

MECHANICAL INVESTIGATION INTO

**THE FAILURES OF WATER PUMP GEARBOXES FITTED
TO FIRE TENDERS OPERATED BY ST HELENA AIRPORT**

PREPARED AT THE REQUEST OF:

St Helena Government

BY:

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EXECUTIVE SUMMARY

BACKGROUND

GBB were instructed by the St Helena Government to consider mechanical failures observed in the water pump gearboxes fitted to three Airport Rescue and Firefighting (ARFF) vehicles operated at St Helena Airport that resulted in the closure of the airport and suspension of routine commercial operations between 6 and 15 February 2026.

The failure related to the ‘eccentric’, a subcomponent of the water pump gearbox that drives a secondary ‘primer’ pump that ejects any air from within the pump system and fills (primes) it with water, removing any airlocks that could prevent or impede the discharge of water. Consequently, the primer pump and its constituent components are critical for correct operation of the ARFF water pumps.

As part of my investigation into the failure of the eccentrics, I attended St Helena Airport between Monday 27 July 2026 and Friday 7 August 2026. During this time, I was assisted by all operational teams of St Helena Airport in all aspects of my investigation.

The investigation considered mechanical examination and testing, oil analysis, operational matters of the ARFF vehicles, maintenance and servicing, the water source used by the ARFF vehicles, and the material of the failed component.

CONCLUSIONS

The eccentrics each appeared to have failed as a result of disintegration of their structure, and the material properties had altered when compared with an unused exemplar eccentric.

There were numerous cracks throughout the eccentrics, in a multitude of locations and across all planes of the structures. The multiplanar directionality and multiple locations of these cracks did not appear to coincide with any one loading direction. This would suggest that the cracks were not solely caused by the applied mechanical loading, but likely at least partly due to a breakdown of the structure and changes to the material properties.

There was differential staining affecting different regions of the structure that was likely caused by the presence of the oil. The different extent of staining is likely related to the duration of exposure to the oil, where the darker areas were exposed for a longer period of time than the lighter coloured areas. There was also localised staining that had penetrated into some of the cracks, thereby increasing their visual contrast. The presence of staining within the cracks would suggest that these cracks had been developing for an extended period of time, and long enough for the oil to have penetrated the cracks and have caused the observed staining.

There was also scoring damage to the metal collars that fit around the outer circumference of the eccentrics, which could suggest insufficient lubrication, for example, insufficient viscosity.

The exact point at which the damage first commenced could not be determined from the available evidence. However, the evidence would suggest that it had been developing over an extended period of time.

The eccentric is formed of an elastomer, that while resistant to oils and greases, is susceptible to hydrolysis, a chemical breakdown and decomposition of the structure in contact with water.

Analysis of the oil used in the gearboxes of each of the ARFF vehicles has indicated water contamination at different points in time since the incident. However, no oil samples from prior to the incident were retained or sent for testing. As such, the extent of any previous water ingress is not known. Nevertheless, a potential link has been identified between water exposure and a possible change in the structure and/or properties of the elastomer material, and degradation and/or disintegration of the structure.

At the point that the damage to the eccentrics was observed, they had not yet failed completely and catastrophically, and were still performing their function, despite their developing damage. This meant that there was no means through the routine testing and use of the ARFF vehicles that any developing damage could have been detected.

The eccentric components are housed within a sealed gearbox, and as such there was no way in which the routine inspection and servicing as stipulated by the manufacturer could have detected the developing damage.

In light of the continued functionality of the eccentrics (at the point that the damage was first observed) and the lack of inspection of the eccentrics, there would have been no prior indication or expectancy of any developing failure.

At the point that the damage was first observed, there would also have been no way to predict the remaining working life of the eccentrics, or the duration that the pumps could continue to be operated without sustaining a complete and catastrophic failure of the eccentrics.

Had the eccentrics failed completely, the primer pump would have immediately lost all functionality, meaning that it might not have been capable of removing any airlocks that were within the system. In such a scenario, an airlock could potentially completely prevent, or severely restrict the flow of water through the pump.

Consequently, a complete and catastrophic failure of the eccentrics has the potential to render the ARFF vehicle(s) incapable of discharging any water.

OTHER RELEVANT FACTORS

The ARFF vehicles were retrofitted to provide firefighting capability by a third-party company, Marcé, who have also provided ongoing servicing for the vehicles. The water pumps used in the ARFF vehicles were not manufactured by Marcé, but by a separate company, Ziegler.

When St Helena Airport acquired the ARFF vehicles from Marcé, an operating manual for the pump (prepared by Ziegler) was provided. The operating manual had an issue date of 2014. This manual stipulated the use of a particular oil within the gearbox (SAE 10 oil). In 2021, Ziegler issued an updated manual that stipulated a different oil (SAE 10W40), the viscosity of which is over approximately twice that of the original oil, i.e. a significantly thicker oil.

In general, an oil of higher viscosity will be able to support greater loads than an oil with lower viscosity, and as such, can in some circumstances provide greater lubrication properties, and make components less prone to wear than a thinner oil. However, a higher viscosity oil will flow less readily than a lower viscosity oil.

The updated manual was not provided to St Helena Airport until 2026 following the failure of the eccentrics, when Marcé attended to conduct repairs. This meant that St Helena Airport was using a different oil to that stipulated by Ziegler for a period of approximately five years before they took receipt of the updated manual. On receipt of the updated manual from Marcé, St Helena Airport subsequently adopted the use of 10W40 oil. This then raises questions as to why the specified oil was changed by the pump manufacturer, and why the updated manual was not provided to St Helena Airport by the service partner.

Aside from the different oil used in the gearboxes, review of the maintenance and servicing, and routine testing of the pumps *prima facie* suggest that all actions were conducted in accordance with the operating manual.

There is no evidence to suggest that prior to the failure of the eccentrics, St Helena Airport have operated, maintained, serviced, or otherwise managed the ARFF vehicles in any way other than that stipulated by the manufacturer and as set out in the operating manual that had been provided to them (i.e. the 2014 issue OEM operating manual from Ziegler).

OTHER OCCURRENCES OF FAILURES

This investigation has identified a number of other, independent cases where the same eccentrics have failed in seemingly identical manners, whereby the structure has disintegrated and crumbled, suggesting that this failure was not an isolated occurrence.

FUTURE RECOMMENDATIONS

While the routine maintenance schedule, and operating and testing procedures for the ARFF vehicle water pumps as conducted by St Helena Airport all appear to be within the specification as stipulated by the manufacturer, a number of actions relating to enhanced monitoring of the eccentrics, as well as a more proactive management strategy with the service provider, have been recommended to help mitigate the risks of similar incidents occurring again in the future.

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PREFACE

1. INTRODUCTION & EXPERIENCE

- 1.1. I am Dr Ross Beesley, a Forensic Engineer of GBB (UK) Ltd, of Unit 8, Caxton Road, Fulwood, Preston, United Kingdom.
- 1.2. I am a Chartered Engineer and Forensic Engineer in the Large Loss division of GBB, where I specialise in mechanical failure investigation. My professional experience includes examination and analysis of mechanical defects and material failures in a wide range of applications including pedal cycles, passenger cars, commercial and agricultural vehicles, highways maintenance vehicles, and domestic infrastructure.
- 1.3. I have a Master's degree in mechanical engineering and an Engineering Doctorate in nuclear engineering where I specialised in structural integrity, material failure, component fatigue life assessment, and computational modelling.
- 1.4. My qualifications and experience are attached at Appendix A.

2. TERMS OF REFERENCE

- 2.1. I have been instructed by the St Helena Government to consider mechanical failures observed in the water pump gearboxes fitted to three Airport Rescue and Firefighting (ARFF) vehicles operated at St Helena Airport that resulted in the closure of the airport and suspension of routine commercial operations between 6 and 15 February 2026.
- 2.2. In addition to this investigation report, I have provided a separate independent summary report in EXHIBIT RB/1. This report is presented such that it can be read independently of this report if required, for example as part of a press release.

3. OBJECTIVES

- 3.1. The key aims of this investigation are to provide an independent investigation into critical faults identified on the three ARFF vehicles at St Helena Airport that resulted in the closure of the airport. More specifically, the objectives are to:
 - (1) *Determine the root cause(s) leading to failure/unavailability of the ARFF vehicles;*
 - (2) *Assess whether the failures indicate systemic weaknesses in design, manufacture, installation, operation, maintenance and/or inspection practises;*
 - (3) *Recommend corrective and preventative actions to eliminate recurrence.*
- 3.2. As part of the investigation, the following specific questions have also been raised:

- *What failed, and what is its function?*
- *How did it fail? What were the mode(s) of failure?*
- *Why did it fail? Were there any underlying causes?*
- *When were the failures initiated?*
- *Could the failure have been detected earlier? Were monitoring, inspections, maintenance etc. adequate?*
- *What are the implications for similar systems or assets at the Airport?*
- *What actions are required to prevent recurrence?*

4. PARTIES INVOLVED

- 4.1. For clarification and ease of reference through this report, an overview of the involved parties, and their abbreviations used throughout this report are provided below.
- 4.2. This investigation has been instructed by the St Helena Government ('SHG').
- 4.3. The mechanical failure involves three Airport Rescue and Firefighting ('ARFF') vehicles operated by St Helena Airport Ltd ('SHAL'). The ARFF vehicles are identified by SHAL as Response 1, Response 2, and Response 3, and displayed the identifiers 'R1', 'R2' and 'R3', respectively.
- 4.4. The ARFF vehicles are Mercedes-Benz Actros heavy-duty truck vehicles that have been retrofitted to provide ARFF capability by Marcé Fire Fighting Technology PTY Ltd, 1012 Ergon Road, Lyttelton Manor, Centurion, Gauteng, South Africa ('Marcé'). Marcé have also provided servicing of the ARFF vehicles operated by SHAL.
- 4.5. The specific failures of this investigation were sustained to a sub-component of the gearbox of the water pump of each ARFF vehicle, and in particular, the 'eccentric' (described further below). The water pump assembly, including the gearbox, were manufactured by Albert Ziegler GmbH, Albert-Ziegler-Straße 1, 89537 Giengen/Brenz, Germany ('Ziegler').
- 4.6. It is reported that SHAL do not have any direct relationship with Ziegler, but rather all communication and interactions with regards to maintenance, servicing, spare parts or the like is done through Marcé.
- 4.7. For ease of reference, the involved parties are summarised below:

St Helena Government	SHG	Instructor of investigation
St Helena Airport Ltd	SHAL	Operator of index ARFF vehicles
Marcé		Retrofitter of ARFF vehicles & servicing provider
Ziegler		Manufacturer of water pumps
Response 1	R1	
Response 2	R2	The ARFF vehicles operated by SHAL
Response 3	R3	

BACKGROUND

5. BACKGROUND & GENERAL CIRCUMSTANCES

- 5.1. The reported circumstances are that critical faults were identified in the water pumps of all three Airport Rescue and Firefighting (ARFF) vehicles at St Helena Airport that in turn rendered the airport unable to meet the minimum firefighting capability required for Category 6 flight operations. In light of this, the Accountable Manager made the decision to close the airport, cancelling scheduled Airlink services on 7 and 10 February, a Major Incident was declared, and Gold Command was activated.
- 5.2. Initial maintenance indicated cloudy gearbox oil in the ARFF vehicle water pump gearboxes. This was believed to be due to water ingress and so replacement seals were ordered. Subsequent disassembly of one of the pumps and gearboxes in preparation for replacement of the seals revealed significant deterioration of a sub-component of the gearbox, the 'eccentric'.
- 5.3. Disassembly of the other two fire tender gearboxes showed similar early stage deterioration of the same eccentric component.
- 5.4. The domestic fire vehicles operated on St Helena cannot substitute the ARFF units; therefore, even if support from the domestic fire vehicles was provided, the airport could not meet the regulatory firefighting requirements for the Embraer E190, the connecting aircraft to the Island, operated by Airlink.
- 5.5. Emergency mitigations were conducted, and following review on 8 February 2026, Air Safety Support International (ASSI) reinstated Category 4 capability.
- 5.6. Following observation of the failed eccentrics, the retrofitter and supplier of the ARFF vehicles, Marcé Fire Fighting Technology PTY Ltd, attended St Helena Airport via private charter flight to conduct repairs on the ARFF vehicles, allowing them to be returned to service, the airport be reopened, and flights reinstated.
- 5.7. This investigation serves to consider the apparent near simultaneous failure of all three tenders that resulted in the closure of the airport.
- 5.8. In conducting this investigation, I have been provided with a large number of documents from St Helena Airport Ltd, which I have set out at Appendix B.
- 5.9. I have also conducted my own on-site investigation, including mechanical examination of the failed components, endoscopic inspection of the gearboxes, inspection of the retained oil samples, performing preliminary testing, witnessing routine testing and servicing procedures, and interviewing relevant members of staff.
- 5.10. It is on the provided documentation and my on-site investigation that I base my analysis.

6. RESPONSE VEHICLES INVOLVED

6.1. Overview

6.1.1. As described previously, mechanical failures were sustained to three ARFF vehicles operated by SHAL. Also as described previously, the ARFF vehicles are based on Mercedes-Benz trucks, retrofitted and converted by Marcé to fire fighting vehicles. Each of the ARFF vehicles are referred to by SHAL as Response 1 (R1), Response 2 (R2) and Response 3 (R3). For ease of reference throughout this report, further information relating to each of these vehicles, their vehicle registration, Vehicle Identification Number, and pump serial numbers are described below.

6.2. Response 1 (R1)

6.2.1. R1 is a 6x6 Mercedes-Benz Actros 3358 of Vehicle Identification Number (VIN) 'WDB9301832L907177', bearing the vehicle registration number (VRN) '4757'.

6.2.2. R1 is fitted with a Ziegler FPN10-4000-2HH pump of serial number 'N/0000005744'.

6.2.3. A photograph of R1 is provided in Figure 1, below, and the VIN and pump serial numbers are shown in Figure 2 and Figure 3, respectively, both overleaf.



Figure 1: Response 1 (R1) overview

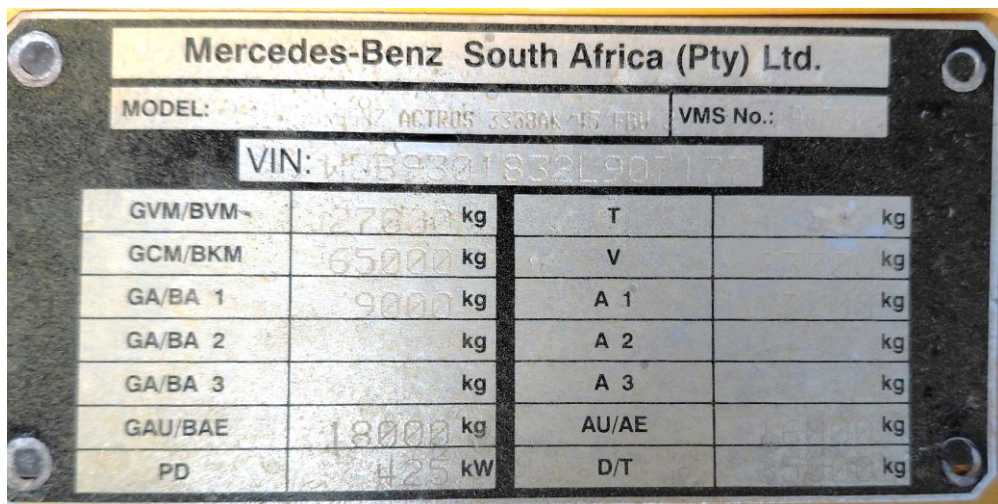


Figure 2: Response 1 (R1) Vehicle Identification Number (VIN)

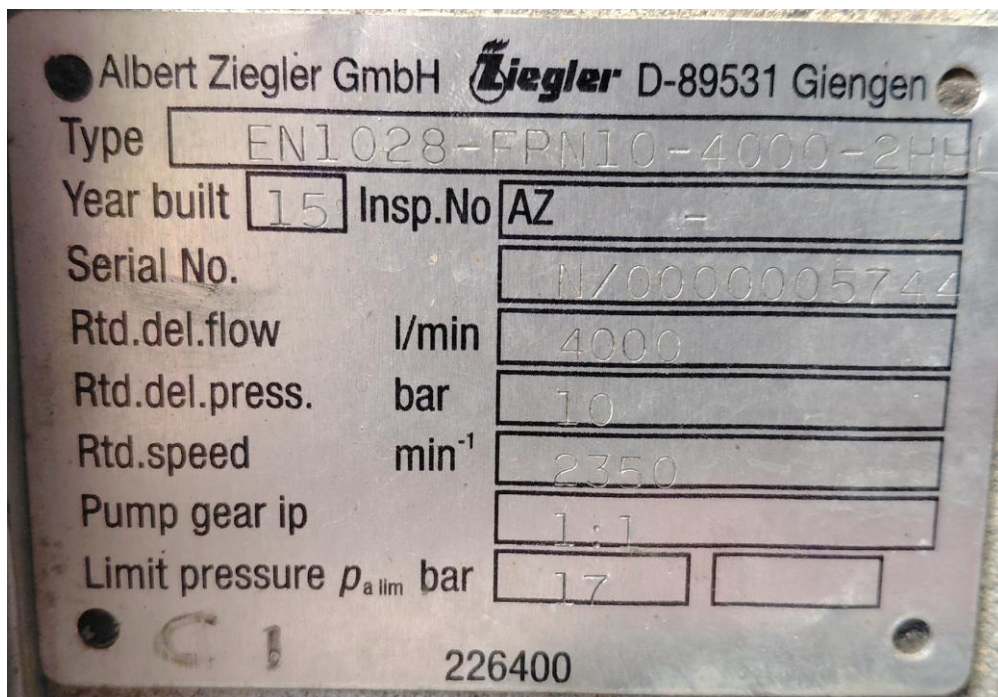


Figure 3: Response 1 (R1) pump serial number

6.3. Response 2 (R2)

- 6.3.1. R2 is a 6x6 Mercedes-Benz Actros 3358 of VIN 'WDB9301832L907178', bearing the VRN '4758'.
- 6.3.2. R2 is fitted with a Ziegler FPN10-4000-2HH pump of serial number 'N/00000005743'.
- 6.3.3. A photograph of R2 is provided in Figure 4, overleaf, and the VIN and pump serial numbers are shown in Figure 5, overleaf, and Figure 6, on page 7.



Figure 4: Response 2 (R2) overview

Mercedes-Benz South Africa (Pty) Ltd.			
MODEL: MERCEDES-BENZ ACTROS 3358AK/45 FBV		VMS No. 2987306	
VIN: WDB9301832L907178			
GVM/BVM	27000 kg	T	kg
GCM/BKM	65000 kg	V	23700 kg
GA/BA 1	9000 kg	A 1	7700 kg
GA/BA 2	kg	A 2	kg
GA/BA 3	kg	A 3	kg
GAU/BAE	18000 kg	AU/AE	16000 kg
PD	425 kW	D/T	65000 kg

Figure 5: Response 2 (R2) VIN

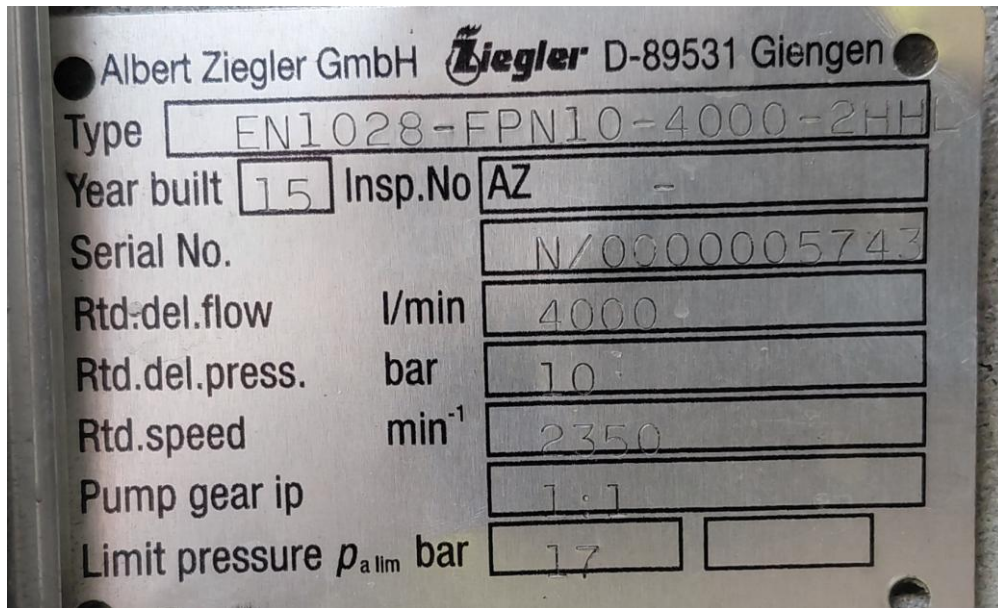


Figure 6: Response 2 (R2) pump serial number

6.4. Response 3 (R3)

- 6.4.1. R3 is a 4x4 Mercedes-Benz Actros 1858 of VIN 'WDB9320732L908284', bearing the VRN '4759'.
- 6.4.2. R3 is fitted with a Ziegler FPN10-4000-2HH pump of serial number 'N/00000005742'.
- 6.4.3. A photograph of R3 is provided in Figure 7, below, and the VIN and pump serial numbers are shown in Figure 8, and Figure 9, both overleaf.



Figure 7: Response 3 (R3) overview

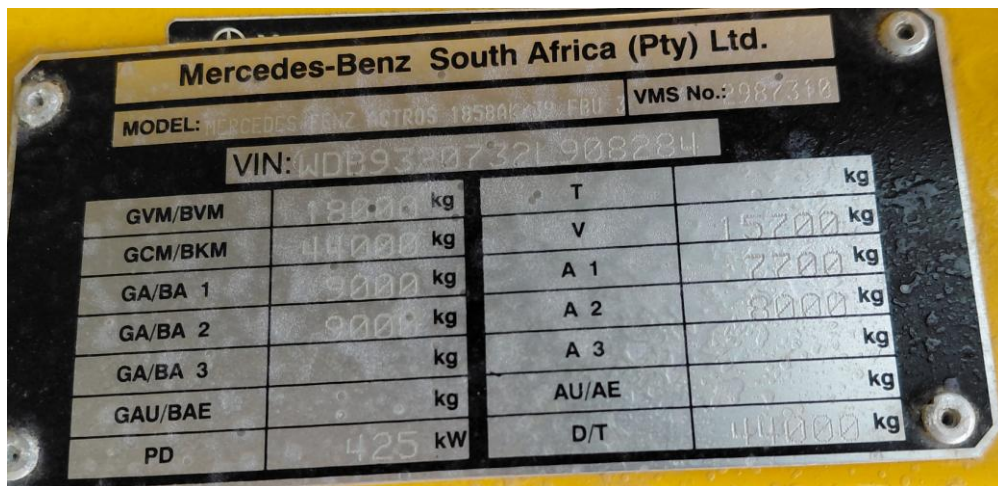


Figure 8: Response 3 (R3) VIN

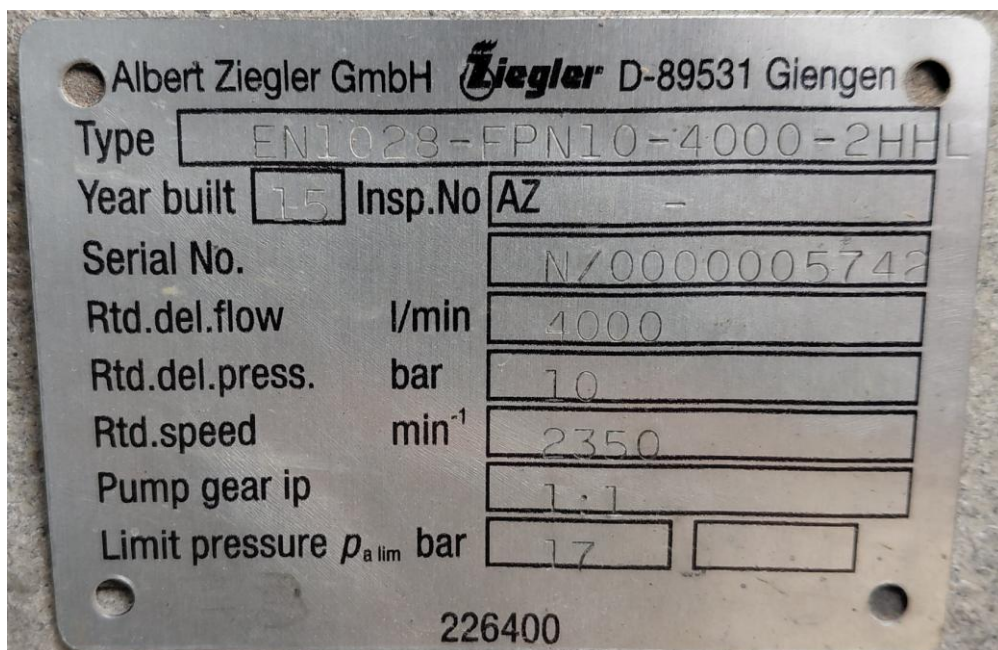


Figure 9: Response 3 (R3) pump serial number

7. SEQUENCE OF EVENTS

7.1. For ease of reference, a brief overview of the sequence of events is provided below.

29/11/2025 R1 undergoes annual service, which was completed satisfactorily, with no issues or defects identified.

02/12/2025 R2 undergoes annual service where oil is found to be contaminated with water, resulting in failure of the service. Suspected cause is due to the gearbox oil seal leaking, but requires further investigation. The oil is drained and replaced.

03/12/2025 Requests are made to a number of suppliers to acquire replacement seals.

