Report of the Chief Inspector

of Marine Accidents into the

Reopened Inquiry into the explosion

on the Motor Tanker

ESSO MERSEY

on 4 September 1991 resulting

in the loss of two lives

Marine Accident Investigation Branch
5/7 Brunswick Place
Southampton
Hants SO15 2AN

London: HMSO

ISBN 0 11 551820 7

ABOUT HMSO's STANDING ORDER SERVICE

The Standing Order service, open to all HMSO account holders*, allows customers to receive automatically the publications they require in a specified subject area, thereby saving them the time, trouble and expense of placing individual orders.

Customers may choose from over 4,000 classifications arranged in more than 250 sub groups under 30 major subject areas. These classifications enable customers to choose from a wide range of subjects those publications which are of special interest to them. This is a particularly valuable service for the specialist library or research body. All publications will be despatched to arrive immediately after publication date. A special leaflet describing the service in detail may be obtained on request.

Write to Standing Order Service, HMSO Books, PO Box 276, LONDON SW8 5DT quoting classification reference 03.03.062 to order future titles in this series.

* Details of requirements to open an account can be obtained from HMSO Books, PO Box 276, LONDON SW8 5DT.

Marine Accident Investigation Branch
Department of Transport
5/7 Brunswick Place
Southampton
Hants SO15 2AN

24 January 1996

The Right Honourable Sir George Young Bt MP
Secretary of State for Transport

Sir

My Report following the Inspector's Inquiry into the explosion on the tanker ESSO MERSEY on 4 September 1991 resulting in the loss of two lives was published in January 1993. New evidence was later produced which brought into issue a particular finding of that Inquiry. In pursuance of Regulation 14 of the Merchant Shipping (Accident Reporting and Investigation) Regulations 1994 I deemed it necessary to re-open the Inquiry in respect of that part which was in issue.

In pursuance to Regulation 9 of the above mentioned regulations I submit my Report of the re-opened Inquiry.

I am, Sir,
Your obedient servant

Captain P B Marriott
Chief Inspector of Marine Accidents

Extract from

The Merchant Shipping

(Accident Reporting and Investigation)

Regulations 1994

The fundamental purpose of investigating an accident under these Regulations is to determine its circumstances and the causes with the aim of improving the safety of life at sea and the avoidance of accidents in the future. It is not the purpose to apportion liability, nor, except so far as is necessary to achieve the fundamental purpose, to apportion blame.

CONTENTS

1. SUMMARY

An Inspector's Inquiry into the explosion on the motor tanker ESSO MERSEY on 4 September 1991 resulting in the loss of two lives established that an immediate cause of the accident was vibration induced failure of No 4 cargo pump. This failure led to the leaking of volatile cargo which ignited.

The Report of the Chief Inspector of Marine Accidents, published in January 1993, identified deficiencies in the maintenance work carried out on the cargo pump involved in the explosion and in the supervision of that work.

Since publication of the Report, evidence has been produced which has brought into issue the particular finding that the contractor who carried out work on the cargo pump failed to exercise acceptable quality control procedures.

In the light of this new evidence the Inspector's Inquiry was reopened. This further Inquiry has determined that quality control procedures were inadequate but the contractor was not alone in this respect.

PART 1 FACTUAL ACCOUNT

2. NARRATIVE

2.1 An Inspector's Inquiry into the explosion on the motor tanker ESSO MERSEY on 4 September 1991 resulting in the loss of two lives established that an immediate cause of the accident was vibration induced failure of No 4 cargo pump. This failure led to loss of cargo through the top mechanical seal and eventual ignition by contact between the cardan shaft and its guard. Development of vibration originated due to the first stage impeller outer locking nut becoming loose and backing off. This in turn led to free movement of other internal components which culminated in excessive vibration. Movement of the outer locking nut was due to the absence of two locking grub screws which secured the locknuts. Grub screws should have been installed during the 1989 overhaul and rebuild of the rotating element. There was no evidence to show why they were missing. It was deduced that they were not fitted, or that they vibrated loose and fell out, or that they were of an incorrect material and corroded away. It was concluded that whatever the reason for the absence of the two locking grub screws, indications were that it occurred as a consequence of a failure on the part of the contractor to exercise acceptable quality control procedures during refurbishment of the rotating element. These and other causative factors, which relate to Esso's quality control system, are reported in the Report of the Chief Inspector published in January 1993.

2.2 Since publication of the Report, evidence has been produced which has brought into issue the finding that the contractor was responsible for the missing grub screws. In the light of this new evidence, the Inspector's Inquiry into the pump-room explosion was reopened. Matters investigated related solely to the criticism in the Report of the Chief Inspector that a principal contributory factor of the accident was "a failure on the part of the contractor .... to exercise acceptable quality control procedures" during the refurbishment of the pump rotating element.

2.3 The evidence submitted consisted of three documents:

- A material parts list entitled "McGraw-Edison Service Weir 2 Stage Cargo Pump Modification". The list provided a material specification for components of the rotating element - dated June 1982.

