Annex A

Survey Report no. 091909

[redacted]
Naheweg 1
46286 Dorsten

For questions and payments, please quote the survey report no.

Zeppelin Baumaschinen GmbH
Hydraulikservice
Zeppelinstr. 2

28832 Achim

May 5, 2009

Survey Report
no. 091909

According to the commissioning by [redacted], company of Zeppelin Baumaschinen GmbH, on April 14, 2009, the cause which led to the destruction of a hydraulic motor shall be examined.

The following persons participated in the examination on site on April 16, 2009:

[redacted]

Inventory: Machine:

Hydraulic drive for a combined windlass and mooring winch:

Type: CSH 1907 – 8820 LW / W1

No.: 74162

Winch block:

Type: NG 32 AV 4567 OF

No.: 5755

Planetary gear:

Type: 05.20 10028

No.: 316

Hydraulic motor:

Type: A 6 VM 107 HD1 63 W020 VAB020 B

No.: 6275772

Technical data - hydraulic motor

Swallowing capacity	Vgmax	107 ccm
Swallowing capacity	Vgmin	0 ccm
Max. rotation speed at	Vgmax	3550 1/min
Max. rotation speed at	Vgmin	6300 1/min
Max. absorption capacity	L /min	380
Torque constant	Vgmax	1,70 Nm/bar
Max. torque	Vgmax	681 Nm
Filling capacity	Liter	1,5
Mass moment of inertia around drive axle	J	0,0127 kgm²
Mass	kg	47

Damage description:

The hydraulic motor presented to me for examination, A 6 VM 107 HD1, was completely destructed (see picture 1).

Housing – see picture 2
The cast housing is broken into several individual pieces.

Bearing – see picture 3
One taper roller bearing was completely destructed.

Drive shaft – see picture 4
The drive shaft is destructed in the area of piston entry.

Cylinder – see picture 5
The exterior housings of four cylinder bores have broken out.

Piston – see picture 6
Only three pistons were left.

Valve plate – see picture 7
Considering the circumstances, the valve plate was in a quite good condition.

Connecting plate with valve – see picture 8
The regulating screw of the flanged pressure relief valve had broken off.

The construction parts were not complete.

Examination of the hydraulic control:

Control of the main valve is effected by means of a reduced control pressure. This main valve controls the sense of rotation of the hydraulic motor (Lift, Stop, Lower). It is connected to two shock valves which eject the oil into the other oil motor pipe respectively in the case of overpressure. A controlled lock valve with connected pressure control valve is attached to the connecting plate of the oil motor. The lock valve prevents an unintended rotation of the hydraulic motor which might be caused by a leakage. The pressure control valve protects the construction parts from overpressure (280 bar) (see diagram).

Examination of the lock valve and the pressure control valve on the hydraulic motor:

The lock valve and the pressure control valve were taken apart and all construction parts were examined for possible damage. No damage was found in the lock valve. The pressure control valve was damaged in the area of the regulating screw (see picture 8). A recent rupture was clearly visible on the regulating screw.

A functional test at a hydraulic test stand showed the following result: The lock valve functioned normally. The pressure control valve could not hold the pressure of 280 bar.

Opinion:

The damage to the hydraulic motor presented to me for examination was caused by a too high rotation speed.
An extremely high rotation speed brought in through the drive shaft caused a reversal of the pressure ratio. These combined conditions of rotation speed, low-pressure and pressure, which could not be supported any more, led to a destruction of the hydraulic motor from the interior.

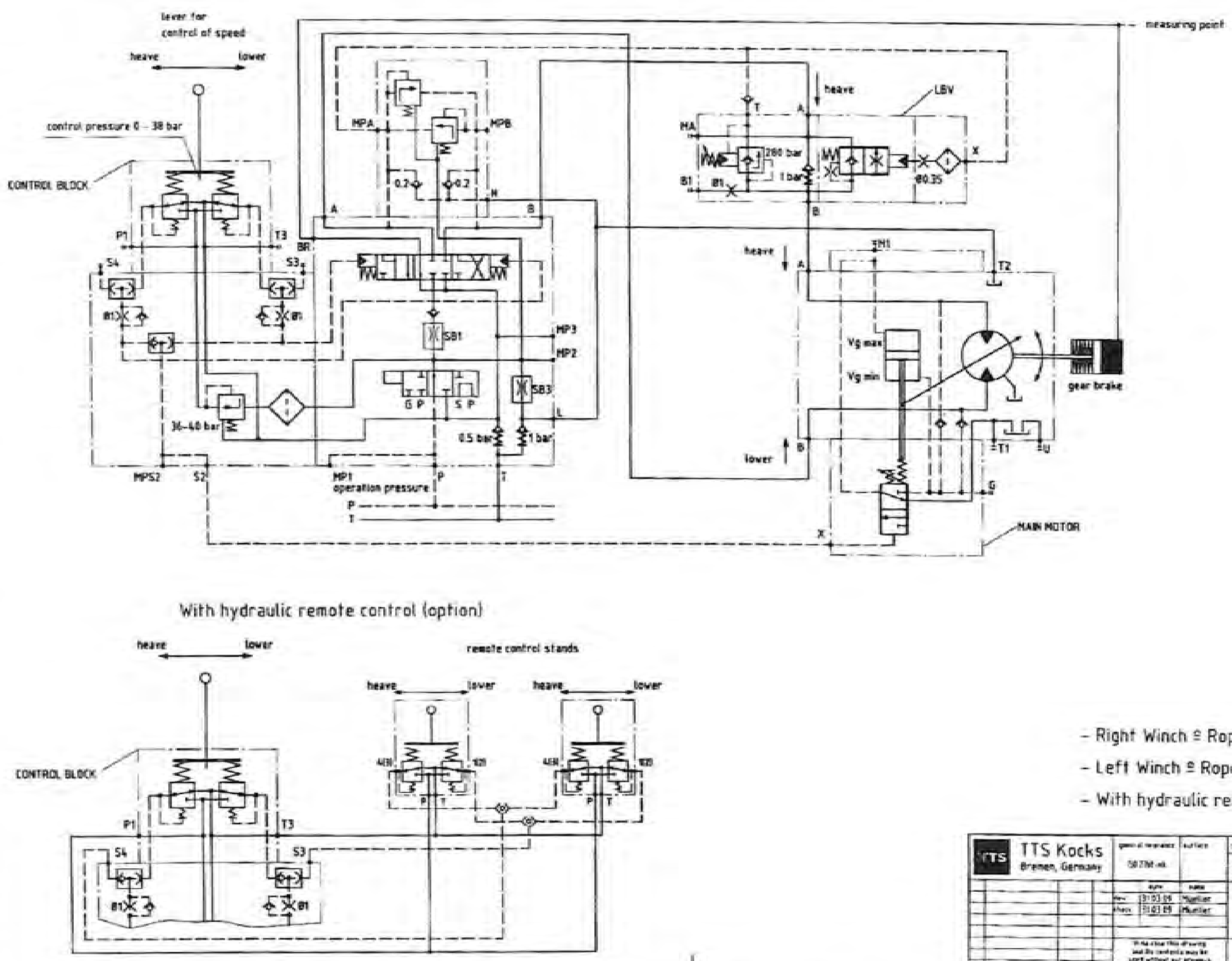
Explanation: The cylinder "lifts off" from the valve plate due to the combination of high rotation speed, low-pressure and pressure. Due to strong centrifugal forces and because the guidance of the cylinder is no longer guaranteed the cylinder bounces from one side to the other in the housing. Most likely, the first rupture in the housing was caused by a housing overpressure due to the cylinder "lift-off".

The machine I examined does not show any construction defects. The damage to the pressure control valve (regulating screw broken off) is regarded a subsequent damage.

This survey report was prepared objectively and impartially to the best of my knowledge. The presented documents and statements of all parties involved form the basis for the surveyor's findings and statements. A proprietary liability of the signatory is excluded. The circumstances of possession and ownership were not examined.

Surveyor

Naheweg 1, 46286 Dorsten
BUNDESVERBAND
Mitgl.-Nr. 2762/4280
FREIER SACHVERSTÄNDIGER e.V.
Sachverständiger für
Hydraulik / Fluidtechnik (BVFS e.V.)



- Right Winch ≙ Rope Lead "under line"
- Left Winch ≙ Rope Lead "above line"
- With hydraulic remote control (option)

TTS Kocks
Bremen, Germany

CSH-Hydraulik-Schaltplan
CSH-hydraulic diagram

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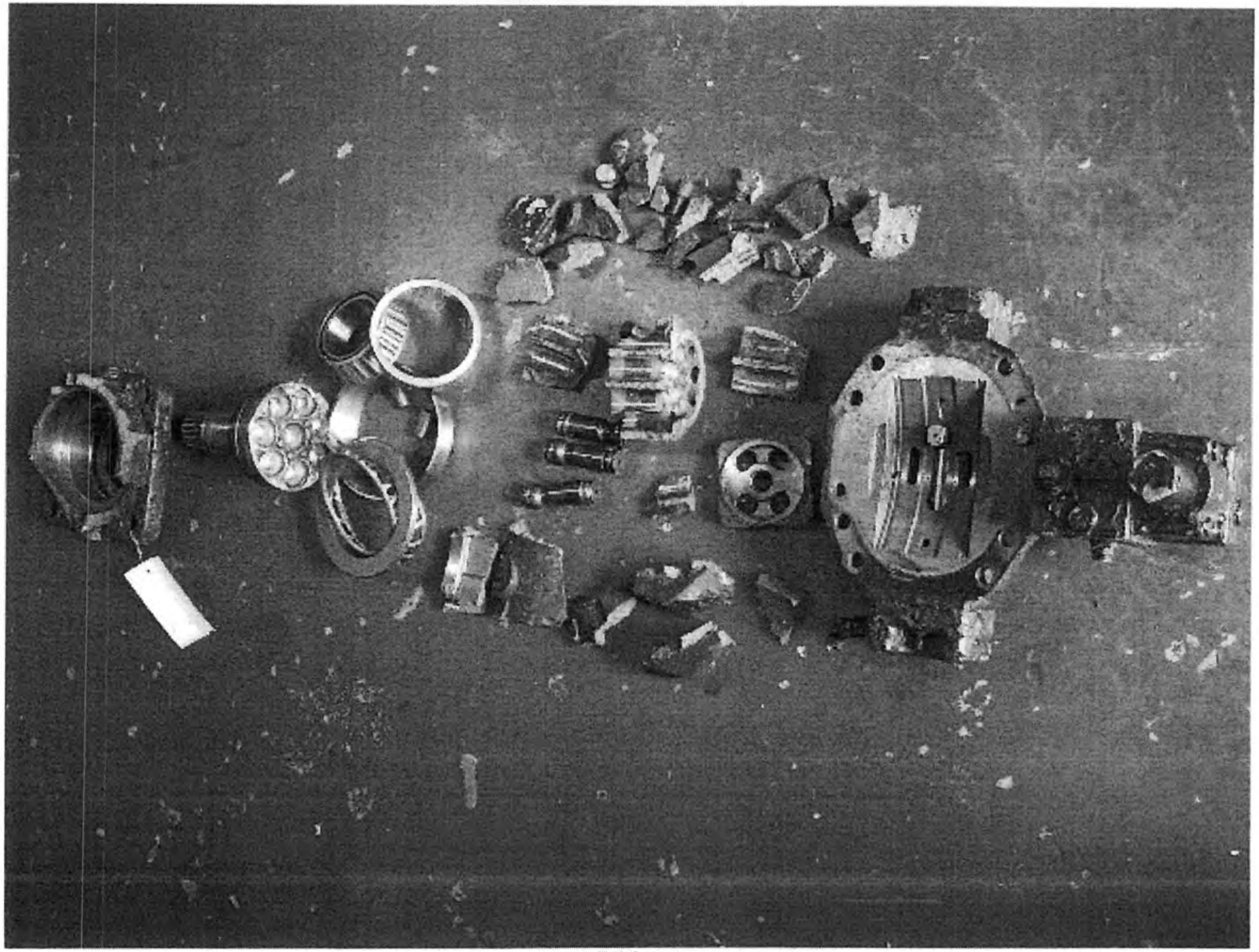

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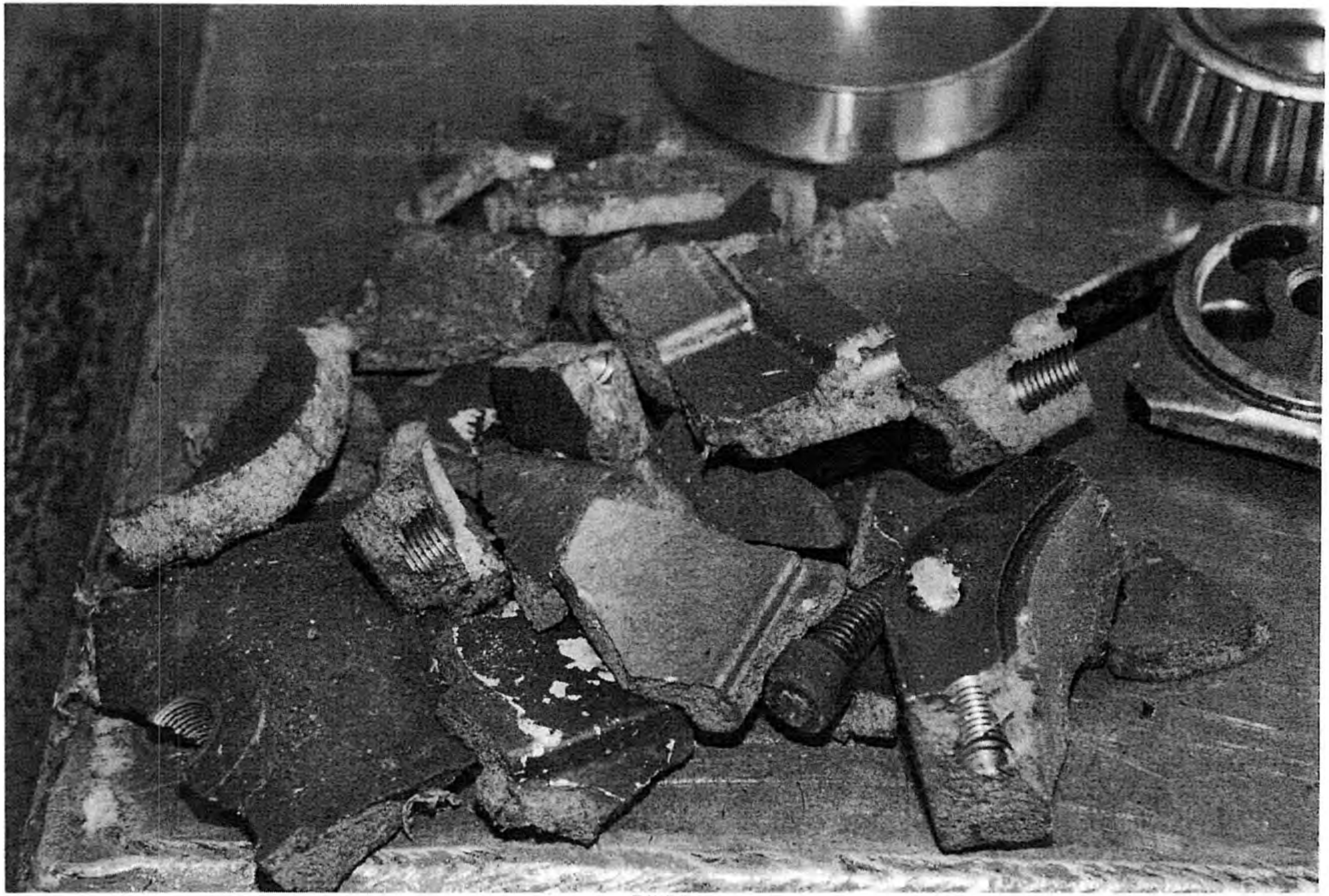

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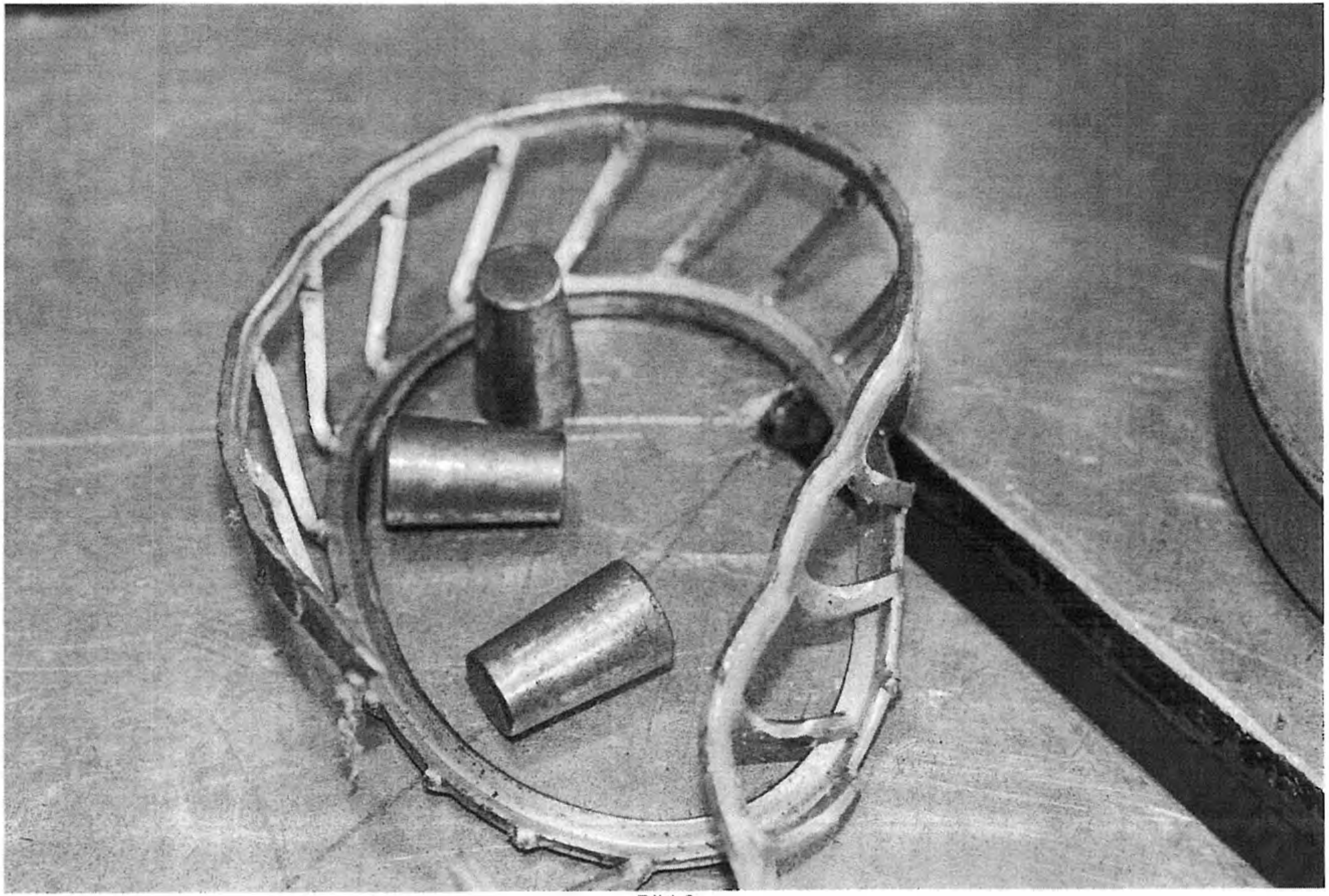