- 08/12/2025 R2 gearbox oil monitored again where further contamination of the oil is observed. The oil is drained and replaced.
- 10/12/2025 R3 undergoes annual service where oil is found to be contaminated with water, resulting in failure of the service. The extent of contamination is reported to be less than that of R2 and it is deemed that R3 is fit to remain in service subject to routine monitoring of R3 gearbox oil on flight days going forward.
- 08/01/2026 Further inspection of R1 gearbox oil finds oil to be satisfactory, but it is agreed that R1 gearbox oil will be subject to bi-weekly monitoring going forward.
- 10/01/2026 R2 is withdrawn from service.
- 12/01/2026 Removal and disassembly of R2 pump commences in preparation for replacement of the seals. During removal, damage to the eccentric is observed.
- 05/02/2026 Bi-weekly check of R1 finds contamination of the gearbox oil. The oil is drained and replaced, and daily monitoring of the oil commences going forward.
- 06/02/2026 Major incident is declared, the airport is closed and a press release is issued.
- 13/02/2026 Removal and disassembly of R1 pump is commenced where damage to the eccentric is observed. Assembly of R2 gearbox commences and broken bearing found.
- 22/02/2026 Refit work of R3 pump and replacement of the eccentric commences.
- 27/02/2026 Job cards signed and completed for repairs for R1, R2 and R3 pumps.

Following the first observation of contamination of the gearbox oil of R1 on 5 February, all oil samples taken from the gearboxes of each fire tender were retained for further analysis. However, it is reported that no oil samples prior to this date were retained. Further information relating to the oil analysis is described in Section 19.

8. RELEVANT BACKGROUND INFORMATION

8.1. Overview

- 8.1.1. In order to consider the observed mechanical failures of the eccentrics, it is first important to understand the general overall construction and assembly of the water pumps, and any potential interaction between the sub-components. To this end, a brief description of the assembly of the water pumps, and definitions of the terminology used in this report are provided below.

8.2. Water Pump Assembly

- 8.2.1. The water pumps used on the ARFF vehicles at St Helena Airport are two-stage centrifugal pumps, each comprising a low-pressure pump and a high-pressure pump.
- 8.2.2. In general, centrifugal pumps convert rotational kinetic energy into hydrodynamic energy of a fluid. During use, a fluid is drawn into the pump by a rotating impeller, which accelerates the fluid in a radially outwards direction towards a spiral-shaped funnel, from where it exits. This arrangement has the effect of increasing the pressure of the fluid at the exit. As fluid exits the pump, it creates a region of lower pressure at the inlet, in turn drawing more fluid into the pump, thereby creating a continuing flow.
- 8.2.3. The pumps are powered by a power-take-off (PTO), which is a system that transfers mechanical drive from the vehicle's engine via a drive shaft.
- 8.2.4. In this instance, the low-pressure pump is driven directly from the PTO. However, the high-pressure pump is driven via a gearbox rather than by direct drive from the PTO. A lever switch actuates the high-pressure pump.
- 8.2.5. In use, the PTO is activated, which powers the low-pressure pump, pumping water from the supply through the low-pressure pump, towards the outlets. From the low-pressure pump, the water can be directed to one of three outlets: the roof mounted turret; the front mounted turret; or the low pressure hoses situated at the rear of the vehicle. The low-pressure pump operates up to approximately 10 bar of pressure.
- 8.2.6. To activate the high-pressure pump, the lever switch is actuated, which engages a clutch within the gearbox, which in turn engages a drive gear that powers the high-pressure pump. Water from the outlet of the low-pressure pump is then simultaneously directed to the high-pressure pump, where its pressure is increased further, before being directed to the high-pressure hose outlets situated at the rear of the vehicle. In this way, the high-pressure pump acts as a supplementary boost to the low-pressure pump. The high-pressure pump operates up to approximately 30 bar.
- 8.2.7. The ARFF vehicles are capable of pumping water from two separate supplies: either from the on-board water storage tank, or from an external source via a 'drafting inlet'. Pipework connects the on-board water storage tank to the low-pressure pump, and an isolator valve situated between the tank and the low-pressure pump controls the flow of water from the tank to the pump.
- 8.2.8. Alternatively, an inlet hose can be connected to a separate inlet port on the pump (the 'drafting inlet') which can be used to draw water from an external supply, for example, an external water storage tank, bowser, pond or the like. When not in use, a sealing cap is connected to the drafting inlet, thereby blocking the flow from the drafting inlet.
- 8.2.9. When using the on-board water supply, the isolator valve between the water tank and the low-pressure pump is opened, and the sealing cap on the drafting inlet is engaged.

- 8.2.10. However, when using an external water supply, the isolator valve between the water tank and the low-pressure pump is closed, the sealing cap on the drafting inlet is removed, and a feed hose connected, which is then inserted into the external water supply. When the pump is operated in this manner, it will create a vacuum at the drafting inlet, which in turn will then create suction on the feed hose, drawing water from the external source into the pump, rather than from the on-board tank supply.
- 8.2.11. The pump also comprises a supplementary foam dispense that can feed into the water supply, which when mixed, creates a fire-retardant foam for use on fuel fires. However, this is not considered in this investigation.
- 8.2.12. If there is air within the pump, it can create an air-lock, impeding or restricting the fluid flow. To prevent this, a 'Trokomat' primer pump, situated immediately adjacent the gearbox and powered by the PTO, works to dispel any air from the pump and fill (or prime) the pump with water prior to use, thereby preventing any air-locks from forming within the pump system. This is described further separately below.
- 8.2.13. A schematic illustration of the pump arrangement is provided in Figure 10, below.

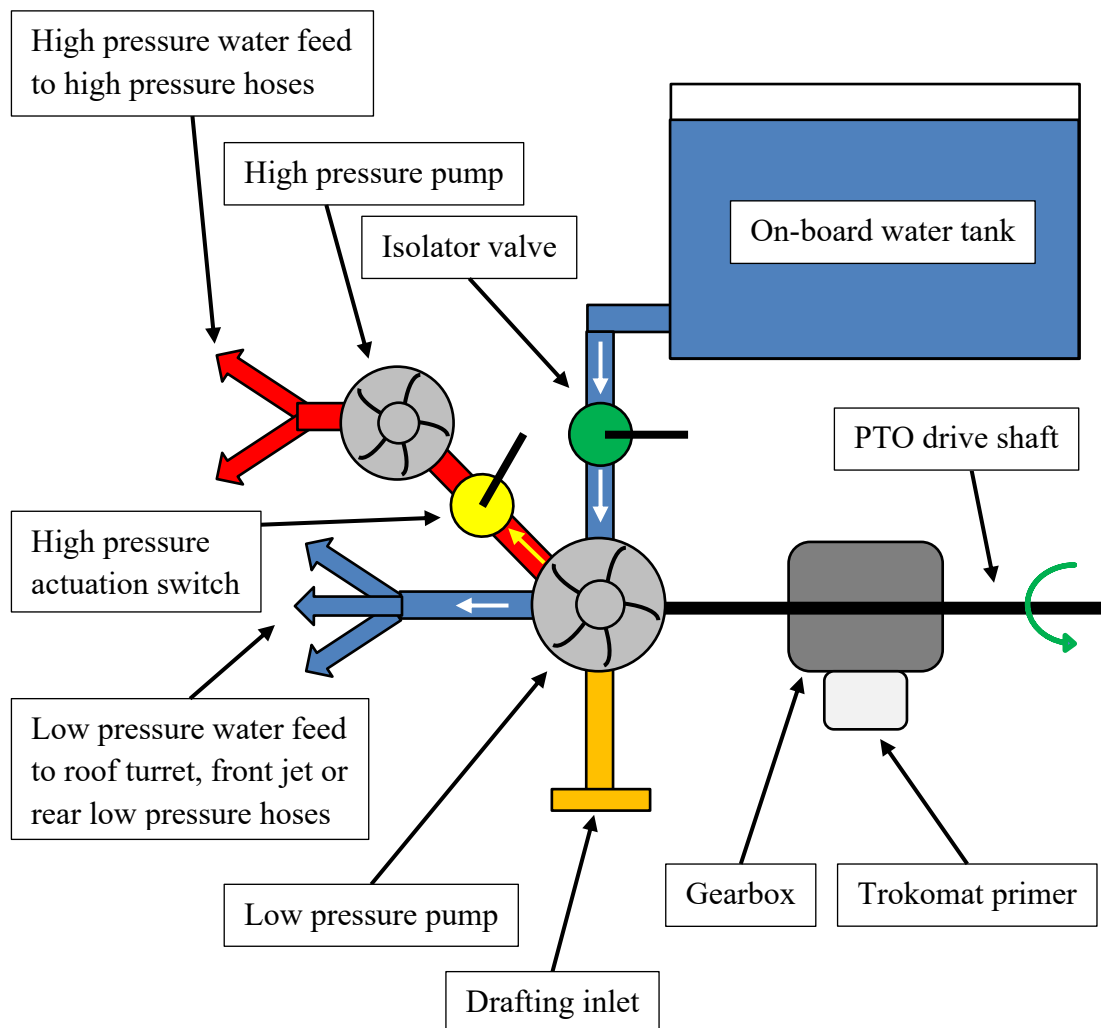


Figure 10: Schematic illustration of pump arrangement

8.3. Gearbox Assembly & Trokomat

- 8.3.1. As described previously, the high-pressure pump is not driven directly off the PTO, but rather via a gearbox. The gearbox comprises a single gear. When the lever switch is actuated, a clutch is engaged which then in turn engages the drive gear, thereby transmitting power to the high-pressure pump.
- 8.3.2. Also as described previously, the pump is fitted with a Trokomat primer, used to remove air from the pump and prime it with water ready for use. The Trokomat system comprises an ‘eccentric’; a metal collar; a pair of pistons; and hydraulic cylinders. It is the eccentrics that failed in this instance and are the focus of this investigation.
- 8.3.3. The hydraulic cylinders form a secondary pump that removes air from the main pump. The hydraulic cylinders are driven by the pistons, which are themselves actuated by the eccentric and metal collar. The eccentric and metal collar are situated within the gearbox, with the eccentric engaged on the PTO shaft, and the metal collar fitted to the outer circumference of the eccentric. The pistons pass through the outer casing of the gearbox, to the hydraulic cylinders on the exterior of the gearbox.
- 8.3.4. The eccentric is a generally annular shaped cylindrical component that is configured to engage with the PTO driveshaft via locking keyways that mate between rectangular channels in both the eccentric and the PTO shaft. This means that as the PTO shaft rotates, the eccentric will also rotate. The cross-sectional hole of the annulus through which the driveshaft passes is not central and is rather asymmetrical and offset from (i.e. is eccentric to) the axis of rotation. This means that the radius of rotation of one side of the eccentric side is greater than that of the opposing side. This creates a protruding lobe that rotates with the PTO shaft. When viewed from the side, the eccentric is generally cylindrical in shape, but the outer diameter of one end of the cylinder is greater than the other, forming a generally ‘T’ shaped cylinder. An exemplar eccentric is shown in Figure 11, below.



Figure 11: Eccentric component

- 8.3.5. In use, with the eccentric fitted to the PTO shaft, the metal collar is fitted around the circumference of the thinner end of the eccentric. Two diametrically opposing pistons pass through the outer casing of the gearbox, and are spring-loaded such that the tips of the pistons are pushed towards and rest against the outer surface of the metal collar.
- 8.3.6. The eccentric profile means that as it rotates, it will push the pistons to varying extents depending on the specific point of the eccentric in contact with each piston. For instance, as the off-axis lobe comes into contact with the first piston, its eccentric profile will result in that piston being pushed away from the PTO. As the PTO continues to rotate, the lobe will then move away from the first piston, and that piston will be pushed back towards the PTO by the spring. This process then repeats with the second piston as it makes contact with the eccentric lobe.
- 8.3.7. Due to the diametrically opposing positions of the pistons (i.e. on either side of the PTO shaft), as one piston is at its furthest position from the PTO shaft, the other piston is at its closest position to the PTO shaft. In this way, the eccentric and metal collar ring act as a cam, that as they rotate, drive the pistons backwards and forwards.
- 8.3.8. On the exterior of the gearbox case, the pistons connect to the hydraulic cylinders. The hydraulic cylinders comprise a series of intake and exhaust ducts. The intake ducts are connected to the main pump chamber, and the reciprocal linear motion of the pistons on the hydraulic cylinders provides a pumping action which draws in any air from the pump, through the suction lines, and discharges it via the exhaust ducts. In this way, the rotation of the eccentric automatically removes any air from the pump.
- 8.3.9. As the air is removed from the suction lines, water is drawn into the pump chamber in its place, thereby filling (priming) the pump with water, ready for use. The Trokomat is also configured such that when pumping has commenced, the flow of water applies pressure on the hydraulic cylinders, which overcomes the spring force, and moves the pistons radially outwards and away from the metal collar and eccentric. In this way, once the pump is operating and pumping water, the Trokomat will automatically and passively disengage, preventing unnecessary wear on the metal collar and eccentric.
- 8.3.10. The eccentric is formed of an elastomer material with a degree of malleability, such that it provides shock absorption to the shaft and Trokomat. The presence of the metal collar means that direct contact between the pistons and the eccentric is avoided. The tips of the pistons are formed of a different material to that of the main body of the piston. At this stage, I have not been provided with specific material properties of the piston; however, the appearance of the piston suggests that the main body of the pistons are formed of stainless steel, and the tips are formed of brass.
- 8.3.11. A schematic illustration of the gearbox is shown in Figure 12, overleaf, and a photograph of the gearbox assembly is shown in Figure 13, also overleaf. Further schematic diagrams of the operation of the Trokomat in response to the rotation of the eccentric are provided in Figure 14, and Figure 15, both on page 15. For simplicity, the hydraulic cylinders and intake and exhaust ducts are not shown. For further

simplicity, the additional components of the gearbox, for example, the gear and clutch, are not shown in Figure 14 and Figure 15.

- 8.3.12. In use, the gearbox case is filled with a suitable gearbox oil to ensure lubrication of the internal components (e.g. gear, eccentric, collar, pistons etc.). However, it is important to note that the oil was drained from the gearbox prior to these photographs being taken, and hence is not visible. The gearbox is reported to have an oil capacity of 1.5 litres.

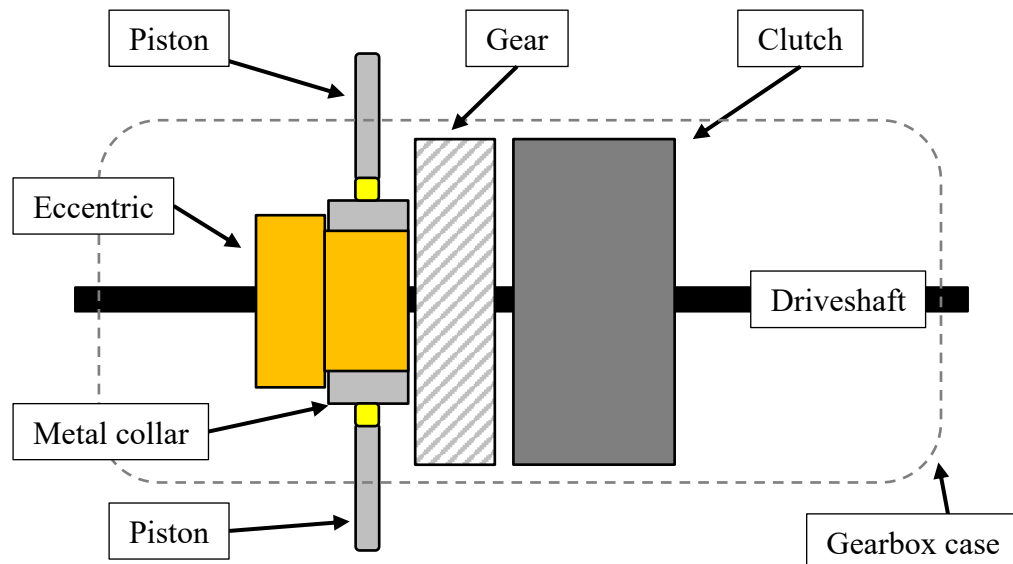


Figure 12: Schematic illustration of gearbox assembly

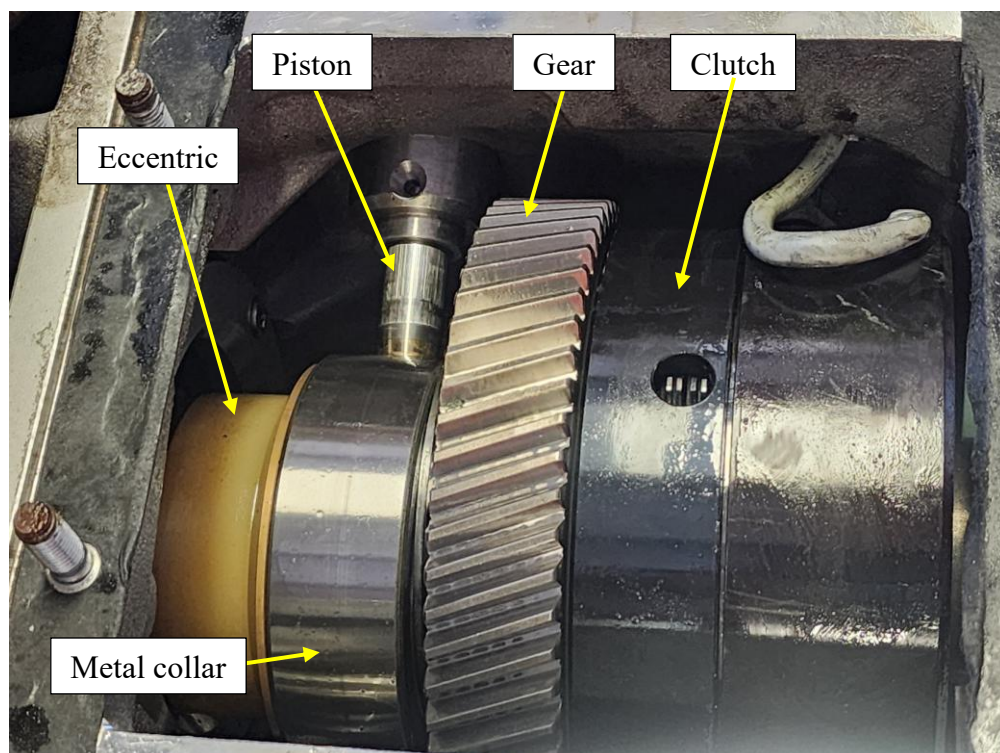


Figure 13: Photograph of gearbox assembly

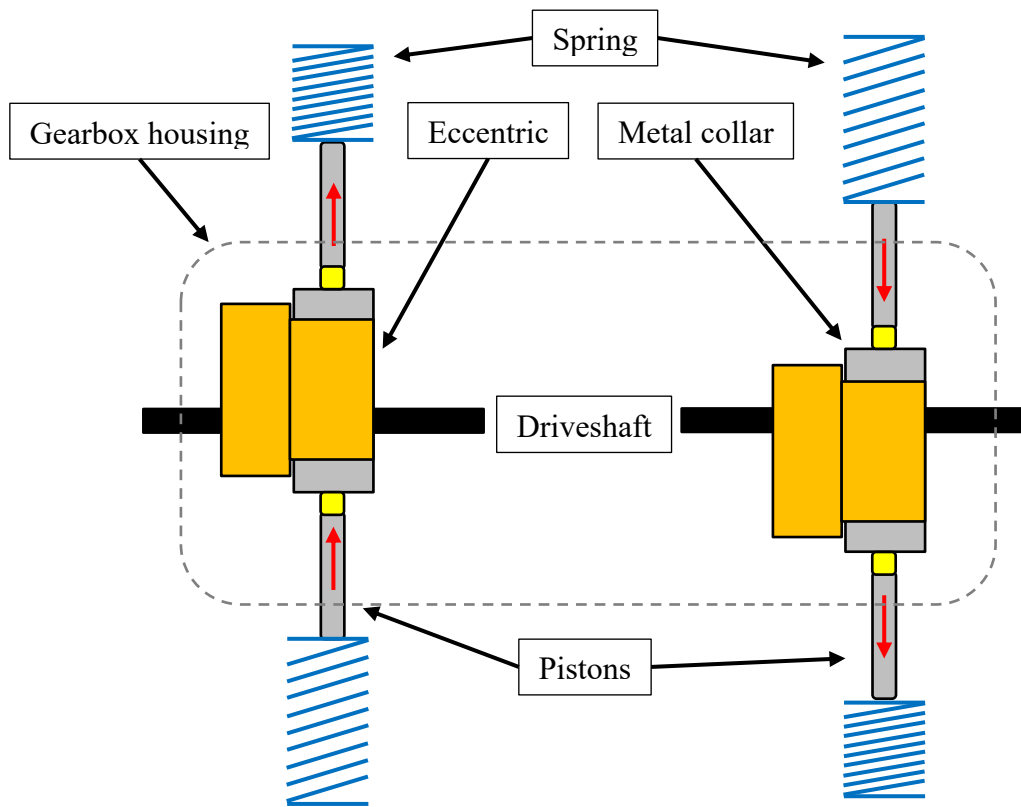


Figure 14: Schematic illustration of eccentric drive system of Trokomat (plan view)

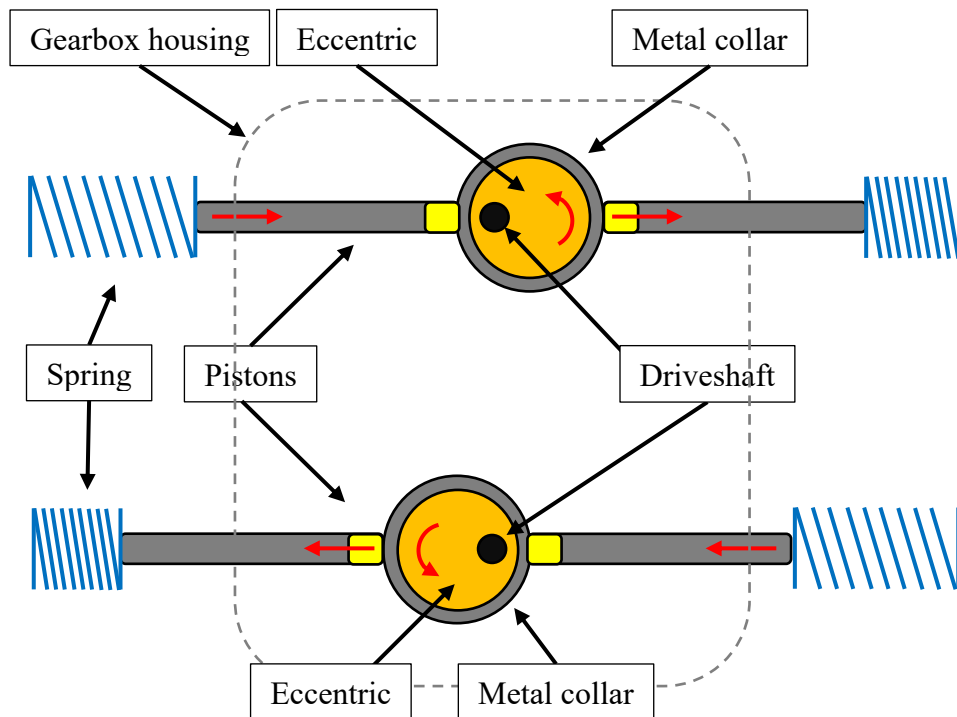


Figure 15: Schematic illustration of eccentric drive system of Trokomat (side view)

9. OTHER RELEVANT FACTORS

9.1. There are a number of factors that are potentially of relevance in this investigation: namely the frequency of stipulated changes of the gearbox oil; the specific gearbox oil as stipulated by the manufacturer; and the nature of the water supply used in and pumped by the ARFF vehicles. These factors are introduced below, but are discussed in further detail in the ANALYSIS section.

9.2. Oil Change Frequency

9.2.1. The original equipment manufacturer (OEM) pump operation manual stipulates that the gearbox oil be changed after every 50 operating hours of the pump, or at least once per year.

9.2.2. To date, the ARFF vehicles at St Helena Airport have not exceeded 50 pump operation hours per annum, and so instead the oil is replaced once per year.

9.2.3. This frequency means that if any issues arise with the oil, for example, contamination, it may not necessarily be detected until the following annual service, in turn meaning that an oil issue could go undetected for up to one year. Consequently, if an issue with the oil is detected at an annual service, it is not possible to determine when, during the time since the last oil change, that the issue commenced.

9.3. Specific Oil Use

9.3.1. As described previously, while the OEM of the pump is Ziegler, the ARFF vehicles were retrofitted by, and provided to SHAL by Marcé. Upon receipt of the ARFF vehicles from Marcé, SHAL were provided with the OEM pump operation manual from Ziegler. This manual had an issue date of 2014. In this 2014 manual, Ziegler stipulated the use of SAE 10 oil in the gearbox.

9.3.2. Ziegler issued an updated version of the pump operation manual in 2021. In this 2021 manual, Ziegler then stipulated the use of 10W40 oil. However, this updated 2021 manual was not issued to SHAL until 2026, when Marcé attended SHAL to conduct repairs on the ARFF vehicle water pumps.

9.3.3. For reference, the lubrication schedule for FPN10-4000-2HH pumps as stipulated in the 2014 issue of the manual is shown in Figure 16, overleaf, and as stipulated in the 2021 issue of the manual in Figure 17, on page 18. For ease of reference, the relevant sections are shown highlighted. As can be seen, in the reissued 2021 manual, the lubricant was changed from SAE 10 oil, to SAE 10W40 oil. At this stage, the reason for this change of oil is not known, nor is it known why the updated manual was not provided to SHAL following its reissue in 2021.