- A letter, dated 16 September 1982, from the contractor signed by their Service Superintendent to Esso Petroleum Company Ltd. This letter related to the ESSO MERSEY cargo pump modification indicating the difficulty that the contractor's service engineers experienced while fitting the second modified rotating element into its respective pump casing.

- Undated notes entitled: "Installation Procedure for Two Stage Weir Cargo Pumps, ex ESSO MERSEY." The origin of these notes is not known, but it is thought they were prepared by the contractor for ship's staff assigned to install spare rotating elements in the future.

2.4 This evidence, which had not been made available at the time of the original inquiry, was considered and it was concluded that re-examination of issues related to the quality control of the refurbishment of the rotating element and its installation was justified. The issues examined were:

- the material specification requirements of the components of the rotating element; and,

- the quality controls exercised to ensure that the impeller locking arrangements were secured before installation of the rotating element in No 4 cargo pump.

PART II CONSIDERATION OF POSSIBLE FACTORS

3. BACKGROUND TO THE HISTORY OF THE DESIGN AND MODIFICATION OF NO 4 CARGO PUMP

3.1 In May 1981 a fire occurred in the pump-room of ESSO MERSEY. While pumping petroleum product the top seal on No 4 cargo pump failed causing the subsequent oil leakage to ignite. There were no injuries as a result of the accident. This pump was one of four similar pumps installed in the pump-room and manufactured and supplied by Weir Pumps Limited, Cathcart Works Glasgow. Similar pumps were installed on sister vessels ESSO SEVERN and ESSO CLYDE. Investigations, undertaken by Esso Petroleum Co Ltd, and by the Surveyor General's Organisation of the Department of Transport, concluded that the pump required new top and bottom seals, new material on bearing surfaces, the pump to be balanced and a review of the current maintenance system undertaken. It was also concluded that a vibration analysis should be carried out.

3.2 These findings led Esso to instruct a firm of consultants to conduct a vibration analysis of the cargo pumps in June 1981. As a result of this analysis the consultants conducted a further investigation to consider the pump design. They concluded that the main cause of failure was insufficient shaft thickness to resist anticipated dynamic forces leading to contact between the central part of the rotor shaft in way of the impeller distance sleeve and the intermediate bush. This led to recommendations that the pump shaft be redesigned with a greater diameter and impeller bores and keyways altered to suit. Also that the compatibility of the intermediate bush and impeller distance sleeve materials be optimised and that in future the rotor shaft assembly be dynamically balanced before installing into the pump casing. The purpose of this redesign was to stiffen the shaft to minimise contact between the rotating impeller distance sleeve and the intermediate bush, and to prevent undue heat build up and possible shaft distortion when intermittent contact between the two did take place. This redesign assessment gave opportunity for improvement to the bearing and seal configurations. The consultants specified a redesigned pump shaft made from stainless steel to BS 970 347 S17, the same material that was specified in the Weir design. They also specified the same quality stainless steel for the impeller lock nuts which differed from the original Weir design which specified aluminium bronze. In October 1981 tenders were sought from three contractors for fabrication of the redesigned shaft. It was envisaged that if the modification was successful on one pump of ESSO MERSEY, the modification would be advised for the other pumps installed on this and the other two sister vessels - a total of 12 units in all.

3.3 The contractor selected for the work was a firm which had been recommended to Esso's Operations Manager by the Technical Department at the Esso Milford Haven Refinery. Subsequent to meetings between Esso, their consultants and the contractor, the scope of work to be accomplished was agreed in an exchange of correspondence. The contractor did not recommend to shrink fit the impellers because of the need to adjust the position of the shaft to suit the casing and the need to remove one impeller to fit impeller wear rings and the intermediate bush housing after balancing and before finally fitting the assembly into the pump casing. However, Esso decided that the impellers should be an interference fit onto the shaft. Two drive keys were fitted to each impeller instead of one key as used in the original Weir design. Other features of the modification included: a new type of top and bottom pump seal; a stainless steel impeller distance sleeve with a sliding fit on the shaft which, like the original Weir design, was located in position by one of the impeller keys; an intermediate bush lined with "Deva" metal, a sintered bronze bush impregnated with carbon graphite. Like the original Weir design, the two impellers and impeller distance sleeve were secured in the correct position on the shaft by impeller nuts, (inner nuts). However the original design specified that the impeller nuts were locked tight by two grub screws located radially around each nut. With the modified design, the nuts were specified to be locked by locking nuts, (outer nuts), with an additional locking feature which comprised two grub screws positioned longitudinally through each outer nut and screwed against the face of the inner nut which is in contact with the adjacent face of the outer nut, (see Figure).

3.4 Esso's consultants supplied the contractor with a detailed drawing No AT 1160-02 showing the shaft, locknuts and impeller bore, required dimensions and material specification as stainless steel to BS 970 347 S17. Based on this drawing, the contractor completed their own design work which included new types of bottom bearing, top and bottom seal assemblies and a "Deva" metalled intermediate bush. In April 1982 the contractor produced a prototype shaft assembly which also included new case wear rings. To assist correct setting up of the prototype shaft assembly, its corresponding pump casing cover was made available in order to establish the correct axial position of the impellers on the shaft. The shaft, impellers, impeller nuts, lock nuts and grub screws, and the impeller distance sleeve were assembled to make up the rotating element which was then dynamically balanced to ISO Standard G2.5. The rotating element was then dismantled to enable fitting of the intermediate bush and impeller wear rings. The rotating element was reassembled and despatched to the ship for fitting into the pump casing. The contractor installed the rotating element assembly into No 4 cargo pump aboard ESSO MERSEY in April 1982.

