CRANKCASE EXPLOSION

CASUALTY INVESTIGATION

BRITISH VALOUR - OFFSHORE BERMUDA

23.03hrs (GMT) 18 MARCH 2001

INDEX

SUMMARY

Whilst en route between her loading port of Sture (Norway) and her discharge port of Freeport (Texas) and when the vessel was some 80 nautical miles South East of Bermuda, the Isle of Man registered ship British Valour suffered a crankcase explosion creating an oil mist external to the main engine, which ignited.

There were no personnel injuries although physical damage and heat damage in the engineroom was significant. The vessel's main engine was also disabled.

Ships staff conducted crankcase and scavenge space inspections. They found no obvious hot spots in the crankcase that could be expected to have initiated the explosion, there were however cracks and oil found on the crowns of no 1 and 6 pistons.

Upon dismantling, the crack on no. 1 piston was found to be a hole through to the piston cooling oil space. This allowed direct communication between the combustion space and crankcase through cooling oil passages and considered to be the heat source that initiated the explosion.

The reason for the crown failure was abnormal wear and a reduction in material strength due to erosion from fuel impingement.

The reason for the external oil mist ignition was failure of the flame arrestor to function as designed/anticipated.

Following repairs to the engine and safety and control systems, the vessel proceeded under her own power to her nominated discharge port, completed cargo and subsequently travelled to dry dock in Portugal for permanent repairs and repainting.

1.0 NARRATIVE

1.1 The vessel has a length of 343.71m overall, beam of 56.40m and depth of 30.40m, accommodation is situated aft, above and around the engineroom casing. Decks are identified by their distance above the baseline in the engineroom and by letter in the accommodation, ascending from the main deck and finishing with the navigating bridge.

1.2 The main engine is a B&W 8 UEC 75 LLII built under licence by Mitsubishi Heavy Industries in Japan, it has a bore of 750mm, stroke of 2800mm and develops 23,535 kW at 84rpm. Cylinders are numbered by the normal marine method of the free end being unit number one counting up towards the drive end, it rotates anticlockwise when looking on the free end. The main engine has a crankcase oil mist monitoring system manufactured by QMI which links into a main engine slowdown function if the measured oil mist exceeds a pre-set level.

1.3 A fixed CO_2 system protects the engineroom and pumproom in addition to manual dampers and fan remote stops. The control room is located within the engineroom and has means of access not normally requiring passage though the machinery space itself.

Common factors arising from witness declarations made by crew members and from general conversation during the investigation follow.

1.4 The vessel was full away on passage carrying a cargo (272,386 tonnes) of Oseberg crude oil. Normal navigational watches were being maintained and the engineroom was operating in an unmanned condition.

1.5 Just after 18.00hrs local time, two detonations were heard in the engineroom followed by activation of the general alarm, numerous zones of the engineroom fire detection system were in an alarm condition, the system then failed.

1.6 Crew proceeded to muster at their fire stations, the second and fourth engineers, went to their station in the control room and were able to advise the master of the presence of thick smoke in the engineroom (and control room through a damaged window) but with a low level of associated heat. Suspicion of a crankcase explosion was indicated to the master and the second engineer also voiced his concerns that all personnel be accounted for, which muster reports later did.

1.7 The second and fourth engineers were instructed by the master, not to proceed into the engineroom but to wait in the control room if the atmosphere allowed it. The ventilation fans had tripped and the main engine which had gone into automatic slowdown was stopped from the bridge and allowed to run down to standstill as the vessel lost speed.

1.8 Fire parties arrived in the control room, by which time the diesel alternators were starting to give high exhaust temperature alarms through air starvation, caused by soot choked turbocharger air filters. Permission was given by the chief engineer (who had by now taken command in the engineroom), for the third engineer to change the filters in order to maintain the vessels power and lighting for firefighting purposes.

1.9 Fire parties and the second engineer made a search of the engineroom to confirm there was no longer a fire. Caution had to be employed since it was observed that many of the deck plates were no longer in their correct position and light fittings had been damaged reducing overall illumination levels.

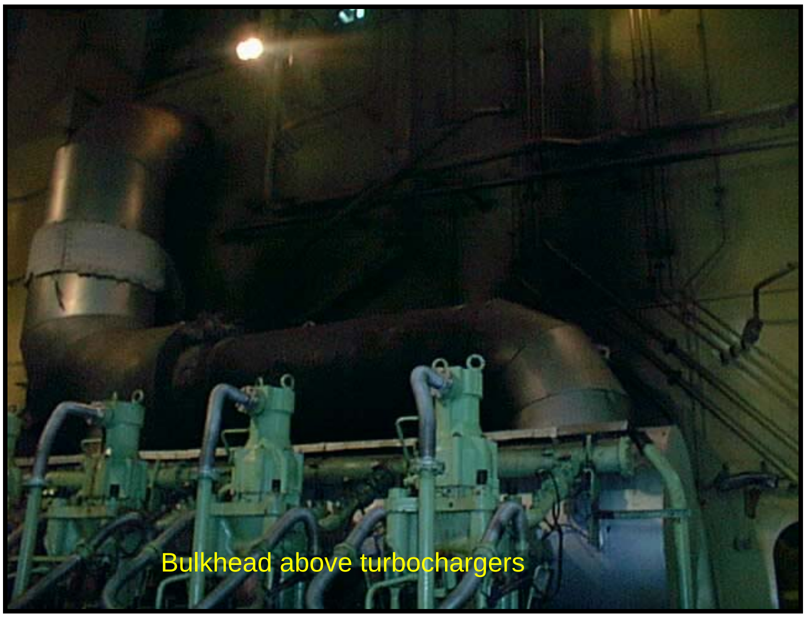
1.10 The second engineer confirmed to the chief engineer there were no fires still burning in the engineroom and the Chief gave the order to re-start the exhaust ventilation fans to clear the smoke. Fan overload protection required to be re-set and on start up, No.3 exhaust fan made a lot of noise. It was immediately stopped again, No.4 exhaust fan continued to extract smoke.

