measurements should be taken, or what data was required. The amount and character of the data was based on long experience with operational analyses and the system had been worked out to its present form in co-operation with a number of Scandinavian shipowners.

Mr. McNaught as well as Mr. Burnett and Mr Couchman, touched on the question of the use of this standardized report system—who could use the system—who was the user—and the communication in the system. The answer was that all who used a B and W engine, whether built in Copenhagen or by a licensee, could make use of this system.

As shown in Fig. 19, B and W in Copenhagen had established the necessary computer facilities for a central file system. Input to this central file was made via punched cards which were prepared on the basis of the individual report forms sent to B and W.

The users; the engine room personnel, or the technical personnel of the shipowners, depending on which working method the shipowner's had adopted, i.e. centralized or decentralized management, would receive a feedback similar to the pattern shown.

A service review would be sent out at intervals containing news or operational experience, analyses, tips and, of course, a correspondence column where direct and general questions sent in by readers would be answered. This service review would be issued in such large editions that all on board would get their own copy.

The CCI system had been developed for the new K-GF engines and would gradually, as more and more affiliated themselves to the system, so the amount of data increased, abnormal operational symptoms would quickly be discovered and effective advice would be given.

Mr. McNaught commented on the operation with automatized condition-based monitoring system, CC10, preferring time-based planning. On this point attention could be drawn to the fact that one of the advantages with having an automatic monitoring plant such as CC10 was that the vital functions of the engine were being continuously analysed. Information on the condition of the engine was shown as a trend picture making advanced planning possible to an extent which manual supervision could never reach, and by following the trend picture, the engine crew would seldom be taken by surprise.

Both Mr. Burnett and Mr. Ruscoe commented on the reliability of an automatic monitoring plant. Mr. Burnett asked whether the search for reliable transducers was a problem while Mr. McNaught mentioned an example concerning the significance of poor sensors in operational conditions lacking in reliability.

For obtaining optimal operation security, the choice of transducers and sensors was very important for the reliability of the entire automatic system. The sensors and transducers which incurred in a monitoring system and which, via cables, were coupled to the computer unit in the engine room must be robust and able to resist the special conditions found in an engine room regarding vibrations, and atmospheric conditions, and must especially be able to withstand the jolts and knocks necessitated by dismantling work, etc.

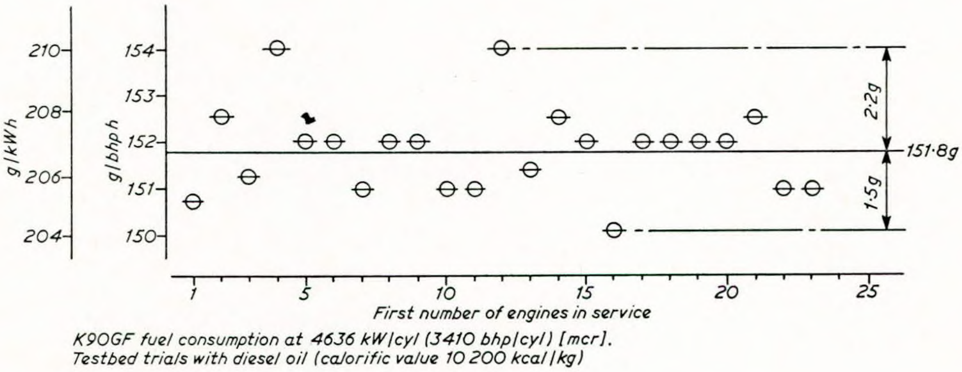

FIG. 24

In the CC10 system, consideration was already taken on the positioning of the sensors and transducers when the engine was designed to obtain the best conditions for protecting the more sensitive parts.

The sensors which were used had been developed and executed for use in ships in co-operation with specialists within this branch. To reduce the risk of getting unreliable measurement results, the system was provided with a number of check points, as alteration of a parameter caused a logical alteration of a number of other parameters, and if such logical alterations were avoided, faults could be traced.