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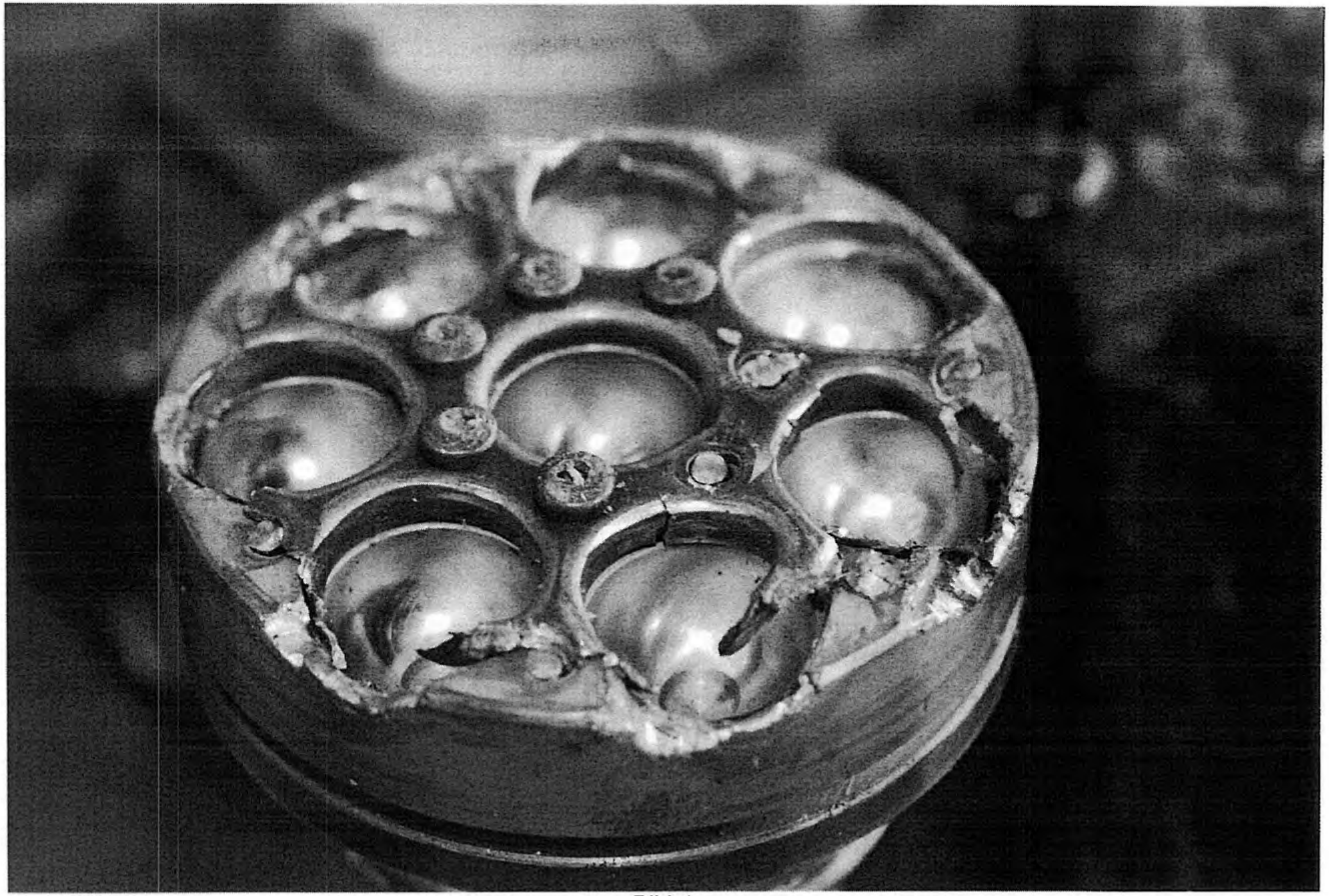

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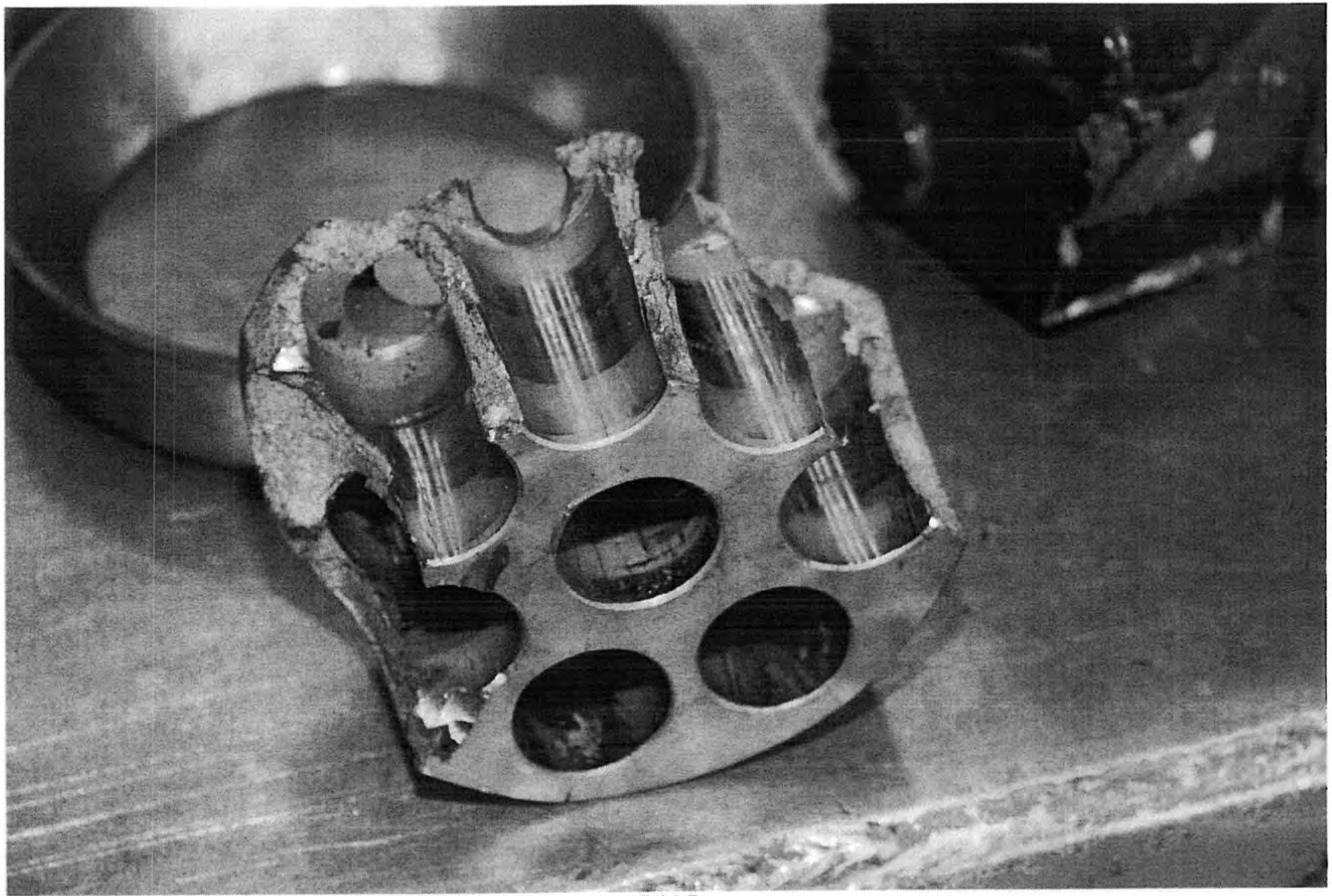

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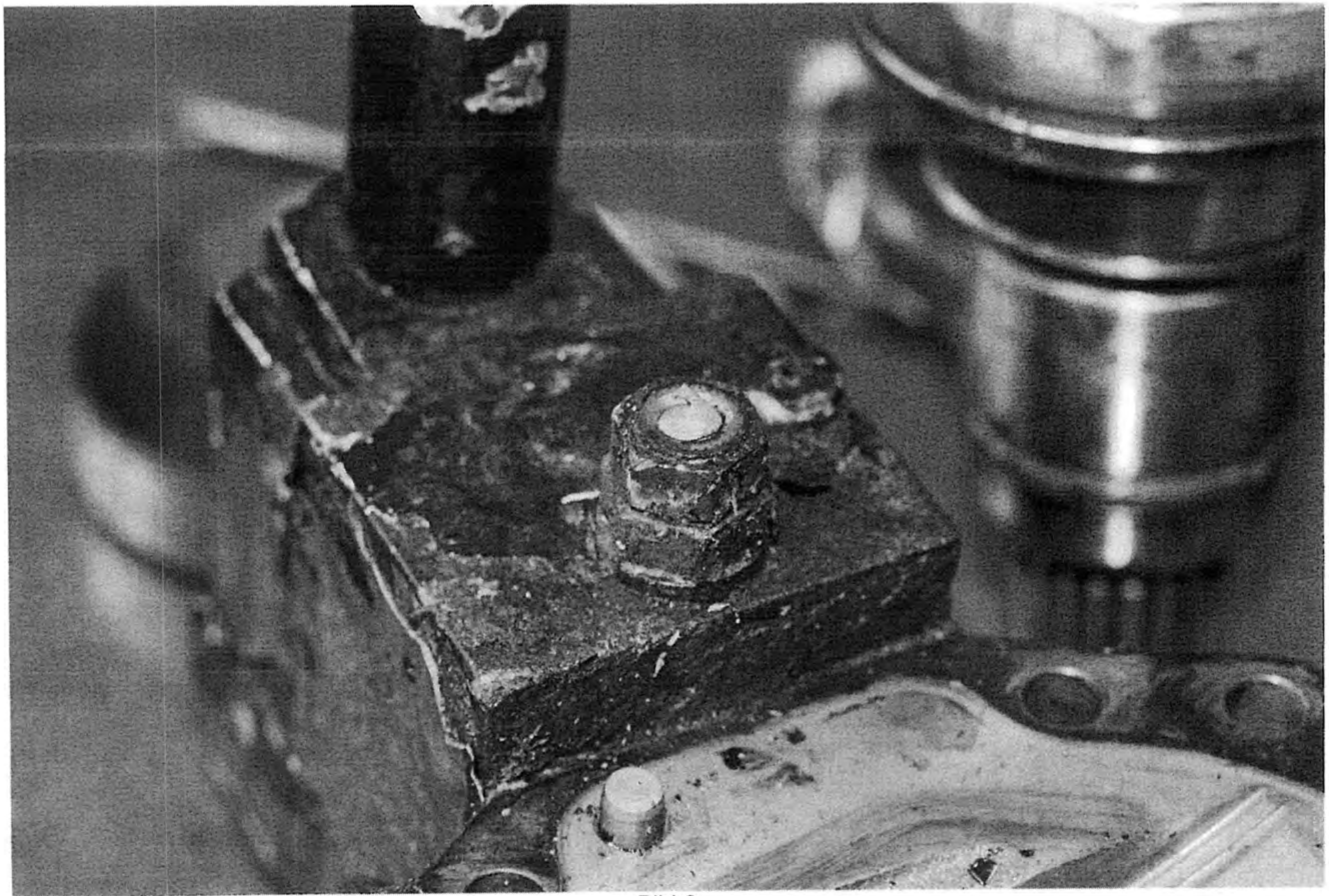

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The Test House Laboratory Report

THE TEST HOUSE (CAMBRIDGE) LTD. JOB AND REPORT REFERENCE: T90996

LABORATORY REPORT

EXAMINATION OF A FRACTURED AXIAL DISPLACEMENT HYDRAULIC MOTOR CYLINDER BLOCK AND ASSOCIATED ITEMS FROM THE ANCHOR WINDLASS OF *MT STELLAR VOYAGER*

For: Marine Accident Investigation Branch
Mountbatten House
Grosvenor Square
Southampton
SO15 2JU

This Report Comprises:
Title Page: 1
Text Pages: 1 to 14
Figure Sheets: 1 to 33
Appendices: 1 to 3

UKAS DISCLAIMER

This project includes tests and examinations, some of which were completed against UKAS accredited procedures. The scope of laboratory accreditation does not, however, include the analysis of test data or the offering of professional opinions.

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EXAMINATION OF A FRACTURED AXIAL DISPLACEMENT HYDRAULIC MOTOR CYLINDER BLOCK AND ASSOCIATED ITEMS FROM THE ANCHOR WINDLASS OF *MT STELLAR VOYAGER*

For: Marine Accident Investigation Branch
Mountbatten House
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THE TEST HOUSE (CAMBRIDGE) LTD REFERENCE: T90996
RECEIPT DATE: 1 JULY 2009
RECEIPT DATE (CLIENTS INSTRUCTION): 3 JULY 2009
REPORT DATE: 5 August 2009

1. INTRODUCTION AND BACKGROUND

Instructions to examine the fractured hydraulic cylinder block and associated items were received from Marine Accident Investigation Branch (MAIB).

The laboratory was provided with most of the fractured hydraulic motor cylinder block, parts of its fractured outer casing, the control lense, the output shaft, shaft roller bearings, planetary gear and a brake plate set.

The hydraulic motor was reported to be from the forward deck mounted anchor windlass of MT STELLAR VOYAGER, which had failed catastrophically during operation.

The parts were jointly inspected with the Inspector of Marine Accidents at the Test House (TTH) on the evening of Friday 3rd July 2009. During the examinations, TTH confirmed that it had the necessary laboratory facilities and staff resource to identify the critical fracture and damage mechanisms apparent in the failed parts provided. TTH, however, declared that it had no expertise in hydraulic engineering, and that any analysis or review of the motor design and hydraulic system would need to be commissioned from other suitable experts in this field.

Not withstanding the earlier qualification in respect of hydraulic engineering system and design considerations, objectives of the laboratory based examinations was firstly to identify the prevailing fracture types apparent in the parts provided. Then from the fractographic evidence, the investigation was to establish the type and direction of the critical damaging fracture stresses or forces. In this latter regard, the parts of interest were examined in the metallurgical laboratory of TTH as follows.

2. EXAMINATION OF THE HYDRAULIC MOTORS FRACTURED AND CLOSELY RELATED PARTS

2.1 Control Lense

2.1.1 Visual Inspection

The hydraulic motors control lense appeared free from visually apparent cracking and damage (Figures 1 and 2). The cylinder block facing side at the lense (Figure 2) exhibited some service rubbing wear, none of which, however, appeared significant or material in respect of the motors failure. No evidence of cracking was apparent in any of the four inlet and outlet ports.

2.2 Cylinder Block

2.2.1 Visual Inspection

The cylinder block had comprised seven equally spaced cylinder holes on a pitch circle diameter of approximately 70mm, and a single centre pin hole. The block had fractured into a number of pieces, of which four had been recovered for examination (Figures 3, 4 and 5). The piece or pieces not recovered for examination comprised the outer and inter wall parts of two adjacent cylinders (Figure 6).

The cylinder blocks control lense mating face exhibited evidence of light service rubbing wear and what appeared to be extensive post fracture mechanical impact type damage (Figure 5).

The fractures were consistently oriented in a generally longitudinal direction. They were located in both the ligaments between the cylinders and the blocks outer diameter, and at a number of inter cylinder ligament locations (Figures 7, 8, 9 and 10). The pieces exhibited evidence of multiple random post fracture impact marks, which were apparent at both the pieces fracture surfaces and the blocks outer diameter (Figures 11 and 12). No evidence of pre-casualty fatigue type cracking was apparent at any of the fracture surfaces.

Cylinder holes at the blocks output end exhibited evidence of extensive secondary radial cracks, which were apparent both at the blocks end (Figures 13, 14 and 15) and along individual cylinder walls (Figures 16 and 17). The cracking was noted to be at its most severe adjacent to the fracture sites, and appeared to have resulted from a post yield hoop stress acting upon the cylinder walls.

A number of the individual cylinder walls at the blocks fractured side exhibited evidence of piston mechanical indenting damage (Figures 18, 19 and 20), which appeared to be consistent with immediately pre-fracture yielding and deformation of the respective cylinder bores.

Though not apparently causative or related to the fracture process, a number of the cylinder bores exhibited evidence of incipient service wear or spalling type damage (Figure 21).

2.2.2 Detailed Fractographic Examination

Fractured pieces of the cylinder block were cleaned and examined in detail via both an optical stereo microscope and a Scanning Electron Microscope (SEM).

The cleaned fracture surfaces were seen to comprise what appeared to be a coincident series of fast brittle fractures (Figures 22, 23, 24, 25, 26 and 27), as exemplified by the widespread evidence of both brittle and chevron type fracture markings. Though the fracture surfaces were seen to exhibit numerous sites of post fracture impact type damage, the more detailed examination identified no evidence of pre-existing manufacturing defects or fatigue cracking.

The detailed SEM examination of the cylinder block fracture surfaces confirmed the fracture mode to be one of brittle transgranular cleavage (Figures 28, 29 and 30). Examination of the incipient cylinder wall damage (Figure 31) appeared less definitive (Figure 32) and could have resulted from either local micro cracking of the hard chromium plating, or more likely, sliding contact fatigue type surface spalling.

The detailed fractographic examination served to confirm that failure of the cylinder block had resulted from a single event brittle fracture process. The examination also served to confirm that the block had been free from significant manufacturing defects, and similarly that the block body exhibited no evidence of prior fatigue cracking.

2.2.3 Metallographic Examination

A single metallographic specimen was removed from the fracture sites in one of the detached pieces from the cylinder block (Figure 33). The specimen was Bakelite mounted and prepared for examination by conventional metallographic techniques, including final polishing to a 1 micron diamond finish. Examination of the prepared specimen was subsequently completed in the unetched condition and then again after etching in Nital.

The prepared specimens included three fracture sites (Figure 34), all of which exhibited similar features. The fracture sites were accompanied by extensive evidence of secondary radial cracking of the cylinder walls (Figures 35 and 36), and the fracture process appeared to be essentially brittle (Figure 37).