3.5 After approximately 60 running hours the consultants carried out on board a post installation vibration analysis on the pump. The condition of the modified rotating element in No 4 cargo pump was reported to be good and vibration levels found acceptable. The consultants considered that the design objective of increasing the pump critical speed to outside operating range had been achieved. Subsequent to this successful outcome, in June 1982 the contractor was awarded the contract to modify the three remaining pumps in ESSO MERSEY and four

in each of ESSO SEVERN and ESSO CLYDE. The contractor produced a drawing to aid their own machinists to fabricate and assemble the components of the rotating element. The drawing's material parts list, dated June 1982, indicated that three impeller keys were to be of EN6A, (plain carbon steel), and the fourth impeller key, which located the impeller distance sleeve, was specified to be EN57, (BS 970 431 S29 stainless steel). The pump shaft material was similarly specified as EN57 stainless steel which contrasted with the consultants' specification - BS 970 347 S17. Material for the grub screws was specified as cup point 14.9. Whether this drawing was released to Esso is a matter of dispute. The contractor claims he did pass it to Esso for approval, but no records can be found to substantiate this. The contractor supplied a sectional arrangement drawing No MH 1025 to Esso, dated August 1982, to assist ships' crews when they where required to maintain the pumps. The material requirements for the impeller keys and grub screw were not specified on this drawing. The pump shaft material was specified as BS 970 347 S17, the same material as specified by the consultants.

3.6 The second modified rotating element was manufactured, assembled and tested like its prototype, then despatched to the ship. However, during installation of the rotating element into its respective casing, the contractor found that because the internal dimensions of the second casing were different to the first, the required axial locations of the wear rings and thus the length of the distance sleeve differed from that required of the first rotating element. The assumption had been that all the pump casings were similar, so that each modified rotating element would be identical and therefore interchangeable. However, in order to ensure that the impellers were centralised within their impeller casing part, the contractor considered it necessary to reduce the distance between the two impellers on the shaft. To achieve this required the application of heat to remove one impeller, followed by removal of the impeller distance sleeve and machining ¼ inch off one end. The work was completed on board without having to resort to removal of the rotating element ashore, but the size and weight of the element did cause problems with it having to be physically transported from the pumproom to the engine room and back again. The contractor informed Esso of the problem which had been encountered. The contractor completed manufacture of the modified pump assemblies on all three ships in 1983 within approximately a 12 month period. These were installed by the respective ships' staff.

4. BACKGROUND OF THE CONTRACTOR

The contractor had a service centre at Milford Haven, and at the time that the pump modifications were taking place Esso dealt directly with that company's District Manager and it's Service Superintendent. In 1986 the Milford Haven service centre was closed down and the business relocated in Bristol. The Service Superintendent left the employ of the contractor and, along with others, formed a partnership to operate two engineering companies. The objective of these companies was to provide mechanical and fabrication services to the petroleum and shipping industries. The companies were based in Waterstone, Pembrokeshire, and work undertaken included overhaul of all types of rotating machinery, gear boxes, compressors and steam turbines. In April 1989 the partnership in these companies was dissolved and the Service Superintendent created a new company. Because of the Service Superintendent's past involvement with the modifications and refurbishment of the rotating elements, Esso awarded him the contract to continue on-going refurbishment of ESSO MERSEY's rotating elements. The contractor refurbished four rotating elements during the period March 1988 to December 1990 including the one in No 4 cargo pump which failed.

PART III DISCUSSION OF EVIDENCE

5. THE MATERIAL PARTS LIST ENTITLED: "McGRAW-EDISON SERVICE WEIR 2 STAGE CARGO PUMP MODIFICATION" DATED JUNE 1982.

5.1 This document provided a material specification list of components for the rotating element. It was devised by the contractor and included the following:

Description	Material
Pump shaft	EN57
Impeller keys	EN6A
Impeller key - centre sleeve	EN57
Impeller Nuts - 2 off LH + 2 off RH	316 ST.ST
Centre sleeve	316 ST.ST.COATED-METALOY "2"
Grub screws 5/16" U.N.C. and 5/16" long	14.9 cup point

The list is dated June 1982 and appears to be part of a drawing for use by the contractor's machinists and fitters. This drawing no longer exists. The contractor advised that this materials parts list was agreed at a meeting between the contractor, Esso and their consultants, with the consultants having the final word in all matters concerning design and material selection. There is no record of this meeting. For their part Esso considered it to be illogical as well as implausible that they would ever have agreed to the use of materials which did not accord with their consultant's specification or with accepted industry standards. Moreover, there is no identification tying this materials parts list into that one shown on the contractor's drawing No MH 1025, dated 26 August 1982, and supplied to Esso for use by ship's staff. The material parts list on this drawing excluded the keys and grub screws.