Of course, the crew members who attended and gave a hand on the engines were a very important factor, as a sound assessment could often be a deciding factor when judging a certain situation. It was thus not contemplated that the computer took over the control but to make it possible to obtain a trend picture which put the people responsible in a favourable position when a decision on the action to be taken had to be made.

Mr. McNaught wondered to what extent the new engine had been built for allowing flexibility downwards, and to what power it could go down to where it could run indefinitely without major engine adjustments. This question was also asked by Mr. W. P. Noble in his written contribution.

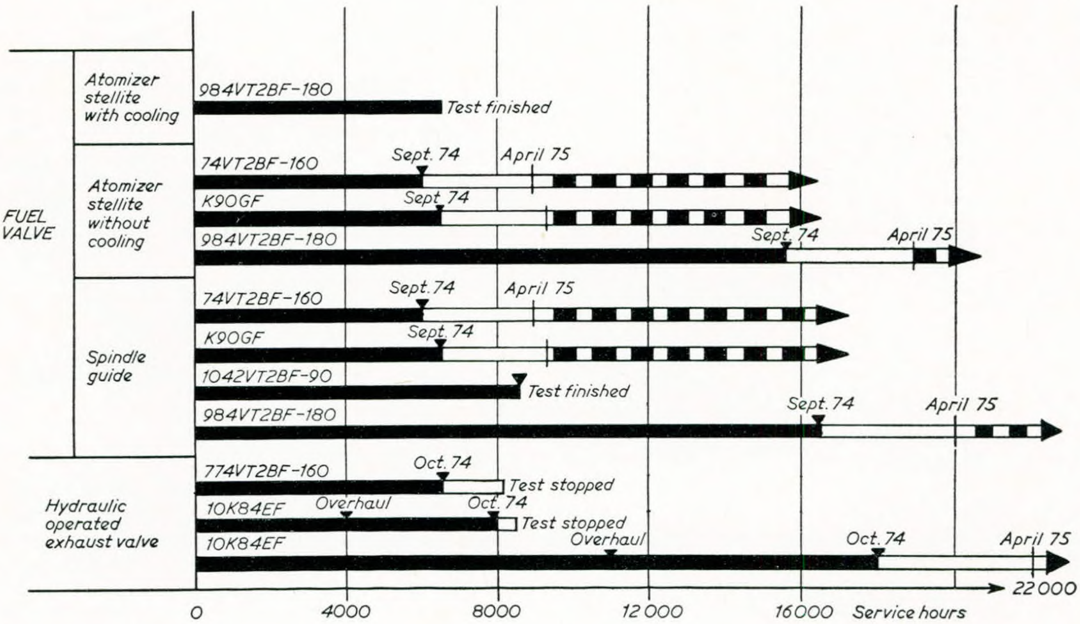

FIG. 25

At the end of 1973 when oil restrictions caused alterations in operational methods, this question was very much in the news, and in December 1973 the author's company sent out a general notice on two-stroke diesel engine running at reduced load as follows:

> "In this connexion we can inform you that our two-stroke engines can, without adjustment of any kind, operate continuously with the normal service rating reduced by 50 per cent, and at this reduced load the fuel oil consumption per bhp h is expected to be 2–3 grammes below the specific consumption at CSR.
>
> If over a longer period it proves necessary to operate at reduced load—down to approx. 50 per cent—we advise against using heavily worn atomizers, as the injection pressure should be kept at a reasonable level, in order to maintain a good atomization. When operating below 50 per cent load, a reduction of the area of the atomizer holes will be advantageous.
>
> We would remind you that existing barred speed ranges must be observed.
>
> If it should prove desirable, the cylinder oil feed rate can (in addition to the reduction which automatically follows a reduction of the rev/min) be gradually reduced proportionally to the indicated mean pressure, but not, however, below 40 per cent of the normal dosage at CSO."

With regard to the average consumption of diesel oil of 205 g/kW (151·8 g/bhp) for the first 24 engines of type K90GF, as shown in Fig. 24, it could, in connexion with the question raised by Mr. McNaught concerning fuel oil of 1500 sec. Redwood and higher, be stated that the consumption would be proportional with the calorific value of the oil.