The cylinder bores were seen to have been hard chromium plated, and near surface regions of the steel block substrate exhibited very widespread evidence of sub grain strain induced twinning (Figure 38). Widespread evidence of cracking was also apparent in the chromium plating (Figure 38), which coupled with the near surface sub grain strain damage suggested that extensive hoop stress type yielding of the cylinder bores had occurred immediately prior to the terminal fracture.

The cylinder blocks microstructure clear of the immediate cylinder bore regions comprised pearlite colonies in a hyper-fine ferritic matrix, consistent with that of an engineering type steel that had entered service in a normalised type condition (Figure 39).

2.2.4 Vickers Hardness Test

A Vickers hardness test was completed on the metallographic specimen after documenting of salient microstructural features, the test results of which were as follows:

VPN 198, 193, 199 with an average of 197 (HV10)

From the hardness data obtained, an Ultimate Tensile Strength (UTS) of circa 637 N/mm² was obtained for the block steel via hardness to tensile strength conversion tables. The estimated tensile strength accorded well with the microstructural observations.

2.2.5 Tensile Test

A single longitudinal tensile test specimen was removed from the opposite side of the cylinder block to that of the fracture sites. The test was completed in accordance with BSEN 10002-1:2001, with a calculated stressing rate in the pre-yield elastic region of the test of 22.4 N/mm^2/second (BSEN10002-1:2001 specified stressing rate 6 to 60 N/mm^2/second) and a total test duration from commencement of loading to specimen fracture of over 3 minutes. The certified test results are reproduced in Appendix 1, and the associated Stress/Engineering Strain and Force/Displacement graphs are shown in Appendices 2 and 3 respectively.

The tensile test results were free from anomalies and in good agreement with what could have been predicted from the cylinder blocks prevailing microstructure and the hardness test results. Clearly, at tensile test type stressing rates the block steel was seen to exhibit a significant capacity for post yield ductile plastic deformation; as evidenced by the reported elongation, reduction of area and the two graphical Appendices. The block steel was also seen to exhibit a relatively low Yield to UTS ratio, which under most circumstances should also have facilitated significant capacity for conversion of post yield stressing into ductile plastic deformation.

The tensile test data clearly formed a sharp contrast with the blocks apparent service overload performance, which was characterised by brittle behavior and a near absence of post yield plastic deformation. The steels apparent absence of embrittlement, as demonstrated by the tensile test data, and the conflicting service fracture evidence, would collectively suggest that stressing rate was significant in the service failure. In turn, this suggested that the apparently brittle fracture of the cylinder block had resulted from a very rapid or near instantaneous rate of overloading, and that stressing rate rather than embrittlement of the steel was the most probable reason fore the apparently brittle service fracture.

2.3 Hydraulic Motor Pistons

Though the motor had comprised seven pistons and a central pin, only three pistons had been recovered and presented for laboratory examination (Figure 40).

2.3.1 Visual Inspection

The three pistons appeared free from primary or significant damage. One piston was seen to have lost one and a half of its two rings and some local associated post failure impact damage to the piston crown end was also apparent (Figure 41). The three pistons also exhibited signs of incipient service related surface wear or spalling damage (Figure 42, 43 and 44).

2.3.2 Detailed Fractographic Examination

One of the pistons was cleaned, to facilitate examination of the surface damage via the SEM.

The surface damage, which was apparent at both the pistons main body and between the two rings (Figures 45, 46, 47 and 48), was confirmed to have resulted from a common sliding contact fatigue spalling type mechanism. The detailed examination confirmed that the spalling resulted from very shallow sub-surface sliding contact fatigue cracks which had grown upwards to the surface and then coalesced to result in spalling. In no case had the cracks grown into the piston body, and the damage was not related to the casualty in any way. Rather, the damage was attributed to accumulated non-critical service wear.

2.4 Hydraulic Motor Output Shaft

The motors output shaft (Figure 49) comprised a series of eight pin pockets at one end and a spline type gear drive at its other end. The shaft also retained the inner raceway cone from the larger of the two output shaft rolling element type bearings.

2.4.1 Visual Inspection

The shafts pin pockets exhibited evidence of local seizure type damage and a number of end plate retaining cap-head studs had sheared off (Figure 50). The shafts gear drive end appeared generally free from service wear, and the spline damage apparent was thought to post date failure of the cylinder block (Figure 51). The local seizure damage at a number of the pin pockets was similarly consistent with post cylinder body failure type damage, and probably resulted from loss of oil lubrication that would have occurred during failure of the cylinder block.

In the absence of any primary failure damage the shaft was not examined further.

2.5 Large (First) Hydraulic Motor Output Shaft Bearing

The inner raceway cone of this bearing was retained on the motors output shaft (Figure 49). Its rolling surface was in good condition and totally free from both service and casualty related damage. Only three of the tapered rollers were recovered, all of which were free from significant service wear or damage (Figure 52). The outer raceway ring was similarly free from significant service wear and damage (Figure 53). The roller cage had suffered extensive deformation and tearing type damage (Figure 54) all of which was thought to represent consequential type of damage.

In the absence of any primary damage, parts of the bearing were not examined further.

2.6 Small (Second) Hydraulic Motor Output Shaft Bearing

This second rolling element bearing was received fully assembled (Figure 55). The bearing was found to turn freely and all the rolling elements were found to be in good, damage free, serviceable condition.

In the absence of any visually apparent damage the bearings parts were not examined further.

2.7 Hydraulic Motor Casing

The hydraulic motor casing had suffered a catastrophic fracture event and its remnants comprised the mounting flange end and twenty four broken pieces (Figures 56 and 57). All but one of the fractured pieces exhibited evidence of impact damage and the fracture surfaces exhibited the typical grey brittle appearance of a grey flake type cast iron (Figures 58 and 59).

2.7.1 Detailed Fractographic Examination

One fractured piece (Figure 58) was cleaned and examined via the SEM.

The material was confirmed to be of a grey flake graphite cast iron type and as one would expect, the fracture process was entirely brittle (Figure 60).

2.7.2 Metallographic Examination

A single metallographic specimen was removed from a piece of the fractured casing (Figure 58). The specimen was mounted, prepared and examined as described earlier in section 2.2.3 of this report.

The motor casing casting was confirmed to be of a grey flake graphite type cast iron, comprising graphite flakes in a largely pearlitic iron matrix (Figures 61 and 62).

The material type identified would have exhibited near zero fracture ductility, and well explains why it had suffered such a catastrophic multiple fragment consequential fracture.

2.8 Planetary Gear and Brake Assembly

The output from the hydraulic motor drove through a brake type assembly into a planetary gear set.

The brake plate pack and associated shafting appeared to have suffered very recent overheating type damage and one of the plates was seen to be physically broken (Figures 63 and 64). The planetary gears also appeared to have suffered some shaft overheating, as evidenced by bluing of one of the end plates (Figure 65). It was also noted that the gear associated with the most extreme bluing was also seized.

The collective damage was again thought to be consequential in nature and no further more detailed examinations were, therefore, completed.

3 SUMMARY

3.1 The cylinder block of the hydraulic motor had suffered a catastrophic fracture into a number of pieces, of which only four had been recovered for examination.

3.2 The evidence was consistent with the cylinder block fracturing in response to a hoop stress on the individual cylinder walls, that exceeded the block steels tensile strength.

3.3 The evidence of generally longitudinal cylinder block fractures and very extensive evidence of secondary radial cracking of the cylinder walls suggested that the damaging hoop stress had resulted from over pressurisation.

3.4 The cylinder block had been produced from an engineering type steel, which had entered service in the normalised condition. The steel was found to exhibit a tensile strength of 646 N/mm^2 and an accompanying anomaly free tensile property set that appeared demonstrably free from embrittlement.

3.5 Our examinations found no evidence of pre-existing material defects or fatigue cracking in the cylinder block that could have pre-disposed the cylinder walls to premature failure.

3.6 Based on its normalised type microstructure and anomaly free tensile properties, the cylinder block could have been expected to have behaved in a more ductile manner than had apparently been the case during the failure process.

3.7 In the absence of detectable embrittlement of the cylinder block, the apparently brittle service performance may suggest that the rate of application of the overloading hoop stress had been very high or near instantaneous, and that a super fast stressing rate had produced the brittle fracture.

3.8 The hard chromium plating of the cylinder walls and the running surface of the pistons were both seen to be exhibiting evidence of early service wear damage in the form of sliding surface spalling. The presence of the incipient damage had neither caused nor contributed to the cylinder blocks catastrophic failure.

3.9 The hydraulic motors casing was confirmed to be of a grey flake graphite type cast iron, an inherently brittle material with near zero fracture ductility. The use of such a material had facilitated the consequential fracture which had resulted from either its internal impacting by fractured pieces from the cylinder block, post cylinder block fracture over pressurisation, or a near instantaneous combination of the two.

3.10 The motors output shaft rolling element bearings were both confirmed to have been in a satisfactory wear free condition immediately prior to the failure.

3.11 The Brake and planetary gear both exhibited evidence of damage, but this was again thought to be of a consequential nature and type.

4 CONCLUSIONS, DISCUSSION AND RECOMMENDATIONS

Based on the evidence, we conclude that catastrophic failure of the hydraulic motor had resulted from gross over pressurisation of its cylinder block. The block had fractured in response to an unsustainably high hoop stress acting on the cylinder walls. A number of pieces had fractured from the block in a brittle manner and these in turn had impacted with the grey flake graphite cast iron casing. The consequential fracture of the motor casing had then in turn either resulted from impacting by cylinder block fragments, from post cylinder failure over pressurisation, or more likely as a consequence of a near instantaneous combination of both.

The cylinder block exhibited no evidence of pre-existing defects or prior fatigue cracking that could potentially have pre-disposed it to premature failure. The damage apparent in other items from the system was all judged to be of a consequential nature and it was not thought to have caused or contributed to the failure.

The cylinder block had entered service in a suitably normalised metallurgical type condition, and at normal tensile test rates of stressing the parent steel exhibited adequate ductility and a capacity to fracture in a more ductile manner than was evident in the catastrophic service failure. It, therefore, appears likely that the apparently brittle fracture had resulted from a very rapid or near instantaneous rate of overload stressing.

We have no expertise in hydraulic engineering and are consequently not able to confirm the suitability of the system design under consideration, or the viability of realising the necessary hydraulic pressure to account for the apparent failure. In this latter regard, we would suggest that the services of an hydraulics specialist be commissioned to both review the system design, and confirm its ability to produce a pressure sufficiently high to have generated the critical cylinder wall hoop stress.

We would also suggest that there may be better materials for the motors casing than grey flake graphite cast iron. The use of either a cast steel or a grade of Ductile Iron with guarantees on both fracture elongation and Charpy toughness, would offer better chances of both pressure and fragment containment in conditions of off design overload or impact.

Report prepared and authorised by

Director and Head of Laboratory

Client: MAIB, Southampton SO15 2JU
Job reference: T90996 MT STELLAR VOYAGER

Figure 1: Rear side of the control lens.

Figure 2: Cylinder block facing side of the control lens, showing evidence of only light non critical service rubbing wear.

Figure 3: Fractured cylinder block, showing recovered pieces mated together.

Figure 4: As above, viewed from a different camera angle.

Figure 5: Fractured cylinder block, showing recovered pieces mated together and viewed from the control lens mating face.

Figure 6: Fractured cylinder block, showing the location of the unrecovered fractured piece or pieces (between arrows).

Figure 7: Largest of the recovered cylinder block pieces, showing the orientation and locations of the fracture sites (post fracture impact damage noted).

Figure 8: Second of the recovered cylinder block pieces, showing the orientation and locations of the fracture sites (post fracture impact damage noted).

Figure 9: Third of the recovered cylinder block pieces, showing the orientation and locations of the fracture sites (post fracture impact damage noted).

Figure 10: Fourth of the recovered cylinder block pieces, showing the orientation and locations of the fracture sites (post fracture impact damage noted).

Figure 11: Typical sites of post fracture impact damage.

Figure 12: Typical post fracture impact damage at the cylinder clocks outer diameter.

Figure 13: Secondary radial cracks, which were apparent at the cylinder blocks output end.

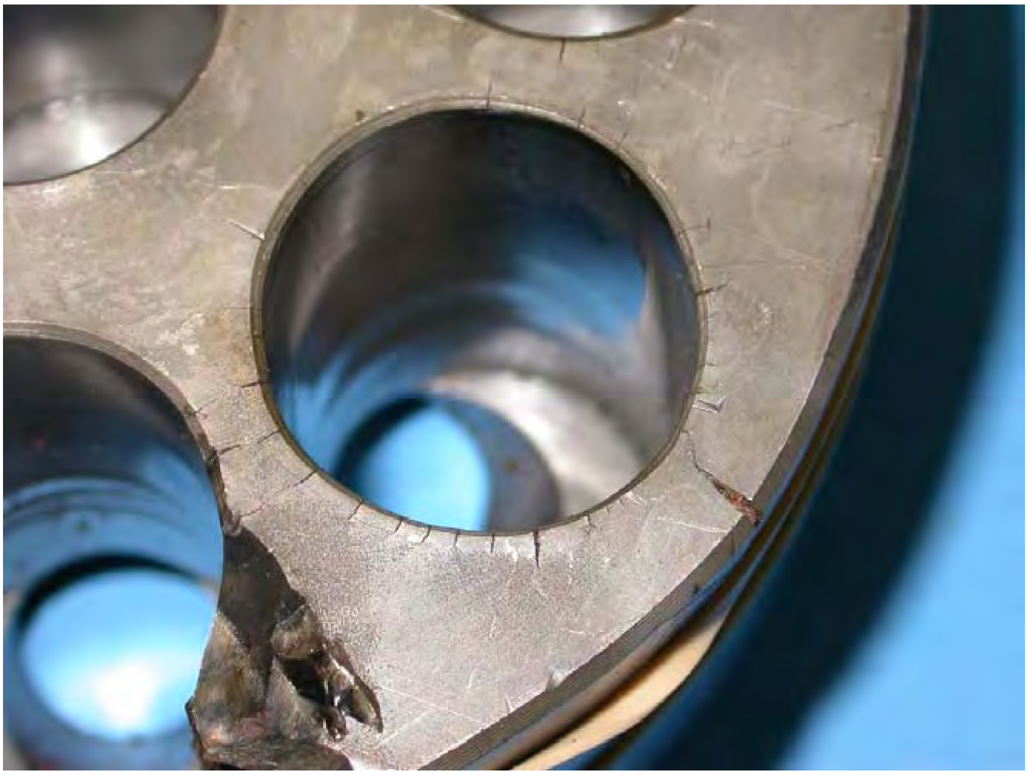


Figure 14: Detail of the output end secondary radial cracks around an individual cylinder.

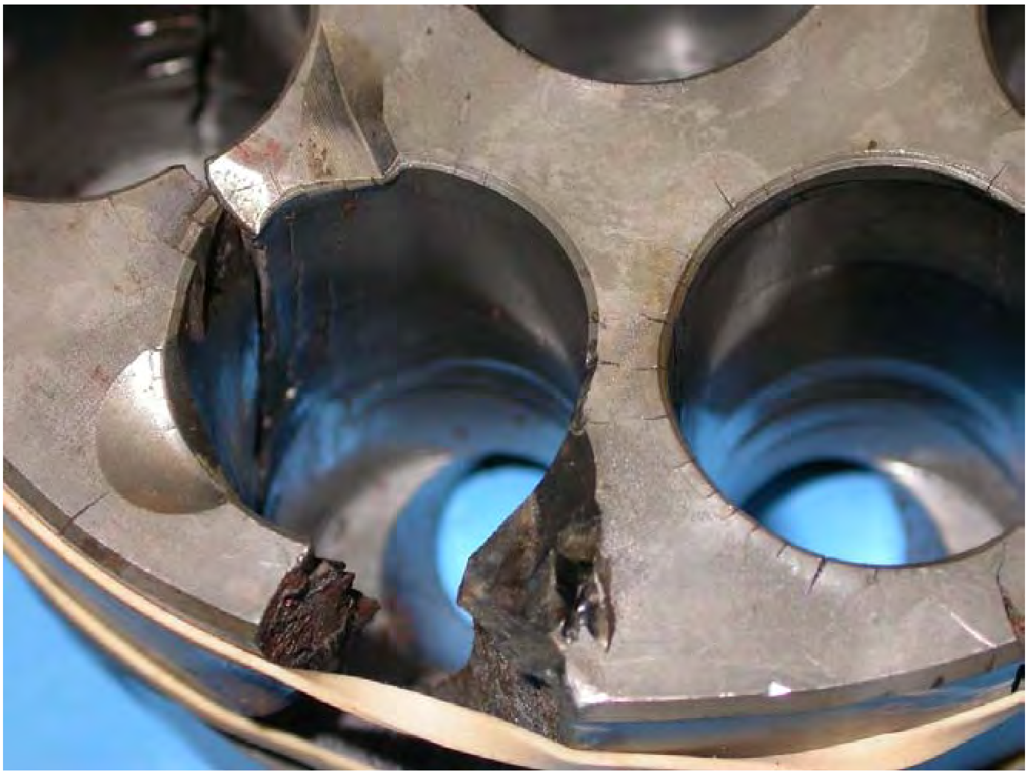


Figure 15: Detail of output end secondary radial cracks at two further adjacent cylinder sites

Figure 16: Secondary radial cracks, originating from the cylinder bore surface.

Figure 17: Detail of secondary radial cracks in two further cylinder bores.

Figure 18: Piston mechanical indenting damage (arrowed) at the walls of a cylinder.

Figure 19: Detail of piston mechanical indenting damage (arrowed) at the walls of a second cylinder.

Figure 20: Detail of piston mechanical indenting damage (arrowed) at the walls of a third cylinder.

Figure 21: Incipient cylinder bore wear or spalling type damage.

Figure 22: Region of the cylinder block fracture surface, showing features consistent with a single event brittle fracture (post fracture mechanical damage noted).

Figure 23: Second region of the cylinder block fracture surface, showing features consistent with a single event brittle fracture (post fracture mechanical damage noted).

Figure 24: Third region of the cylinder block fracture surface, showing features consistent with a single event brittle fracture (post fracture mechanical damage noted).