5.2 An undated service contract drawn up by the contractor proposed to Esso a work specification to modify the cargo pumps. The specification advises that the pump shaft is manufactured with nuts and keys as per drawing AT 1160-02 -revision B dated 4.1.82. This drawing does not now exist but it is probably a revised version of the consultants' original drawing numbered AT 1160-02 which had already been supplied by them to the contractor. This drawing indicates the shaft to be of BS 970 347 S17 stainless steel, as specified in the original Weir design. The same material specification is also indicated on the contractor's drawing No MH 1025 supplied to ships' staff. Since the material parts list on the two drawings are similar, it is probably this material parts list that was approved at the aforementioned meeting between the contractor, Esso and their consultants and not the list dated June 1982.

5.3 The material parts list submitted by the contractor to the Inspectors as new evidence, indicates that the pump shaft is to be made from EN57, a BS 970 431 S29 grade stainless steel. This specification neither accords with that specified on the contractor's drawing No MH 1025, nor with that on the consultants' drawing numbered AT 1160-2, both of which are the same, ie BS 970 347 S17 stainless steel. The reason why the contractor changed from the original specification is a matter for speculation. It is possible that because EN57 grade steel is easier to machine, there could be a saving in production costs. However it is considered that EN57 stainless steel is an equally suitable material for the pump shaft although less corrosion resistant.

5.4 There are a number of published standards, both national and international, with regard to the materials specification for centrifugal pumps, examples being the API and BSI Standards. Many facets of these standards are interchangeable. There is no standard which addresses itself directly to pumps for use in the marine industry, however the standards which do relate to centrifugal pumps give clear guidance as to good engineering practises which are equally appropriate for the marine industry. For example the petroleum industry bases its standards of pump design and operation on those set out in the publication, "Centrifugal Pumps for General Refinery Service API Standard 610". Paragraph 2.11.1.9 of that Standard states:

> *"Minor parts that are not identified (such as nuts, springs, washers, gaskets and keys) shall have corrosion resistance at least equal to that of specified parts in the same environment. Gasket or seal material between the shaft and the shaft sleeve under the packing or mechanical seal shall be verified by the vendor as being satisfactory for the service conditions.*
>
> *Note: When dissimilar materials with significantly different electrical potentials are placed in contact in the presence of an electrolytic solution, galvanic couples that can result in serious corrosion of the less noble material may be created. If such conditions exist, the purchaser and the vendor should select materials in accordance with the NACE Corrosion Engineer's Reference Book."*

The Standard gives a clear warning of the serious hazard of matching dissimilar materials operating in a corrosive environment. Plain carbon steel and stainless steel are considered to be in this category. The warning in the Standard reflects what is common knowledge amongst engineers. Specified on the contractor's material parts list dated June 1982, were three plain carbon steel keys (EN6A) and one stainless steel key (EN57). The cargo pumps were used to pump petroleum products and sea water ballast. The latter has considerable electrolytic properties. The material selection for the three plain carbon keys, which were in direct contact with the stainless steel shaft, was therefore incorrect and contrary to the API Standard.

Indeed, a post accident examination in 1991 of No 4 cargo pump summarised in the Chief Inspector's Report indicated that a plain carbon steel key belonging to the second stage impeller was corroded, thus confirming the wisdom of the API Standard and the failure of the contractor to follow both the Standard and common engineering principles with regards to material choice for the impeller keys.

5.5 The same conclusion is reached with the grub screws. Examination in 1991 of the damaged No 4 cargo pump revealed that the two locking grub screws for the locknut of the first stage impeller, (the lower impeller), were missing therefore the material for these grub screws could not positively be identified. However, they were probably made in the same material as the grub screws which were found corroded and ineffective in the upper locknut of the second stage impeller and observed to be plain carbon steel. Corrosion of the grub screws could be expected since, like the plain carbon keys, they were in contact with stainless steel operating in an electrolytic solution.

5.6 The Chief Inspector's Report considered that the missing grub screws were a principal contributory factor in the accident to No 4 cargo pump and gave three possible reasons why the grub screws in the lower locknut were missing. These were that the grub screws were not fitted in the first place, or that they vibrated loose and fell out, or that they were of incorrect material and corroded away. The first two reasons for the missing grub screws did not occur necessarily as a consequence of inadequate quality control procedures on the part of the contractor alone. The pump rotating element was fitted into the pump casing by the ship's staff after first being examined for clearances and physical damage. No specific check of the grub screws appears to have been carried out by the ship's staff as this was not specifically identified in the onboard assembly procedures (see Section 6). Despite this, there is a case that a degree of responsibility lay with ship's staff to check the correct assembly before installation. Thus, because of the uncertainty surrounding the possible reasons for the missing grub screws, it cannot be assumed that the contractor was solely responsible for their loss.