The greater part of the shown tests had been carried out on gas oil, which normally had a lower calorific value of 10 200–10 250 kcal/kg.

In connexion with the questions raised by Mr. McNaught, Mr. Couchman, Mr. Ruscoe, and Mr. Noble concerning the fuel valves for the K–GF engines—Fig. 25 specifying the latest up-to-date test periods—the following comments could be given.

The uncooled fuel valve had functioned extremely well on K–GF engines as well as on VT2BF and K–EF engines, tested since 1972. The new type of fuel valves had been in use on a 984VT2BF–180. Three of the fuel valves fitted in one cylinder had been in service for 19 000 hours without any overhaul being made and still proved to function satisfactorily with negligible wear of the atomizer holes. The remaining eight cylinders have been in service for 6500 hours also without any overhaul being made and they were still in a very good condition.

Accordingly, it was recommended an inspection of the fuel valves which comprised only one pressure test every year after 6000 to 8000 hours. After a further 6000 to 8000 hours, the fuel valves should be overhauled and spindle guide and atomizer tip possibly replaced.

The new type fuel valves which had a conical seating against the cylinder cover had always been easy to remove from the cylinder cover, and dismantling of the valves had not caused any trouble.

With regard to testing of the fuel valves, experience was that the fuel valves would function in a satisfactory way, if tightness on the spindle seat was achieved up to a pressure 50 kg/cm^2 below the opening pressure, which was 250±20 kg/cm^2, and if the atomizer holes were not worn more than about 0·03 mm.

By using pressures and wear tolerances as criteria for the applicability of the fuel valve rather than individual visual judgment, a generally more reliable checking was achieved, as the differences between the methods of evaluation were eliminated.

Through modification of the fuel valves, the old traditional attitudes which formed the basis of the previous testing had to be altered in compliance with the functional conditions for the specific fuel valve.

For the last 6500 hours the plant with new type of fuel valves mentioned above had operated exclusively on heavy fuel, during manoeuvring and channel passages, and circulated during stays in ports.

With regard to the use of a deep bedplate, as mentioned by Mr. McNaught, and a possible modification on account of wearing out of the supporting chocks, there had been measures taken for the K–GF engines to counteract this wear. A long time ago the deep bedplate was designed as an alternative solution for some of the licensees, who have produced this type of bedplate ever since.

Due to the increase in the size of ships and the application of high tensile steels, the development in the shipbuilding field during recent years made it possible to achieve a higher flexibility of hull and thereby also of the ship's bottom in relation to the size of the engine. Therefore, the introduction of the deep type of bedplate as a standard for K90GF and the other new and larger engine