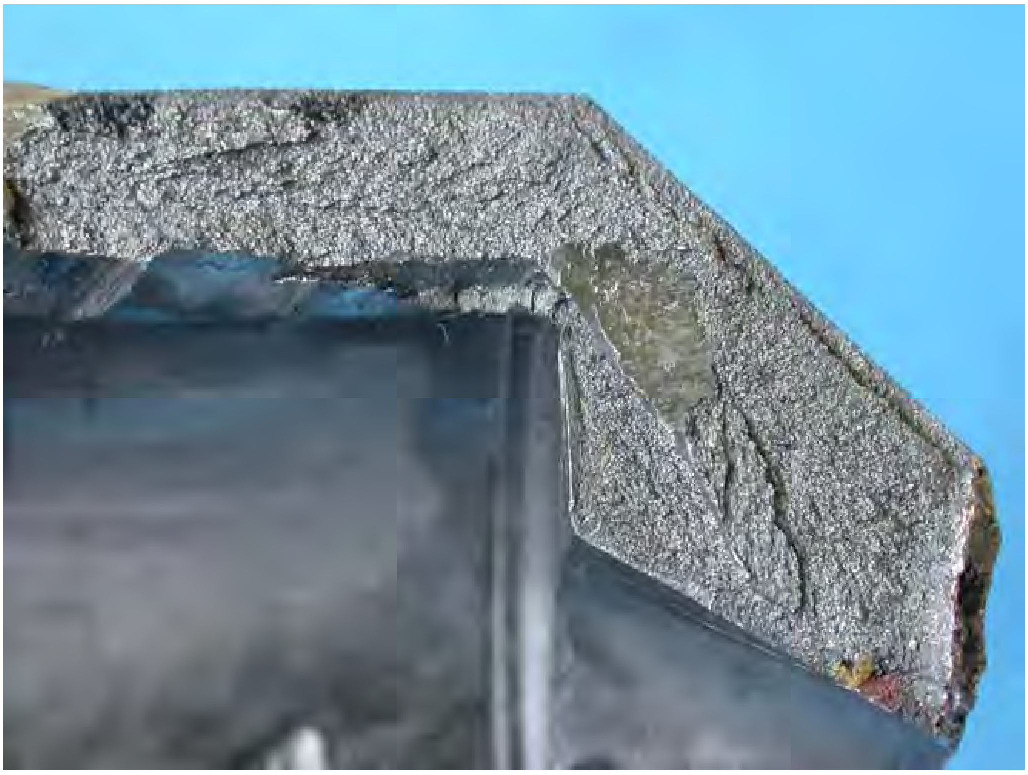


Figure 25: Fourth region of the cylinder block fracture surface, showing features consistent with a single event brittle fracture (post fracture mechanical damage noted).

Figure 26: Fifth region of the cylinder block fracture surface, showing features consistent with a single event brittle fracture (post fracture mechanical damage noted).

Figure 27: Sixth region of the cylinder block fracture surface, showing features consistent with a single event brittle fracture (post fracture mechanical damage noted).

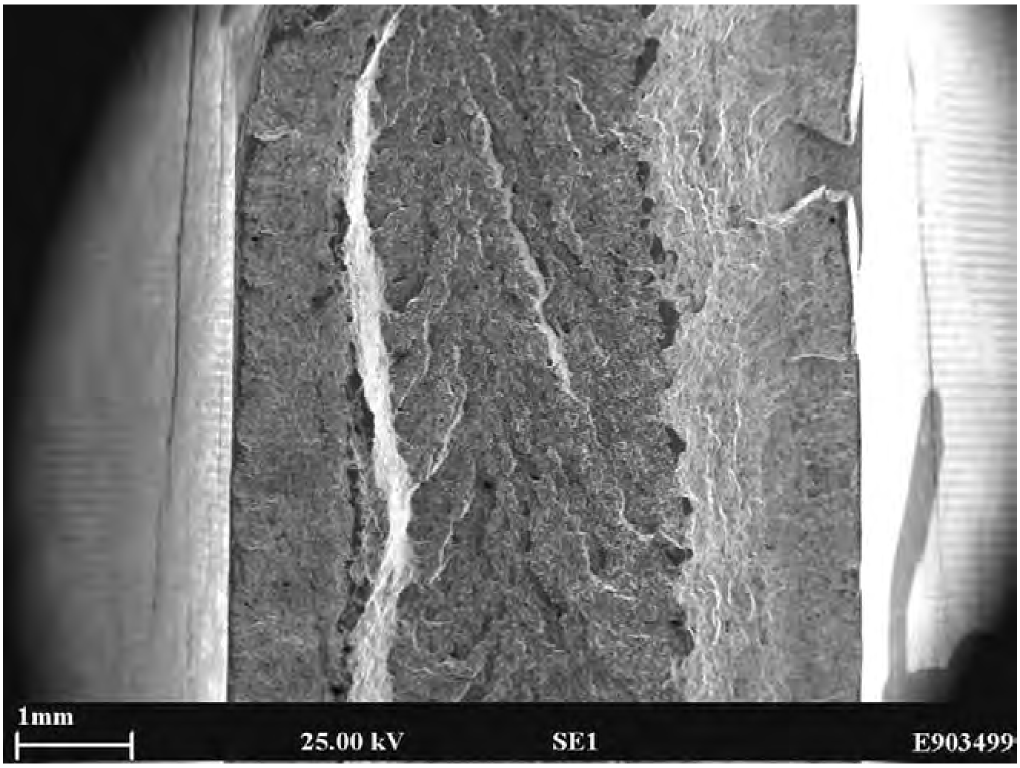


Figure 28: SEM fractograph, showing a typical cylinder block fracture surface field and one characterised by fast fracture “chevron” type markings.

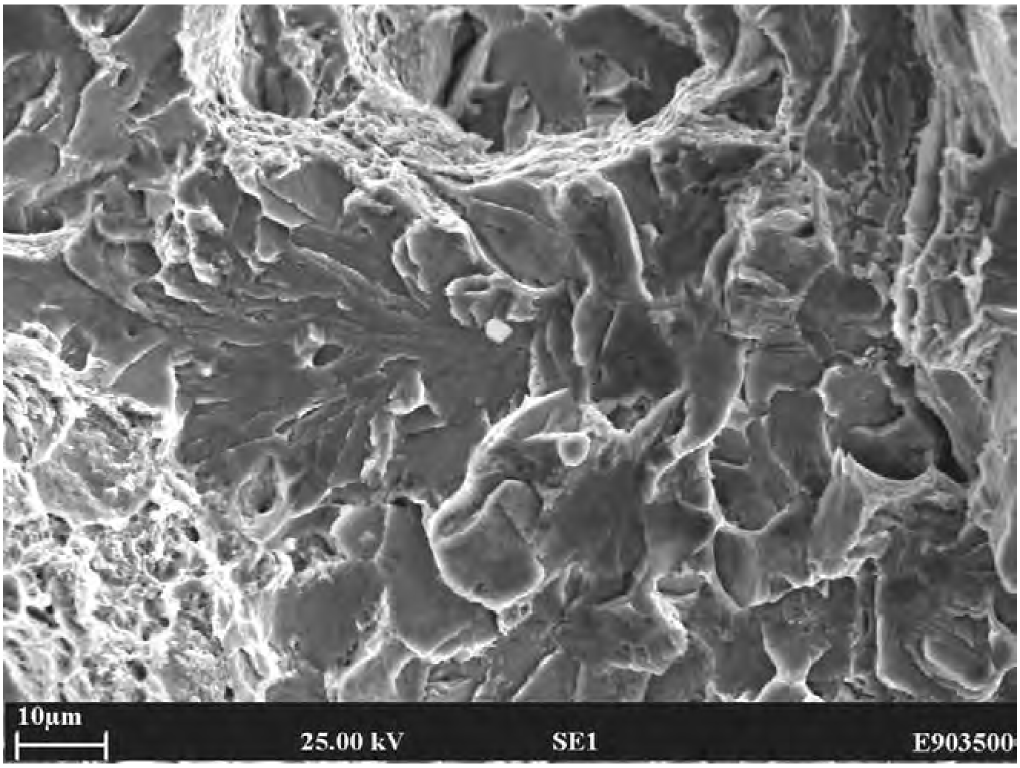


Figure 29: SEM fractograph, showing detail of cleavage fracture apparent at the right hand hole edge of figure 28.

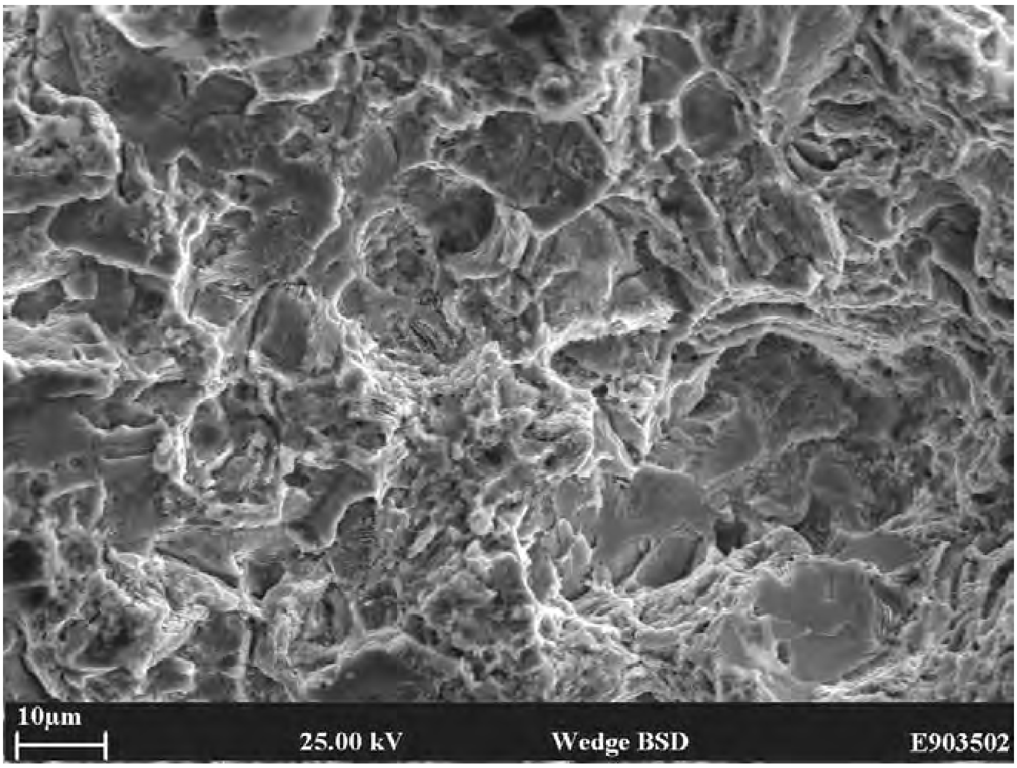


Figure 30: SEM fractograph, showing cleavage fracture apparent at the left hand hole edge of figure 28.

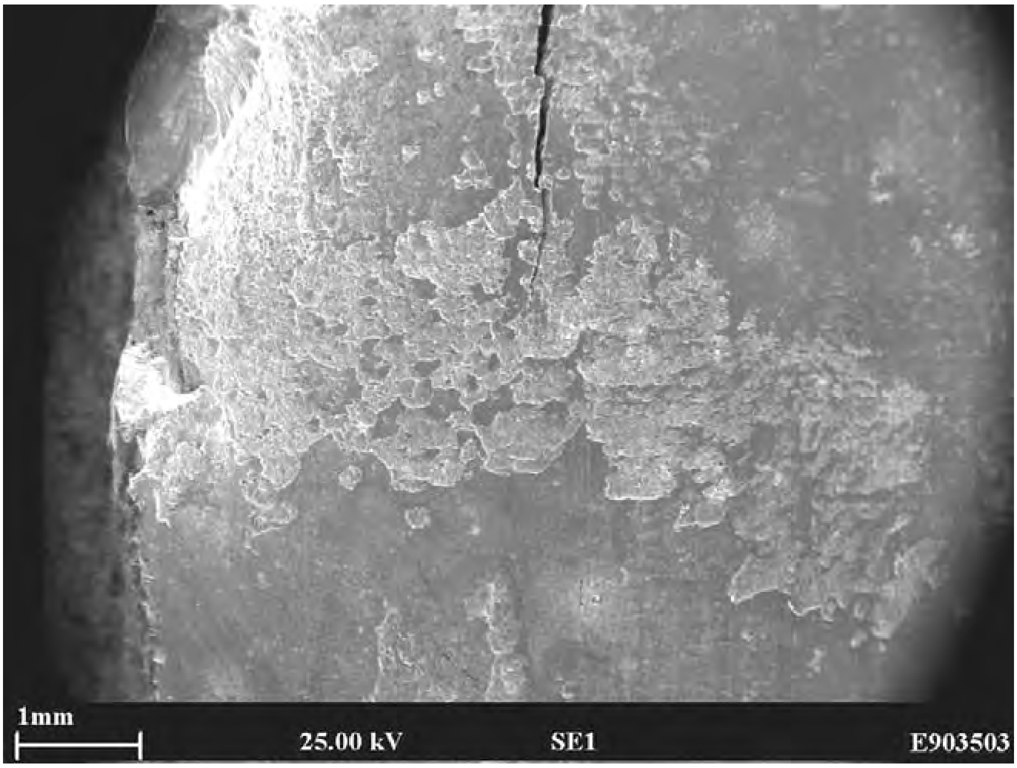


Figure 31: SEM fractograph, showing a local site of incipient cylinder bore wear or damage (secondary radial crack noted at top centre field).

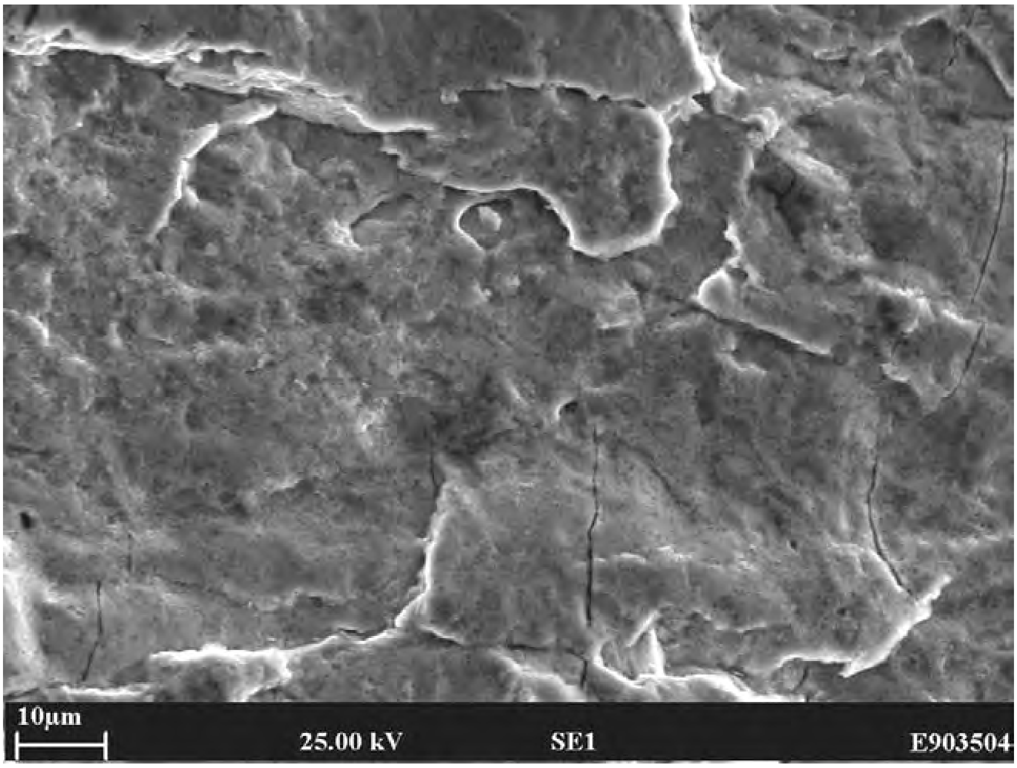


Figure 32: SEM fractograph, showing indeterminate nature of the incipient cylinder bore surface damage shown in figure 31.

Figure 33: Detached piece from the cylinder block, showing (arrowed) the section removed for metallographic examination.

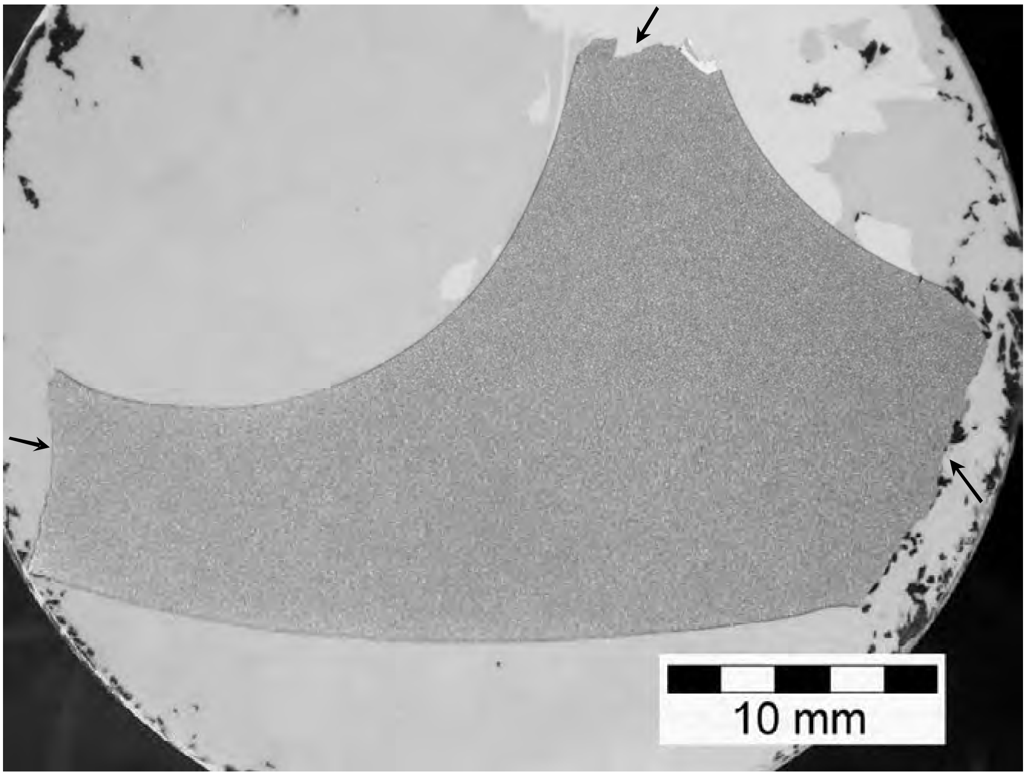


Figure 34: Macrograph, showing three fracture sites (arrowed) in the prepared metallographic specimen.