6. UNDATED NOTES ENTITLED "INSTALLATION PROCEDURE FOR TWO STAGE WEIR CARGO PUMP, ex ESSO MERSEY"

6.1 This was the contractor's second piece of evidence offered to the Inspectors. The Inspectors have been informed that these notes were an extract from the pump handbook with additions relating to grub screws. The notes were supplied by the contractor during the period of pump modifications for use by ship's staff when installing a rotating element into the pump casing. Included in these notes was advice on how to centralise the rotor shaft impellers in the pump casing which stated:

> "- *back off impeller nut same distance required to centralise the impellers from the hub faces to locknut faces;*
>
> - *heat impellers and move along pump-shaft to sit against pre-set lock-nut;*
>
> - *tighten inner lock-nut after impellers have cooled to ambient temperature and back off each nut 1/8th turn;*
>
> - *tighten outer lock-nuts and grub screws;*
>
> - *peen grub screw threads over to secure screws.*"

6.2 During installation of the second rotating element the contractor had to machine the stainless steel distance piece on the second rotating element in order to achieve alignment of the impellers in the casing. As a result of this experience they were of the opinion that the rotating elements were not interchangeable. In a letter to Esso dated 16 September 1982, they informed the ship's staff that an amendment to their guidance notes would be necessary. (This letter was the third piece of new evidence offered to the Inspectors). Advice in the letter included:

> *"We encountered problems whilst assembling the second pump rotor into the casing. The case axial locations for the wear rings and centre diaphragm bush differ from the first modified pump by 5/16" and had to machine 1/4" away from the centre sleeve face to achieve correct axial location of impellers. We also had to manufacture another roller bearing spacer to align roller bearings. We informed your staff and they have made amendments to the assembly procedure."*

6.3 Esso prepared their own guidance notes (two pages) for centralising and installing the rotating element in the pump casing. These notes were based on the original guidance notes prepared by the contractor and dealt effectively with problems reported in the contractor's letter of 16 September 1982. The first page of Esso's guidance notes is dated 10 August 1982. The contractor's pump drawing No MH 1025 was issued on 26 August 1982 prior to the installation of the second rotating element. The second page of the Esso guidance notes is undated and is in place of the contractor's advice on how to centralise the rotating element. This included the following statement:

"note: should the element require centralising then item 5 bearing distance piece must be increased or decreased in length to suit."

However, this note contains an error in that the distance piece is not Item 5 but Item 7 - Item 5 is the distance sleeve. Adjustment of the distance sleeve does not alter the position of the rotating element whereas the adjustment of the distance piece does. That the guidance notes were correctly interpreted was confirmed during subsequent interviews conducted with ship's staff - adjustment of the rotating element position was achieved by using the bearing adjusting screws and then fitting distance pieces of the correct thickness.

6.4 Esso's installation procedure did not require removal of an impeller from the shaft and machining of the impeller distance sleeve. Their guidance notes, along with drawing No MH 1025, is used to this day as an aid to ship's engineers to correctly assemble and install the rotating element and bearings into the pump casing. Esso submit that the new procedure did not require adjustment of the impeller and locking arrangement on board ship and, as a consequence, considered that the contractor should have locked tight the impellers with grub screws inserted and peened over at their works. They also considered it unnecessary to remove and machine the impeller distance sleeve in any case since, if despite following the new procedure, any further discrepancy in the central alignment of the impeller would result only in an acceptable lowering of efficiency without affecting safety of operation. Esso's view was that their procedure would enable all refurbished elements supplied in future to be interchangeable between different pumps. However, there is no written evidence to indicate that the contractor was required by Esso to secure the impellers before despatch to ESSO MERSEY. Before the accident on ESSO MERSEY a work specification agreement between Esso and another engineering firm, to refurbish the rotating element for one of the other sister ships, required the impellers to be secured before despatch to the ship. It was also required that the 4 impeller keys should be replaced by BS 970 316 S11 stainless steel keys. Therefore, a clear understanding of what was required existed between Esso and this engineering firm. If a similar specification had been agreed between Esso and the contractor for the ESSO MERSEY pumps, then there would have been no possibility of any confusion or misunderstanding by the contractor as to exactly what was required. However, the contractor steadfastly states that it was always their intention to leave the impeller locking arrangement slack on delivery to the ship, in case the impellers had to be shifted along the shaft

7. QUALITY CONTROL OF THE CONTRACTOR

7.1 It is considered that the responsibility for approval of material choice for the pump lies with Esso. However the contractor is a self proclaimed expert in pump design and refurbishment. It is to be expected that Esso would rely on the expertise of the contractor to identify the correct material for components such as the keys and grub screws, items considered by the API Standard to be minor parts. As explained in the previous section, to some extent, the contractor did not adhere to the requirements of paragraph 2.11.1.9 of the API Code when developing the design modification. However, Esso should have been equally aware of its requirements and ensured that the contractor worked to the correct and preferred specification. Safe and effective systems of quality control exercised by both Esso and the contractor were questioned in the Chief Inspector's Report and both Esso and the contractor were criticised. However, since publication of the Report, the contractor has argued that criticism of their quality controls was unfair. This criticism has therefore been reconsidered.