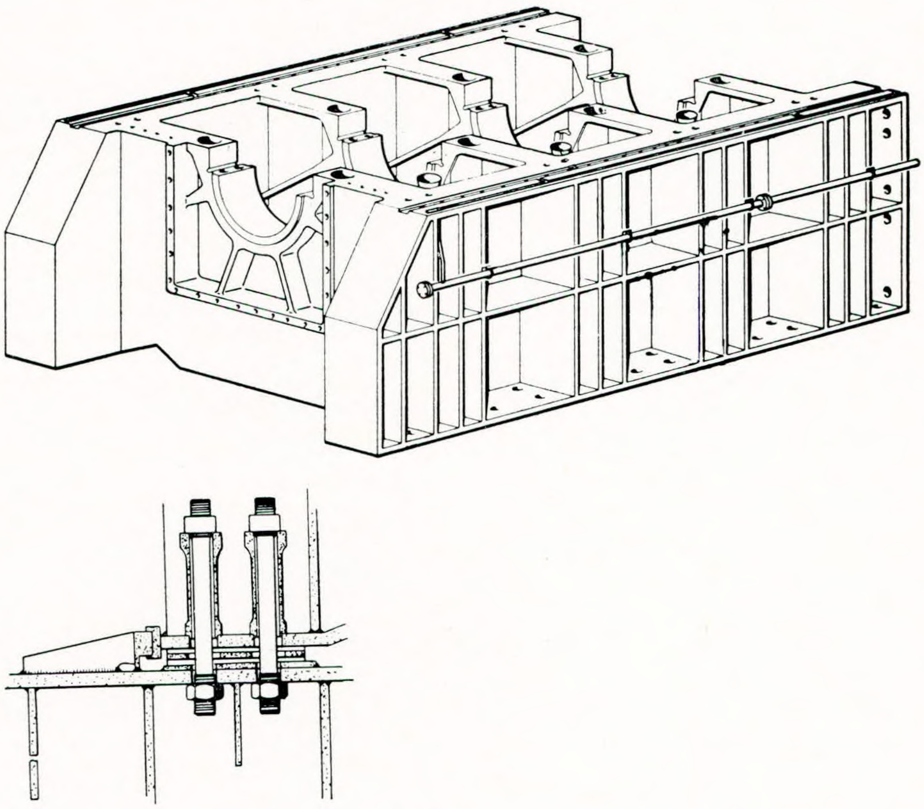

FIG. 26

types was found to be appropriate as it improves the conditions of the engine and the connexions between the engine and the bottom of the ship.

Due to the through-going tank top, the relative displacement in transversal direction of the ship between the holding-down bolts and the pads on either side of the engine would be smaller with a given deflexion of the bottom of the ship.

In longitudinal direction the conditions were of a more complicated nature and demanded special attention. In co-operation with Det Norske Veritas the hull deflexions of typical ship bottoms had been calculated and measured, and been in charge of the development and application of a special laser beam equipment.

According to these investigations, the most dangerous condition occurred when the bottom of the ship curves upwards during heavy loading of the ship, especially at the front of the engine—considering that the engine was aligned in a lightly loaded ship when installed. Therefore, it had been found necessary to provide the front of the bedplate with a projection and an extra group of holding-down bolts (Fig. 26). A normal security against shipping would thus be maintained, also at the holding-down bolt connexions at the foremost transverse girder.

To achieve a higher accuracy and durability in the pre-stressing of the holding-down bolts, these bolts have been lengthened and provided with cast iron spacing pipes to give the bolts a higher elasticity. This also had the advantage that the bolts—which were tightened by hydraulic tools—were easily accessible.

The tension of holding-down bolts in plants which were in service had been checked several times. And the slackening pressure for hydraulically tightened nuts always proved very close to the normal tightening pressure; thus, the performance up to now, after about 10 000 hours in service, had been very satisfactory.

In his written contribution Mr. A. C. Brotherston requested opinions with regard to introducing methods for the tightening of holding-down bolts and main tie-bolts which were similar to the method for tightening the cylinder cover nuts on the large K–GF engines.

Considering the improvements achieved through the above modifications of the bedplate and holding-down bolts, it would be realistic in future to permit a longer service interval between re-tightening of the holding-down bolts, which enabled the manpower necessary for this work to be reduced. Therefore, in this light it had not been found necessary to execute holding-down bolts for simultaneous tightening-up of the large number of bolts; from a purely labour-saving point of view, this was also economically realistic as compared with the extra costs which such a system would involve.

With regard to simultaneous tightening-up of the main tie-bolts, different conditions came into question, as the concerned a relatively small number of bolts. As a standard the main tie-bolts were provided with extra effective thread for the use of a separate hydraulic jack; the standard supply included two hydraulic jacks which enabled the bolts to be re-tightened in pairs. As an extra facility the main tie-bolts could be designed with nuts which had an inter-connected hydraulic arrangement which made simultaneous tightening-up possible. At the request of customers, a number of engines delivered from the works in Copenhagen had been supplied with such an arrangement.

In reply to the question raised by Mr. Burnett as to whether an effort was made during the design of new engines to use plain materials to a high degree and to avoid materials which might be difficult to obtain, the prices highly unstable, and which might not be permanently available on the market, the following comment could be given: The engine design as such was based on ordinary plain steel. However, it was impossible to base the construction on plain steel alone, as this might have led to a disastrous situation. The reason for this was that the ship builders wanted a light engine, and this could only be achieved by using high-tensile steel and alloyed steel for key-components and the structure, a very small percentage of the weight of the engine that consisted of special material.