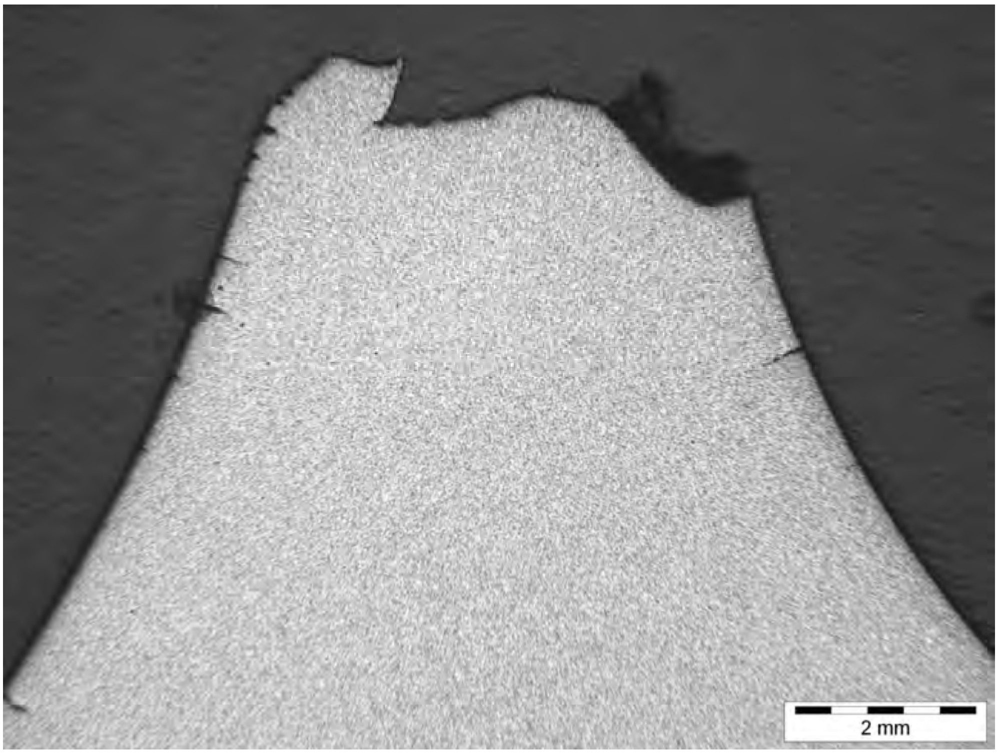


Figure 35: Micrograph (original image captured at X12.5), specimen etched in Nital. Fracture site (top of field) and associated radial cracking in the two cylinder bores.

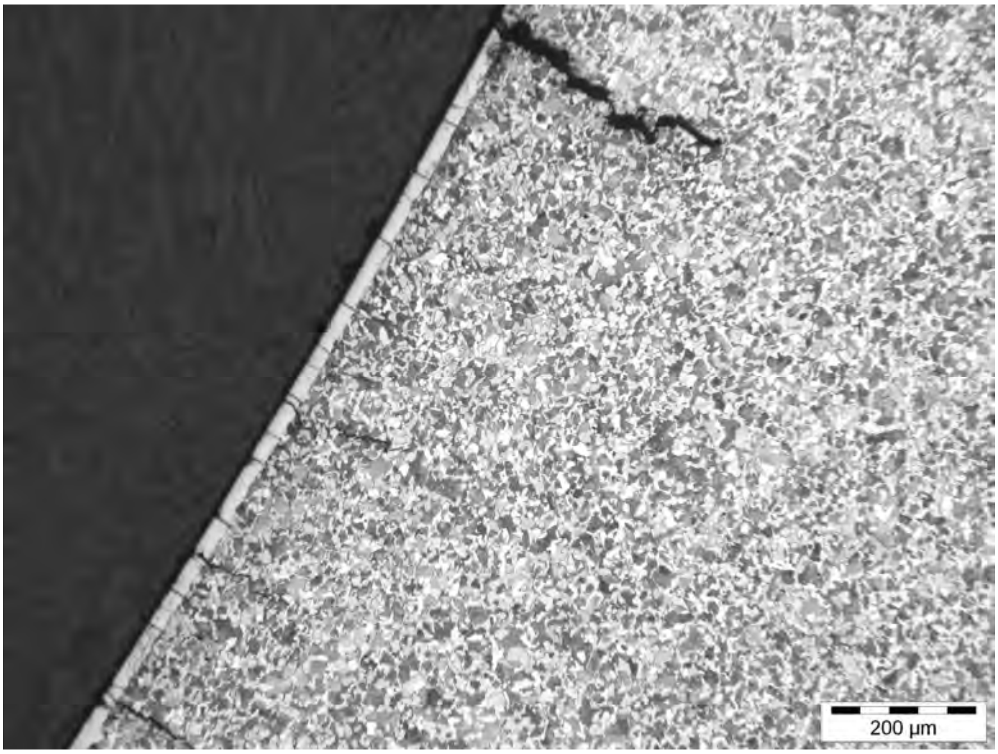


Figure 36: Micrograph (original image captured at X200), specimen etched in Nital. Detail of radial cracks propagating into the cylinder block and post yield differential ductility cracks in the chromium plating.

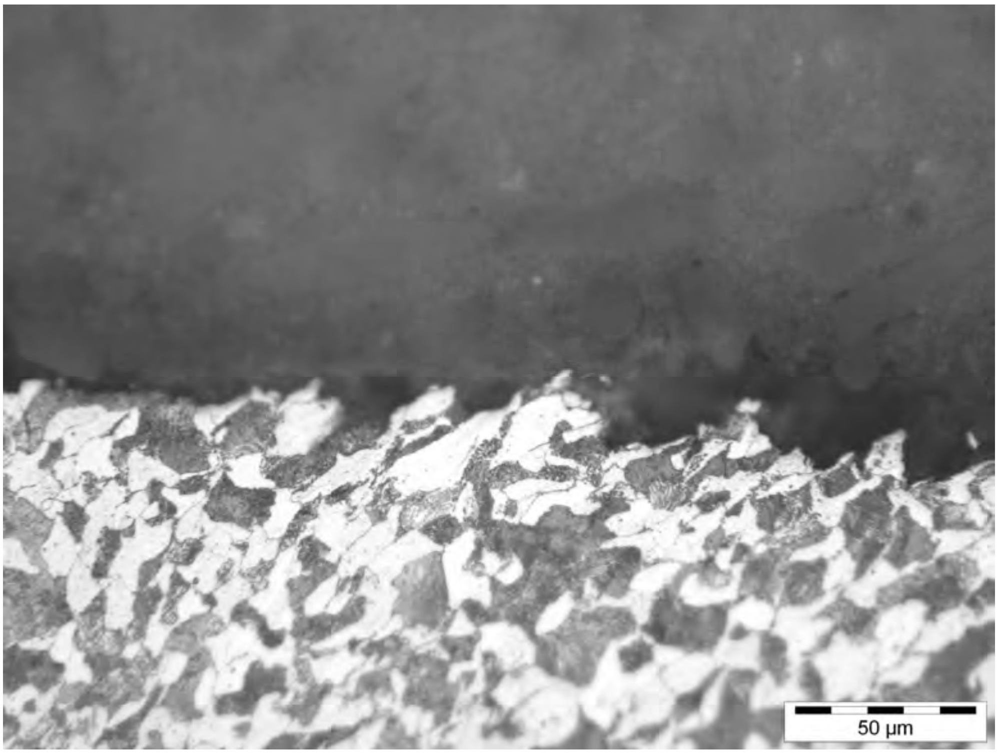


Figure 37: Micrograph (original image captured at X500), specimen etched in Nital. Detail of one of the fractured cylinder block walls, showing evidence of an essentially brittle fracture mechanism.

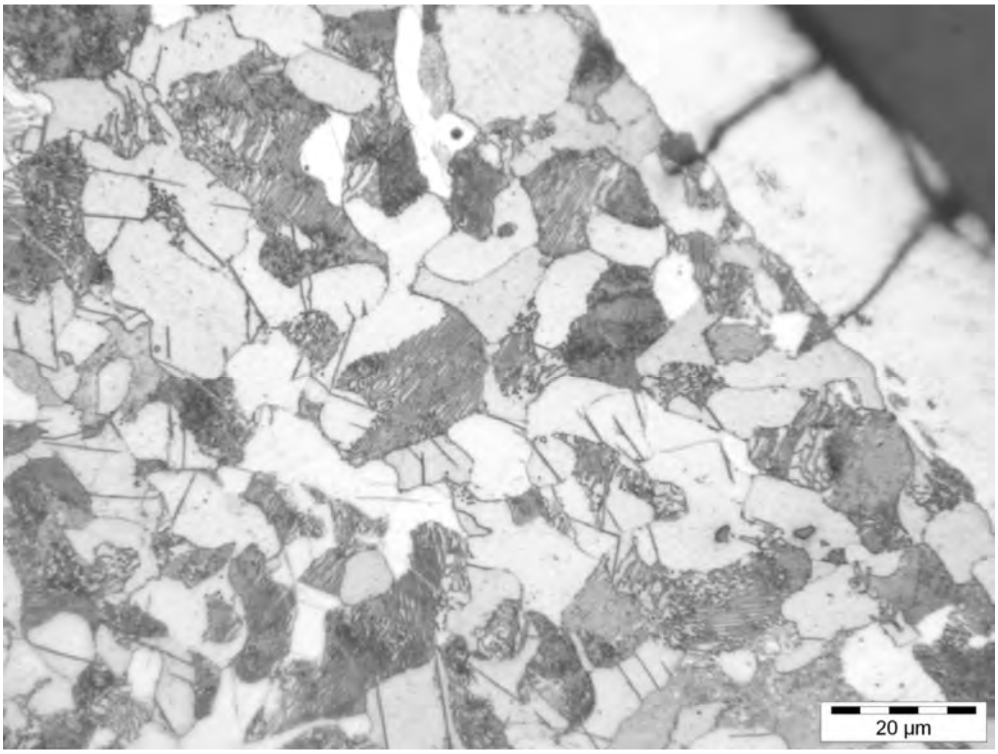


Figure 38: Micrograph (original image captured at X1000), specimen etched in Nital. A field adjacent to a cylinder bore, showing extensive post yield sub-grain twinning and cracking in the chromium plating.

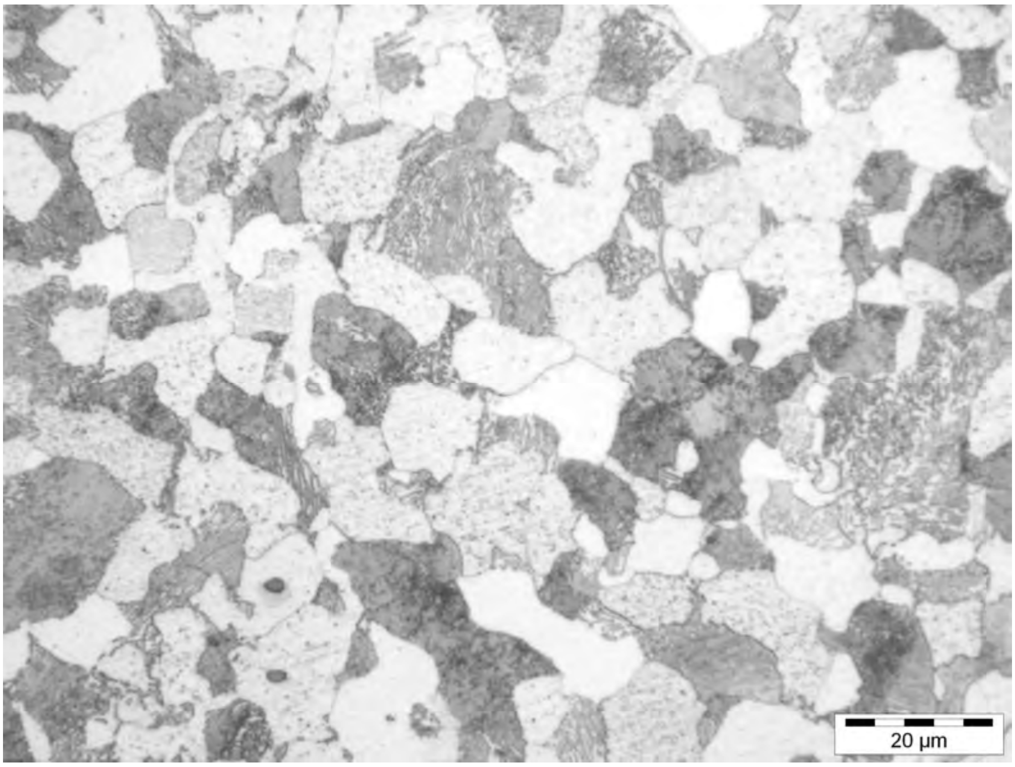


Figure 39: Micrograph (original image captured at X1000), specimen etched in Nital. Cylinder block microstructure clear of fracture sites and associated strain fields, showing a microstructure of pearlite in a hyper-fine ferritic matrix.

Figure 40: Three pistons recovered from the hydraulic motor and presented for laboratory examination.

Figure 41: Piston crown end, showing loss of one and a half piston rings and associated local post fracture damage to the crown end.

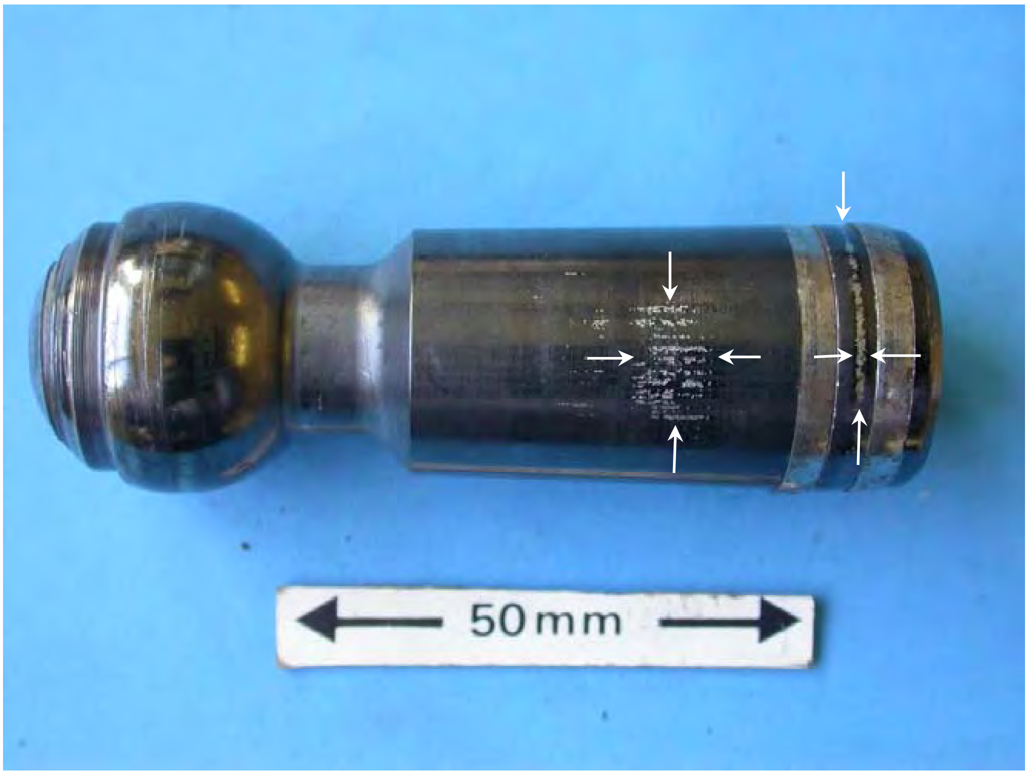


Figure 42: Incipient service wear or spalling type damage (damage sites arrowed).

Figure 43: Detail of figure 42, showing wear or spalling of the main body region.

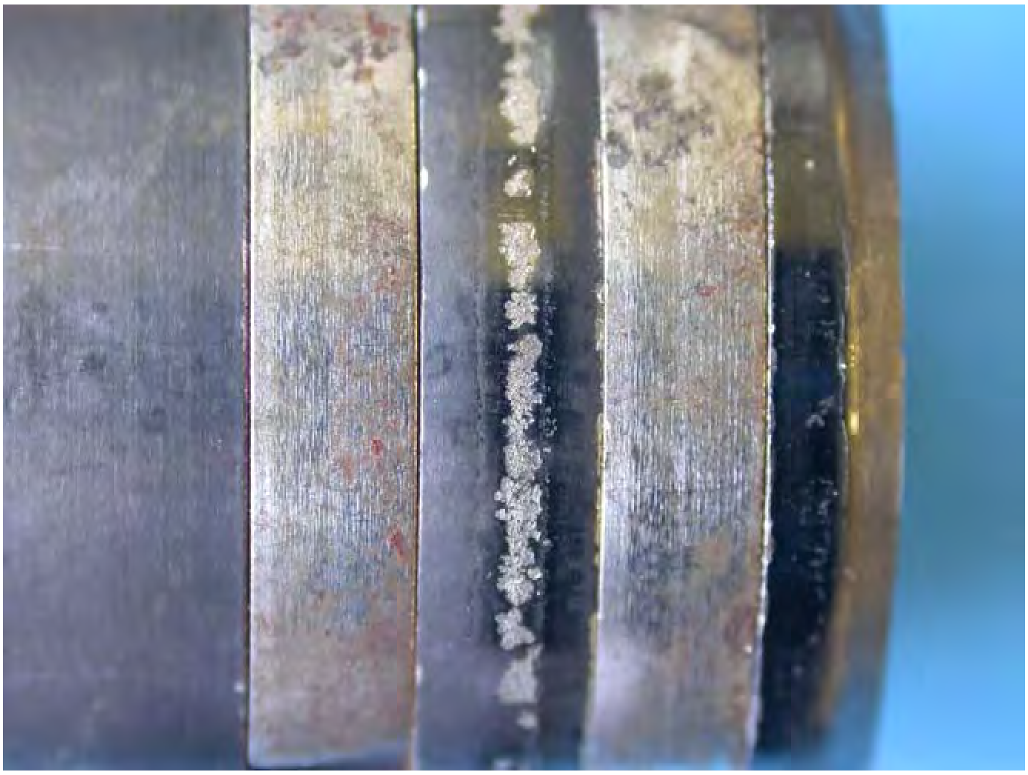


Figure 44: Detail of figure 42, showing wear or spalling of the region between the two piston rings.