7.2 After the accident, Esso commissioned a Lloyd's Register of Shipping Surveyor to attend the strip down of the spare element carried on board ESSO MERSEY and overhauled by the contractor in 1990. The following comments were stated in the Surveyor's Report:

"- *shaft material stated to be stainless steel*

- *mild steel keys fitted*

- *changes in shaft diameter inadequately radiused*

- *end radius of shaft keyway not tangential with longitudinal edges*

- *excessive end and side clearance of keys in the shaft*

- *one key artificially spread to fit the keyway dimensions*

- *impeller shaft locknuts with excessive thread clearance and backlash*"

7.3 The Surveyor commented that in view of the examination carried out and the results found, taking due regard of the fluctuating stresses met in service, it was recommended that the shaft was not put into service.

The Surveyor's report indicates that the contractor did not follow what they submitted to be the correct specification for the impeller keys, ie three carbon steel keys and one stainless steel key. Moreover, their workmanship in refurbishing the spare rotating element was considered to be substandard requiring the Surveyor to recommend that it was not to be used.

8. CAUSE OF EXCESSIVE VIBRATION

The Inspector's Inquiry into the pump room explosion was reopened to reconsider the particular finding in the Report of the Chief Inspector of Marine Accidents, published in January 1993, that the contractor who carried out work on the cargo pump failed to exercise acceptable quality control procedures. In order to further the reopened investigation, a pump engineering consultant was commissioned by the Chief Inspector to provide an independent assessment of evidence uncovered during the strip down of No 4 cargo pump. The evidence was summarised in Section 4.3 of the Chief Inspector's Report, and is repeated below:

> *"**Detailed Examination of No 4 Cargo Pump***
>
> *A further detailed examination of No 4 cargo pump when the pump had been removed ashore revealed the following:*
>
> - *The pump coupling locknut was tight but did not have locking grub screws fitted.*
>
> - *The coupling was a loose fit. Good engineering practices would have required an interference fit of 0.001-0.0015".*
>
> - *The top bearing was well lubricated and fitted well in the housing but it was a poor fit on the shaft and had been fretting on the shaft. This caused the mechanical looseness seen before the strip down.*
>
> - *The top bearing pedestal had not been securely fixed for a period of time. This was indicated by the elongation in the hole which contained the one remaining dowel. There was evidence that the fixing bolt second from starboard side was the last bolt to vibrate free. This was shown by the heavy thread marks in the pedestal clearance hole.*
>
> - *The starboard pedestal fixing hole in the pump body was damaged with threads stripped. Only the bottom 2 threads were still there.*
>
> - *The second fixing dowel had at some time been drifted through the pedestal into the pump casing and not been re-fitted. The dowel was protruding slightly above the flange face.*
>
> - *The top mechanical seal had totally failed. The primary seal had large pieces of its face material missing and some chips out of the carbon face. The seal face was a hard compound sprayed on to a brass alloy base and machined/lapped flat.*
>
> - *The secondary seal had broken up and disappeared completely.*
>
> - *The seal sleeve had been rubbing on the seal plate and seal carrier causing heavy grooving in the sleeve. Some of the seal drive screws had worked loose and one had dropped out, this screw was found on the pump casing while the pump was in the ship.*

- *The bottom bearing was in a heavily rusted condition and the outer track was running ¼" axially out of position to the inner race. The grease point was fitted and although no lubricant remained on the bearing itself, grease was found in the "O" ring groove in the bearing end cap. This indicated that the bearing was grease packed during assembly on the last occasion that the bearing had been replaced/ renewed. The threaded plugs were found to be missing from the two tapped holes situated at the top of the bearing carrier. Brass sleeves in these holes formed an isolation barrier between the lubrication groove and tapped hole. These holes facilitate drifting the outer bearing clear of the carrier. The outer bearing cavity would have had to be full of grease and under pressure before any lubricant could have escaped through these openings.*

- *The "O" ring seal to the bottom bearing cover was not fitted.*

- *The lip seal protecting the bottom bearing had swollen when the bottom seal had leaked product onto it and caused it to fail.*

- *The bottom mechanical seal was severely damaged with sections of the primary seal face chipped off. The secondary containment carbon seal had totally disintegrated and particles of carbon were found in the bottom seal leak chamber. All drive screws etc were intact in this seal.*

- *The first stage impeller outer locking nut had backed off 7/32" from its mating nut. This locking nut should have been fitted with 2 locking grub screws. Both were missing. These may not have been fitted, or if fitted vibrated out and disappeared, or they were fitted and corroded away completely.*

  The inner lock nut, against the impeller, was only hand tight. There were indentations in the mating locknut indicating that on three occasions there had been grub screws fitted in the locknuts.

- *The inter stage sleeve, between impellers, was free to move. This should have been an interference fit.*

- *The top, second stage, impeller lock nuts were tight and the locking grub screws were fitted but were severely corroded as they were mild steel.*

  Like the first stage, there were indentations in the mating locknut indicating that on three occasions there had been grub screws fitted in the locknuts.

- *The wear rings had all rubbed and the clearances which should have been approximately 0.022" were:*

lower wear ring 1st stage	-	*0.085"*
upper wear ring 1st stage	-	*0.105"*
upper wear ring 2nd stage	-	*0.108"*

The lower wear ring on the 2nd stage impeller had come off the impeller and was resting in the intermediate piece. With this ring off there was a clearance of 7/16" between impeller and case wear ring.