1.11 A fire watch was maintained and the full extent of the incident was subsequently assessed by the master and chief engineer which included personnel and vessel safety/integrity issues.

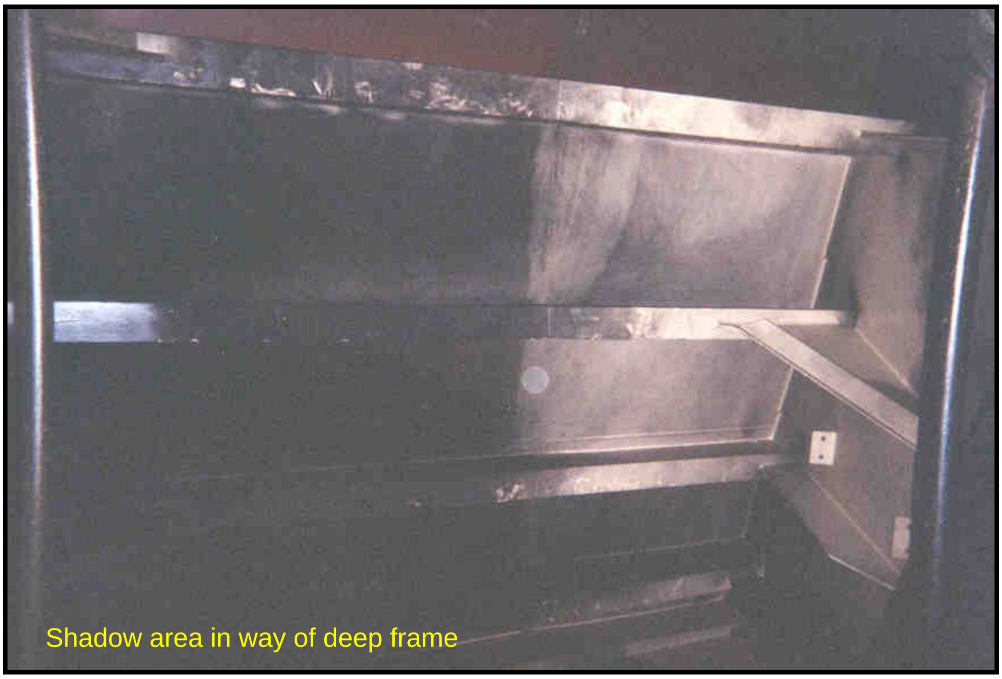
2.0 INVESTIGATION FINDINGS

2.1 The engineroom was smoke/soot blackened on the starboard side, deck plates around the cylinder head area were distorted and dislodged from their original location, thermoplastic diffusers on fluorescent light fittings had melted sufficiently to flow easily under gravity and their own weight, physical contact damage was apparent in a number of locations.


Bottom plates stbd. side


Bulkhead above turbochargers

2.2 Soot was deposited over the entire side of the engine, on walkways, pipework, lagging and fittings facing the crankcase relief valves. Shadow areas (where soot was lightly deposited) existed on the ships side in way of deep frames and web frames in line of sight from the relief valves and where pipes intervened or the walkways turned back on themselves



2.3 On the port side of the engineroom (the opposite side to the relief doors) at floor plate level, some of the fluorescent light diffusers had deformed with heat but not to the degree suffered on the starboard side. Two of the crankcase inspection doors had been buckled slightly.