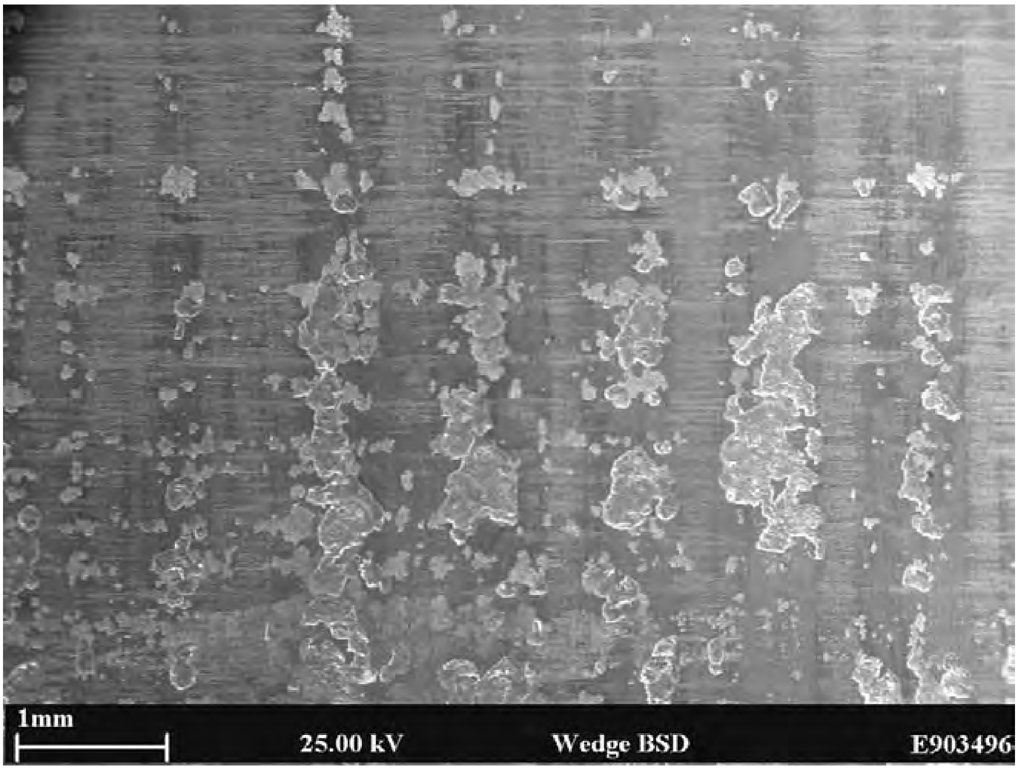


Figure 45: SEM fractograph, showing surface spalling type damage in the pistons main body region.

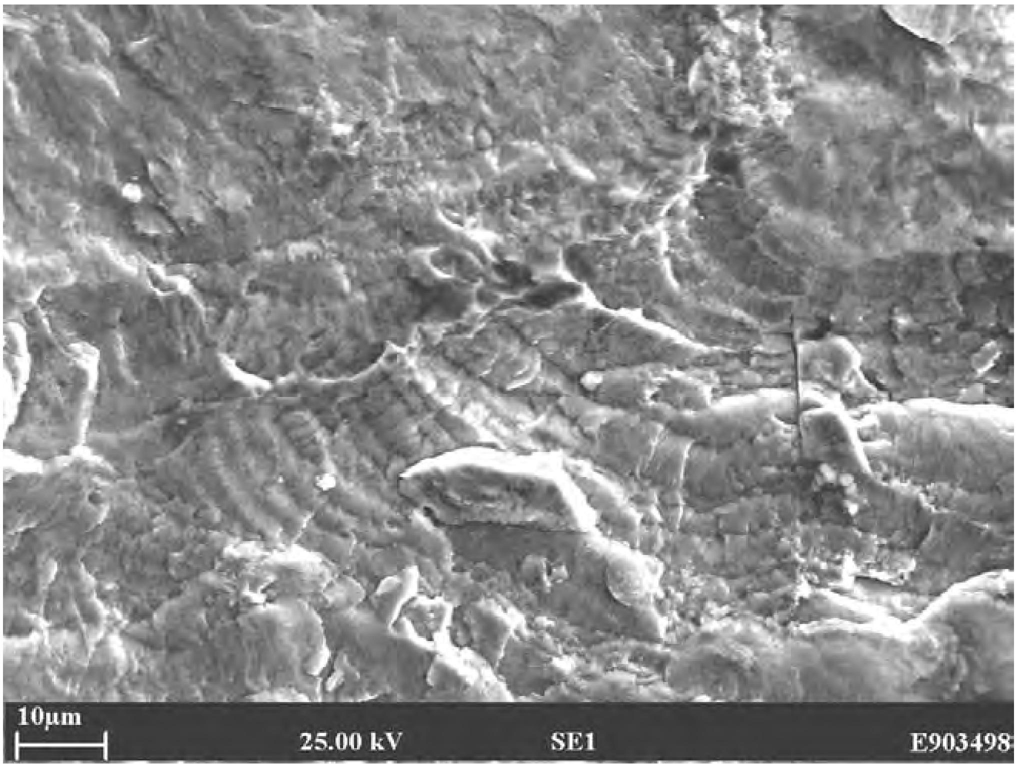


Figure 46: SEM fractograph, showing detail of fatigue beach markings and striations in the damage illustrated in figure 45.

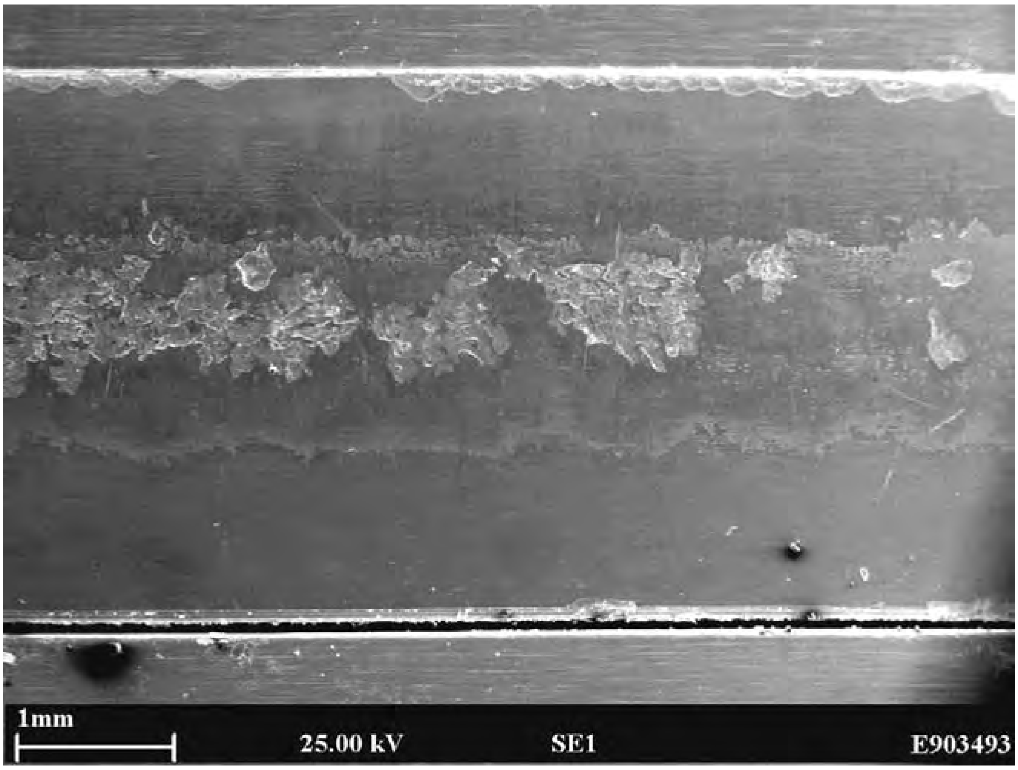


Figure 47: SEM fractograph, showing surface spalling type damage between the two pistons rings.

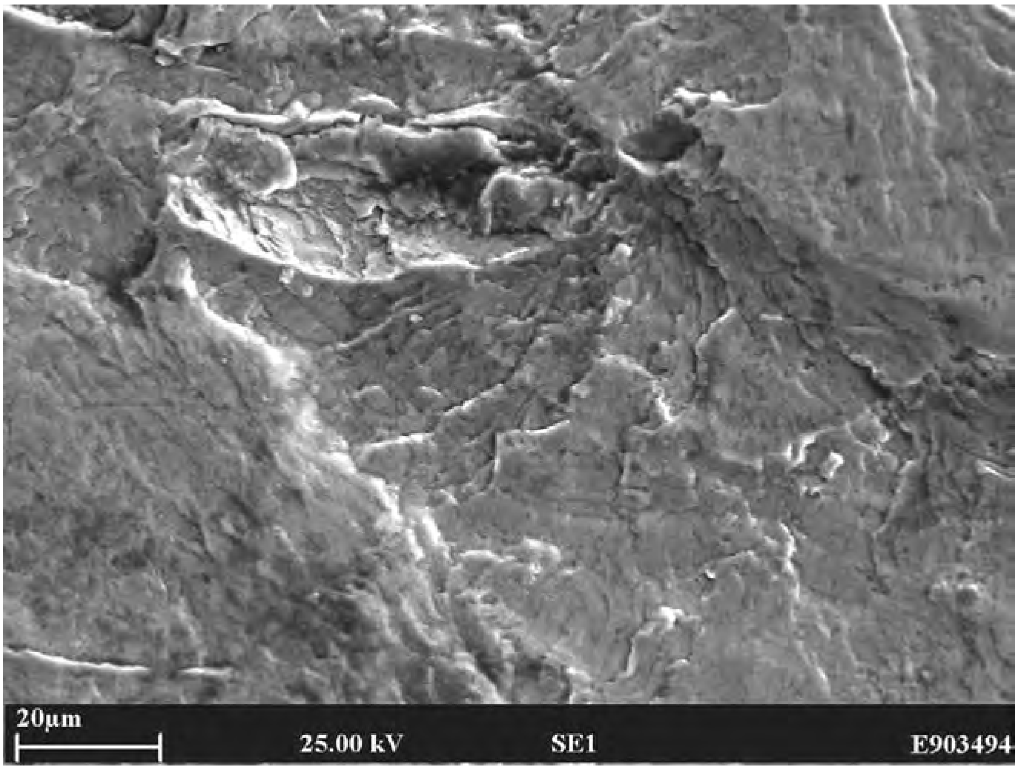


Figure 48: SEM fractograph, showing detail of fatigue like features in the damage illustrated in figure 47.

Figure 49: Motor output shaft, which was supplied retaining the inner raceway cone from one of the shafts two rolling element bearings.

Figure 50: Output shaft pin pockets, showing evidence of local pin head seizure marks, damaged end plate and sheared cap-head studs.

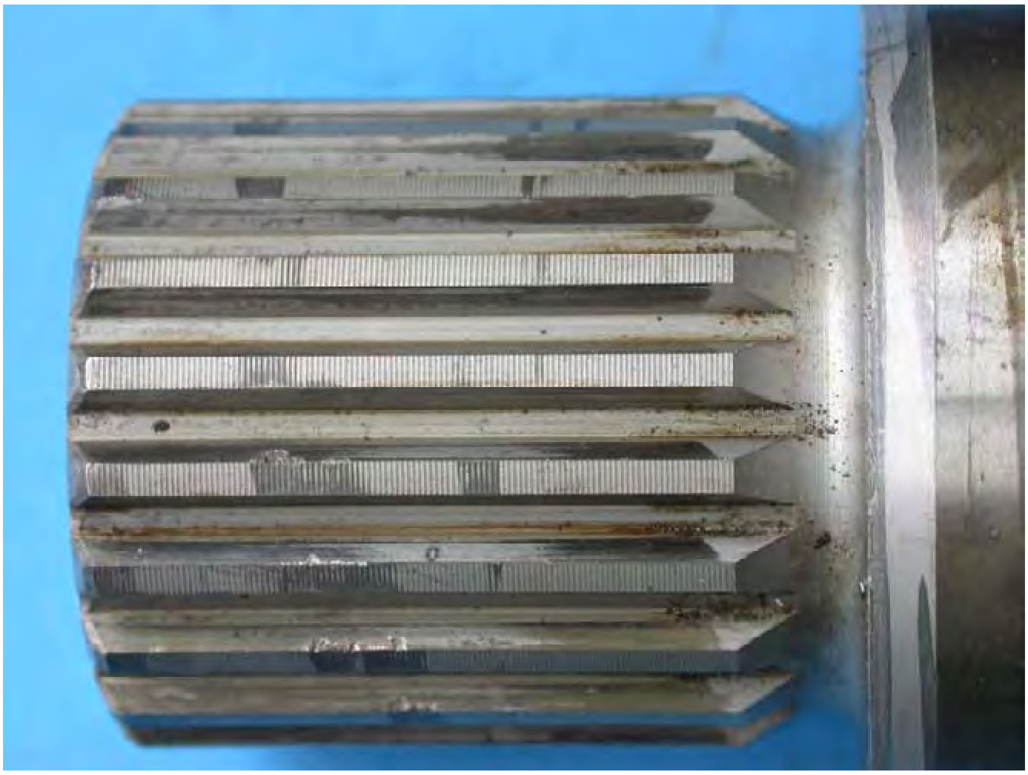


Figure 51: Output shaft splines, which exhibited no evidence of service wear or overloading (sites of local casualty damage noted).

Figure 52: Three rollers recovered from the larger of the two shaft bearings, which exhibited no evidence of wear or pre-casualty damage.

Figure 53: Outer raceway ring from the larger of the two shaft bearings, which exhibited no evidence of severe wear or damage.

Figure 54: Roller cage from the larger of the two output shaft bearings, which exhibited evidence of post casualty damage only.

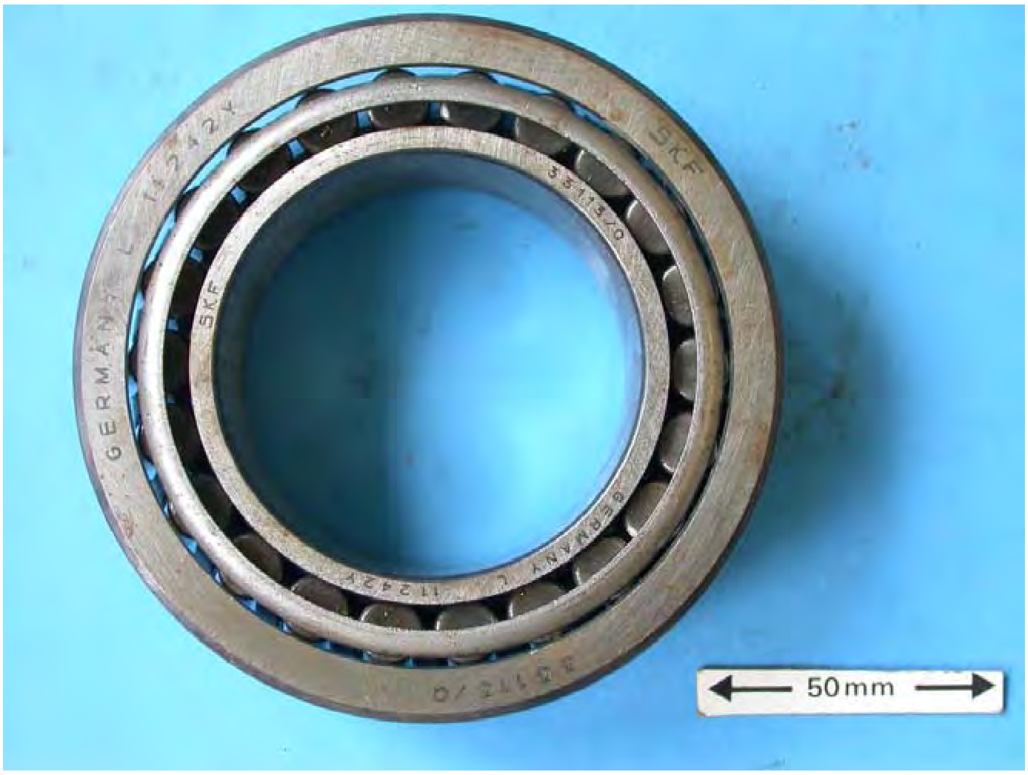


Figure 55: Second output shaft bearing, which was supplied fully assembled and in a good serviceable damage free condition.

Figure 56: Recovered pieces from the extensively fractured cast iron motor casing.

Figure 57: Recovered pieces from the extensively fractured cast iron motor casing, viewed from their opposite sides.

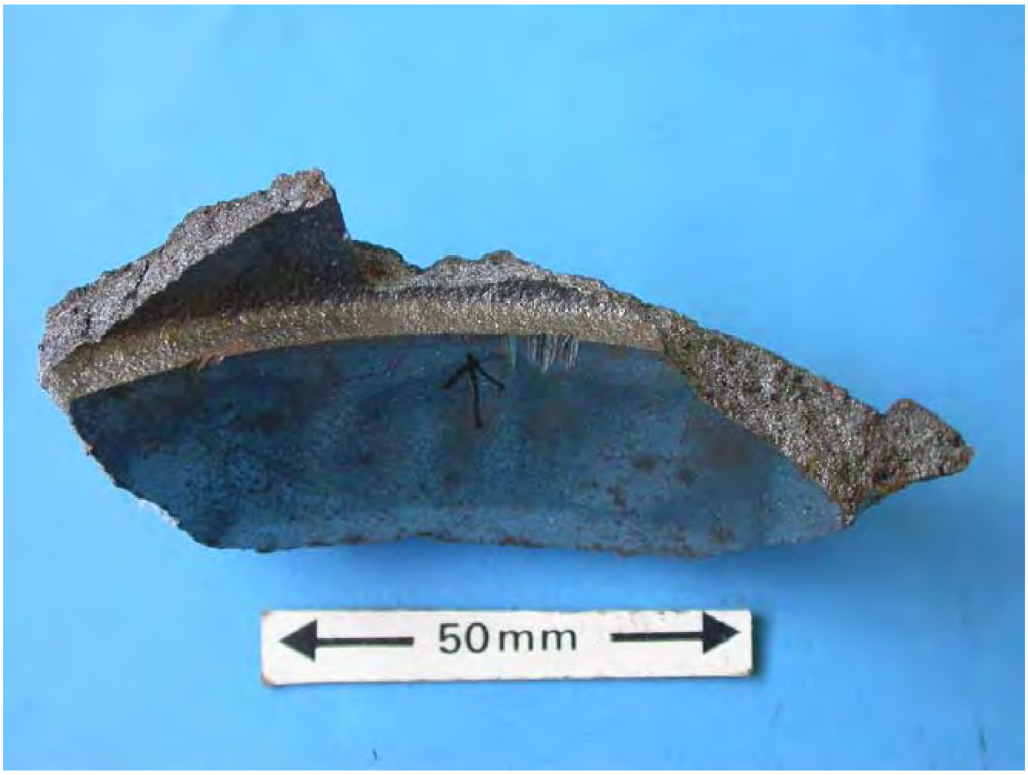


Figure 58: fractured piece from the motor casing, which exhibited fracture surfaces indicative of a cast iron (piece subsequently examined fractographically and metallographically).

Figure 59: Detail of figure 58, showing fracture surface features consistent with a cast iron.