- *All inter stage and neck bushes had excessive clearances with the PTFE liners missing. There was a thin section of liner remaining in the lower neck bush.*

- *The shaft had been spray metal repaired in four locations; this metal had lifted in all locations with only a small percentage left in two of the areas. The areas spray metalled were:*

  2 areas under the top neck bush
  1 area under the bottom neck bush
  1 area under the bottom mechanical seal sleeve

- *The impellers were a good press fit on the shaft. Three of the impeller keys were manufactured from mild steel and had badly corroded. The fourth key was stainless steel and in good condition.*

- *The shaft was checked for straightness and the maximum error was 0.0035" TIR (Total Indicated Reading).*

- *The general condition of the impellers was good showing only slight signs of cavitation and erosion.*

- *The general condition of the pump casing was good apart from a small crack in the second stage volute web. This was an original casting flaw which had been highlighted by product erosion."*

The original findings from this evidence (Section 11.5 of the Chief Inspector's Report) was that the development of vibration originated due to the lower impeller, 1st stage, outer locknut becoming loose and backing off. This in turn led to the free movement of the other internal components which culminated in excessive vibration.

The pump engineering consultant considered that the most likely sequence of events leading to failure was the development of excessive clearance in the intermediate impeller shaft bush, wear rings and neck bushes resulting in lack of shaft support and a subsequent increase in vibration levels. Loss of the lower wear ring on the second stage impeller led to hydraulic imbalance and an excessive upthrust on the top bearing. The high vibration level, probably combined with this excessive upthrust, caused failure of the top pedestal bearing mounting and the top seal.

Whatever the reason for excessive vibration it should not detract from the concern of [illegible] with regards to the grub screws and the tighter [illegible]

PART IV CONCLUSIONS

9. FINDINGS

The Inspectors who carried out the reopened Inquiry have examined thoroughly the background to the three documents which came to light some considerable time after the initial investigation was completed and my first Report was published. The Inquiry has determined that in some instances other records which might have helped the Inspectors are no longer available or that no records were made in the first place.

This does mean there must be an element of speculation in some areas which were considered, but even so I concur with their findings which are given below.

9.1 The reason for the absence of the two locking grub screws was a consequence of inadequate quality control standards.

9.2 Inadequate quality control standards were exercised by both Esso and the contractor they employed.

9.3 The workmanship of the contractor was not up to the required standard of the Classification Society, Lloyd's Register of Shipping.

9.4 The contractor failed to take into account the minimum requirements, such as in the API Standard, and general engineering principles with regard to the rotating element material specification, and Esso's quality control system did not enable detection and rectification.

9.5 There was a failure by the contractor and Esso to agree a comprehensive specification for the refurbishment work to the rotating elements. The production of such a specification would have avoided the possibility of any misunderstanding between Esso and the contractor as to the materials to be utilised, and whether the impellers were to be locked or unlocked prior to despatch to the ship.

9.6 It is considered that the finding of the Inspectors in the Chief Inspector's Report (published in January 1993) that the reason for the absence of the two locking grub screws was due to the failure to exercise adequate quality control procedures is correct. However, because of the doubt attached to the reason for the missing grub screws, inadequate quality controls should not have been laid at the door of the contractor alone. Therefore the finding in the Chief Inspector's Report that a

principal contributory factor of the accident was "a failure on the part of the contractor on this occasion to exercise acceptable quality control procedures during the refurbishment of the pump rotating element" failed to take into account the uncertainty as to the reason for the missing grub screws.

9.7 The reason for the origin of the vibration which led to excessive vibration and failure of pump components is uncertain. It is probable that the origin of the vibration was due to failure of the intermediate bush. However, the influence on vibration levels due to the looseness and the backing off of the 1st stage impeller locknuts cannot be discounted, although this could have less effect than that of wear in the intermediate bush.

10. DETERMINATION

10.1 Because of the uncertainty as to the immediate cause of the accident, Section 11.5 of the Chief Inspector's Report should be deleted. Section 11.5 states:

> "The development of the vibration originated due to the lower impeller, 1st stage, outer locknut becoming loose and backing off. This in turn led to the free movement of other internal components which culminated in excessive vibration."

10.2 Based on the findings of the re-opened Inquiry, it has been determined that the principal contributory factors stated in Sections 11.6, 11.7 and 11.8 of the Chief Inspector's Report, published in January 1993, shall be superseded by the following:

The principal contributory factors:

The development of excessive vibration within the pump is uncertain. However, in descending order of probability the principal contributory factors are considered to be either one or a combination of any of the following:

11.5 Wear occurred in the intermediate bush reducing shaft support so raising vibration levels, increasing radial forces and causing progressive deterioration of the neck bushes and slacking off of the top bearing support. Heavy contact of the impeller wear rings with the fixed seals caused the lower wear ring of the second stage impeller to dislodge. The leakage between stages which would now take place would produce excessive axial forces due to hydraulic imbalance. These axial forces would themselves cause loosening of the bearing pedestal screws and ultimate failure of the upper oil seal.