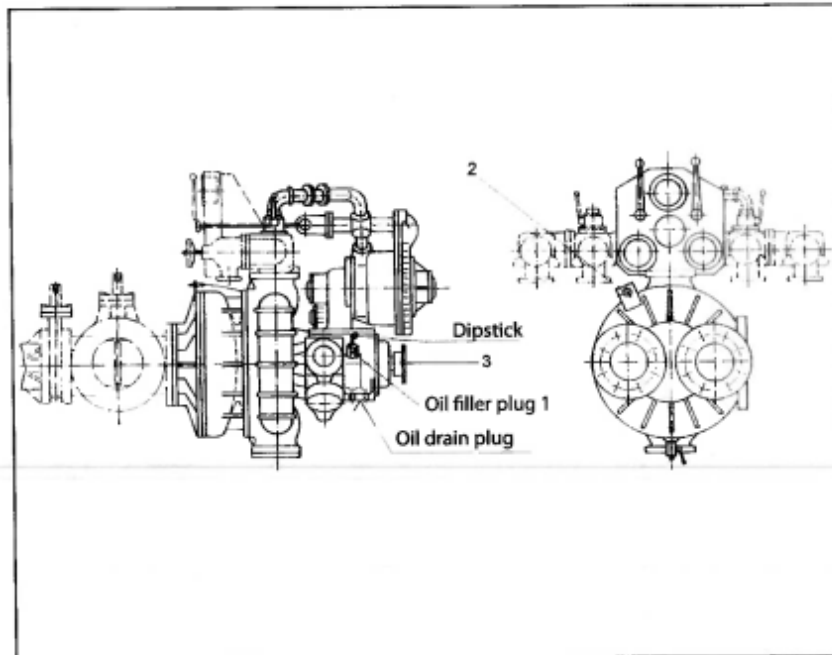
9.3.4. Further discussion of the oil used in the gearboxes is provided in Section 19.



Lubrication
schedule
Fire centrifugal
pumps

FPN 10-4000-2 HH

FPN 15-3000-2 HH



Item	Lubrication point	Quantity	Lubricant	Servicing interval
1	Pump gearbox	1	Gearbox oil SAE 10 capacity 1.5 l ¹⁾	Check after 10 operating hours, oil change after 50 operating hours, at least once a year
2	Pump shaft sealing	1	Special pump grease Divinol Multitherm 2	Lubricate after 20 operating hours, at least once a year
3	Universal joint	Dependent on superstructure	Special pump grease Divinol Multitherm 2	Lubricate after 20 operating hours, at least once a year (not required in case of lubrication for life)

The special pump grease Divinol Multitherm 2 is available from ZIEGLER under article no. 098 810 (400 g can) or article no. 216 096 (25 kg container).

The pump's high pressure unit is maintenance-free!

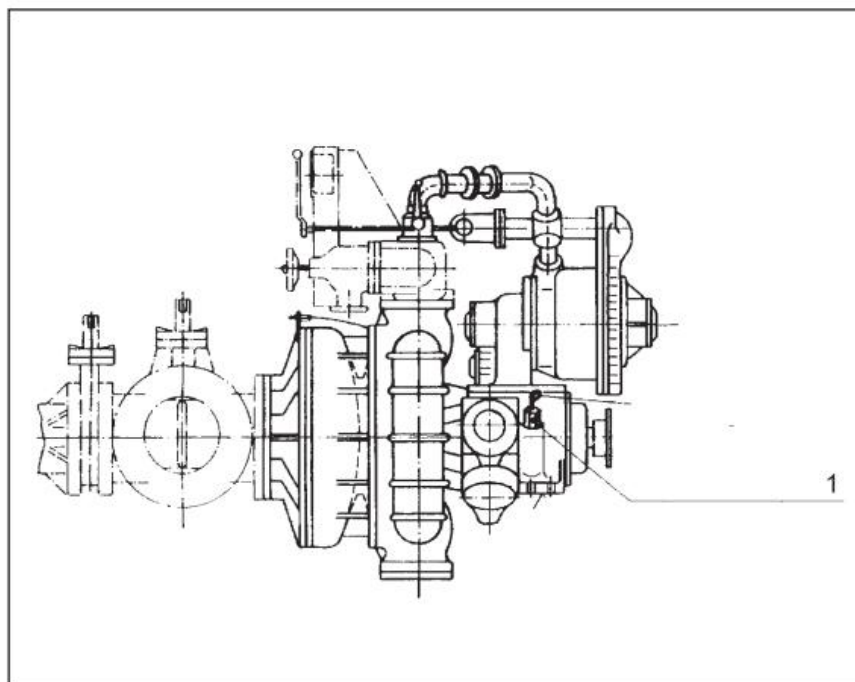
¹⁾ The mark on the dipstick defines the exact oil level!

Figure 16: Lubrication schedule as stipulated in 2014 manual showing use of SAE 10 oil

Lubrication
schedule
Fire centrifugal
pumps

FPN 10-4000-2 HH

FPN 15-3000-2 HH



Item	Lubrication point	Quantity	Lubricant	Servicing interval
1	Pump gearbox	1	Gearbox oil SAE 10W40 capacity 1.5 l ¹⁾	Check after 10 operating hours, oil change after 50 operating hours, at least once a year

The pump's high pressure unit is maintenance-free!

¹⁾ The mark on the dipstick defines the exact oil level!

Figure 17: Lubrication schedule as stipulated in 2021 manual showing use of SAE 10W40 oil

9.4. Water Contamination of Oil

- 9.4.1. Routine testing of the oil used in the gearboxes detected the presence of water in some samples.
- 9.4.2. It is reported that some of the containers used to collect the oil from the gearboxes were previously used for the storage of water. While it is also reported that these containers were drained and dried using compressed air, it has been alleged that the source of the water contamination of the oil could be related to the containers in which the oil was collected. This is described further in Section 19.

9.5. Consultation with Ziegler

- 9.5.1. Following initial observation of the damage to the eccentrics, SHAL made enquiries with Ziegler as to the specific material and purpose of the eccentric, and any potential consequences of its failure. More specifically, the following questions were asked of Ziegler:

- *What material is the eccentric made of?*
- *What is the purpose of the eccentric?*
- *If it fails or breaks up, can the pump still operate?*

9.5.2. In response to these questions, Ziegler provided the following comments.

9.5.3. What material is the eccentric made of?

“It is a high performance elastomer which is well suited for this application. Nevertheless, it cannot be completely ruled out that it may fail at some point, depending on operating time and age.”

9.5.4. What is the purpose of the eccentric?

“It drives the Trokomats, which are necessary to vent the pump.”

9.5.5. If it fails or breaks up, can the pump still operate?

“The pump can no longer draw in water without the eccentric. During tank suction operation, the pump may still be usable, but we strongly recommend repair to prevent consequential damage and ensure full functionality of the pump.”

9.6. Potential Previously Known Issues with Eccentrics

9.6.1. Whilst Marcé were conducting the repairs on the ARFF vehicle pumps, it is reported that the attending engineers alleged that similar failures had occurred in similar vehicles in Botswana; however, I have not been provided with any evidence to support this allegation.

9.7. Water Source

9.7.1. The ARFF vehicles use potable, mains water for fire-fighting and training purposes. This water is supplied to the airport by means of fire-hydrants located at the airport.

9.7.2. However, prior to 17 July 2020, a borehole water supply was used as a water source for the ARFF vehicles. Testing of the borehole water found it had significantly higher levels of salts, dissolved solids, chlorides, and electrical conductivity than the potable mains water, and it was also generally highly corrosive.

9.7.3. Further information relating to the water source is provided in Section 22.

10. PUMP DISASSEMBLY

10.1. Overview

- 10.1.1. As described previously, the water pump and gearbox of R2 was disassembled in preparation for replacement of the seals, at which point, the degradation of the eccentric was first observed.
- 10.1.2. During this disassembly, the seals were considered to be intact and free from damage, and were not considered the cause of the contamination of the oil.
- 10.1.3. As such, when inspecting the eccentrics of R1 and R3, it was deemed unnecessary to fully disassemble the pumps, and rather for these pumps, only the high-pressure stage was removed in order to provide access to the gearbox, and the eccentric contained therein.
- 10.1.4. This work was conducted prior to my arrival at St Helena Airport and as such I have not witnessed the disassembly first-hand. However, I have been provided with a number of photographs taken during the disassembly process of each of the pumps of R1, R2 and R3.
- 10.1.5. I also interviewed the maintenance team who were involved in the disassembly process.
- 10.1.6. While I did not witness the disassembly first-hand, the provided photographs and my discussions with the maintenance team provide some insight into the mechanical condition of the components. These are described below.

10.2. R2 Disassembly

- 10.2.1. As described previously, R2 was the first vehicle to undergo disassembly works, and this involved the complete strip-down of the pump.
- 10.2.2. The maintenance team reported that once they had removed the pump from the vehicle, they attempted to open the pump casing; however, it was fused together, and that continued application of heat and impact forces were required in order to separate the casing. The provided photographs even appear to show that some of the securing bolts had fractured. The separation of the pump casing is shown in Figure 18, on page 22.
- 10.2.3. The maintenance team also reported that once the casing was eventually released, there was extensive corrosion present throughout the interior of the casing, and on the newly exposed mating surfaces. The provided photographs show extensive corrosion and degradation to the surfaces of the casing. This is shown in Figure 19 and Figure 20, both on page 22.

- 10.2.4. If developed to a sufficient extent, corrosion on the mating surfaces of the casing could provide a fusing effect, in essence adhering the casing together. This could explain the difficulty the team had in separating the casing.
- 10.2.5. Taking the comments at face value that an extended application of heat and impact forces was required to separate the casing, this would suggest that the level of corrosion was significant. Furthermore, to my mind, a level of corrosion that required such means to separate the casing would indicate that the corrosion had been developing over an extended period of time.
- 10.2.6. It is also reported that this was the first time over the life of the pump that the casing had been separated. As such, while it is not possible to determine when the corrosion first developed, it is possible that the corrosion had been developing over a number of years, and/or possibly over the entire life-time of the pump.
- 10.2.7. The provided photographs also show extensive pitting damage to the interior of the casing. Pitting, as the name suggests, refers to small, localised pits or holes formed within the surface of the component. This is also shown in Figure 19 and Figure 20.
- 10.2.8. To my mind, the nature and appearance of the pitting as visible in the photographs appear consistent with cavitation.
- 10.2.9. Cavitation is a mechanism that occurs when the local pressure within a fluid reduces below the vaporisation pressure of the fluid (i.e. the pressure at which the fluid will begin to vaporise), causing small vapour bubbles to be produced, which then subsequently collapse. The process of the bubbles collapsing creates shock waves that over time can cause degradation to the surface of the material.
- 10.2.10. As cavitation occurs due to a localised pressure reduction, it can occur in the vicinity of propellers or impellers (or other pressure reducing devices), and/or within pipework connected to propellers/impellers.
- 10.2.11. As described previously, the rotation of a propeller/impeller will generate a region of low pressure on one side of the blades, which in turn will generate suction and fluid flow. If the local pressure falls to such an extent that it drops below the vaporisation pressure, cavitation will occur.
- 10.2.12. On this basis, the presence of pitting on the pump casing could indicate that cavitation has occurred at some point during the life of the pump. However, in a similar manner to the corrosion, since this was the first time that the pump casing was opened, the full extent of pitting would not have been previously detectable, meaning that it is not possible to determine when the pitting first commenced. As such, I cannot preclude the possibility that the pitting had been developing over the entire life-time of the pump.

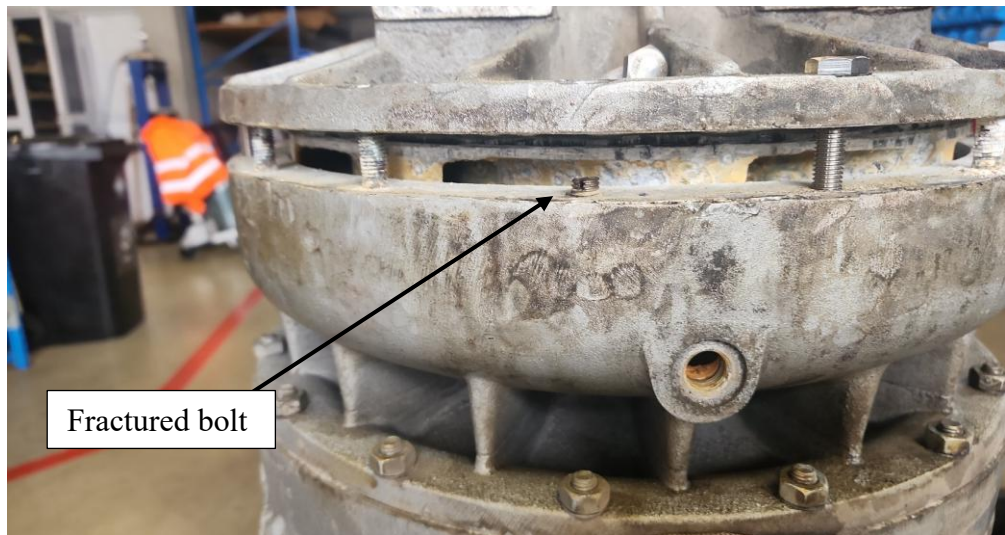


Figure 18: Separation of pump casing

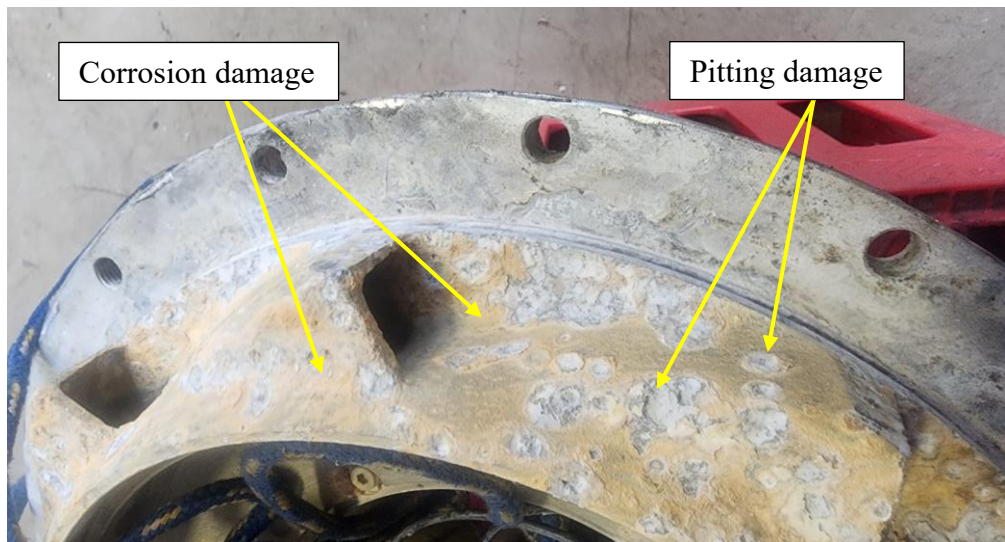


Figure 19: Corrosion and pitting damage to interior of pump casing (1)

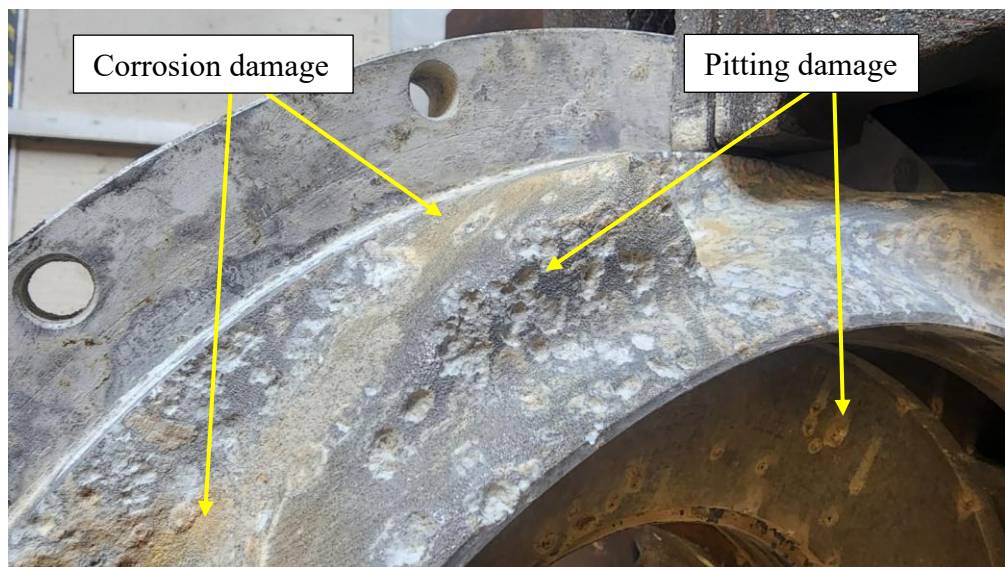


Figure 20: Corrosion and pitting damage to interior of pump casing (2)

10.3. R2 Eccentric

- 10.3.1. When the gearbox was opened, the damage to the eccentric could be observed.
- 10.3.2. A large section to one side of the outer circumference of the larger diameter end of the eccentric (i.e. the region not covered by the metal collar) was detached, exposing the shaft and locking keyway beneath.
- 10.3.3. The remainder of the outer circumference remained attached; however, there was also a large split to one side of the outer circumference.
- 10.3.4. When viewed from the smaller diameter end of the eccentric, there was also extensive fracture damage to the cross-sectional profile that extended in both radial and circumferential directions. Some cracks had also propagated from the corner of the keyway slots.
- 10.3.5. Photographs of the damage to the eccentric of R2 are provided in Figure 21, below, to Figure 25, on page 25.

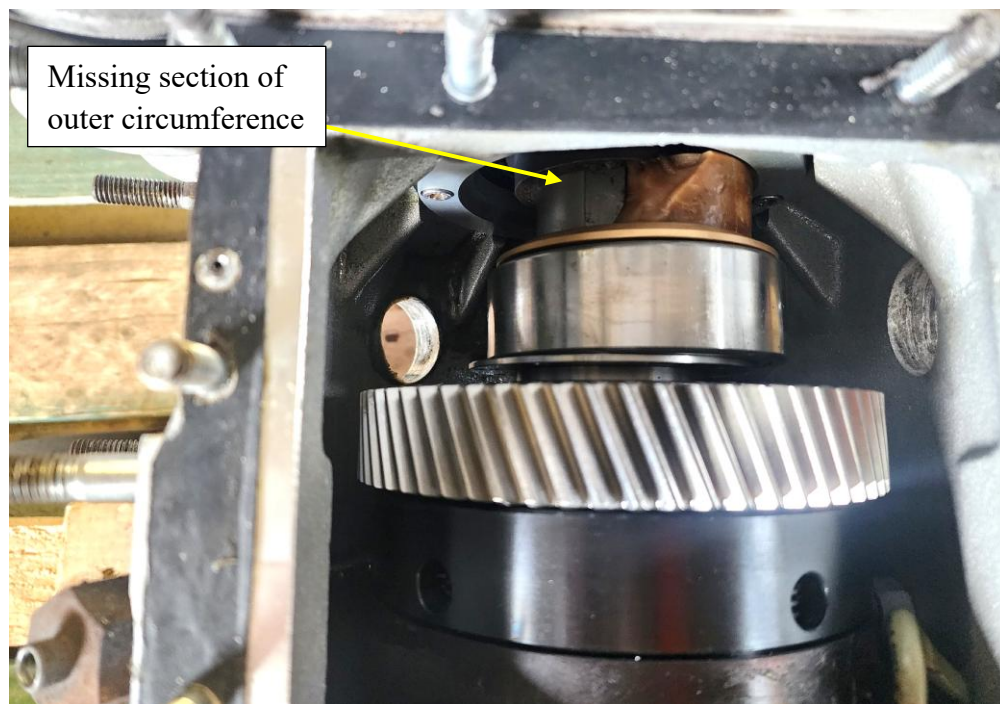


Figure 21: Damage to R2 eccentric (1)

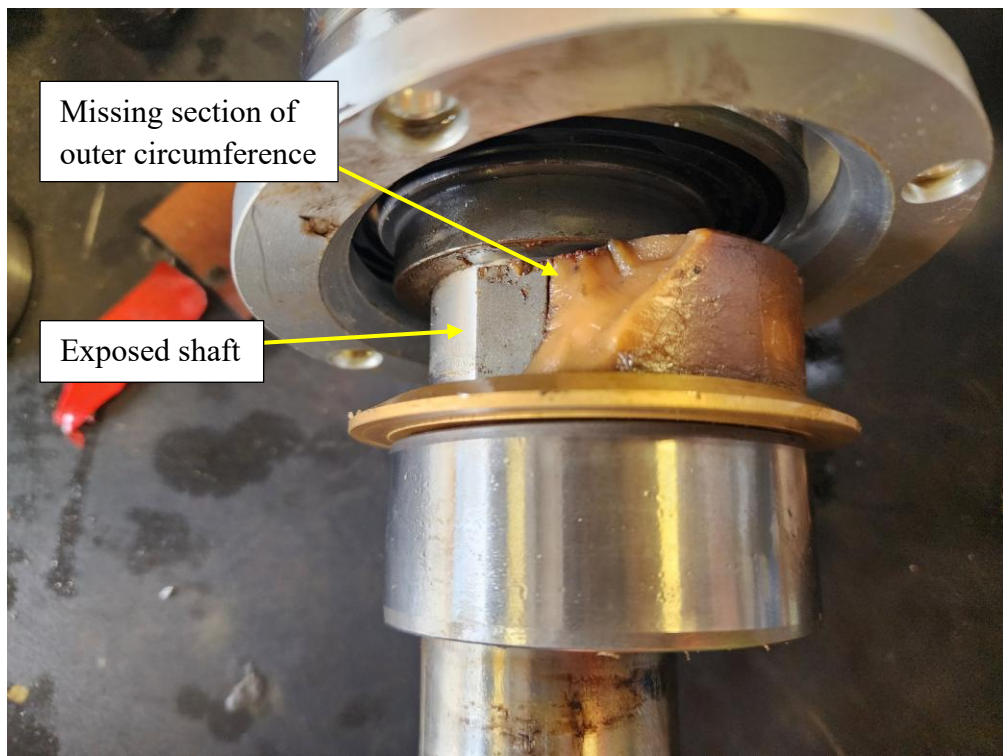


Figure 22: Damage to R2 eccentric (2)

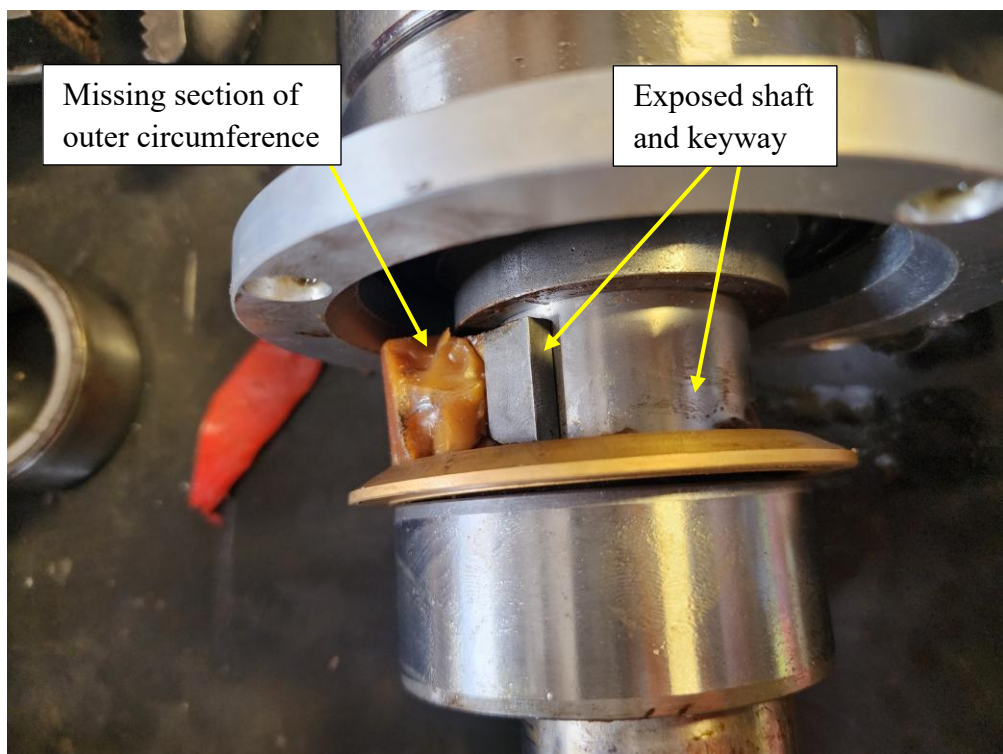


Figure 23: Damage to R2 eccentric (3)

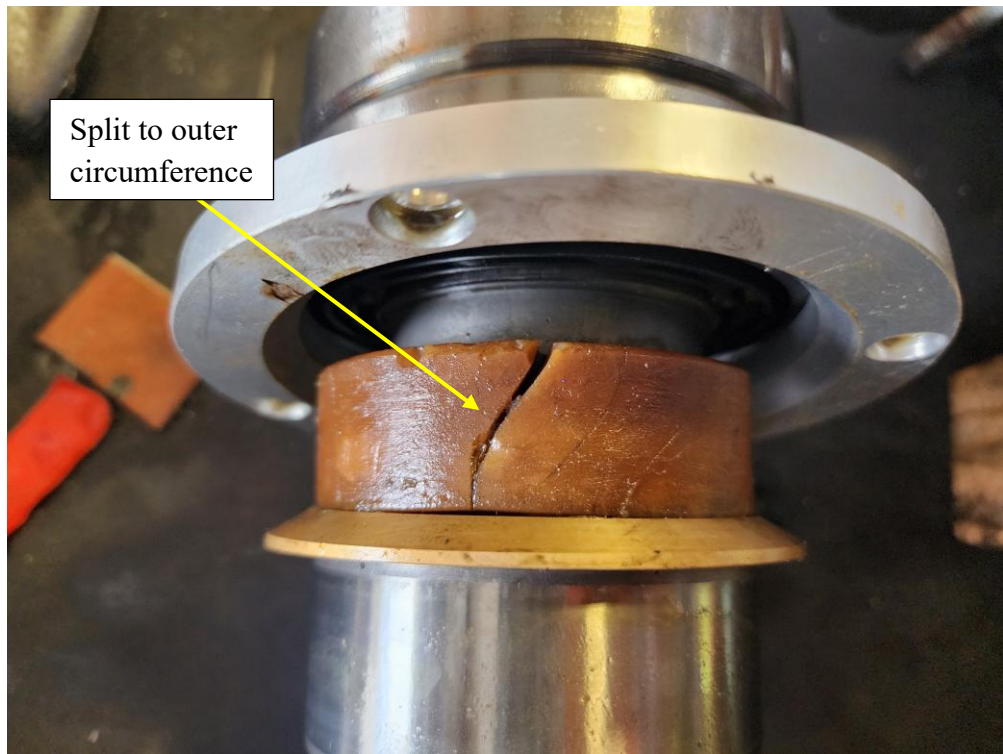


Figure 24: Damage to R2 eccentric (4)

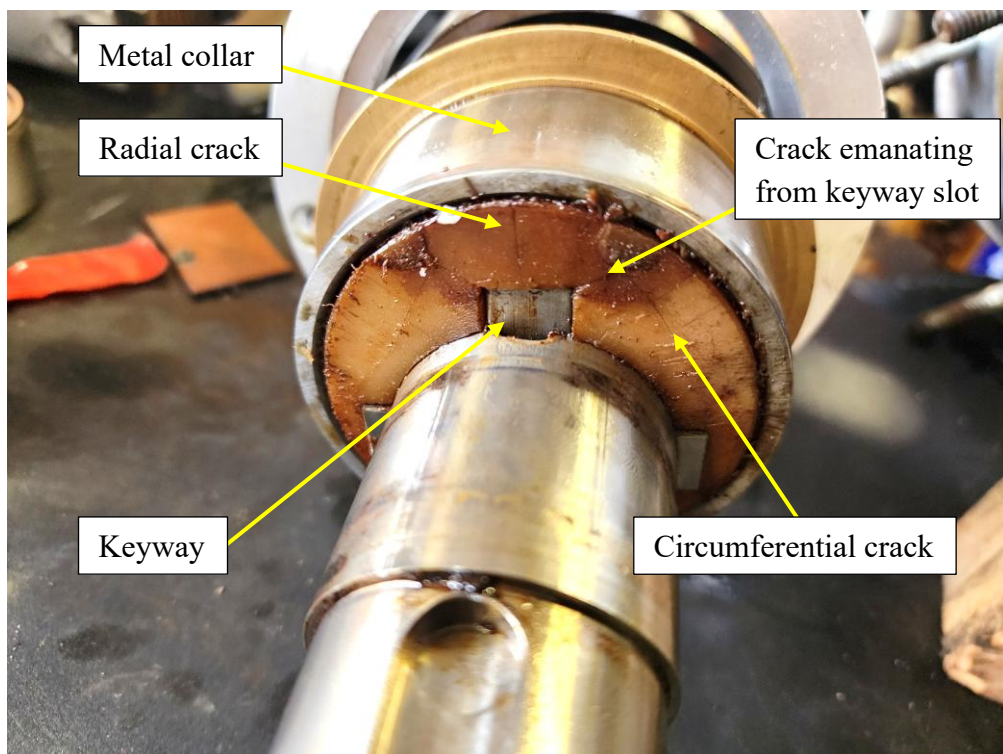


Figure 25: Damage to R2 eccentric (5)

10.4. R1 Eccentric

- 10.4.1. As described previously, full disassembly of the pump of R1 was not performed, and rather only the high-pressure pump was removed to provide access to the gearbox and the eccentric.