High-alloy steel was used for special studs, such as bolts for assembling crosshead shells, crank shells, etc. The improved material enabled hydraulic tensioning to be used with advantage; thereby a more precise tightening-up was achieved together with an adequate pre-stressing; if old-fashioned methods were used; spanner and sledgehammer, this would not have been attained. It was the author's company's experience that when the engine personnel had become familiar with the use of the hydraulic tools, they were very reluctant to resume the use of the more work consuming methods of sledgehammer and impact spanner. The use of the hydraulic tools had the added advantage that personnel were inclined to treat these tools with greater care.

The application of circular nuts, for which a normal spanner could not be used, was based on the experience that it was almost impossible to slacken a hydraulically tightened nut by means of a spanner. Further, the incidence of malfunction of hydraulic tools was so low that it would be inexpedient to dispose of the already restricted space for handling of spanner and nuts.

In connexion with Mr. Couchman and Mr. Noble's remarks concerning tools for cleaning of the charging air coolers, the author stated that it was his company's intention to facilitate this work, as fouled coolers would cause the service conditions to deteriorate considerably. The tools shown in Fig. 9 were included in the standard tools supplied with the engines delivered from B and W works in Copenhagen.

With regard to calculation of the values in Fig. 7, to which Mr. Couchman commented, it could be pointed out that the stoppage intervals were calculated as planned in connexion with normal calls in port. Furthermore, as a basis for calculating of the manhours per year per engine, it was assumed for seven to eight people would be available. Only the work which gave rise to engine stoppage was included in the calculation. That the engine room was provided with two travelling cranes above the engine, enabling two shifts to work simultaneously.

Mr. Burnett and Mr. Couchman touched on the question regarding uniformity of the various parts of a diesel engine, irrespective of which licensee firm the engine and the loose parts had been bought from.

The licensees normally manufactured the engine in accordance with the drawings submitted to them, but if necessary some details could be re-designed due, for instance, to a lack of the same type of material, manufacturing tools, procedures, threads, sub-suppliers etc, although the author's company was generally contacted before any re-assembling of details was carried out.

Quite a lot of errors with regard to spare parts were due to the fact that B and W was one of the first engine builders in the world to have a network of licensees. The drawbacks of the early licence contracts were such that it was not possible to control all the licensees in the same way, as contracts differed. This was one of the things which, on the new series of engines, K-GF etc, a great deal of thought had been given so that spares would be the same whoever supplied them.

Mr. Couchman said that he had often met with the reply go back to the licensee when asking for a part for a particular engine. If the part concerned was a wearing part, i.e. a normal spare part, a part manufactured at another place than the original engine could also be used, but if the specific engine itself only was produced by a restricted number of licensee firms, it would be quite natural that one of these firms supplied the parts for the engine. B and W Motor in Copenhagen had a licensee clarification section which could help in such situations.

First Mr. Adolph and then Cdr. Noble queried the use of tin-aluminium bearings, and the use of alkaline crankcase oil as standard.

The service life of crosshead bearings was limited owing to crackling or wiping-off of the bearing material, or both. Resistance to crackling might be obtained by the application of tin-aluminium bearing metals, but this had poor bedding-in capabilities, having abrasive particles and hence increased risk of wiping-off.

It was therefore preferred to preserve a maximum of dirt insensitivity while avoiding crackling through maintenance of low and even-distributed bearing pressures. The specification of crankcase oil must necessarily be rather rough as the choice of a specific oil was the owner's responsibility.

A number of individual crosshead engines were registered, which were equipped with tin-aluminium bearings and which used alkaline crankcase oil, and the operational results were satisfactory.

The oil lists contained, by the way, directions in the use of alkaline oils, but these were still only recommendations.