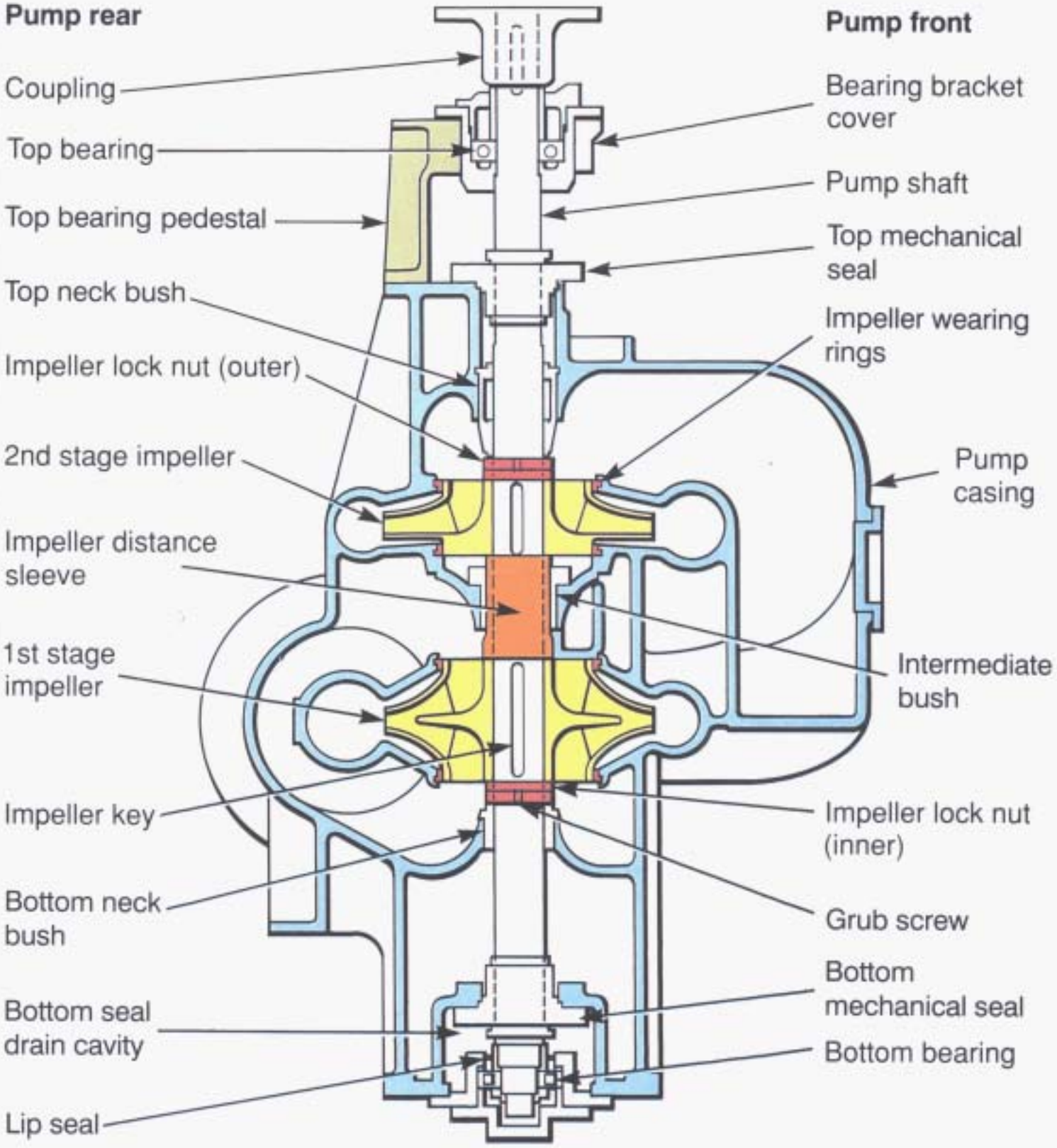
11.6 The looseness and backing off of the first stage impeller locknuts may have been due to a failure to ensure that the outer locknut was adequately secured against the inner locknut, either when the rotating element was refurbished by the contractor or subsequently when it was installed by the ship's staff in August 1989. The effectiveness of the locking arrangement would have been diminished because of the absence of two locking grub screws which secured the outer locknut to the inner locknut. No evidence was found to show why these were missing. It therefore seems that:

- they were not fitted, or
- they vibrated loose and fell out, or
- they were of an incorrect material and corroded away.

11.7 Failure to ensure the effectiveness of the locking arrangement for the first stage impeller was a consequence of inadequate quality control procedures, either during the refurbishment process or subsequently during installation into the No 4 cargo pump casing.

11.8 Renewal of both the top and bottom bearings in February 1991 by the ship's staff resulted in the omission of certain parts and the failure to refit integral parts of the assembly; this indicates that the engineering standards practised were below an acceptable level.

FIGURE



CARGO PUMP

Printed in the United Kindom for HMSO
Dd 302457 C4 3/96 9385 4006