- 10.4.2. When the gearbox of R1 was opened, similar damage was observed to the eccentric. More specifically, a section of the outer circumference was detached, and cracks were visible on the cross-sectional profile.
- 10.4.3. There was also localised polishing and circumferential scoring to the outer surface of the metal collar at the contact patch with the Trokomat pistons.
- 10.4.4. Photographs showing the damage to the eccentric of R1 are provided in Figure 26, below, to Figure 29, on page 28.



Figure 26: Damage to R1 eccentric (1)

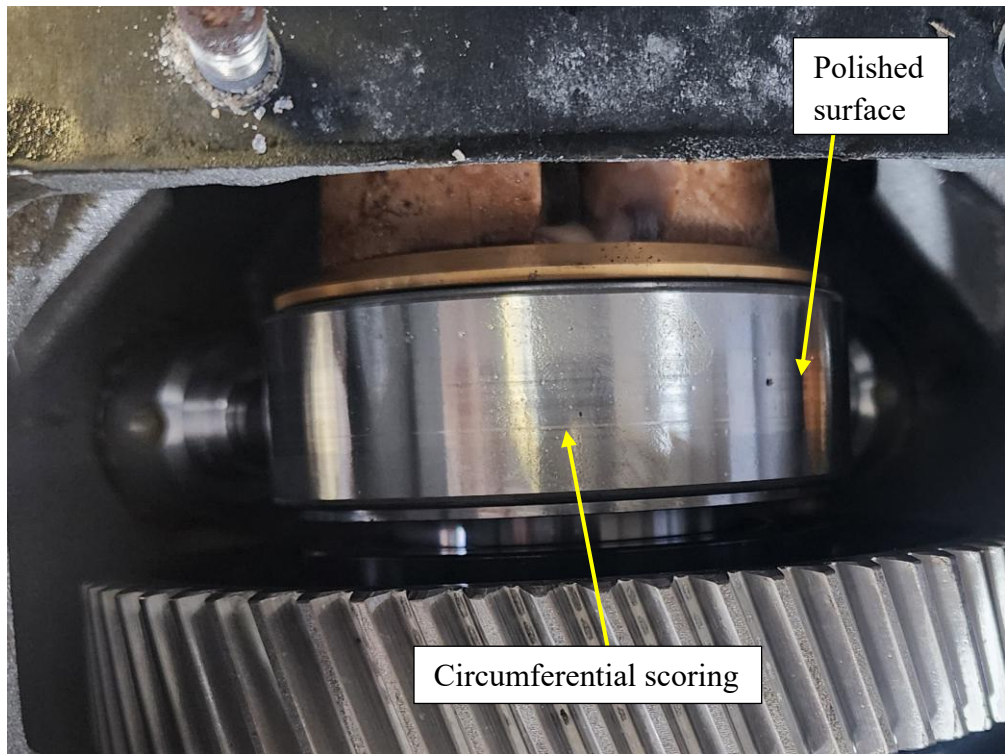


Figure 27: Damage to R1 eccentric (2)

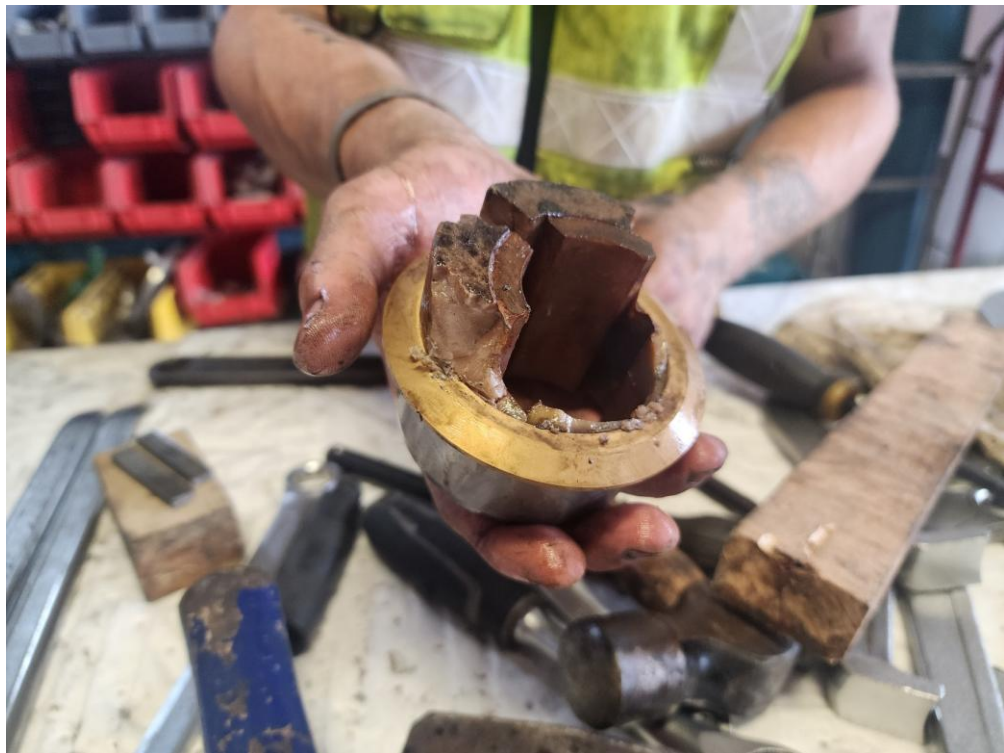


Figure 28: Damage to R1 eccentric (3)



Figure 29: Damage to R1 eccentric (4)

10.5. R3 Eccentric

- 10.5.1. As described previously, full disassembly of the pump of R3 was not performed, and rather only the high-pressure pump was removed to provide access to the gearbox and the eccentric.
- 10.5.2. When the gearbox of R3 was opened, similar damage was observed to the eccentric, and a section of the outer circumference was detached. There was also extensive cracking to the outer circumference of the eccentric in both circumferential and longitudinal directions. It is also reported that as the eccentric was removed, it sustained almost complete disintegration.
- 10.5.3. The extent of disintegration of the eccentric of R3 appeared more significant than that of the eccentrics of R1 and R2.
- 10.5.4. There was also localised polishing and circumferential scoring to the outer surface of the metal collar at the contact patch with the Trokomat pistons.
- 10.5.5. Photographs showing the damage to the eccentric of R3 are provided in Figure 30, overleaf, to Figure 32, on page 30.



Figure 30: Damage to R3 eccentric (1)

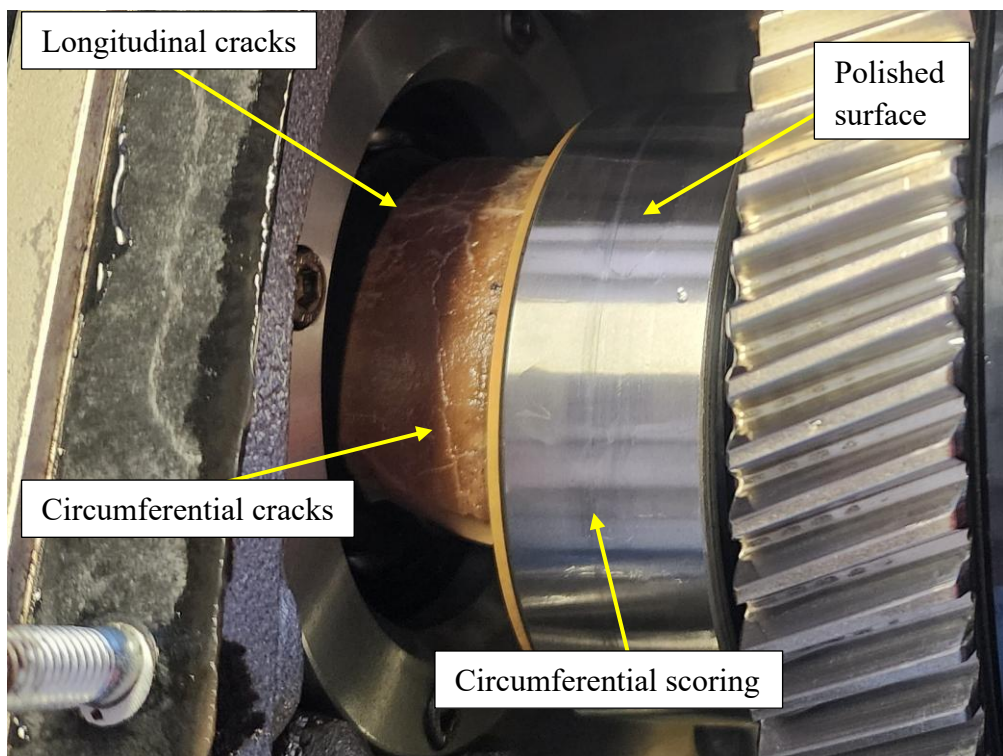


Figure 31: Damage to R3 eccentric (2)



Figure 32: Damage to R3 eccentric (3)

11. ELASTOMER MATERIAL

- 11.1. Initial contact with Ziegler did not provide detailed information relating to the elastomer, only that “*it is a high performance elastomer*”.
- 11.2. During my time at SHAL, further enquiries were made with Ziegler as to the specific material from which the eccentric is formed.
- 11.3. On this occasion, Ziegler were able to provide some limited information, but only that the elastomer was formed of ‘*Vulkollan® 90 Shore A.*’
- 11.4. Ziegler did not provide any other detailed information, material specifications, material data sheets or the like.
- 11.5. Separate research indicates that Vulkollan® is a registered trademark of a polyurethane based elastomer manufactured by the company ‘Vulkoprin NV’, a Belgian manufacturing company.
- 11.6. 90 Shore A refers to the material’s hardness, i.e. its resistance to permanent indentation. More specifically, ‘Shore A’ is a scale of hardness of rubber/elastomer materials from 0 to 100, where the greater the number, the harder the material. Consequently, ‘90 Shore A’ refers to 90 on a scale of 0 to 100 on the Shore A hardness scale.
- 11.7. 90 Shore A is described as a very hard material with high abrasion resistance, and is typically used for hard elastomer/rubber engineering components.

- 11.8. For ease of visualisation, a rubber band would typically have a hardness of 20 Shore A; a pencil eraser would typically have a hardness of 50 Shore A; the sole of a shoe would typically have a hardness of 70 Shore A; and castor wheels would typically have a hardness of 80 to 90 Shore A.
- 11.9. Vulkoprin state that Vulkollan® offers high damping characteristics, it is stable and rigid with minimal heat build-up during use, and is highly wear resistant. Vulkollan® also has an operating temperature range of -40°C to +120°C and it is resistant to oils, greases and various chemicals.
- 11.10. However, it is also reported to be susceptible to hydrolysis, which is the chemical breakdown and decomposition of polyurethane materials in contact with water, where the individual polymer chains can be damaged, potentially causing the material to lose its strength, become brittle and crack or crumble.
- 11.11. It is reported that Vulkollan® can be manufactured to be hydrolysis stabilised through the addition of other compounds/chemicals to the material which can impede/prevent hydrolysis decomposition. However, Ziegler were unable to advise whether or not the Vulkollan® used in the eccentrics was hydrolysis stabilised.
- 11.12. The natural colour of Vulkollan® is light brown/tan. It is reported that exposure to ultraviolet (UV) light can cause the Vulkollan® to change to a darker brown colour. However, it is reported that this colour change does not affect the quality of the material.
- 11.13. For reference, information relating to Vulkollan® can be accessed at the link below, and an information brochure relating to the material is provided in Appendix C.

<https://vulkoprin.be/en/vulkollan-polyurethane/>

INVESTIGATION METHODOLOGY

12. ON-SITE INVESTIGATION

- 12.1. For the purposes of my investigation, I attended St Helena Airport between Monday 27 July 2026 and Friday 7 August 2026.
- 12.2. During this time, I was assisted by St Helena Airport in all aspects of my investigation. I was granted access to the workshop facilities and worked closely with team members from all different operational departments.
- 12.3. More specifically, I worked closely with the airport management, the maintenance team, and the Rescue and Fire Fighting Services (RFFS) Team.

13. INVESTIGATION APPROACH

13.1. Overview

- 13.1.1. In light of the circumstances of the observed failures, the routine use of the vehicle, and the relevant background information provided to me prior to my arrival, my investigation comprised six main aspects:

(1) Mechanical examination and testing;

(2) Oil analysis;

(3) Operational matters;

(4) Maintenance and servicing;

(5) Water source used;

(6) Eccentric elastomer material.

13.2. Mechanical Matters

- 13.2.1. This related to purely mechanical matters of the failed components, the pump as a whole, and the interaction of components within the system. This aspect of the investigation involved mechanical examination of components, review of original equipment manufacturer (OEM) pump operation manuals, and interviewing members of the maintenance team.
- 13.2.2. This also included an endoscopic inspection of the eccentrics currently in use in the ARFF vehicles that were replaced following the incident. This allowed an up-to-date assessment of the condition of the eccentrics to be made.

13.3. Oil Use

- 13.3.1. This related to the specific oil used in the pump gearboxes, and the reported change in stipulated oil by the manufacturer. This aspect of the investigation involved inspection of retained oil samples from all three fire tenders, review of the associated oil analysis reports, interviewing of the maintenance and management teams, and consultation with a UK based oil laboratory.

13.4. Operational Matters

- 13.4.1. This related to the operation of the fire tenders, and the specific manner in which they are used during routine testing, and whether this could have had any causative or contributory effect on the observed mechanical failures. This aspect of the investigation involved interviewing members of the RFFS team, reviewing the pump operating manual, and witnessing the daily, monthly, and quarterly tests of the tenders conducted by the RFFS team, which coincided with my time at St Helena Airport.

13.5. Maintenance & Servicing

- 13.5.1. This related to the ongoing and routine servicing and maintenance conducted on the ARFF vehicles, and specifically the water pumps, and whether this could have had any causative or contributory effects on the observed mechanical failures. This aspect of the investigation involved interviewing members of the maintenance team, reviewing the OEM pump maintenance and servicing manuals, and witnessing the maintenance team conducting some servicing actions on the pumps.

13.6. Water Source Used

- 13.6.1. This related to the nature of the water used by the fire tenders, and any causative or contributory effects that this could have had on the observed mechanical failures. This aspect of the investigation involved interviewing members of the RFFS team, and reviewing water analysis reports conducted on both the bore hole and mains tap water supplies at the airport.

13.7. Eccentric Elastomer Material

- 13.7.1. This related to the specific material composition of the elastomer used for the eccentrics, and whether any combination of the mechanical loading imparted upon the eccentrics and the environmental conditions that the elastomer is exposed to during routine use (for example the oil, and water in the event of water ingress) could affect the integrity of the material.

MECHANICAL INVESTIGATION

14. INSPECTION OF ECCENTRICS

14.1. Overview

- 14.1.1. Following the incident, all evidence relating to the failure (including the damaged eccentrics and oil samples) was retained for the purposes of this investigation.
- 14.1.2. More specifically, all of the evidence was stored in a secure, locked cabinet, with tamper evident seals. I have been provided with the Tamper-Evident Seal Log that documents the specific details of each time that the cabinet was opened and the tamper-evident seal was broken, including the date, time, personnel breaking the seal, witness(es) of the seal being broken, and the reason for opening the cabinet.
- 14.1.3. This log serves to preserve the evidence trail relating to this incident. This log is not included with this report, but can be provided on request.
- 14.1.4. Each item of evidence within the cabinet was also sealed with tamper-evident seals.
- 14.1.5. An image of the secure cabinet at its first opening during my time at the Airport is provided in Figure 33, below.



Figure 33: Secure evidence cabinet

14.2. Exemplar Eccentric

- 14.2.1. In addition to the damaged eccentrics, I was provided with a new, unused eccentric for comparative purposes. This allowed me to gain an understanding of the original structure and composition of the material, prior to use.
- 14.2.2. The exemplar eccentric was light brown/tan in colour, and exhibited a degree of pliability, and light pressure on the structure caused slight elastic (i.e. non-permanent) deformation. The exemplar eccentric is shown in Figure 34 and Figure 35, below.

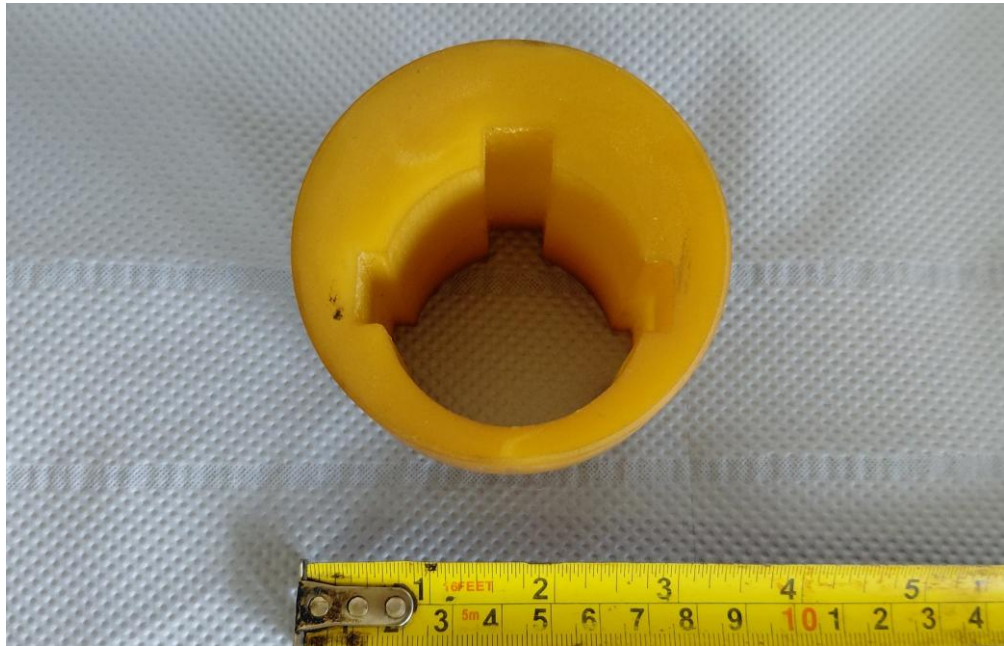


Figure 34: Exemplar eccentric (1)

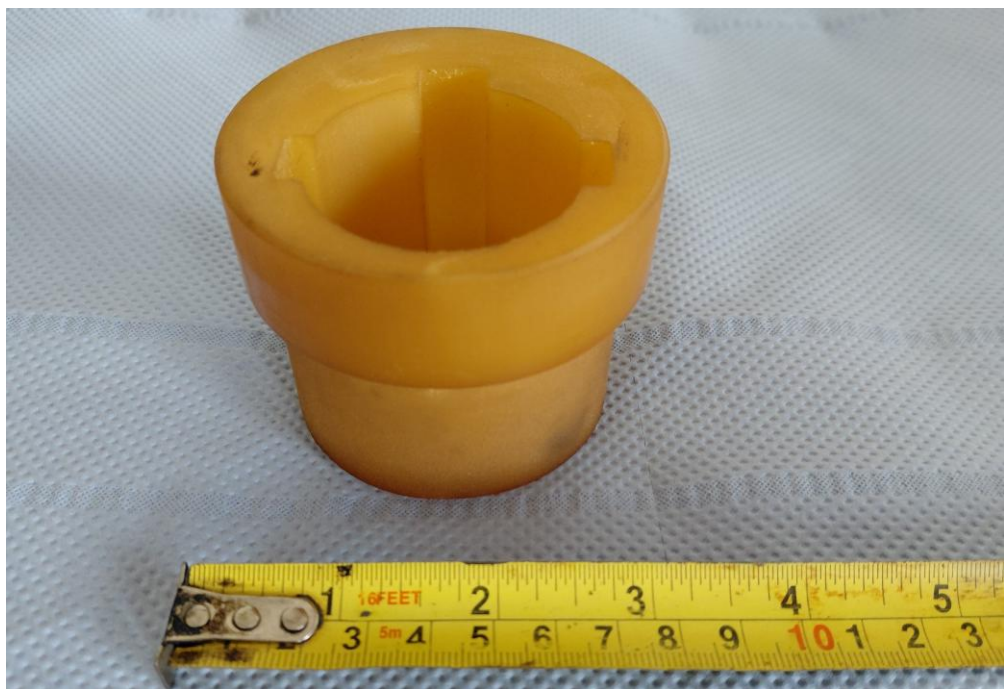


Figure 35: Exemplar eccentric (2)

14.3. Possible Damage Caused During Removal

- 14.3.1. It is important to note that the maintenance team advised that when the gearboxes were disassembled and each of the eccentrics were removed, the act of removal caused some further cracking and crumbling of the already damaged elastomer structure. On this basis, the full extent of damage to the eccentrics as visible to me during my inspection may have been greater than that whilst the eccentrics were still in situ. However, to my mind, it is likely that if the components did crumble as reported, this would indicate that there was extensive cracking present within the structure prior to their removal, and that the full extent of damage was not solely caused by the act of removal. This is supported by the cracking to the eccentrics visible in the aforementioned photographs taken whilst they were in situ within the gearbox.

14.4. Examination of R1 Eccentric

- 14.4.1. The eccentric from R1 was provided to me in a sealed plastic bag, comprising a tamper evident seal.
- 14.4.2. The bag contained a section of the eccentric that was approximately half the size of the original, complete eccentric, as well as a number of smaller fragments.
- 14.4.3. The larger fragment also had a section missing from its outer circumference at the larger diameter end of the eccentric. The exposed fracture surfaces of the eccentric fragments were multi-faceted.
- 14.4.4. There were cracks that emanated from the corners of the keyway slots. The sharp corners of these slots would likely act as stress-raisers, and as such it was not unexpected to observe cracks in this region of the structure. However, I note that the larger section of the eccentric also comprised a multitude of other cracks within the structure. These cracks were present across all planes of the component, including in longitudinal, radial and circumferential directions, and extending from both inner and outer faces of the eccentric. The multiplanar directionality and multiple locations of these cracks did not appear to coincide with any one loading direction.
- 14.4.5. There was also significant staining of the eccentric, particularly to the exterior faces. This staining was dark brown in colour and was likely due to the oil. However, some of the exposed fracture surfaces were of markedly different appearance and generally lighter in colour. The lighter colour could suggest that these fracture surfaces were exposed comparatively more recently, and were in the presence of the oil for less time than the darker coloured surfaces, i.e. these surfaces had not been exposed to the presence of oil for sufficient time to cause such extensive staining. For example, it is possible that these fractures could have occurred during removal of the eccentric. As described previously, it is reported that some of the eccentrics crumbled and cracked upon removal.
- 14.4.6. To further test this, I deliberately force-fractured some partially propagated cracks and examined the resulting fracture surface. This showed that the newly exposed fracture

surfaces were significantly lighter in colour, and more akin to the exemplar eccentric. This confirmed a correlation between the extent of surface staining and the length of time that the fracture surface had been exposed.