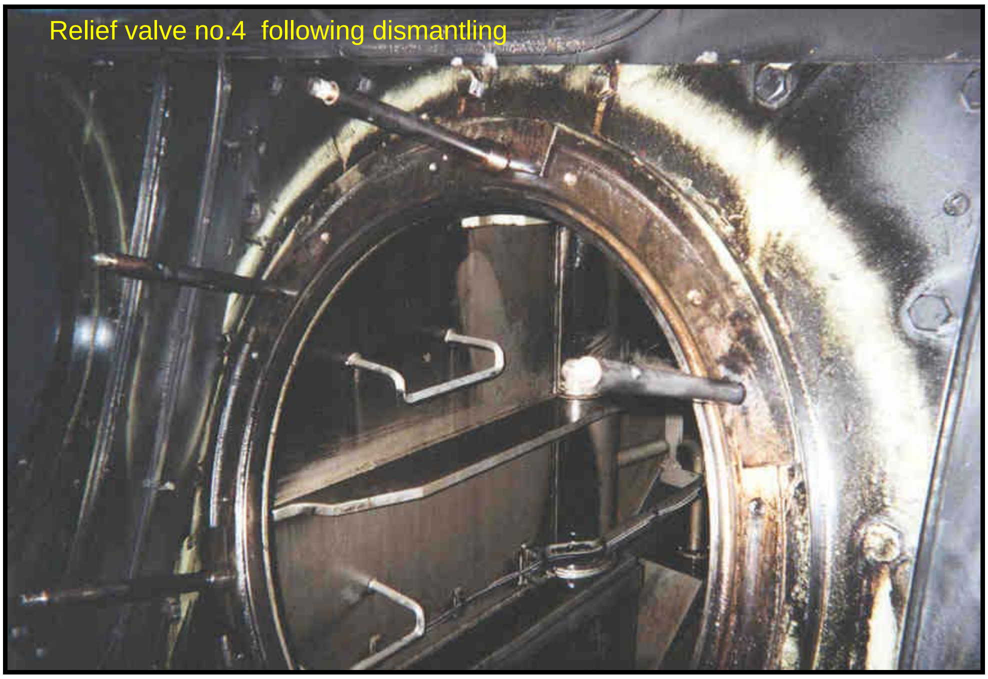
2.4 Ships staff performed a crankcase inspection, bearings and running surfaces were checked but nothing immediately obvious was discovered, a very small amount of ‘squeezed’ bearing white metal was found on top of the oil sump near no.8 main bearing, but not enough to raise suspicion of a hot spot. Engine monitoring systems indicated no bearing high temperature alarms initiated before or after the event and discoloration on internal surfaces was negligible to none existent.

2.5 External signs were that all eight crankcase explosion relief valves (located on the starboard side of the engine) had lifted, nos. 2, 5 and 6 were found to have incorrectly seated after closing under pressure from their return springs. Additionally two of the sealing rubber ‘o’ rings had become dislodged from their seats.

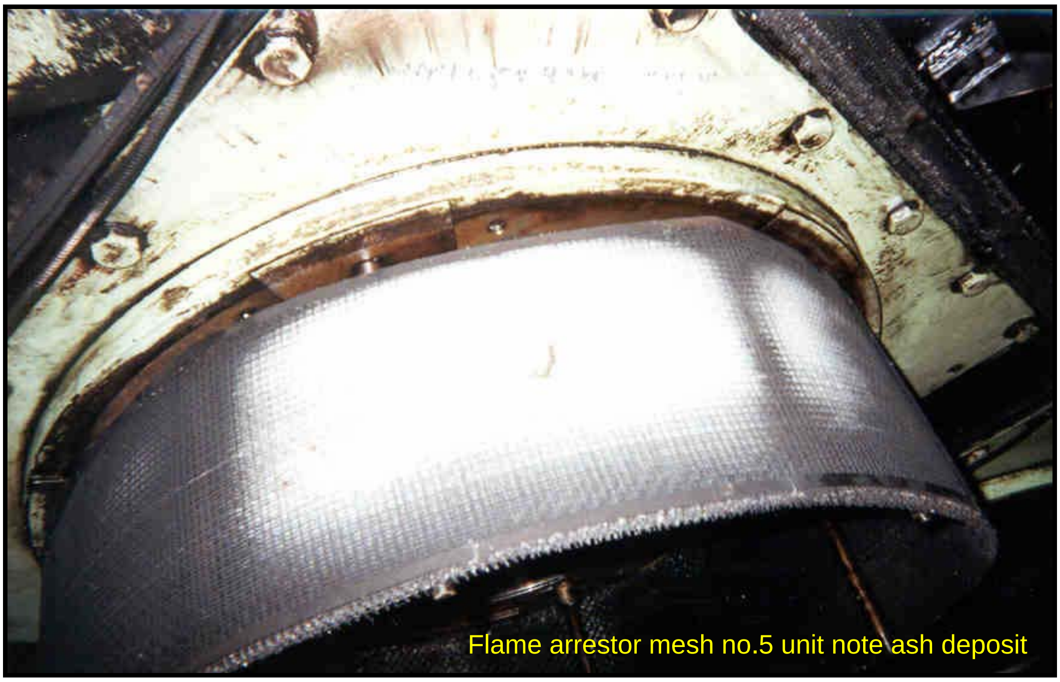
Crankcase relief valves 2 & 3, sooty above, clear below

2.6 Paintwork immediately adjacent to the relief door periphery was relatively clean but approx. 40mm away it was covered in oily soot and approx. 100mm away, it was covered in dry soot. This soot was noted to be in the region “protected by the diffuser shield” (above the doors) whilst in the area below the diffuser shield (where gases are directed) the paintwork was observed to be less affected.