To Mr. Allen, and partly to cover the comments from Mr. Bowers: Since the introduction of neutralizing cylinder oil, a possible increase in sulphur content in the fuel was not regarded as a serious problem. When the fuel quality was mentioned, it was with the thought of those less clearly defined fuel properties which, during the last few years, seemed to have contributed to some cases of scuffing in engine types.

The question of piston ring and cylinder liner wear was a whole science, and it was very difficult to give average obtainable values. It was agreed that 0·05 mm/1000 h was not uncommon for cylinder wear, and still lower figures had been recorded, but the variation was very great. A liner was usable up to a wear of about 1 per cent of the diameter, but most owners preferred to change it at between 0·3 and 0·6 per cent as the number of ring breakages often increased due to wear steps; if these steps were carefully removed, the lifetime of the liner would be increased, therefore, this also depended on the ability of the crew, the policy of the shipowner, and the inspection. Cracks in cylinder liners would occur, but could not be considered a serious problem. Such cracks were not influencing the statistics to such a degree that they would be regarded as having reached the highest control limit.

The values given in Fig. 8 actually indicated a reduction of maintenance by extension of periods between overhauls. Admittedly, the life of 8000 h was low; however, there were many examples of longer life-times, such as 12 000 to 16 000 h, also for engine type K84EF.

According to the current experience gained from the first K90GF in service, the wear of uppermost piston ring proved to increase to about 0·24 mm/1000 h, which within the allowable wear limit gave a life of about 18 000 h; with regard to ring no. 2 the wear amounted to about 0·08 mm/1000 h, giving a life of about 55 000 h.

Regarding Mr. Brotherston's remarks on the design of the piston rings and the ring grooves in the piston, it could be stated that the piston ring grooves in pistons of the K-GF engines as a standard were designed with a chromium layer of about 0·35 mm both on the upper and the lower lands of the ring groove.

It was important that the piston rings function as potential wearing parts, and the chromium-plated ring grooves enabled favourable service conditions for the rings to be achieved. However, the operation of a piston ring to a high degree depended on the actual service conditions, such as lubricating conditions, pressure progression, etc; however, limited space did not permit this voluminous subject to be treated in closer detail.

However, it would be established that the piston rings would be worn and this could cause sharp edges to occur. It was recommended to chamfer such sharp edges during each overhauling, but it was not advisable to use rings with edge roundings larger than the nominal 1·0 to 1·5 mm and relief chamfers at the lock should be avoided.

On normal rings, the small edge rounding and absence of chambers at the lock enabled contact to be made with the liner surface in almost the entire height of the ring. A larger rounding or chamfer would expose an unnecessary extra area of the running surface of the rings to high gas pressure, which was liable to cause ring collapse, loss of tension, and blow-by.

Mr. Couchman called attention to Fig. 17 which showed in schematic form the average life time of a number of components which would be described as wearing parts. The summary showed the life at mcr; however, it should be realized that the spreading could be larger than shown in the illustration, as variation in the service conditions would have a considerable influence on the life times of the components. It was true that maintenance through scrapping and replacing could appear economically demanding; however, with regard to the parts requiring high skill and work effort during reconditioning in cases where such potential work required large investments in tools etc, an analysis would very often show that lower costs were required for the replacement of parts with new ones than for investment in labour force, equipment, etc, At the same time considering that such maintenance and reconditioning work might be of varying quality, which would result in deterioration of the service conditions.

On the whole, the costs of spare parts were small in relation to the fuel costs, for this reason due regard should be paid in each individual case in providing the most favourable service conditions. To keep the engine in the best possible service condition from the point of view of operating economy so as to achieve maximum utilization of the fuel oil.

With regard to the specific question of procedure and costs per set of scraper rings for piston rod stuffing box, it could be pointed out that for the K-GF engine the scraping ring type used had the scraping edge designed as replaceable lamellas.

The replacement of the lamellas for one complete stuffing box set would take about 30 minutes; however, it would rarely be necessary to replace all six sets at the same time. The costs of a complete set consisting of six sets of each three million lamellas were at the present time about d.kr. 505—and, generally, the costs per cylinder per year would amount to about 300–400 d.kr.