- 14.4.7. Surrounding the lighter colour of the exposed fracture surfaces, there was additional staining to the outer perimeter. This would suggest that there was a degree of penetration and impregnation of the oil into the outer surfaces of the eccentric.
- 14.4.8. There was also some localised staining that had penetrated into some of the cracks, increasing their contrast. In light of the above, the presence of staining within the cracks would suggest that they had been developing for an extended period of time, and long enough for the oil to have penetrated the crack and cause the observed staining.
- 14.4.9. There was also a circumferential band of lighter colour that extended around the smaller diameter end of the eccentric. The position and size of this band suggests that this was the region to which the metal collar was previously fitted, and as such, the lighter colour in this region would suggest that the oil was not able to stain this region of the eccentric to the same degree as the other exposed regions.
- 14.4.10. The material also felt hard and brittle to the touch, unlike the exemplar eccentric, which was comparatively soft and pliable. Light pressure on the structure also caused pre-existing cracks to open.
- 14.4.11. Photographs of the eccentric of R1 are provided in Figure 36, below, to Figure 49, on page 44.



Figure 36: Inspection of R1 eccentric (1)



Figure 37: Inspection of R1 eccentric (2)

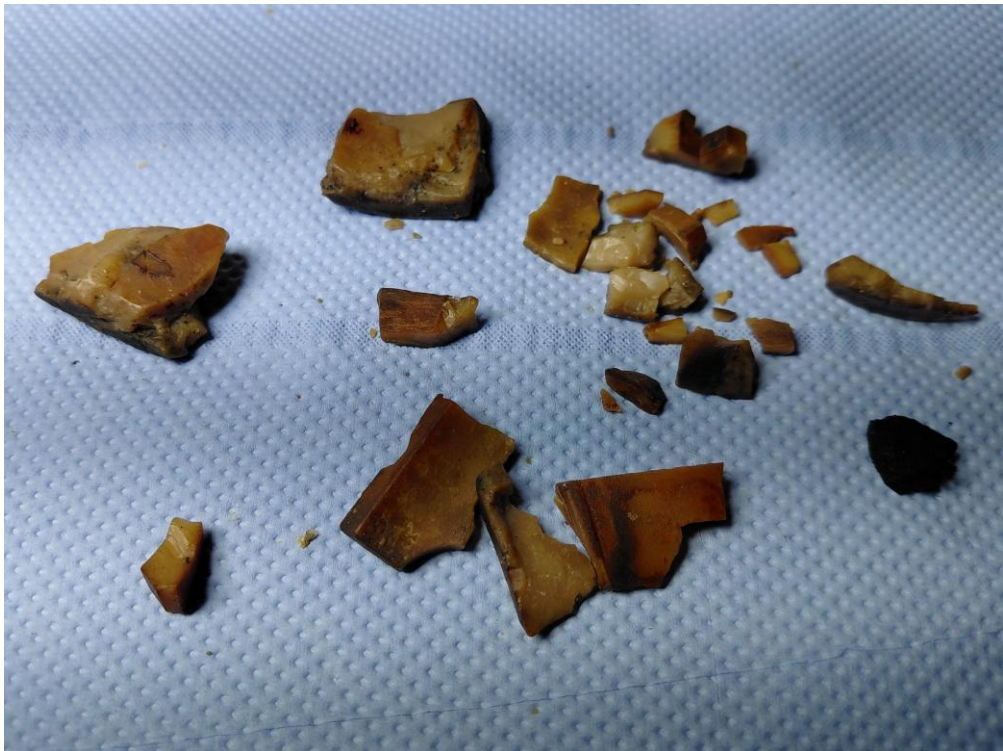


Figure 38: Inspection of R1 eccentric (3)

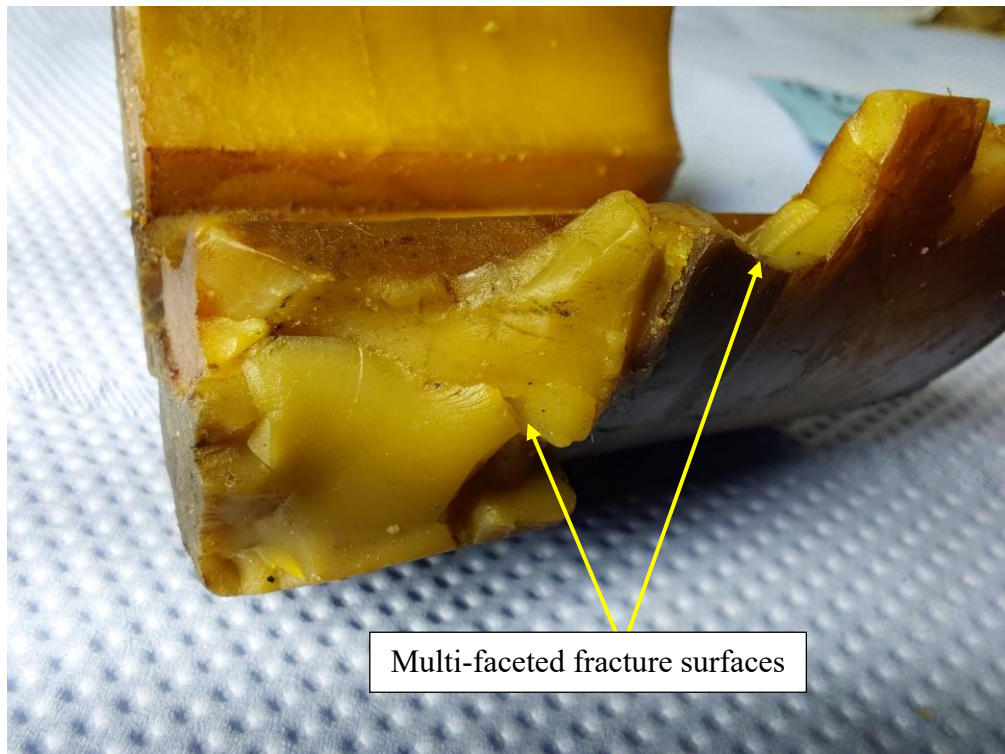


Figure 39: Inspection of R1 eccentric (4)

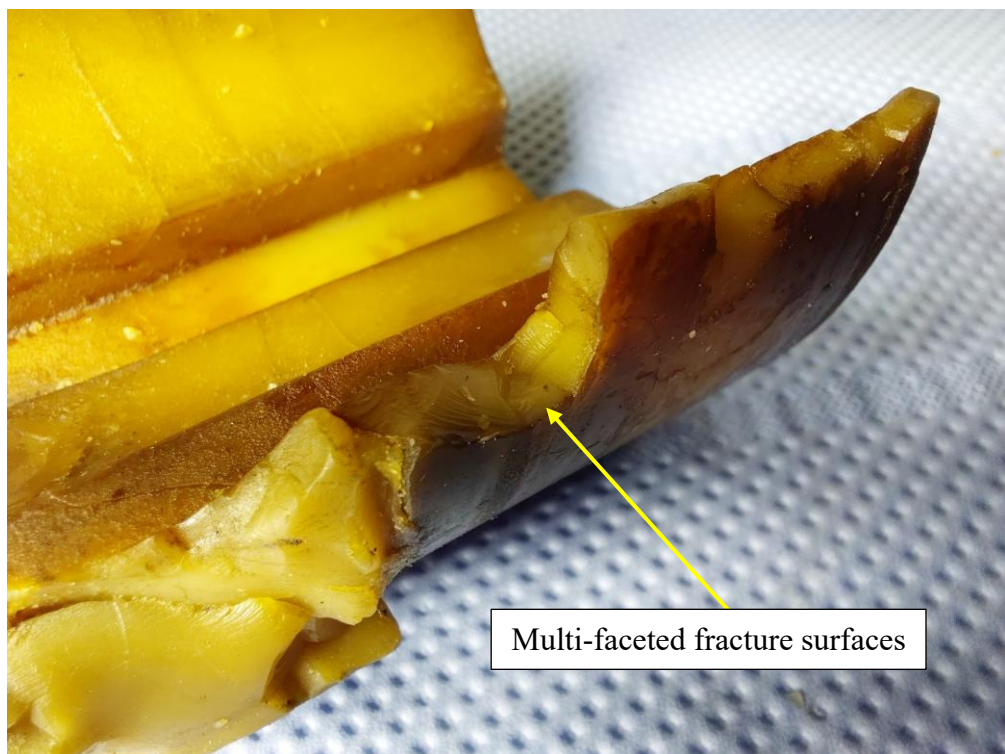


Figure 40: Inspection of R1 eccentric (5)

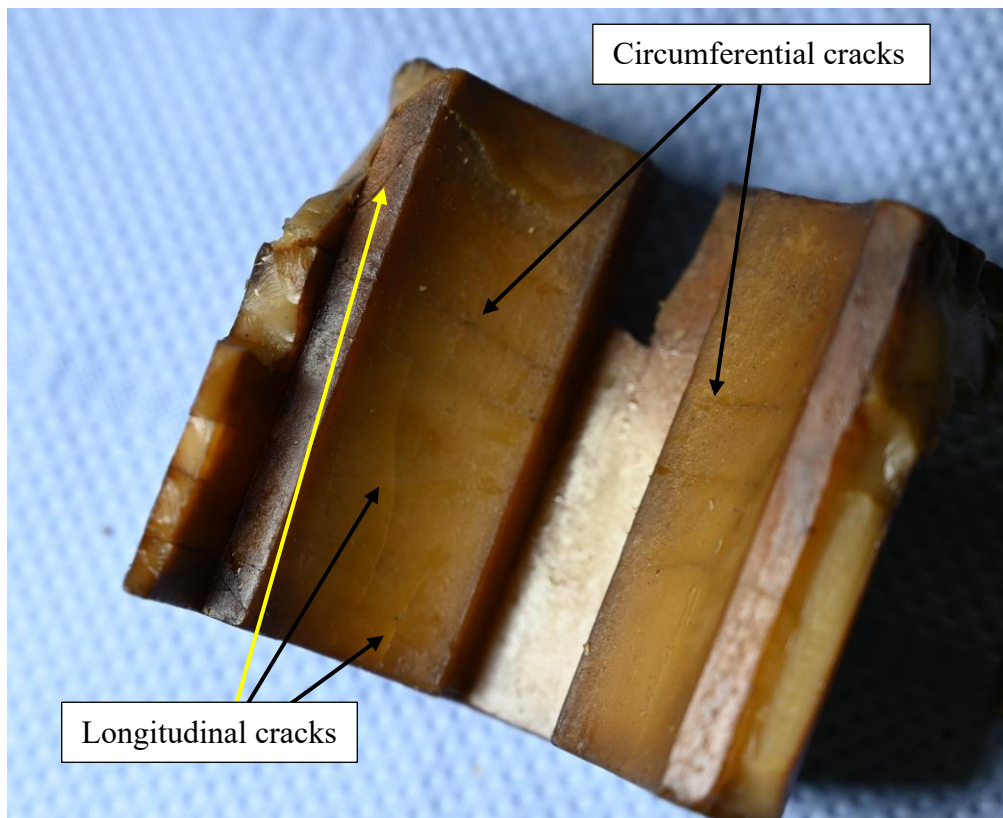


Figure 41: Inspection of R1 eccentric (6)

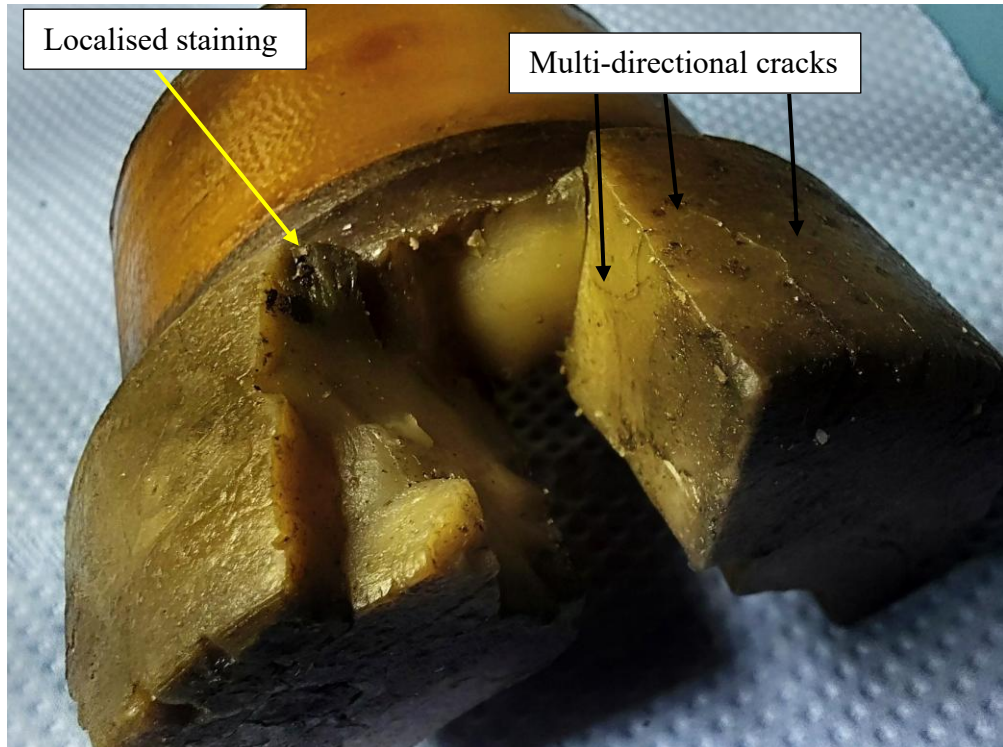


Figure 42: Inspection of R1 eccentric (7)

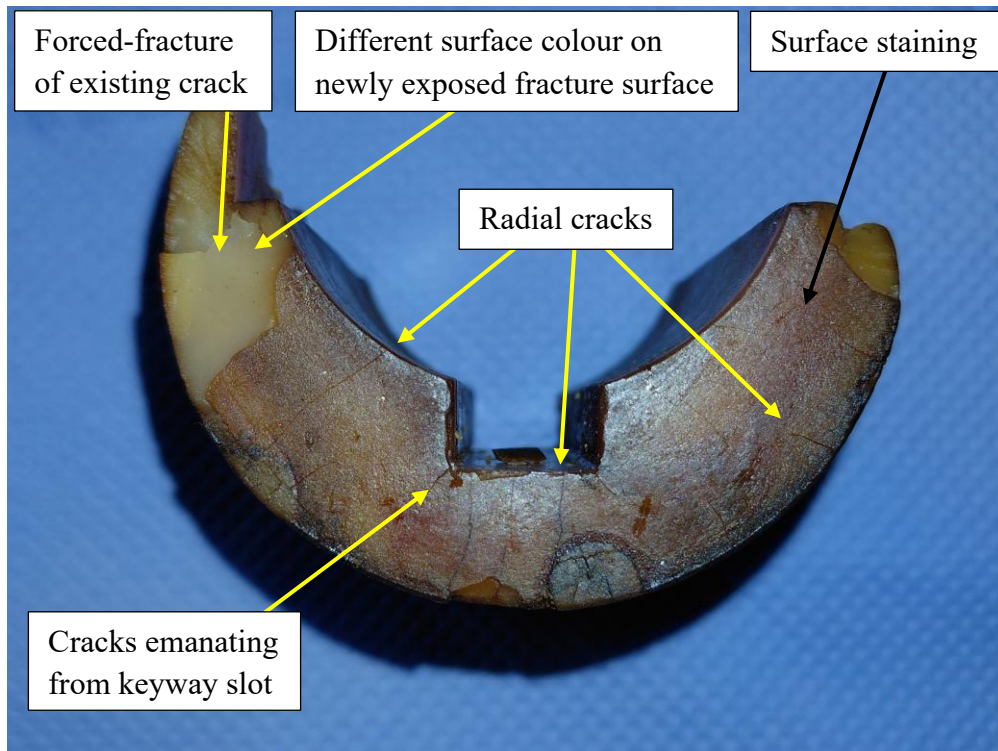


Figure 43: Inspection of R1 eccentric (8)



Figure 44: Inspection of R1 eccentric (9)

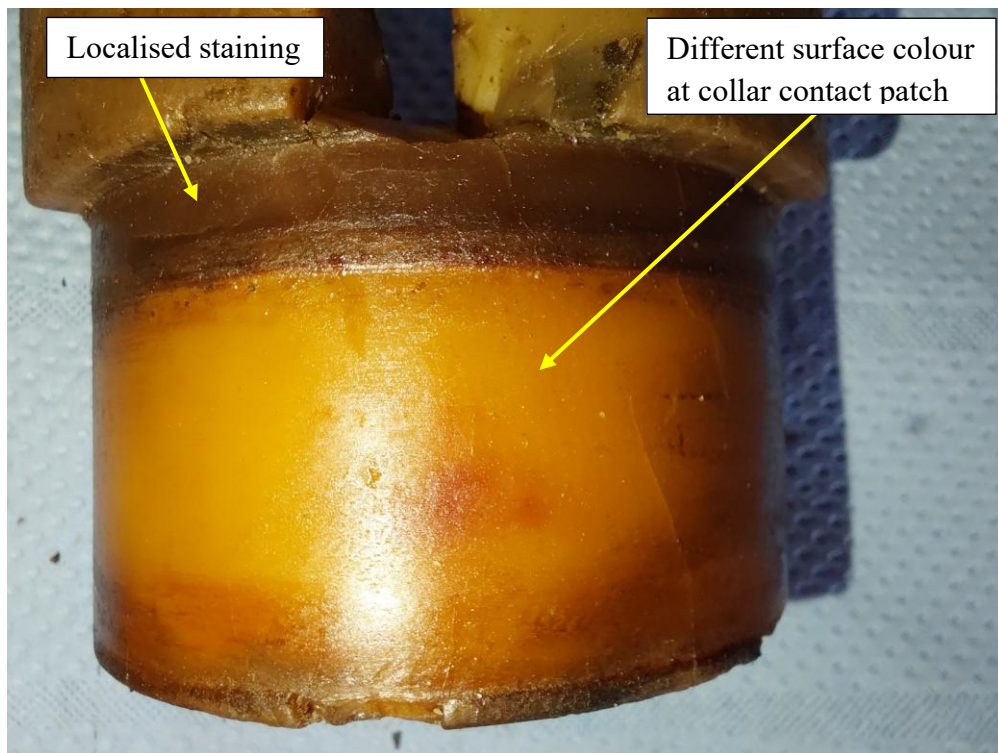


Figure 45: Inspection of R1 eccentric (10)

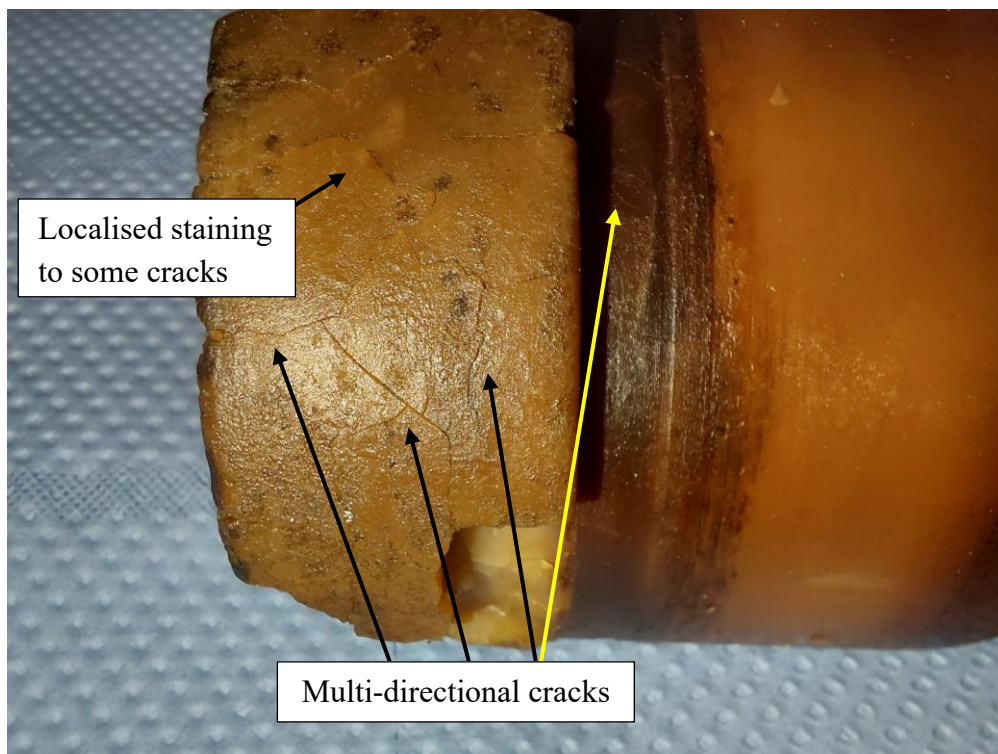


Figure 46: Inspection of R1 eccentric (11)

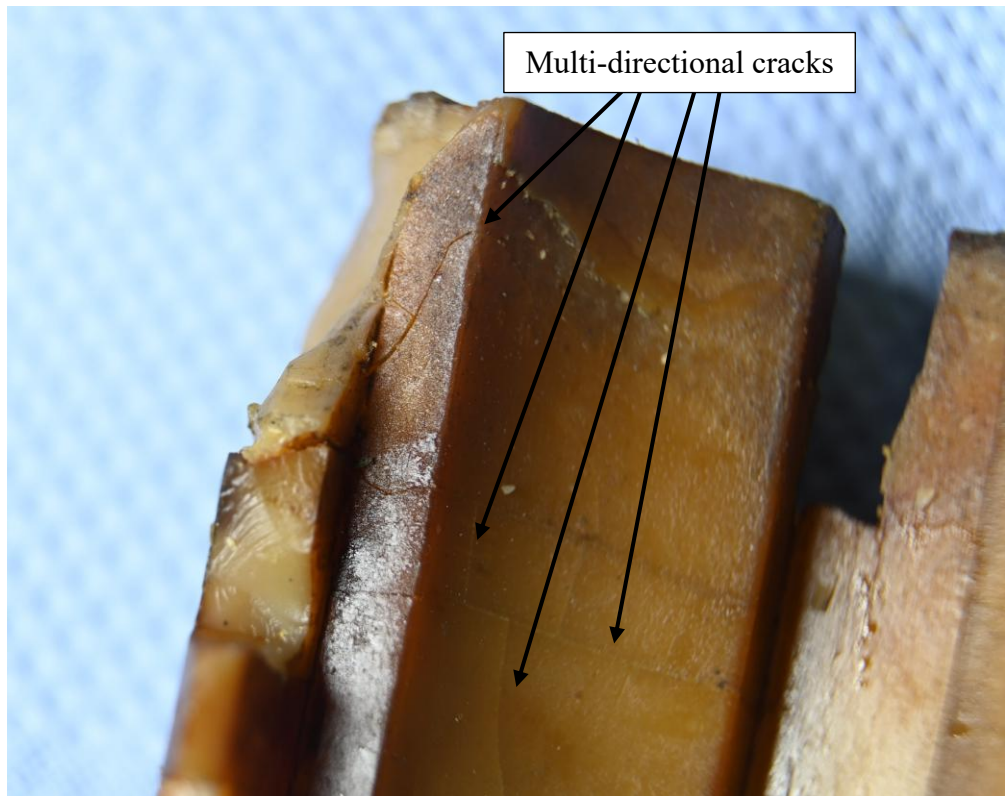


Figure 47: Inspection of R1 eccentric (12)

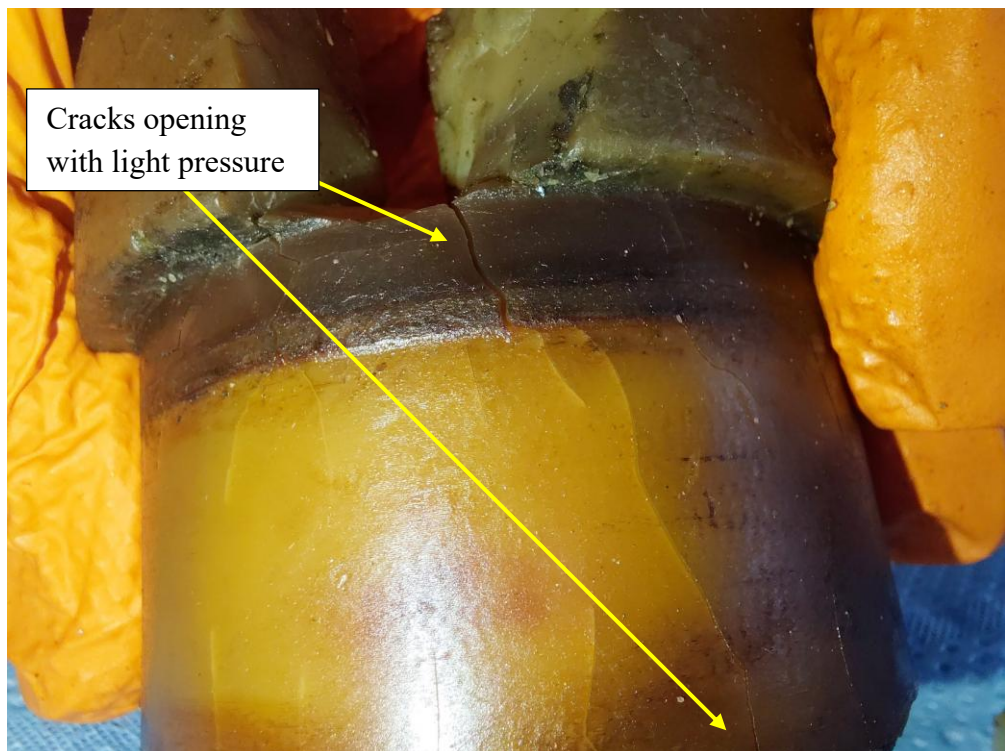


Figure 48: Inspection of R1 eccentric (13)

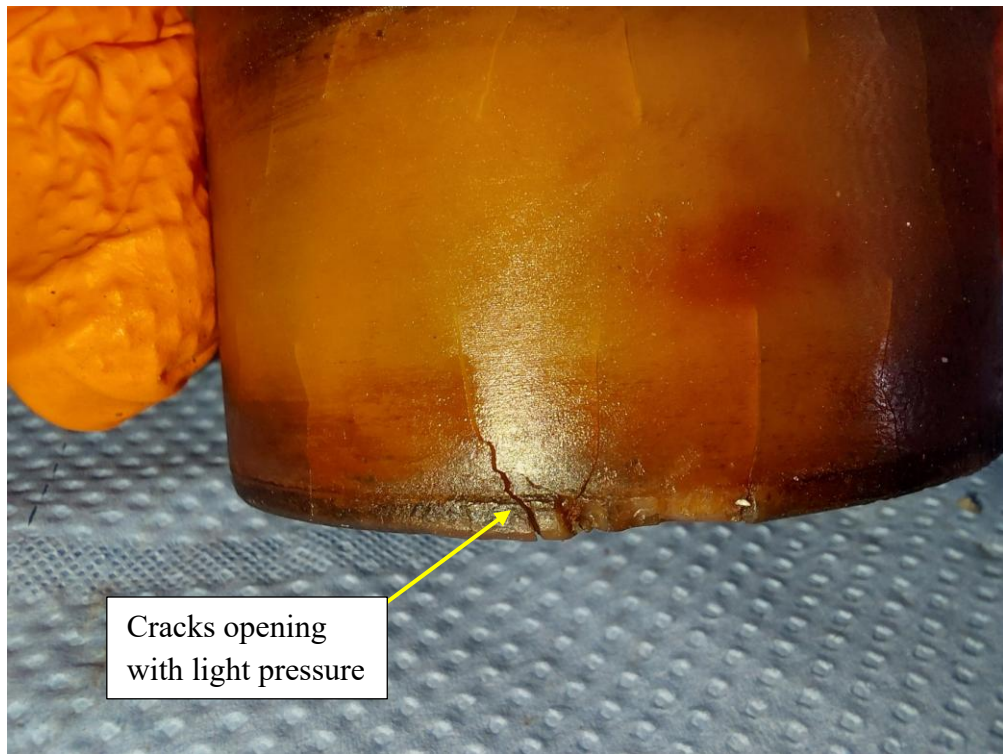


Figure 49: Inspection of R1 eccentric (14)

14.5. R2 Eccentric

- 14.5.1. The eccentric from R2 was provided to me in a sealed plastic bag, comprising a tamper evident seal.
- 14.5.2. The bag contained four quadrants of the outer circumference of one end of the eccentric, as well as a large number of smaller fragments. This was the full extent of the remnants of the R2 eccentric provided to me; however, they did not appear sufficient to form the complete volume of the original eccentric, suggesting some volume of the original eccentric was missing.
- 14.5.3. The exposed fracture surfaces of the eccentric fragments were multi-faceted in a similar manner to the R1 eccentric.
- 14.5.4. There were also a number of cracks present across all planes of the component, including in longitudinal, radial and circumferential directions.
- 14.5.5. The outer circumference of the larger diameter end of the eccentric was partially delaminating from the main body of the eccentric.
- 14.5.6. There was localised staining from the oil, some of which had penetrated into the cracks, increasing their contrast. The presence of staining within the cracks would suggest that the cracks had been developing for an extended period of time, and long enough for the oil to have penetrated the crack and cause the observed staining.