Relief valve no.4 showing clear area and diffuser plate


Relief valve no.4 following dismantling

2.7 Flame arrestor mesh fitted to the relief valves Nos. 2,4,5,6 was seen to be very dry and had a whitish ash on the side exposed to the crankcase during lifting/operation, of these, no.5 exhibited the most obvious signs of high temperature

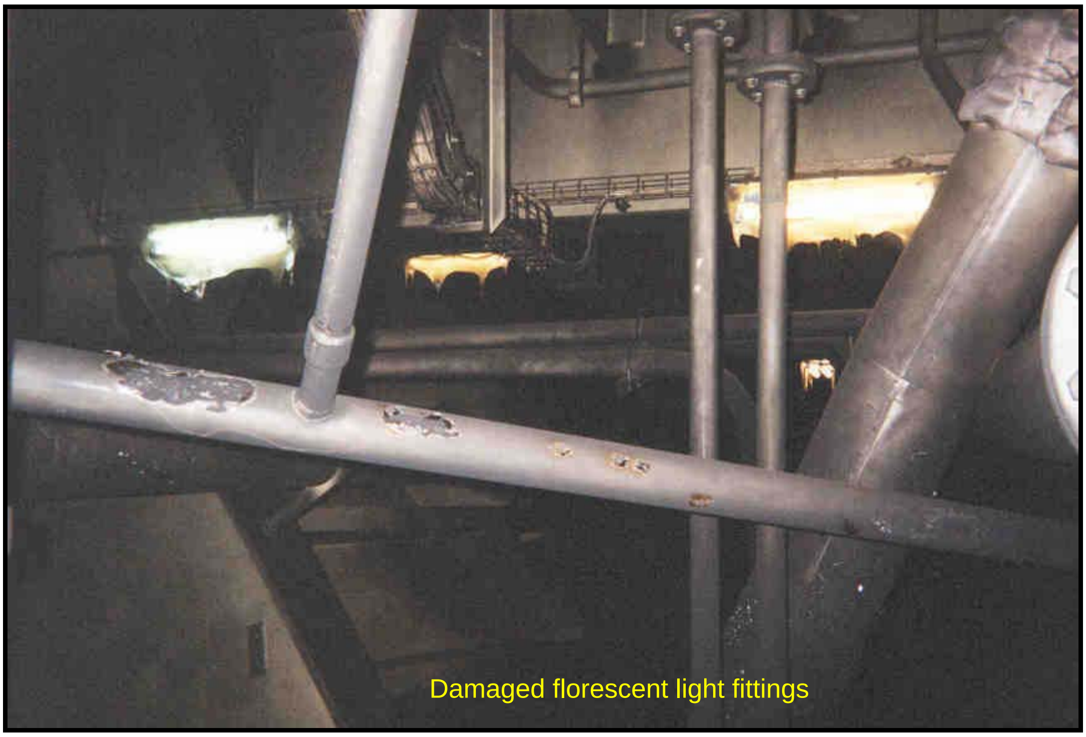

Flame arrestor mesh no.5 unit note ash deposit


Internal view of flame mesh

2.8 Fixed steel deck plating at cylinder head level was dislodged, distorted or lifted, particularly in way of the turbochargers and air coolers where the clear space around the engine is restricted, many securing screws had been sheared or stripped of their threads.

2.9 Significant soot and smoke damage on the starboard ships side, plates, walkways, pipes and ducts was apparent.

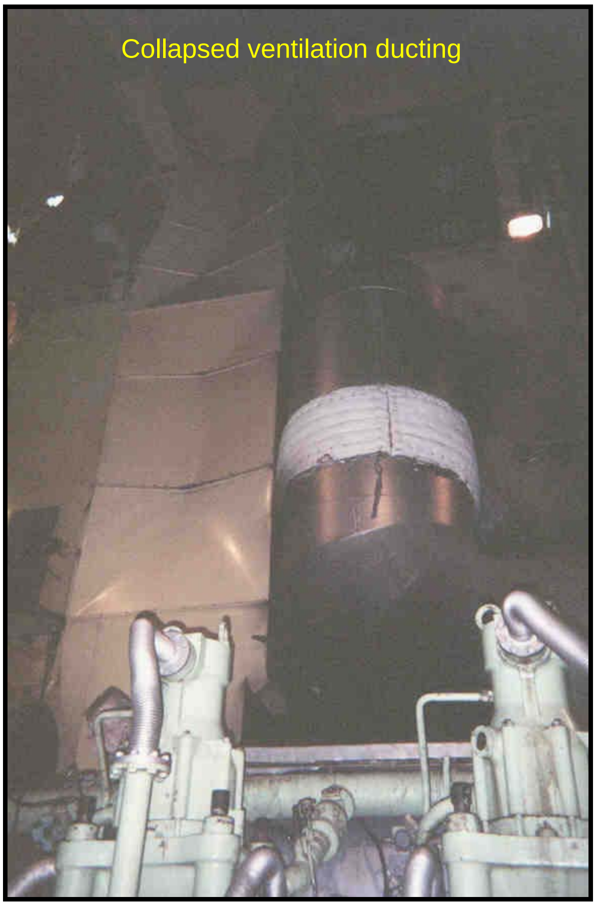
2.10 A number of fluorescent light diffusers had largely melted away, the area from the bottom plates level right up to cylinder head level on the starboard side of the engineroom was affected