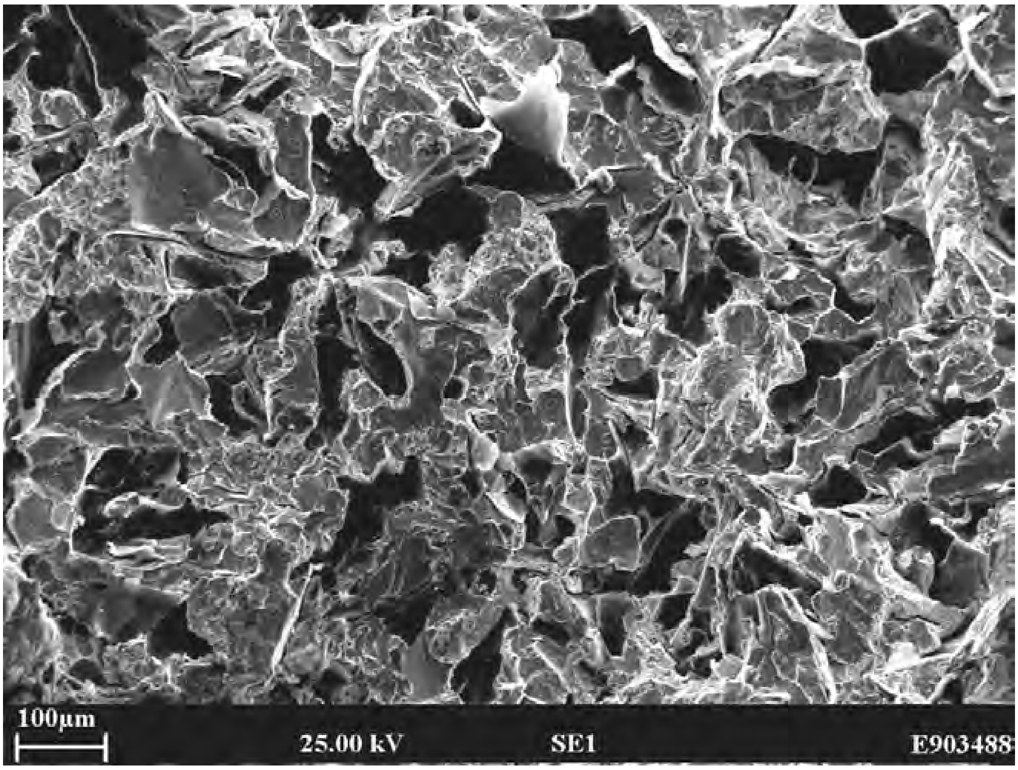


Figure 60: SEM fractograph, showing fractographic detail of the piece shown in figure 58 and comprising graphite flakes (black) in a brittle cleavage fractured iron matrix (grey).

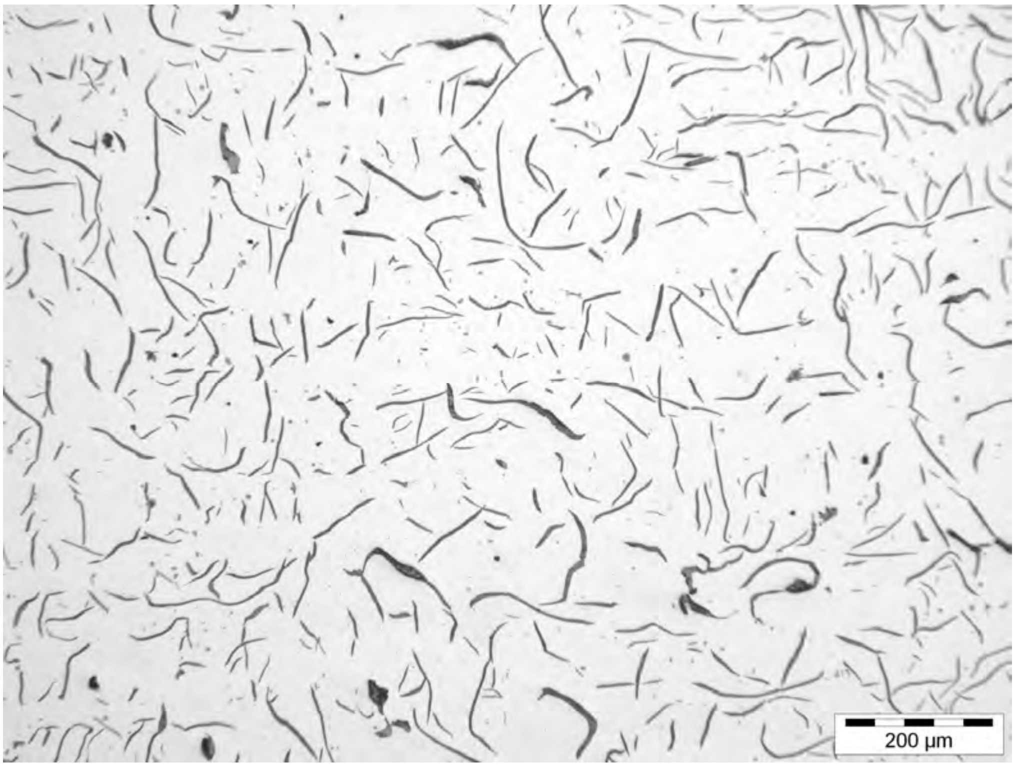


Figure 61: Micrograph (original image captured at X100), specimen unetched. Section from the fractured motor case piece illustrated in figure 58, and showing a flake graphite type morphology typical of a grey cast iron.

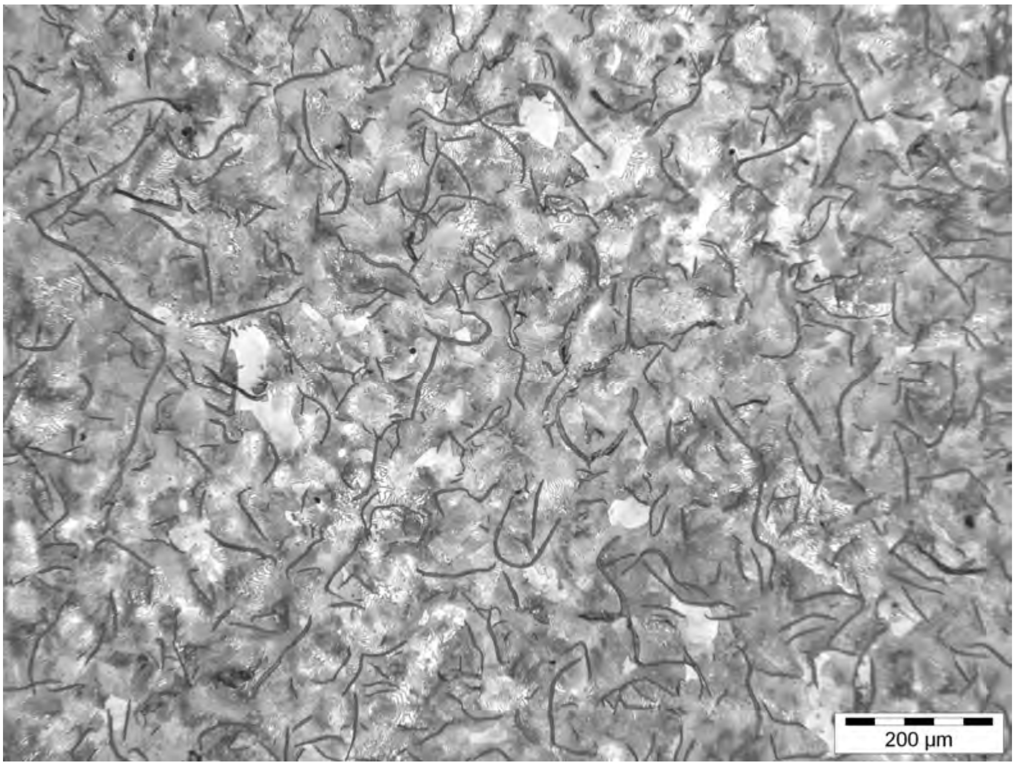


Figure 62: Micrograph (original image captured at X100), specimen etched in Nital. As above showing the castings largely pearlitic iron matrix.

Figure 63: Output gear shafting, showing evidence of recent overheating and local seizure type damage.

Figure 64: Recently overheated and damaged clutch/brake plate set.

Figure 65: Planetary gear set, showing end plate bluing at the three shaft locations (seized shaft arrowed).

Annex C

Oil analysis

SeaTec
CONDITION MONITORING

SeaTec U.K. Ltd.
Skypark
8 Elliot Place
Glasgow G3 8EP
Technical Support: Pact-oilanalysis@seatec-services.com

Vessel:	STELLAR VOYAGER	**Manufacturer:**	KOCKS
		Model:	1907-8820
IMO Number:	9249180	**Serial No:**	
		Oil Grade:	FAMM MEROPA 150
Machinery:	ANCHOR WINDLASS STBD GEARBOX	**Oil Volume Litres:**	

Microscopic Analysis:

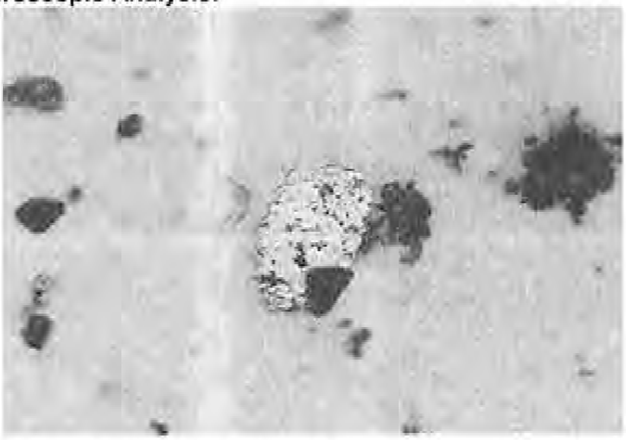


Figure 1 (x100 Magnification)

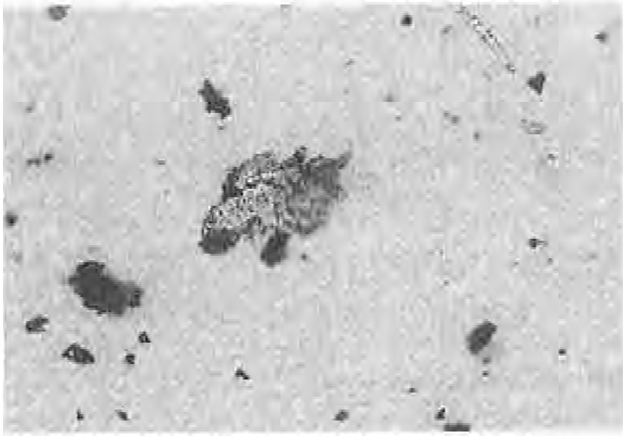


Figure 2 (x100 Magnification)

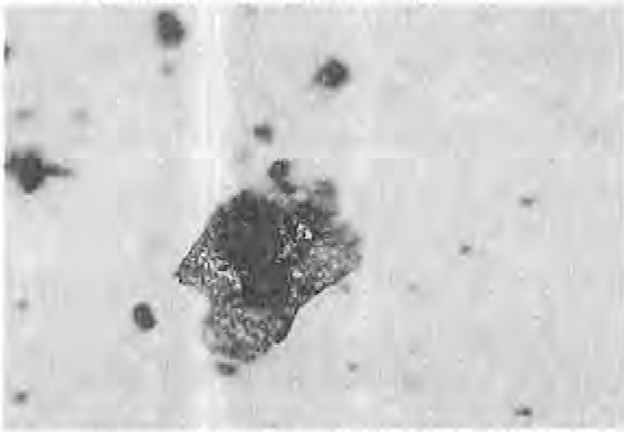


Figure 3 (x100 Magnification)

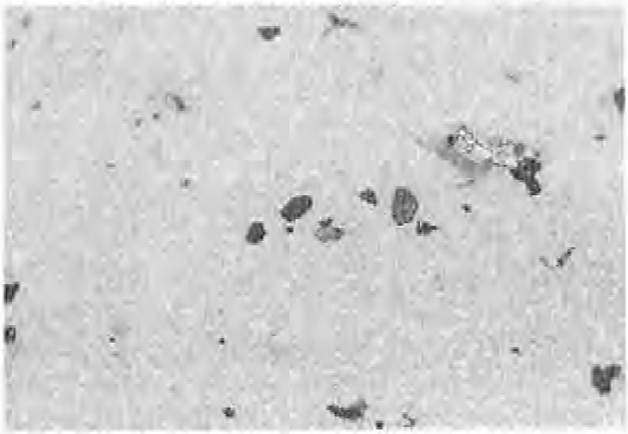


Figure 4 (x100 Magnification)

Method: The sample was analysed by solvent extraction, and FTIR techniques followed by microscopic examination of the debris. The water from the sample was removed and solvents added to precipitate any insoluble organic material and wear debris from the remaining oily fraction. The resultant sludge was analysed by FTIR to identify its chemical nature, before being dissolved in a more polar solvent to isolate the remaining solid material, which was further analysed by microscopic techniques.

Discussion & Conclusion: The FTIR analysis of the sludge identified the presence of a carboxylate soap in the oil fraction, which was of the type normally found in lubricating grease. Elemental analysis of the original sample indicated a high sodium content, which suggests the presence of a sodium based grease and possibly sea water too.

The analysis of the solid material showed evidence of fatigue wear, consistent with sliding and rolling wear (figure 1, 2 & 3). The results also showed evidence of black ferrous oxides material, which are normally caused by high temperature operation in the absence of oxygen (figures 1, 2 and 3).

The microscopic results showed the presence of a small amount of silicate material (sand) within the sample (figure 4). The presence of the silicate material is unlikely to be a cause of failure, as there appears to be no evidence of cutting wear within the sample.

Sliding wear, leading to fatigue particles and the presence of black iron oxides, suggest poor lubrication, which may be a result of lubricant starvation, if the grease present had blocked lubrication port ways; or poor lubrication, owing to the amount of water present within the system.

Report Date: 30th June 2009

SeaTec
CONDITION MONITORING

SeaTec U.K. Ltd.
Skypark
8 Elliot Place
Glasgow G3 8EP
Technical Support: Pact-oilanalysis@seatec-services.com

Vessel:	STELLAR VOYAGER	**Manufacturer:**	KOCKS
		Model:	1907-8820
IMO Number:	9249180	**Serial No:**	
		Oil Grade:	FAMM MEROPA 150
Machinery:	ANCHOR WINDLASS STBD GEARBOX	**Oil Volume Litres:**	

Sequential Results							Current		
Sample Number							3293453		
Date Sampled							26-Mar-09		
Date Dispatched									
Dispatched From							S'hampton		
Date Received							22-Jun-09		
Sampling Point							Gear Sys		
Sampled By									
Unit Service Hours									
Oil Service Hours									
Daily Make Up (litres)									
Analysis								New Oil	Unit
Appearance							Cloudy		
K Viscosity at 40°C cSt							[illegible]	150	
Water % Vol							[illegible]		
Acid Number							0.34		
Additive Elemental Analysis ppm									
Barium							1		
Calcium							9		
Magnesium							6		
Phosphorus							210		
Zinc							51		
Wear & Contaminant Elemental Analysis ppm									
Boron							5		
Sodium							30		
Silicon							4		
Lithium							7		
Aluminium							2		
Chromium							1		
Copper							1		
Iron							16		
Lead							5		
Tin							2		
Molybdenum							1		
Nickel							<1		
Titanium							<1		
Silver							1		
Manganese							<1		
PQ Index/2ml							34		
Oil/Unit Rating							**D/-**		

A = Suitable for Further Service B = Alert Level C = Remedial Action Required D = Unsuitable Charge

Oil Rating: The sample as tested contains a very high level of saline water. There is the risk of corrosion occurring and lubrication being affected. The viscosity is significantly higher than the new oil value of the stated grade and indicates a heavier grade is in use. The oil in should be confirmed and the system manufacturer's recommendations confirmed.

Unit Rating: Elemental analysis of the wear elements shows these to be at low levels. The PQ index which quantifies ferrous debris within the sample of all particle sizes indicates the presence of some larger sized iron debris.