- 14.5.7. There was also localised staining to some regions of the eccentric, where the surface was dark brown in colour. However some of the exposed fracture surfaces were light brown/tan in colour, suggesting that these regions of the eccentric were not exposed to the oil for an extended period of time that was sufficient to cause any staining. As with the eccentric of R1, it is possible that these fractures occurred and these surfaces were exposed comparatively recently, and possibly during removal of the eccentric.
- 14.5.8. In a similar manner to R1, I tested this by deliberately force-fracturing some partially propagated cracks, where the newly exposed fracture surfaces were significantly lighter in colour.
- 14.5.9. There was also visible staining around the perimeter of the fragments. This would suggest that there was a degree of penetration and impregnation of the oil into the surface of the eccentric.
- 14.5.10. As with the R1 eccentric, the material also felt hard and brittle to the touch, unlike the exemplar eccentric, which was comparatively soft and pliable.
- 14.5.11. Photographs of the eccentric of R2 are provided in Figure 50, below, to Figure 63, on page 52.



Figure 50: Inspection of R2 eccentric (1)



Figure 51: Inspection of R2 eccentric (2)



Figure 52: Inspection of R2 eccentric (3)

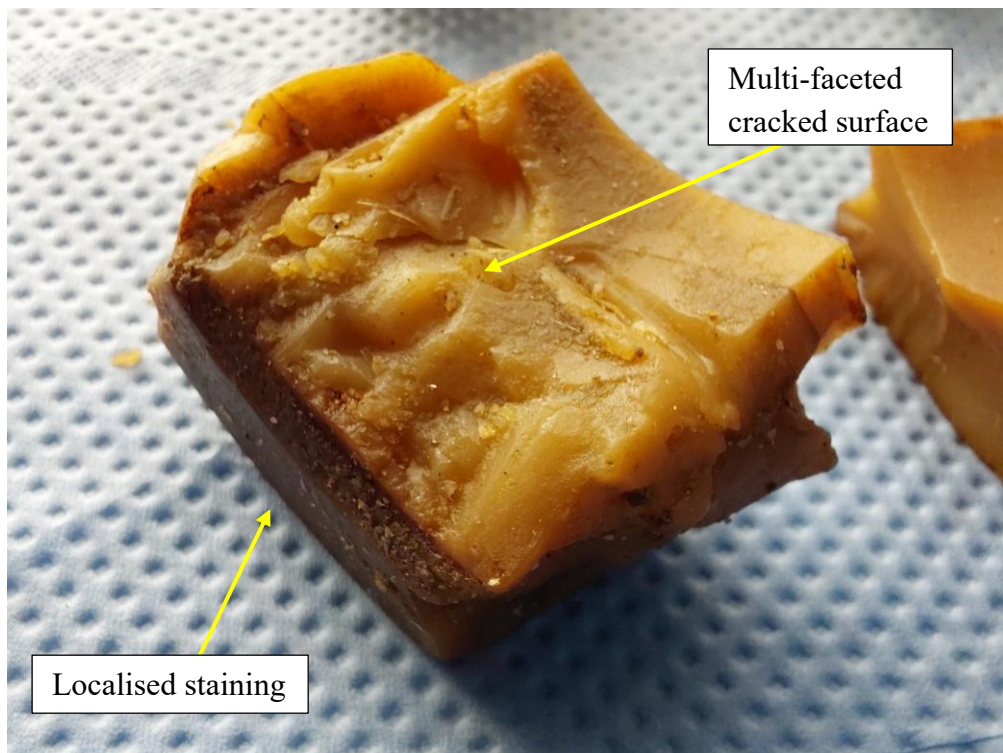


Figure 53: Inspection of R2 eccentric (4)



Figure 54: Inspection of R2 eccentric (5)



Figure 55: Inspection of R2 eccentric (6)

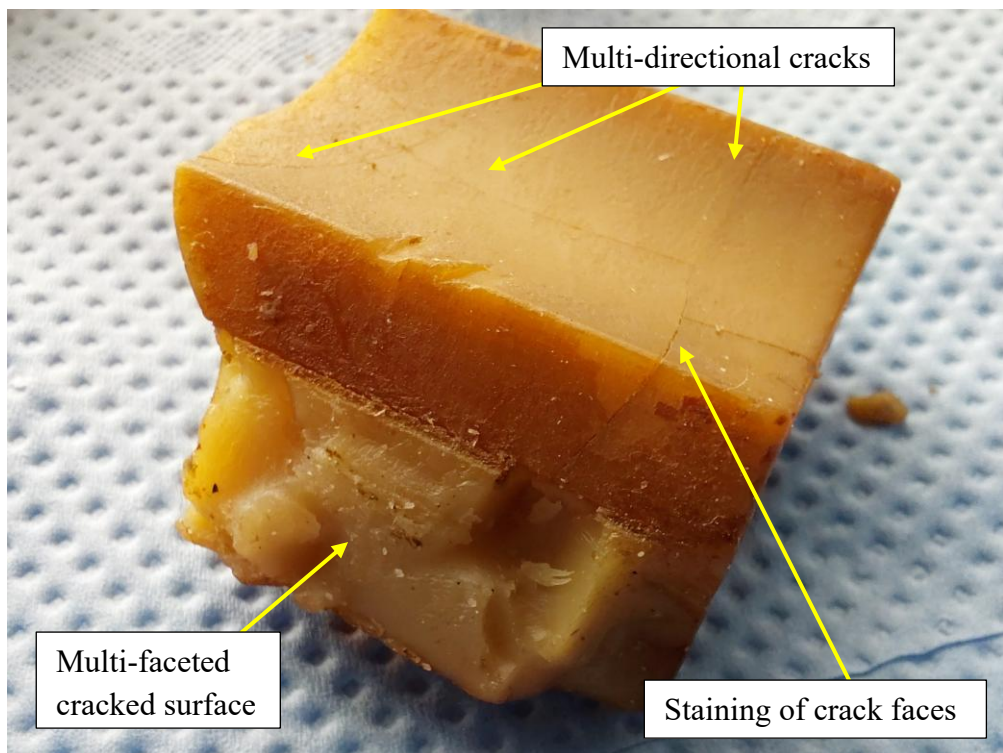


Figure 56: Inspection of R2 eccentric (7)

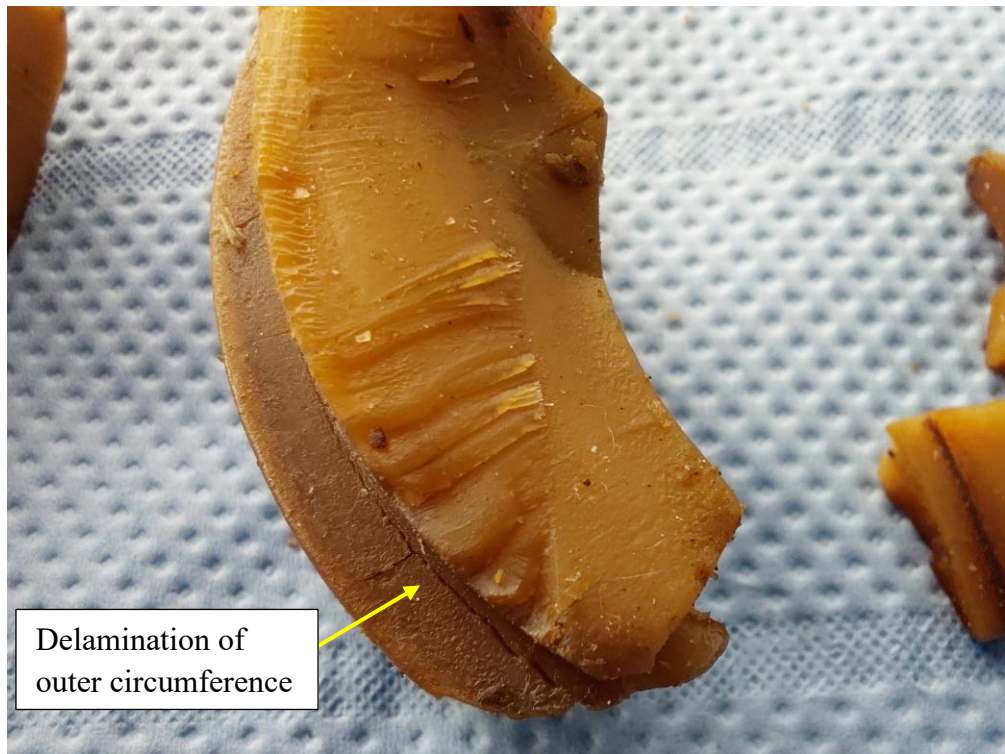


Figure 57: Inspection of R2 eccentric (8)

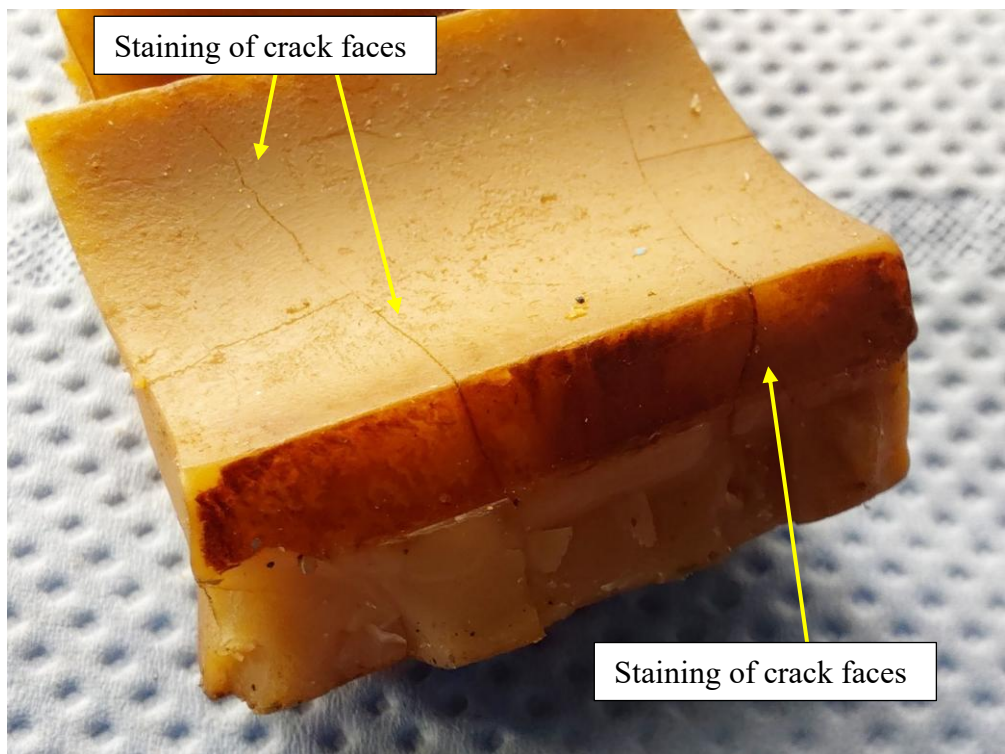


Figure 58: Inspection of R2 eccentric (9)

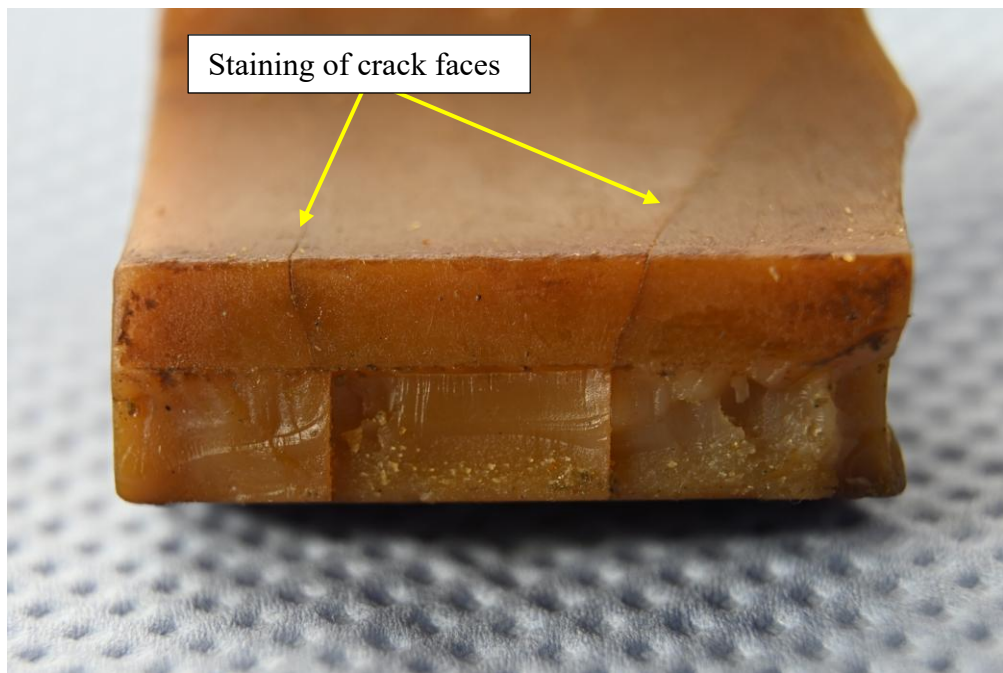


Figure 59: Inspection of R2 eccentric (10)

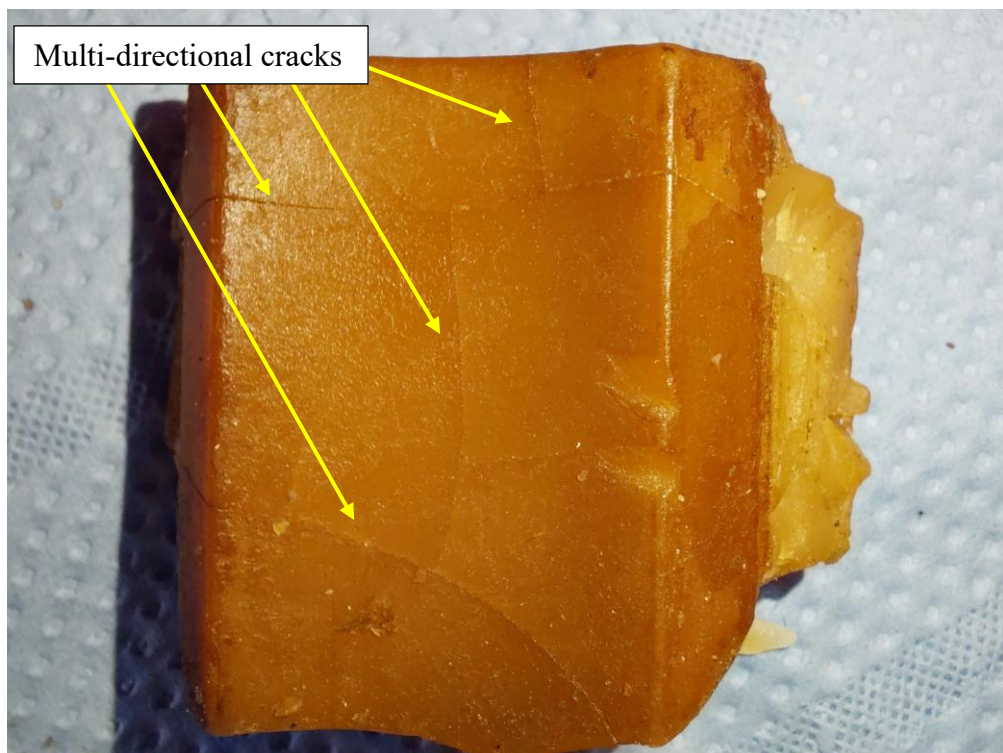


Figure 60: Inspection of R2 eccentric (11)

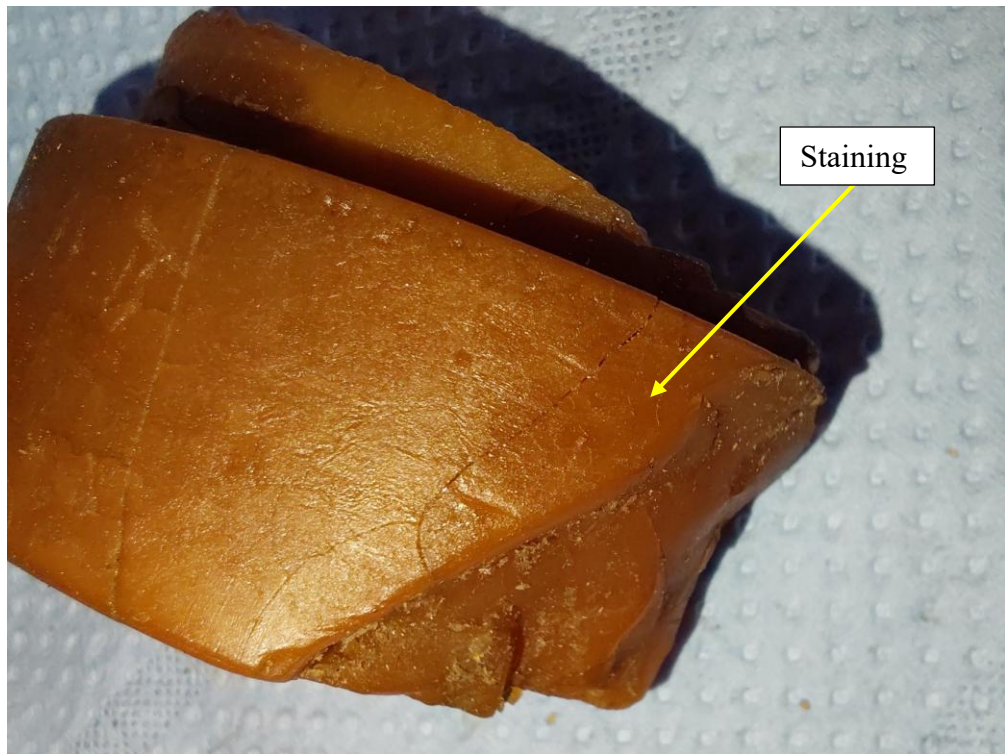


Figure 61: Inspection of R2 eccentric (12)

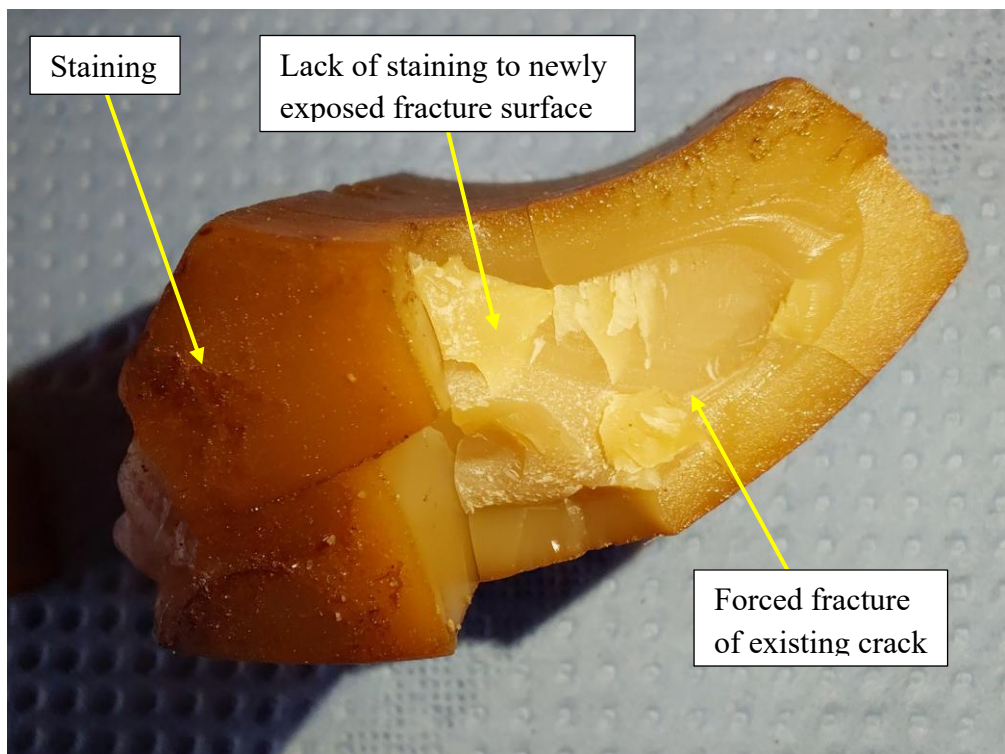


Figure 62: Inspection of R2 eccentric (13)

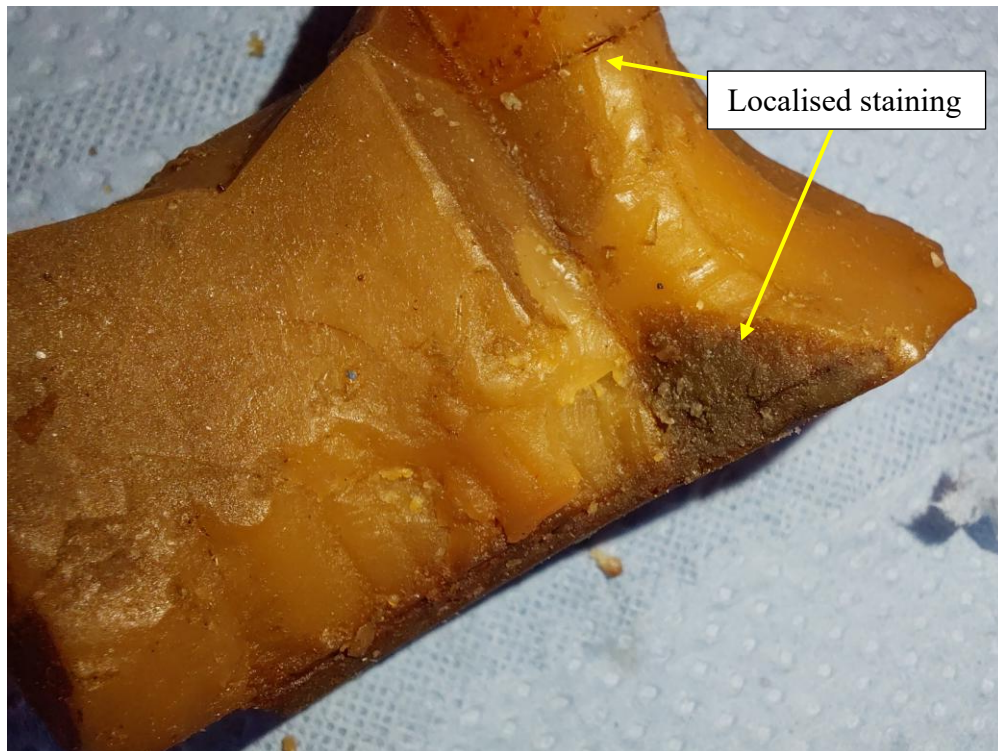


Figure 63: Inspection of R2 eccentric (14)

14.6. R3 Eccentric

- 14.6.1. The eccentric from R3 was provided to me in a sealed plastic bag, comprising a tamper evident seal. The bag contained a section of the eccentric that was approximately half the size of the complete eccentric, as well as a large number of smaller fragments. The extent of disintegration of this eccentric appeared more significant than that of the eccentrics of R1 and R2.
- 14.6.2. The larger fragment also had a section missing from the outer circumference of the larger diameter end of the eccentric and in the vicinity of one of the keyway slots.
- 14.6.3. The fracture surfaces of the eccentric fragments were multi-faceted in a similar manner to the R1 and R2 eccentrics.
- 14.6.4. There were a large number of cracks present across all planes of the component, including in longitudinal, radial and circumferential directions. Some of the cracks had propagated from the corners of the keyway slots.
- 14.6.5. There was significant staining of the eccentric from the oil. More specifically, in a similar manner to R2, there was localised staining from the oil that had penetrated into the cracks, increasing their contrast. The presence of staining within the cracks would suggest that the cracks had been developing for an extended period of time, and long enough for the oil to have penetrated the crack and cause the observed staining.
- 14.6.6. Some of the exposed fracture surfaces were light brown/tan in colour, suggesting that these regions of the eccentric were not exposed to the oil for an extended period of

time that was sufficient to cause any staining. There was also visible staining around the perimeter of the fragment, suggesting a degree of penetration and impregnation of the oil into the surface of the eccentric.