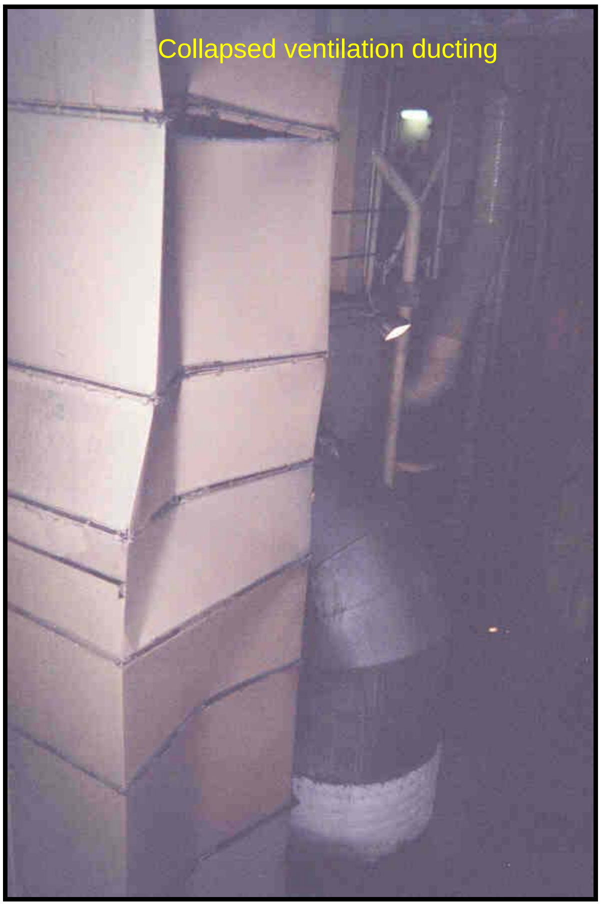

Damaged florescent light fittings

2.11 Paint blistering/lifting damage was evident on thin plate ducting and pipework in the area of the starboard side of the engine and alarm monitoring connection boxes outboard of the turbochargers were damaged by contact and/or melted by excessive heat.

2.12 The control room door wire reinforced glass was blown through into the control room where shards of glass became embedded in adjacent woodwork. The workshop door was buckled and de-laminated. The spare gear store door was buckled through it’s frame and blown off its hinges.

2.13 Engineroom ventilation ducting was significantly deformed, dislodged or collapsed and acoustic insulation was found littered over the after deck .