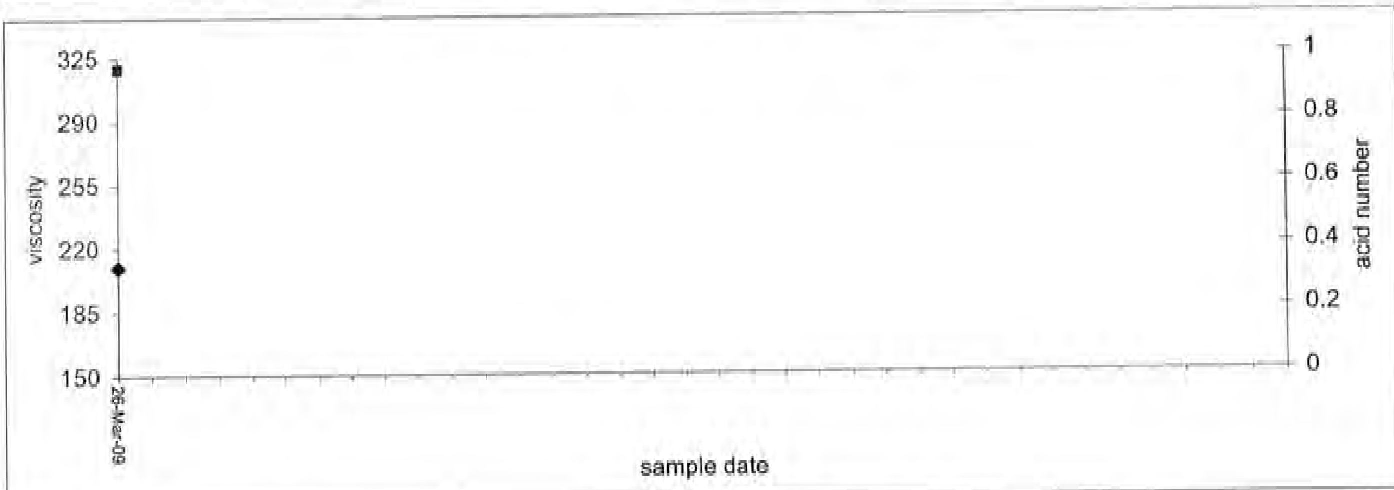
Report Date: 30th June 2009

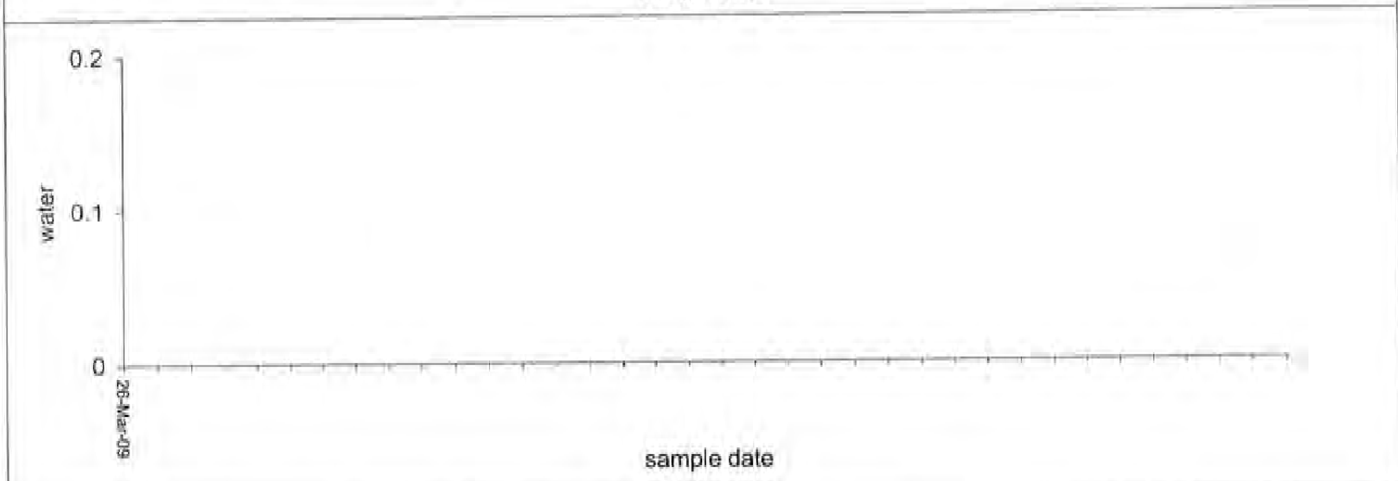
SeaTec

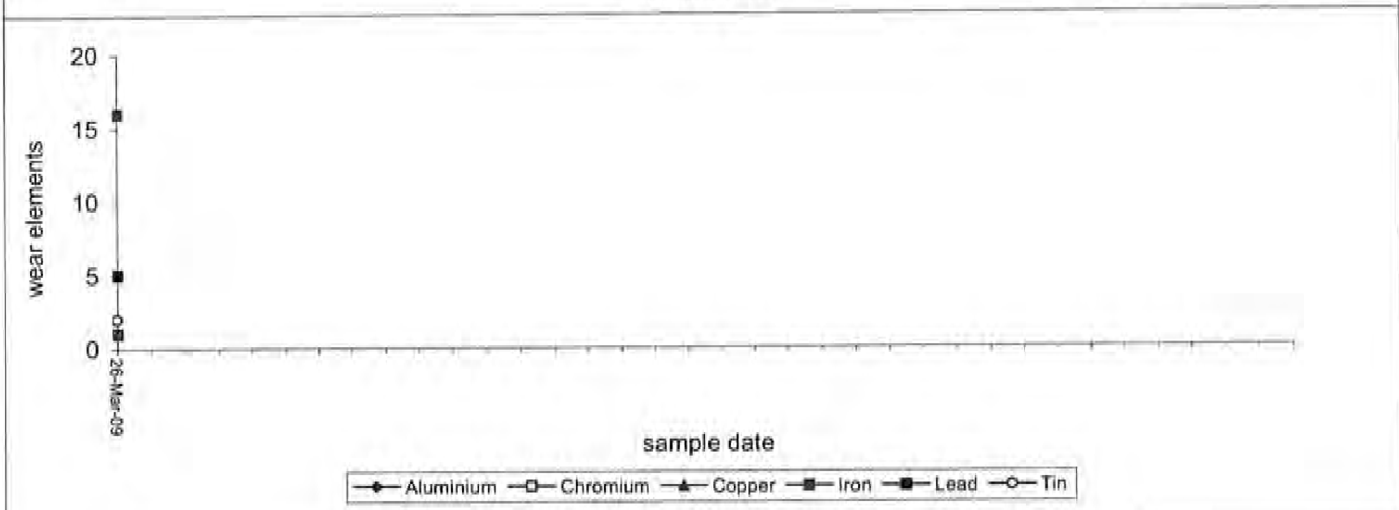
CONDITION MONITORING

SeaTec U.K. Ltd.
Skypark
8 Elliot Place
Glasgow G3 8EP
Technical Support: Pact-oilanalysis@seatec-services.com

Vessel:	STELLAR VOYAGER	**Manufacturer:**	KOCKS
		Model:	1907-8820
IMO Number:	9249180	**Serial No:**	
		Oil Grade:	FAMM MEROPA 150
Machinery:	ANCHOR WINDLASS STBD GEARBOX	**Oil Volume Litres:**	







SeaTec

CONDITION MONITORING

SeaTec U.K. Ltd
Skypark
8 Elliot Place
Glasgow G3 8EP
Technical Support: Pact-oilanalysis@seatec-services.com

Vessel:	STELLAR VOYAGER	**Manufacturer:**	KOCKS
		Model:	1907-8820
IMO Number:	9249180	**Serial No:**	
		Oil Grade:	FAMM RANDO HDZ 32
Machinery:	ANCHOR WINDLASS STBD HYD. SYSTEM	**Oil Volume Litres:**	

Sequential Results							Current		
Sample Number							3293452		
Date Sampled							26-Mar-09		
Date Dispatched									
Dispatched From							S'hampton		
Date Received							22-Jun-09		
Sampling Point							Hyd Sys		
Sampled By									
Unit Service Hours									
Oil Service Hours									
Daily Make Up (litres)									
Analysis								New Oil	Unit
Appearance							Clear		
K Viscosity at 40°C cSt							33.0	32	
Water % Vol							<0.1		
Acid Number							0.60		
ISO Code 4406							21/19/16		
Additive Elemental Analysis ppm									
Barium							<1		
Calcium							45		
Magnesium							<1		
Phosphorus							285		
Zinc							391		
Wear & Contaminant Elemental Analysis ppm									
Boron							<1		
Sodium							1		
Silicon							<1		
Lithium							<1		
Aluminium							<1		
Chromium							<1		
Copper							1		
Iron							1		
Lead							1		
Tin							<1		
Molybdenum							<1		
Nickel							<1		
Titanium							<1		
Silver							<1		
Manganese							<1		
Oil/Unit Rating							**B/-**		

A = Suitable for Further Service　B = Alert Level　C = Remedial Action Required　D = Unsuitable Charge

Oil Rating: The oil is in a clear condition with negligible water and the viscosity is close to the new oil value. The ISO code indicates the oil would benefit from an improvement in cleanliness. The oil is suitable for continued service.

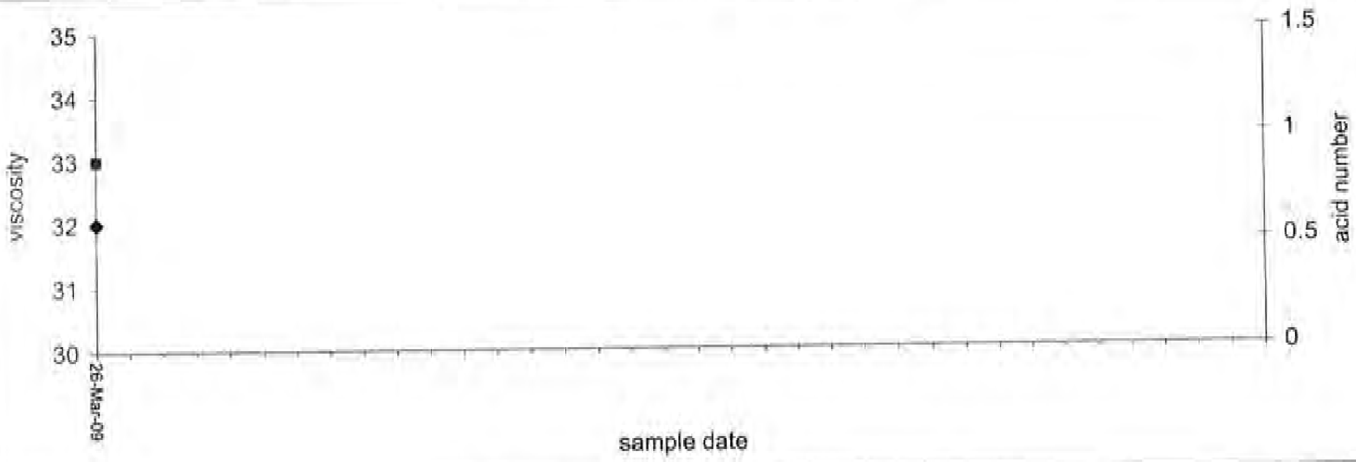
Unit Rating: Elemental analysis of the wear and contaminant elements shows these to be at very low levels.

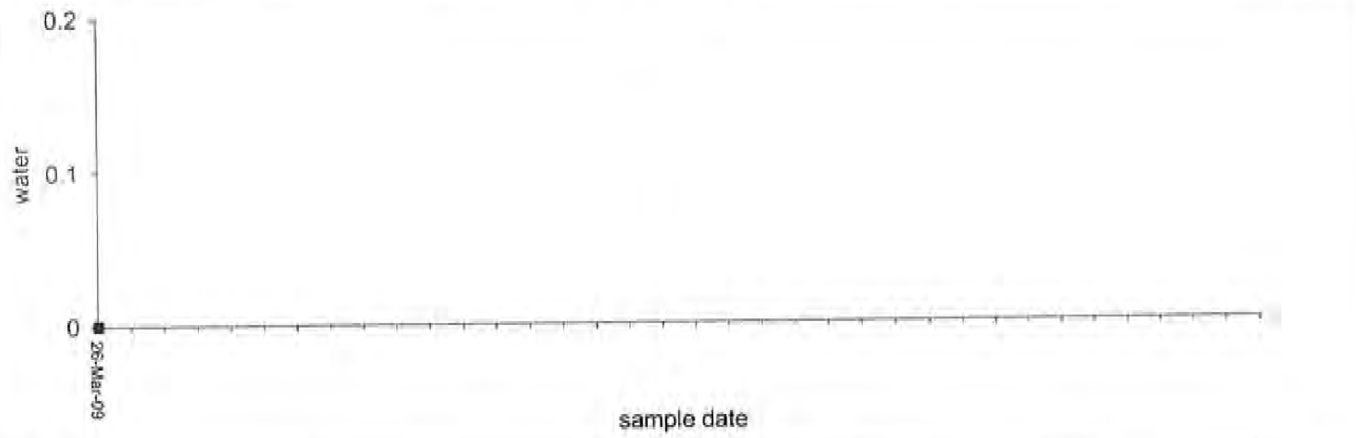
Report Date: 30th June 2009

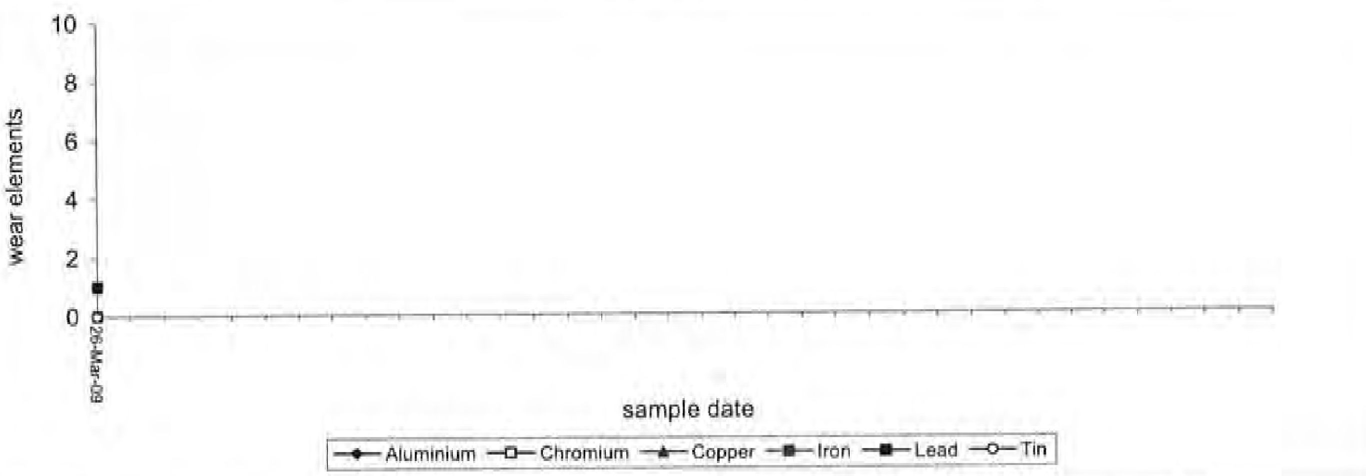
CONDITION MONITORING

SeaTec U.K. Ltd.
Skypark
8 Elliot Place
Glasgow G3 8EP
Technical Support: Pact-oilanalysis@seatec-services.com

Vessel:	STELLAR VOYAGER	**Manufacturer:**	KOCKS
		Model:	1907-8820
IMO Number:	9249180	**Serial No:**	
		Oil Grade:	FAMM RANDO HDZ 32
Machinery:	ANCHOR WINDLASS STBD HYD. SYSTEM	**Oil Volume Litres:**	







Annex D

MAIB Safety Bulletin

MAIB SAFETY BULLETIN 1/2009

Catastrophic Failure of High Pressure
Hydraulic Anchor Windlasses

Marine Accident Investigation Branch
Mountbatten House
Grosvenor House
Southampton
SO15 2JU

MAIB SAFETY BULLETIN 1/2009

This document, containing an urgent safety recommendation, has been produced for marine safety purposes only, on the basis of information available to date.

The Merchant Shipping (Accident Reporting and Investigation) Regulations 2005 provide for the Chief Inspector of Marine Accidents to make recommendations at any time during the course of an investigation if, in his opinion, it is necessary or desirable to do so.

This Safety Bulletin is issued to raise awareness of the potentially life threatening danger caused by a series of accidents involving hydraulic windlass motors, probably as a result of excessive tension being placed on the anchor chain. It recommends windlass manufacturer TTS Kocks GmbH immediately determines the technical causes for several recent catastrophic failures of its equipment and provide engineering and design solutions to prevent similar failures in the future.

The Safety Bulletin is published with the support of the Australian Transport Safety Bureau (ATSB), the German Federal Bureau of Maritime Casualty Investigation (BSU), and the Bahamas Maritime Authority (BMA).

Stephen Meyer
Chief Inspector of Marine Accidents

Australian Government
Australian Transport Safety Bureau

BSU
Bundesstelle für Seeunfalluntersuchung
Federal Bureau of Maritime Casualty Investigation

The Bahamas Maritime Authority

This bulletin is also available on our website: www.maib.gov.uk

Press Enquiries: 020 7944 3231/3387; Out of hours: 020 7944 4292
Public Enquiries: 0300 330 3000

BACKGROUND

Since 2007, the MAIB has been made aware of the catastrophic failure of a number of high pressure hydraulic anchor windlasses. Of those that have occurred, the following are particularly noteworthy:

- On 25 June 2007, the tanker *Young Lady* started to drag her anchor in Tees Bay, UK. The vessel was in ballast, the wind speed was in excess of 40 knots and there was a heavy northerly swell. The master decided to weigh anchor and depart, but during the operation the Nippon Pusnes windlass hydraulic motor suffered a catastrophic failure and the cable ran out to the bitter end. The vessel continued to drag her anchor until the anchor flukes snagged on a submerged gas pipeline (MAIB investigation report 3/2008).

- On 13 December 2008, the hydraulic motor casing of the TTS Kocks high pressure windlass on board the Hong Kong, China registered container ship *APL Sydney,* fractured as the vessel was heaving in her anchor in Port Philip Bay, Melbourne, shortly after the anchor had dragged in gale force winds and had ruptured a submerged gas pipeline. There were no injuries. This accident is being investigated by the Australian Transport Safety Bureau which also identified another failure of anchor windlass hydraulic motor while investigating the grounding of the Singapore registered woodchip carrier *Crimson Mars* in May 2006.

- On 23 March 2009, the hydraulic motor of the TTS Kocks high pressure windlass on board the Bahamas registered crude oil tanker *Stellar Voyager* exploded as the vessel attempted to weigh anchor in Tees Bay, UK. With the wind gusting up to 30 knots and a 2m swell, the anchor chain was under considerable tension. The windlass motor was in the 'heave' position but the anchor chain had started to render or pay out. When the windlass motor casing shattered, the windlass operator was seriously injured by debris, some of which was thrown as far as 40m. This accident is being investigated by the MAIB and the Bahamas Maritime Authority.

  Preliminary findings of metallurgical examination of the failed components recovered from *Stellar Voyager* have identified:

  - There is no evidence of damage caused by fatigue, metallurgical defects or impact.
  - The toughened steel cylinder and pistons of the axial piston displacement motor had been subjected to extremely high internal pressures.
  - Signs that the outer cast iron casing had fractured under extreme internal pressure and on impact with broken components of the hydraulic motor.

- On 19 May 2009, the hydraulic motor of the TTS Kocks high pressure windlass on board a German registered LPG vessel exploded as the vessel was heaving in her anchor off the coast of Florida, USA. The vessel was in ballast and the wind speed was up to 38 knots. The windlass operator was seriously injured by the flying debris. This accident is being investigated by the vessel's owners and her classification society.

SAFETY ISSUES

The frequency and consequences of the catastrophic failures of high pressure windlass motors highlighted is a serious cause for concern. These and other similar accidents appear to have occurred when heaving in the anchor in adverse sea and weather conditions when the anchor chain has been tensioned beyond the intended safe loading of its windlass. This can be avoided by:

- Closely monitoring the predicted weather and sea conditions and ensuring that the anchor is recovered in good time, before the conditions make this difficult to achieve; and
- Using main engines to manoeuvre a vessel to relieve tension in the anchor chain before 'heaving in'. This also helps to prevent an anchor from 'breaking out' and dragging while weighing.

However, the risk of an anchor chain suddenly tensioning can never be fully eliminated. Therefore, until technical solutions are introduced by all windlass manufacturers that prevent the over-loading of high pressure windlasses resulting in their catastrophic failure, it is imperative that an anchor chain is closely monitored when weighing, and that 'heaving in' is stopped as soon as any significant tensioning is observed or difficulty is experienced.

RECOMMENDATION

While it is recognised that in the longer term the risk of catastrophic failures to all windlass motors will need to be addressed by more stringent industry performance standards, in view of the recent accidents involving its equipment, TTS Kocks GmbH is recommended to expedite its action to:

2009/140S **Identify the technical reasons for the catastrophic failures of its windlass motors and determine engineering and design solutions to prevent similar accidents on board vessels fitted with its equipment.**

REQUEST FOR INFORMATION

To gain an accurate assessment of the incidence of the catastrophic failure of anchor windlasses, all ship owners, ship managers, windlass manufacturers, classification societies and marine accident investigation organisations are requested to forward details of any incidents which have resulted in the fracture of the windlass motor casing. All information, which ideally should include the date of the occurrence, the vessel's name, details of any injuries, and the manufacturer of the windlass, will be treated in confidence and only used for the purpose of accident investigation. Reports should be forwarded to maib@dft.gsi.gov.uk with the title '**windlass motor fractures**'.

Issued August 2009