- 14.6.7. I again force-fractured some partially propagated cracks where the newly exposed fracture surfaces were significantly lighter in colour; however, there was localised staining to the surface of the initial, partially propagated crack, indicating that this had occurred over an extended period of time.
- 14.6.8. Finally, in a similar manner to the R1 eccentric, there was also a circumferential band of lighter colour that extended around the smaller diameter end of the eccentric. The position and size of this band suggests that this was the region to which the metal collar was previously fitted, and as such, the lighter colour would suggest that the oil was not able to stain this region of the eccentric to the same degree as the other exposed regions.
- 14.6.9. The material also felt hard and brittle to the touch, unlike the exemplar eccentric, which was comparatively soft and pliable.
- 14.6.10. There was also significant oil residue present on the surfaces of the fragments of the eccentric. This was markedly different to the eccentrics of R1 and R2 which did not have any oil residue present on the surfaces of the fragments.
- 14.6.11. Photographs of the eccentric of R3 are provided in Figure 64, below, to Figure 77, on page 60.



Figure 64: Inspection of R3 eccentric (1)



Figure 65: Inspection of R3 eccentric (2)



Figure 66: Inspection of R3 eccentric (3)

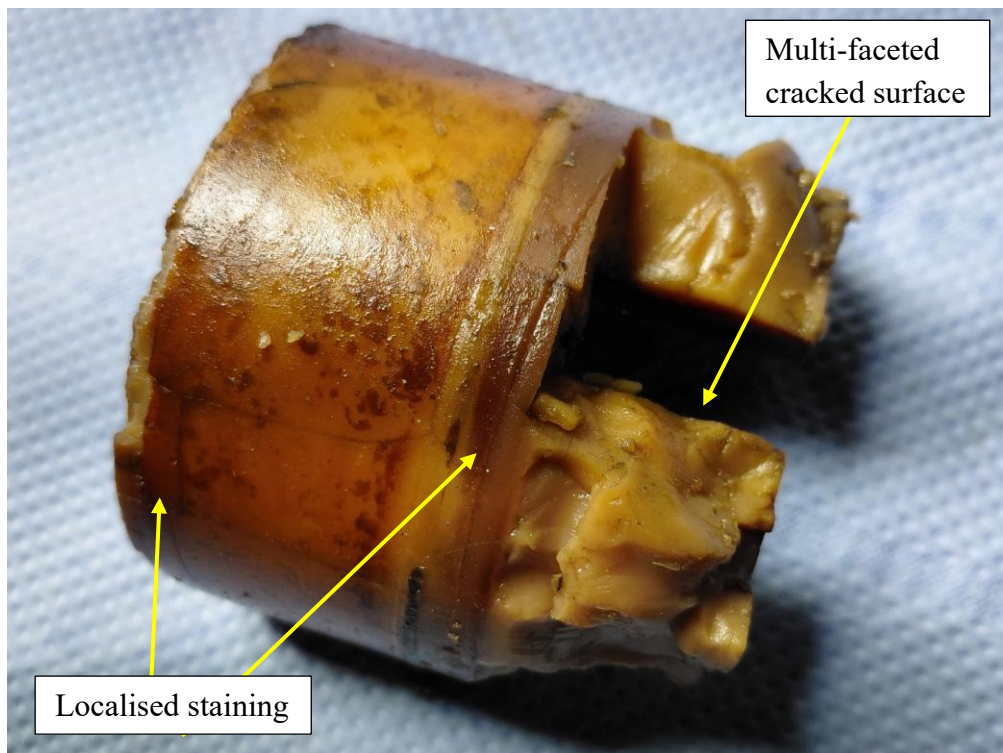


Figure 67: Inspection of R3 eccentric (4)



Figure 68: Inspection of R3 eccentric (5)

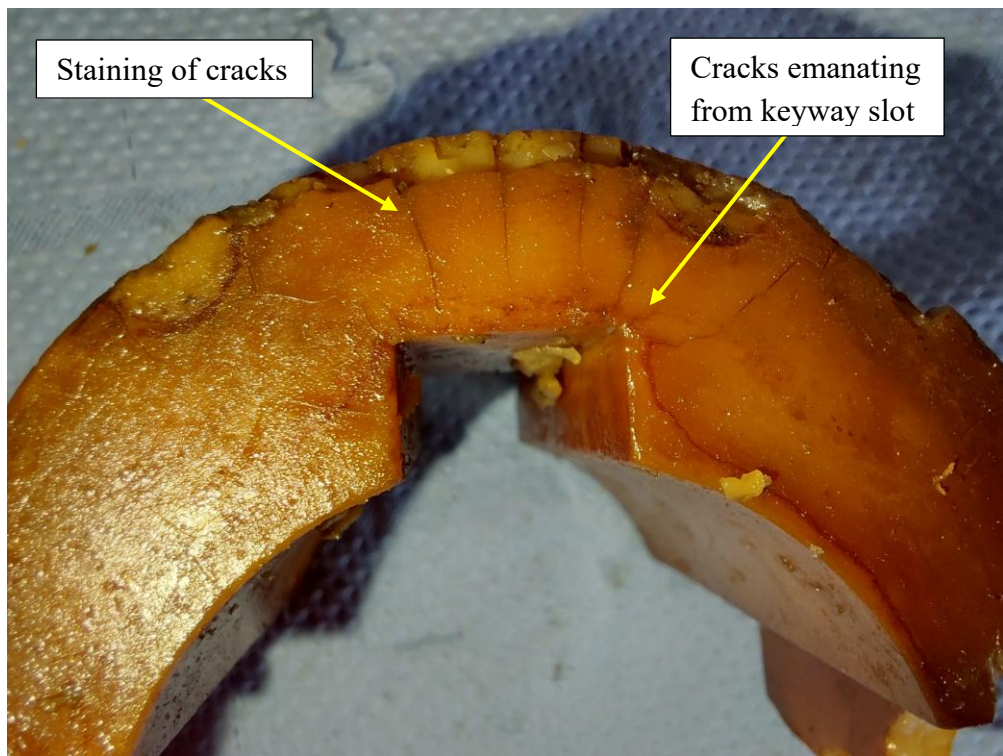


Figure 69: Inspection of R3 eccentric (6)

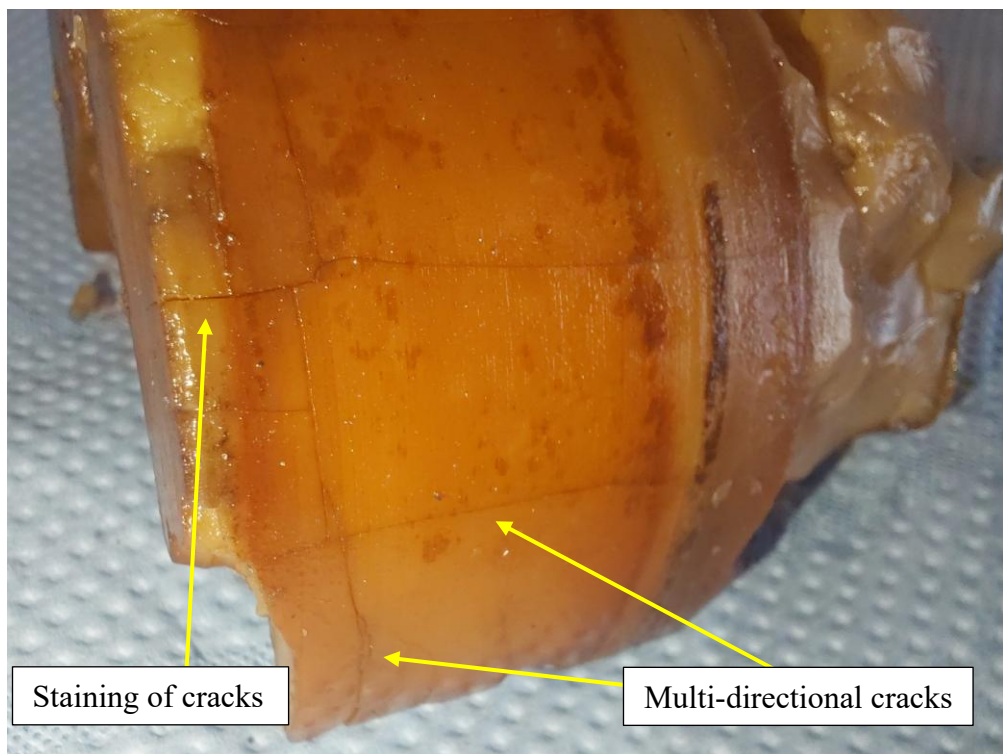


Figure 70: Inspection of R3 eccentric (7)

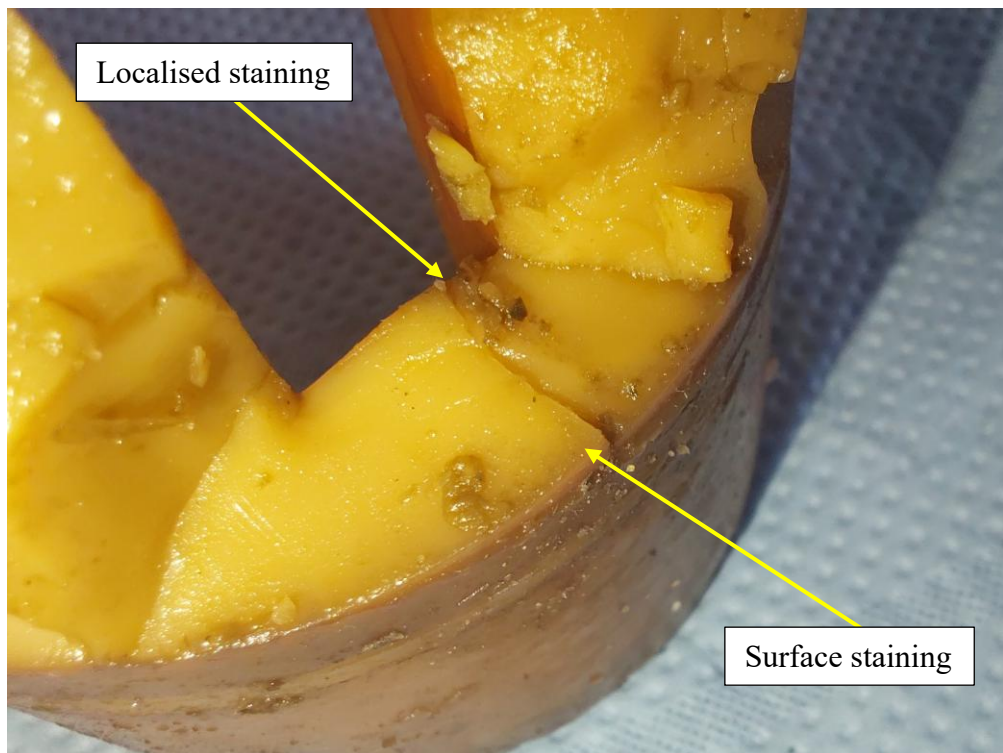


Figure 71: Inspection of R3 eccentric (8)

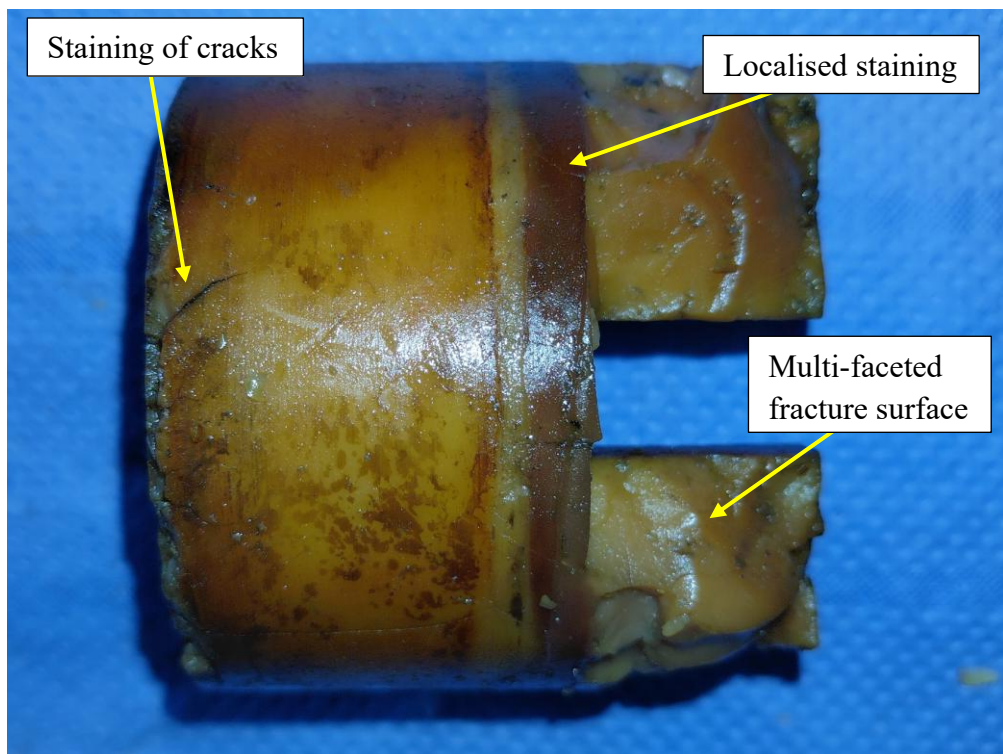


Figure 72: Inspection of R3 eccentric (9)

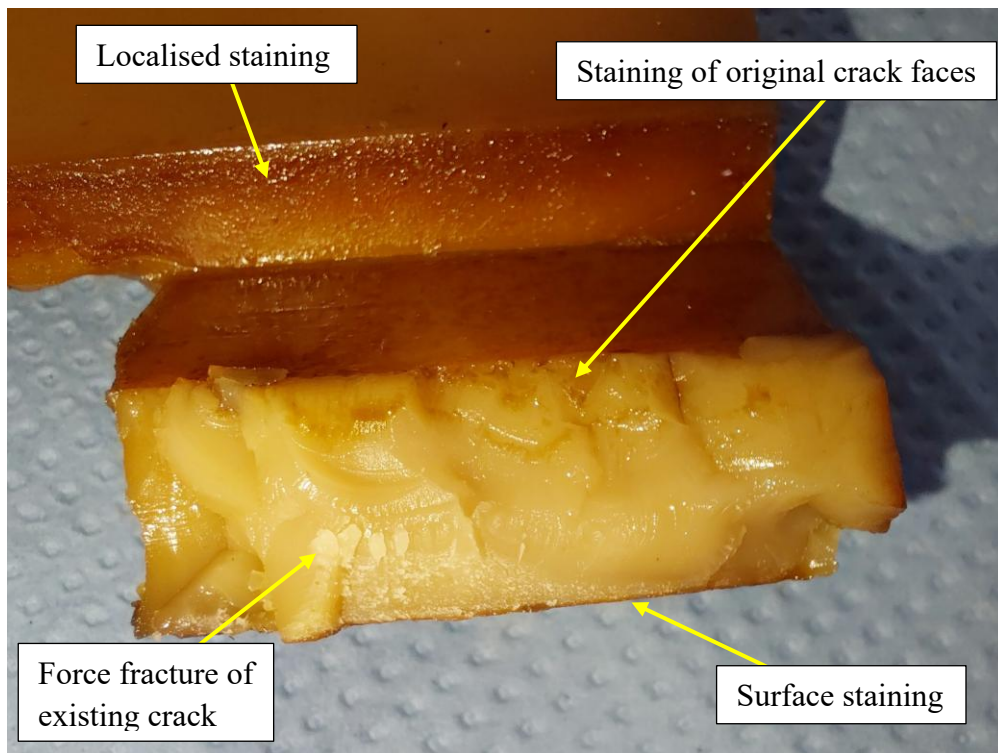


Figure 73: Inspection of R3 eccentric (10)

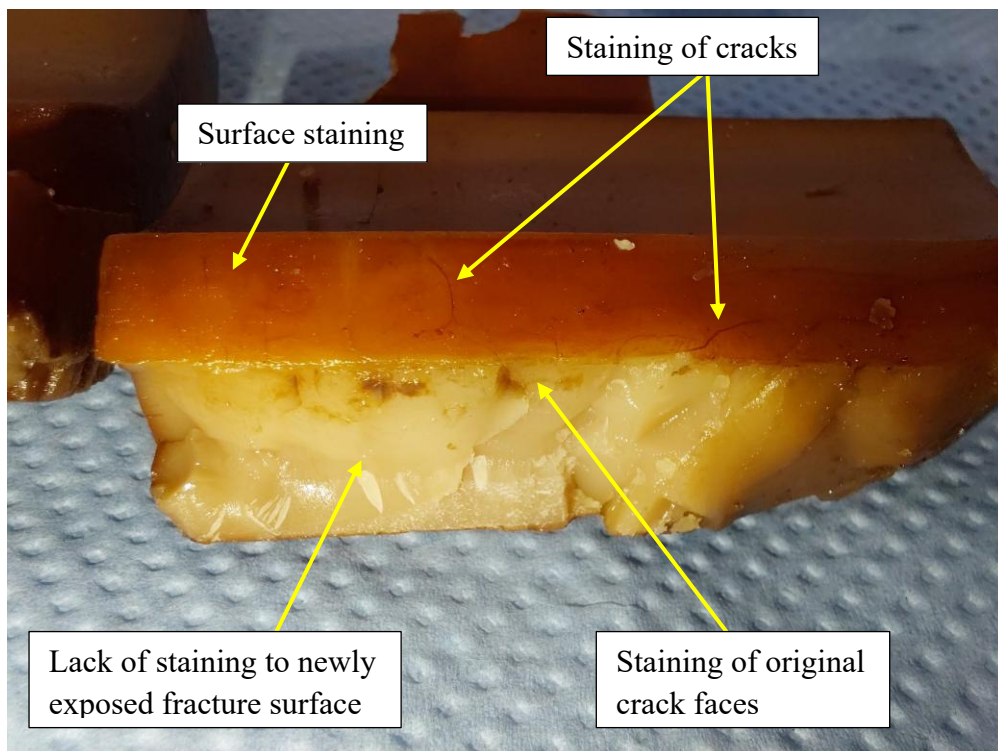


Figure 74: Inspection of R3 eccentric (13)

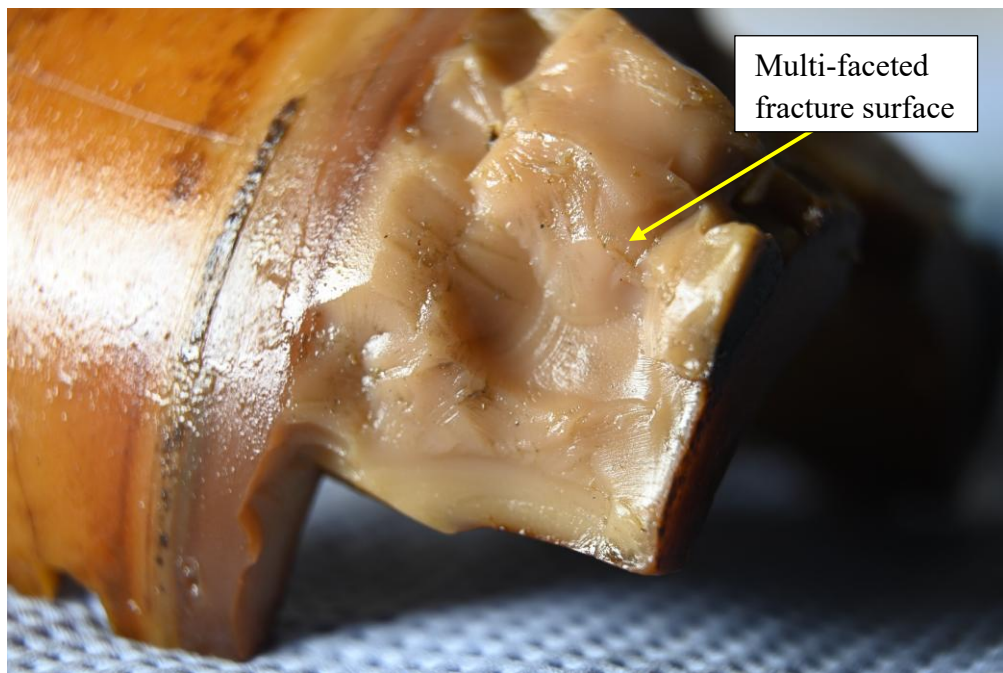


Figure 75: Inspection of R3 eccentric (14)

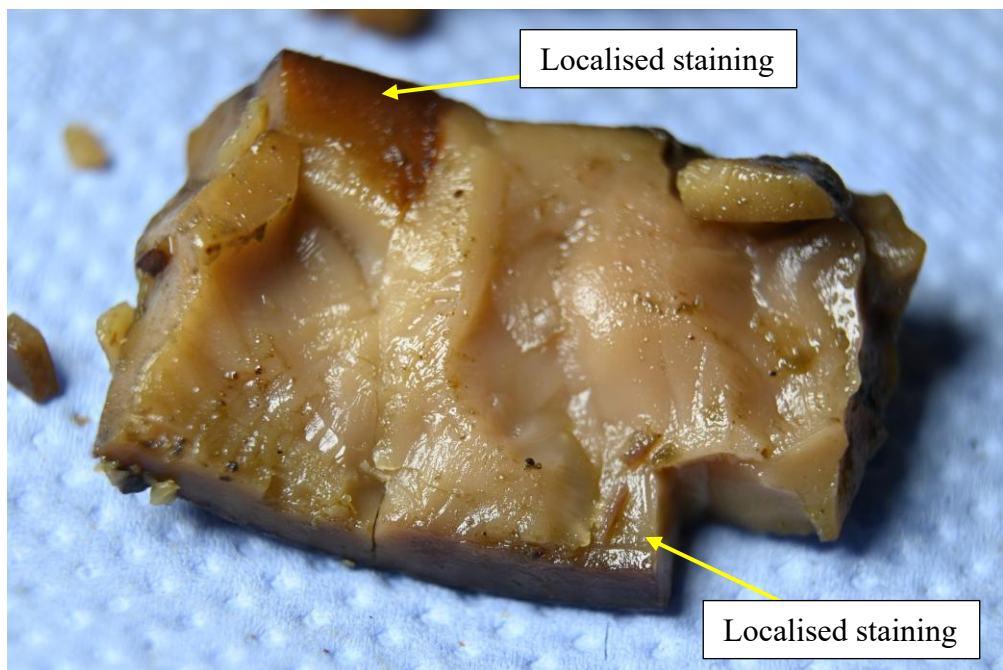


Figure 76: Inspection of R3 eccentric (15)

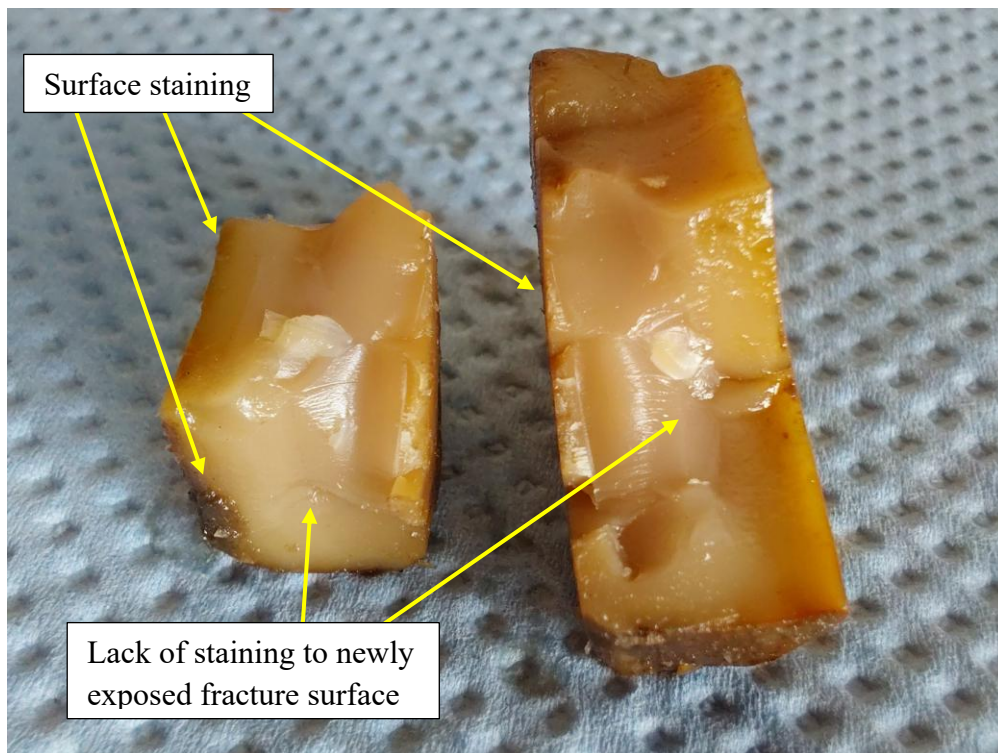


Figure 77: Inspection of R3 eccentric (16)

15. INSPECTION OF BEARING

- 15.1. I was also provided with a fractured bearing that was reportedly originally fitted to the gearbox of R2. This bearing was provided to me in a sealed plastic bag, comprising a tamper evident seal.
- 15.2. The gearboxes are fitted with a number of bearings, and while the bearing is reported to have been originally fitted to the gearbox of R2, the precise location of this bearing is not known.
- 15.3. Nevertheless, the bearing was a ball-bearing type, comprising an inner and outer ring, and 13 ball bearings.
- 15.4. The inner ring was fractured into a number of sections.
- 15.5. The bearing cage (the component that holds the ball bearings in position) was twisted and deformed on one edge. There were also cracks to the bearing cage in places, and deformation to its outer edge.
- 15.6. To my mind, the nature of the fracture surfaces of the broken fragments of the bearing appeared consistent with brittle fracture as a result of a single, over-load type failure, and possibly a shock load. There was no evidence of any progressive degradation mechanisms such as fatigue loading and/or corrosion.
- 15.7. Furthermore, to my mind, the nature of the deformation to the bearing cage appeared consistent with a partial twisting/bending motion.