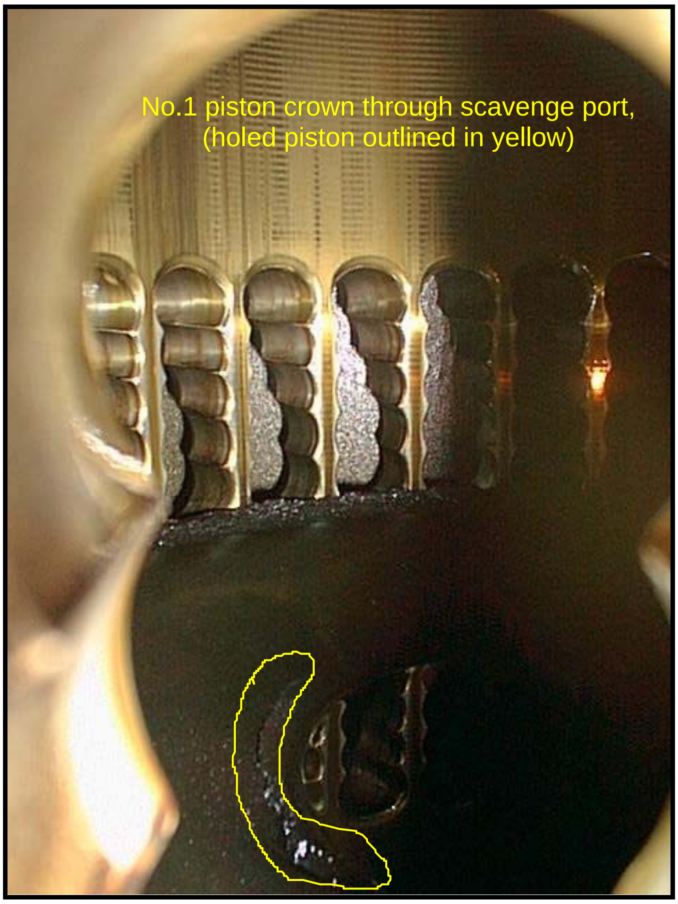


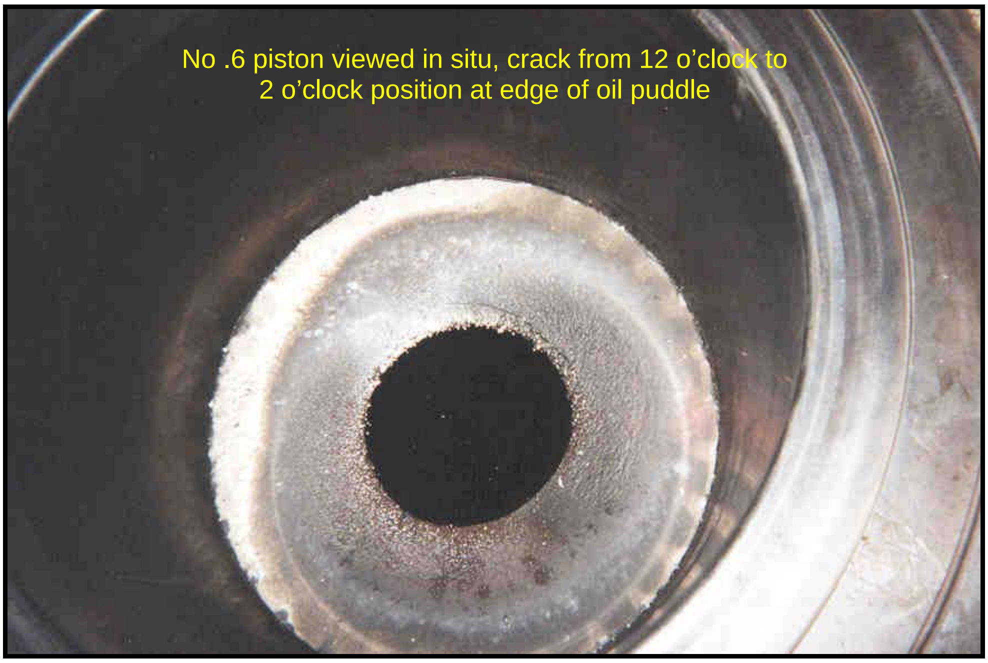


2.14 During the investigation, a further crankcase inspection failed to find evidence of a hot spot in the crankcase sufficient to initiate an explosion.

2.15 The shaft earthing device was found clean and in an operational condition, brushes were free to move within their holders.

2.16 No.1 Piston crown was found to be cracked and holed which penetrated to the oil cooling space thereby allowing direct communication of the combustion space with the crankcase via the cooling oil passages and would indicate a probable initiation site.





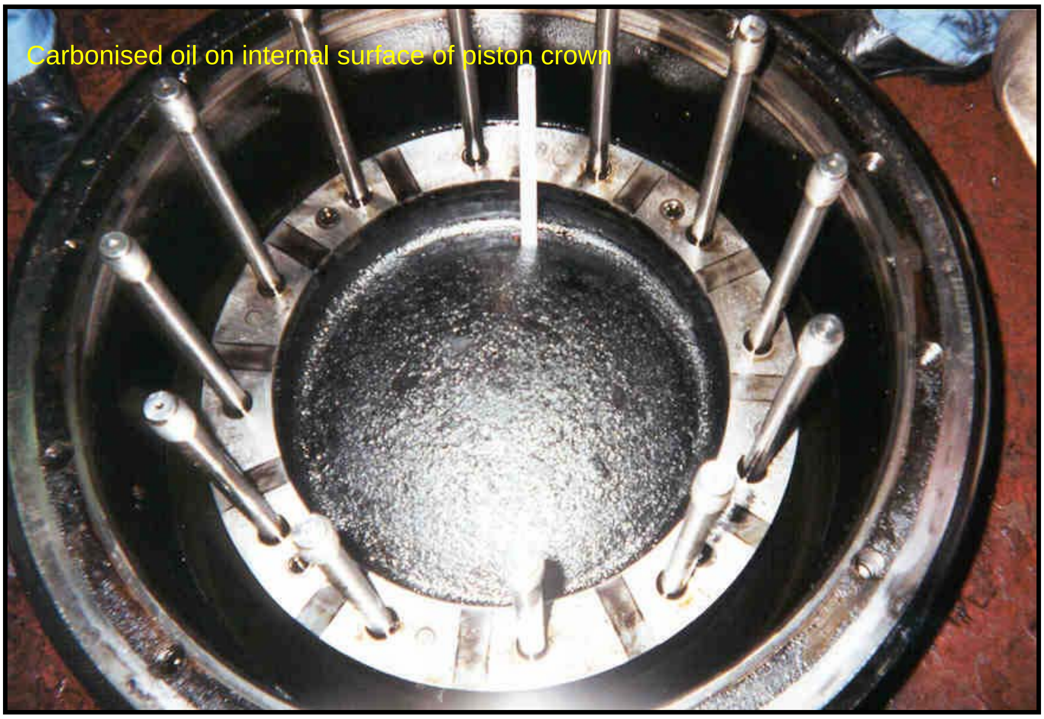
Holed no.1 piston crown, pen included for scale

Hole penetrating to cooling oil space

2.17 The alarm history indicates a period of only 5 seconds between the first abnormality indication - "M.E governor minor fault" and "outlet No. 1 cylinder temperature high alarm" activation. During this period a fire alarm, fire detection system failure and crankcase oil mist alarm also activated, M.E automatic slowdown occurred just 19 seconds after the first alarm.

2.18 The scavenge space was found to be in a normal operating condition and showed no signs of internal fires.

2.19 Following dismantling, carbonised oil sludge was found to be coating the interior of the piston crowns.



2.20 Fuel valves removed from the engine following the incident were found in some instances to have a static opening pressure[1] 20-30 bar lower than design (314 bar), one had blocked atomiser holes and carbon deposits were evident on the tips of others, spares tested before replacement were also found to be wrongly adjusted so a full set of spares was overhauled for complete change-out on the engine. Piston crowns exhibited “elephant skin” surface breakdown, an indicator of fuel impingement.

2.21 This particular engine has no means of manually taking a closed power indicator card as it is not possible to input crankshaft/timing cam position relative to the piston (and thus developed pressure relative to timing). Pressure transducers together with crankshaft position transducers do this electronically where the results are fed into the centralised computer system as a means of performance monitoring and comparison with design parameters.

2.22 This particular engine has no local exhaust temperature thermometers, reliance having to be placed on thermocouples fitted to the engine or an emitted infra red electronic thermometer, to obtain these readings.

1) Static opening pressure - when engine revolutions are over a threshold limit for more than 30s, a solenoid valve changes state to allow L.P. control air to act on an L.P./H.P. pneumatic switch allowing H.P. air to act on a piston inside the fuel valve and raise the injection pressure for better atomisation, static opening pressure is the value obtained without this air signal present and to which the fuel valves are set following maintenance (314bar).

2.23 From historical records, it was determined that the engine performance monitoring system was not fully functional prior to the incident, this may have provided useful diagnostic information to developing problems with the combustion process.

2.24 During the investigation, calibrations showed No.1 and No.6 piston crowns to be out of tolerance for further use, whereas in dry dock less than eight months previously, calibrations had shown they were within wear tolerance for a further service period of 8,000 -10,000 running hours (approximately 11 - 14 months continuous service).

No.1 exhaust valve was also measured with the maximum allowed wear (12mm) and was recommended for exchange and reconditioning.

3.0 ANALYSIS AND COMMENTS

3.1 The findings are consistent with primary and secondary crankcase explosions which resulted in a flash fire external to the engine. The path of this was outwards and upwards from the crankcase overpressure relief valves which is in direct contradiction to normal design parameters (and indeed the installation on board the engine) which is supposed to deflect down and away from the engine.

3.2 The rapid expansion of gases and resulting temperature rise of the flash fire created considerable subsequent damage.

3.3 The crankcase relief valves did not appear to perform as designed to prevent a secondary explosion. The doors did however relieve excess pressure from the crankcase preventing further damage to the engine itself. It was observed that three valves had not re-seated correctly and that o-ring seals had been displaced, this would allow air back into the crankcase to give the conditions needed for a secondary explosion.

3.4 The flame arrestors failed to prevent expelled oily mist ignition and therefore did not perform as designed.

3.5 The crankcase oil mist monitor was found inoperable, the attending service engineer advised this to be a result of overpressure caused by the explosion(s), a crankcase high mist alarm occurred in the five second period between the first abnormality indication - ME governor minor fault and the ME cyl no.1 outlet high temp and would tend to support the theory that the damage occurred as a result of the explosion. Due to the short time-span between first indication and explosion, it would be doubtful if the monitor could have slowed the engine quickly enough to prevent an explosion.

3.6 The shaft earthing device was found to be clean, with freely moving brushes and therefore should be effective in operation to reduce electric potential build-up on the propeller shaft and possible static discharge inside the crankcase.

3.7 Modifications to the relief valve and flame arresting arrangements fitted, have been made by the licensed engine makers for new engines of this type since the incident.

Service note MSI-0156E (dated 11 April 2001) recommends the removal of the diffusing cover and service note MSI-0165E (dated 15 Aug 2001) recommends the flame arrestors be changed to a redesigned type with greater strength and efficiency, these service notes have been circulated recommending a change of fittings to the modified designs.

3.8 Legislation exists that requires ‘every internal combustion engine with a bore which is greater than 200mm or has a crankcase volume greater than $0.6m^3$ to be provided with crankcase explosion relief valves, of a suitable type, which has sufficient area to relieve abnormal pressure in the crankcase and be so arranged or provided with means to ensure that any discharge from them is so directed as to prevent the possibility of injury to personnel’, no regulatory requirement exists for testing of engine crankcase explosion relief valves once fitted to the engine, other than the actual pressure at which they physically open.

3.9 Engine performance monitoring systems form an important part of the safety of the engine, should failure occur, priority should be given to determine the reason and restore correct function with minimum delay, trends may provide advance warning of underlying problems.

Good watch-keeping practice monitors various systems by the use of all an individuals senses, unfortunately the lack of local reading equipment would hinder this process to some degree.

3.10 Five of the fuel valves tested following the incident were found to have failed to maintain their set pressures in service and lifted “too light”, this would in itself give rise to - poor atomisation and combustion, timing problems, power balance and temperature variations.

3.11 During engine trials following permanent repairs and at owners request, investigation by Lloyds Register Technical Investigation Department determined that the HP fuel pump delivery pressures were 100 -150 bars in excess of design (700bar). This was sufficiently high such that reflected pressure pulses (a normal part of the injection process) were still sufficiently great in the fuel lines to again lift the needle valves and cause secondary injection into the cylinders (at approximately top dead centre) before the spill valves opened to relieve the oil pressure.

This in turn led to unburned fuel deposition on the piston crown and exhaust valve flame face, both areas of which were measured as showing abnormal wear. Fuel pump overhaul was undertaken at dry-dock in May 2000 some 10 months prior to the incident although the dry-dock reports contain limited information in this respect. Fuel pumps were subsequently adjusted following repairs to lower this high delivery pressure for service.2.26

3.12 In 1999, a student at University College London - conducted research into the prevention and containment of crankcase explosions in conjunction with Lloyds Register to determine if “the rules” devised in the 1960’s were still applicable to modern engines with their higher powers and greater sizes since there have been a recorded increase in the frequency of crankcase explosions occurring since 1998. The findings however remain confidential and could not made available to the author.

3.13 Research carried out by MAN B&W (the original makers) in 1998 into crankcase relief valve design, determined that by diverting the gas path, the overall effectiveness of the flame arrestor is diminished. They also discovered during their own casualty investigations (since 1995), where fire followed an explosion, the flame arrestors' function had in many cases been spoiled by a local deformation or assembly defect.

As a result, a recommendation was made by them that none of their engines produced under license after 1998 be fitted with any form of diffusion shielding and that arrestors should be regularly checked for damage.

A submission to the International Association of Class Societies with the draft specification of their design/findings was made however it would appear that to date this has not been adopted. The makers should be thanked for their input which has proved valuable in making one of the recommendations of this report, they are still researching more effective ways of reducing the severity of crankcase explosions.

3.14 Owners/operators have gone to extensive lengths, to try and determine the underlying cause of the incident. The speed with which repairs and investigations were put in hand is encouraging. They have been very co-operative throughout the investigation and forthcoming with all requested information with the exception of the final Lloyds Register Technical Investigation Department report which the author understands was for legal reasons only and has been assured will be made available when permissible.

4.0 CONCLUSIONS

4.1 The failure of no.1 unit, piston crown, allowed direct communication of the combustion chamber with the crankcase via the piston cooling oil passages. This allowed hot combustion gases to create and ignite a flammable oily mist mixture from the oil droplets normally present in the crankcase, causing a primary crankcase explosion.

The crankcase explosion relief valves operated to relieve the pressure inside the crankcase but failed to re-seat properly, thus allowing air back inside the engine to give conditions suitable for a second explosion to take place, the source would give the possibility for ignition at every firing cycle until fuel was removed from the injection system.

4.2 The flame arresting system failed to be effective in preventing ignition of the expelled oil mist.

Tests previously conducted by the original engine manufacturers have concluded that diffusers used to direct excess pressure away from crankcase relief valves <u>actually had a negative effect</u> on the flame arresting system, to the extent they have recommended that these diffusers be removed from existing engines and that any engine made under licence after 1998 has nothing fitted other than the main cover directly in front of the valve.

Since the incident, the makers of this particular engine have proposed the removal of these diffusers as per B&W recommendations and have changed the design of the flame arresting system fitted to their engines made under licence. This supports the proposals made by B&W as being valid.

4.3 Unusually large piston crown wear had occurred since overhaul in dry-dock in October 2000, the evidence gained indicates fuel impingement from poor atomisation which caused localised overheating and cooling oil breakdown on the internal surfaces of the crown and in turn increased the high temperature erosion in the areas of failure, ultimately leading to the mechanical failure of no.1 and no.6 piston crowns.

Unfortunately this poor atomisation would not have come to light until the next scheduled inspection/service period, or sufficient variation existed between individual cylinder power indicator diagrams to alert engineering staff, or mechanical failure occurred.

5.0 RECOMMENDATIONS

5.1 As a result of the evidence discovered during the investigation, we would propose in the interests of safety to recommend that crankcase relief valve diffusion plates be removed due to the reduction in effectiveness of flame arresting systems caused by the concentration of expelled gases. It is proposed that this would be achieved by making a submission to IMO for consideration and discussion at DE 46 (2003).

5.2 It is further recommended that owners/managers take steps to ensure engine performance monitoring equipment is functioning reliably, especially if alternative means of monitoring are limited, deficient monitoring equipment should be rectified as a priority. Planned maintenance routines should include external visual inspection of flame arrestors since in many instances where fires have resulted from crankcase explosions, defective/damaged flame arrestors have been found.

5.3 We would recommend further research into modern large engine designs in an attempt to determine what has been the cause for the increased number of incidences of crankcase explosions since 1998 and try to determine if current “rules” are sufficient for modern engines. Available data produced by class societies, universities and engine makers should be analysed for common factors.

5.4 The licensed engine makers have brought about a design change both to the relief valve itself and the flame arrestor for this type of engine as a direct result of this casualty, they have circulated information in respect of this and they recommend that in the interests of safety, the modifications be undertaken. Whilst costs for this work will be included in new engine pricing, existing modifications would have to be carried out at a cost to the owners.

We would recommend, that in the interests of personnel safety and property protection, these recommendations be observed despite the costs.

ACKNOWLEDGEMENTS

The author would like to thank :-

MAN B&W diesel AS for making available research presentation material into the design and effectiveness of crankcase relief valves and flame arresting systems.

BP Shipping Limited for readily supplying historical records and information that they discovered in respect of this incident.