- 15.8. Based on the currently available evidence, it is not possible to confirm the precise cause of the failure, or the moment at which it occurred. However, the maintenance team advised that when the Marcé engineers were reassembling the gearbox of R2 after the eccentric had been replaced, they used a mechanical press to mount components on the driveshaft, and it is alleged that they applied a force of 14 tons.
- 15.9. I also note that in Work Order 17449, the engineer's sign off notes entry dated 10/02/26 states "*Assist engineers with fitting gear box, found bearing broken.*".
- 15.10. At this stage, I have not been provided with any evidence to support the allegation that a load of 14 tons was applied on the gearbox.
- 15.11. However, I will add that to my mind, a load of this magnitude could be sufficient to cause the observed fracture of the bearing.
- 15.12. Furthermore, as described previously, to my mind, the nature of the deformation could suggest a twisting/bending force. This could suggest some misalignment of the bearing at the point that the force was applied. However, at this stage, I am unable to make any further comment in this regard.
- 15.13. Photographs of the R2 bearing are provided in Figure 78, below, to Figure 88, on page 66.
- 15.14. An excerpt from Work Order 17449 showing the first recorded observation of the damage bearing is provided in Figure 89, on page 67.



Figure 78: Inspection of R2 gearbox bearing (1)



Figure 79: Inspection of R2 gearbox bearing (2)



Figure 80: Inspection of R2 gearbox bearing (3)



Figure 81: Inspection of R2 gearbox bearing (4)

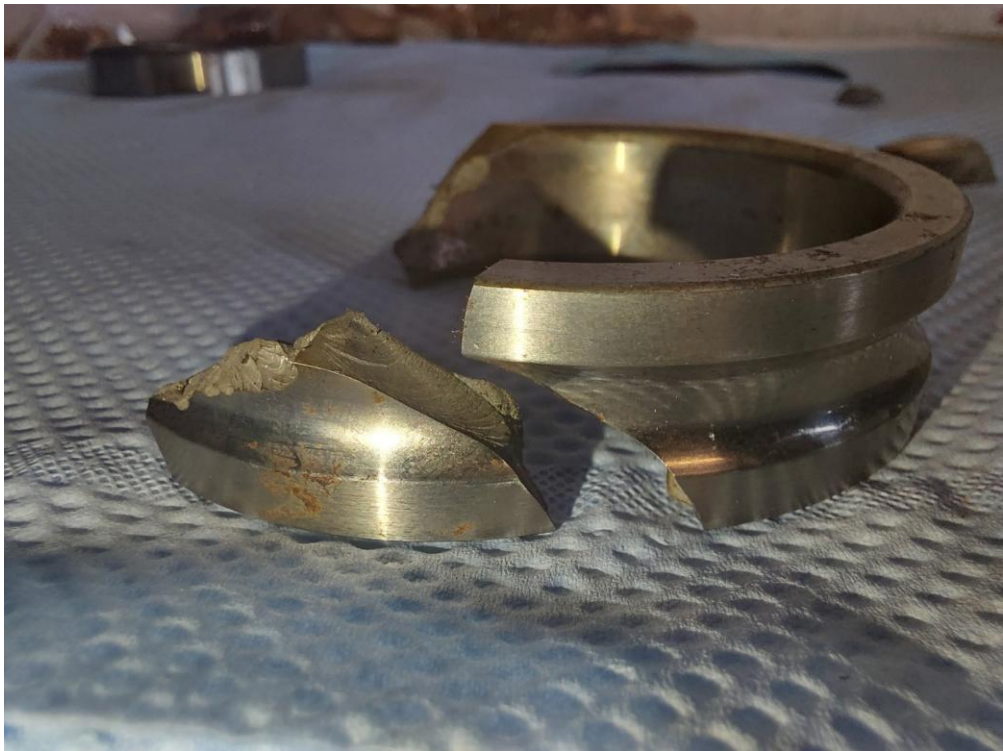


Figure 82: Inspection of R2 gearbox bearing (5)

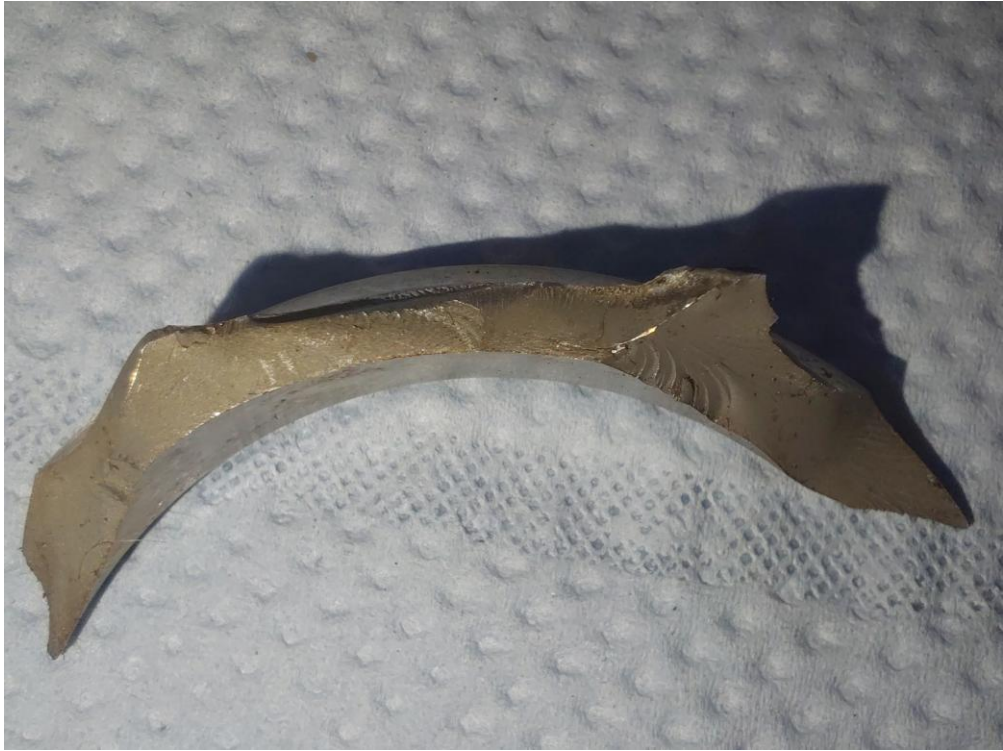


Figure 83: Inspection of R2 gearbox bearing (6)



Figure 84: Inspection of R2 gearbox bearing (7)

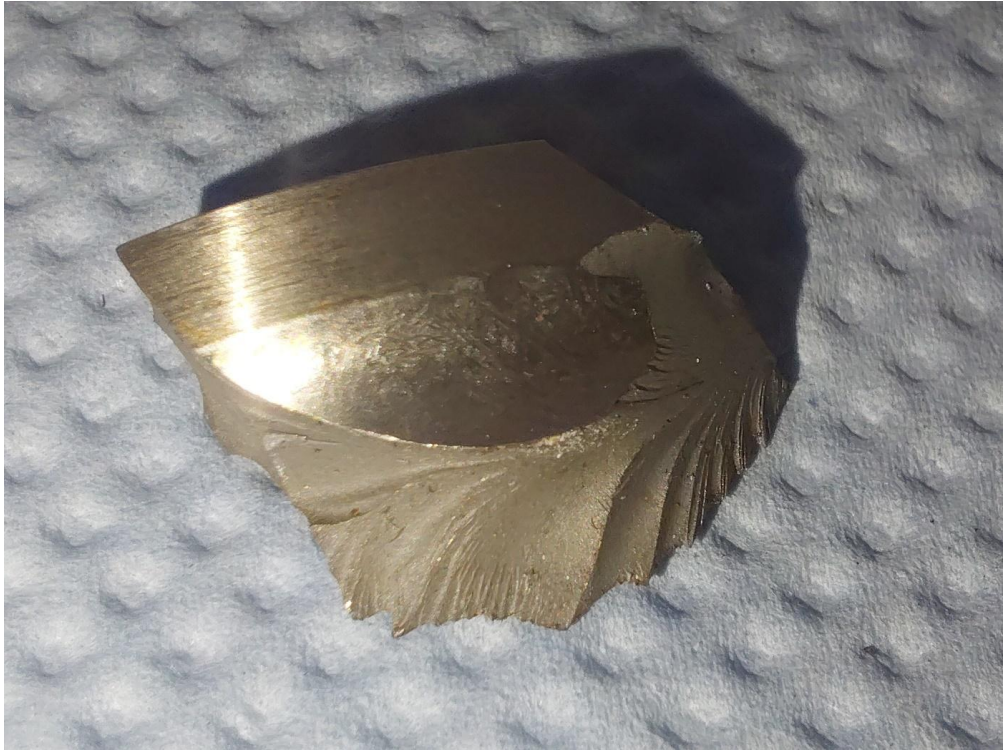


Figure 85: Inspection of R2 gearbox bearing (8)



Figure 86: Inspection of R2 gearbox bearing (9)



Figure 87: Inspection of R2 gearbox bearing (10)



Figure 88: Inspection of R2 gearbox bearing (11)

Engineers Sign Off Notes

Notes

12/01/26 - Strip pipework and electrical cables from pump and rear cubical to prepare for lift
13/01/26 - Continue to strip pipework and electrical cables from pump and rear cubical. Lift rear cubical. Brought Fire Truck into workshop and dismantle pipework from pump.
15/01/26 - Continue to dismantle pipework from pump and lift off pump from truck. Remove high pressure pump from gearbox.
17/01/26 - Start to dismantle low pressure side of pump. Casing seized, manufacture pully system to separate casing.
17 -24/01/26 - Continue stripping pump and cleaning pump casings.
9/02/26 - Made up new gaskets for pump, engineers on site, started fitting gearbox together
10/02/26 - Assist engineers with fitting gear box, found bearing broken.
13/02/26 - Fit rear cubicle onto truck and connect wiring at the rear end.
14/02/26 - Continue with fixing at the rear end of truck.
15/02/26 - Start fitting low and high pressure side of pump together
17/02/26 - Continue refitting Gearbox together
18/02/26 - Install pump back in truck with all the piping and test pump, found clutch on gearbox not working.
19/02/26 - Remove high pressure side of pump and repaired clutch cables, Reinstate high pressure pump, Test run.
20/02/26 - Test truck with RFSS and found foam mixture incorrect, adjust foam mixture, satisfactory. Leak on high pressure seal
21/02/26 - Remove high pressure pump, replace seal and reinstate, found foam gauge not working. Correct wiring.

Figure 89: Excerpt from Work Order 17449 showing first recorded observation of broken bearing

16. CORROSION & PITTING DAMAGE

- 16.1. As described previously, during the disassembly of the R2 pump casing, corrosion and pitting damage was observed.
- 16.2. While a complete disassembly of the pumps was not conducted during my time at St Helena Airport, I inspected the drafting inlets and impellers of each of the ARFF vehicles, which showed surface corrosion to the inlets and pitting damage to the impeller blades. There also appeared to be limescale deposits at the inlets. It is important to note that the drafting inlets are fitted with a metal grate that acts as a coarse filter to prevent large foreign objects from entering the impeller. This impeded access to the impeller for inspection. Nevertheless, the pitting and corrosion could still clearly be seen.
- 16.3. Images of the impellers and drafting inlets of each ARFF vehicle are provided in Figure 90, overleaf, to Figure 95, on page 70.

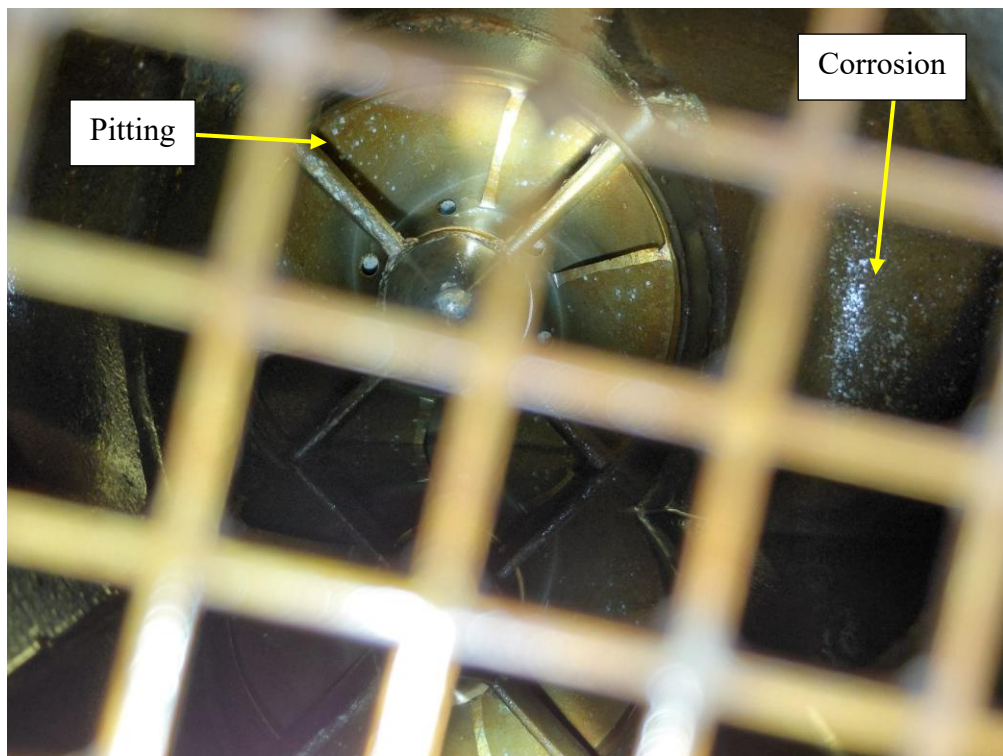


Figure 90: Pitting damage to R1 impeller



Figure 91: Limescale deposits on R1 inlet

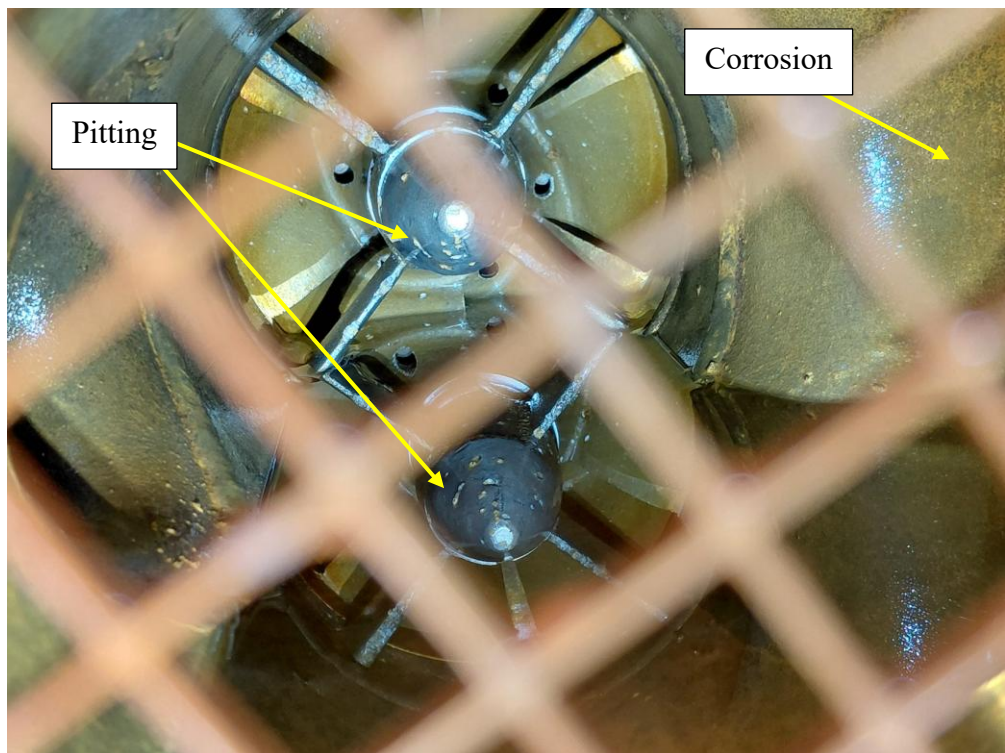


Figure 92: Pitting damage to R2 impeller

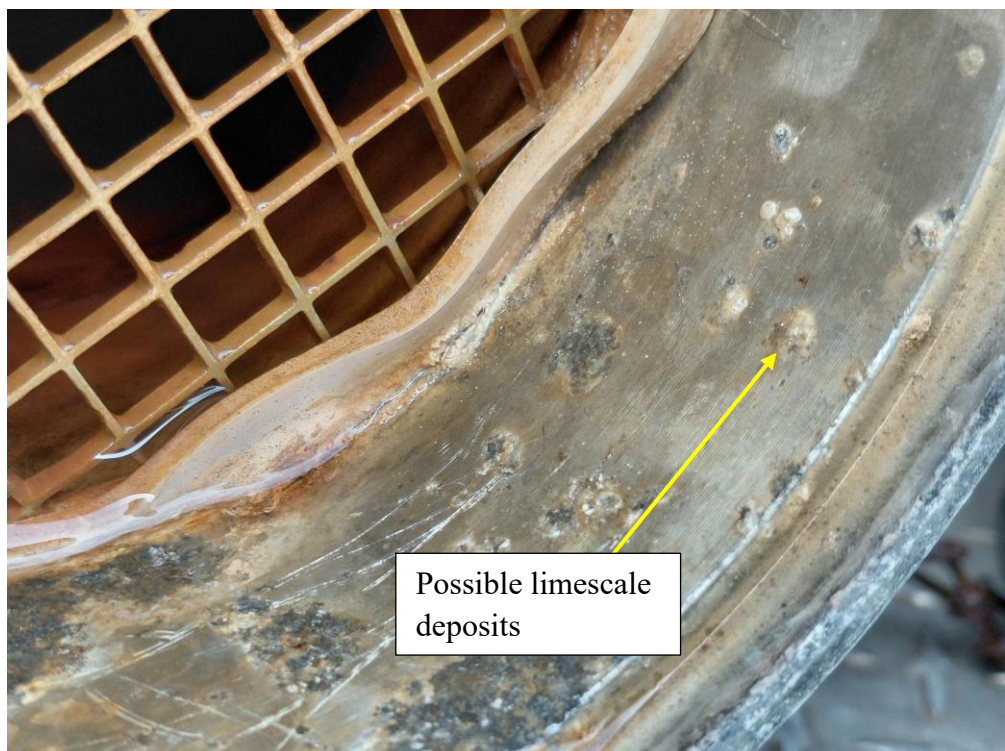


Figure 93: Limescale deposits to R2 inlet

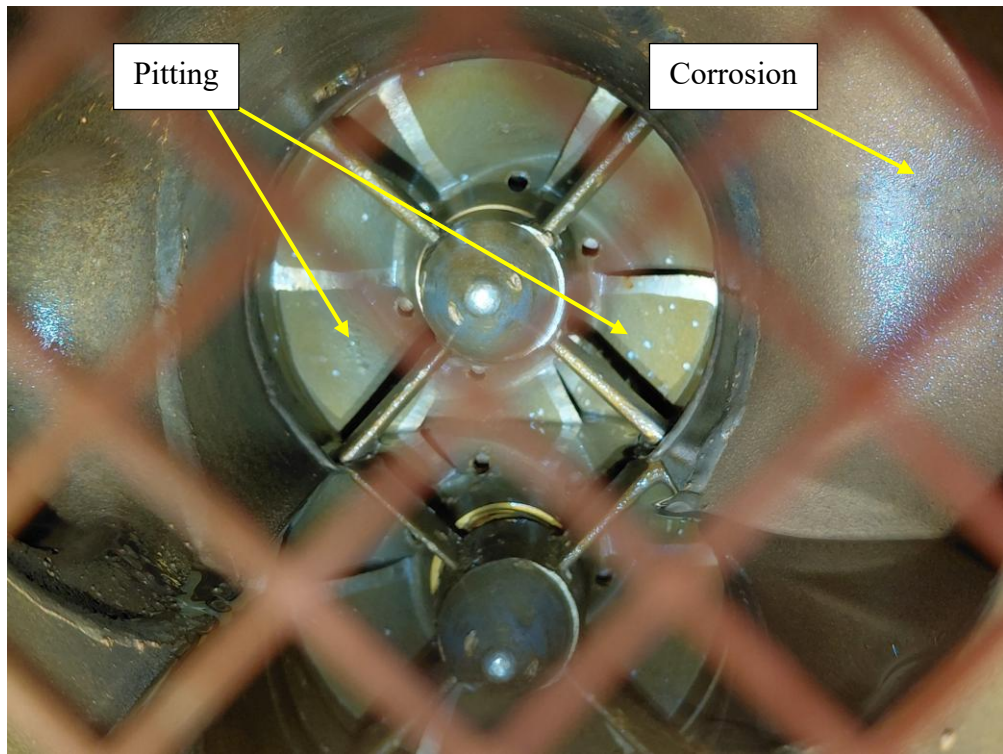


Figure 94: Pitting damage to R3 impeller

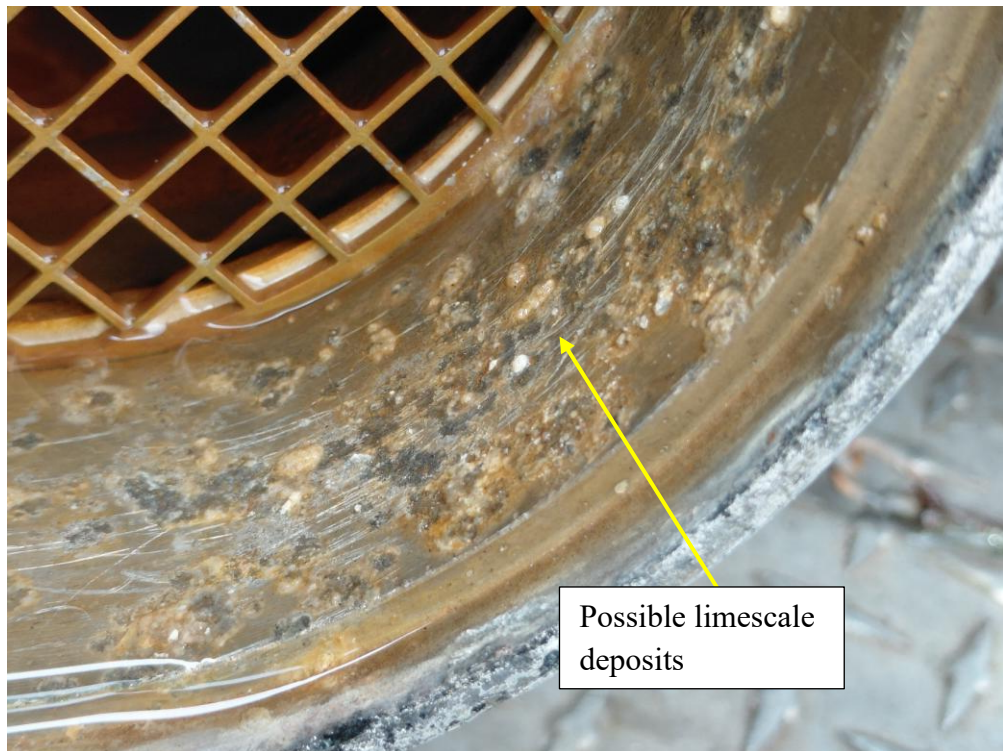


Figure 95: Limescale deposits to R3 inlet

17. ENDOSCOPIC EXAMINATION

- 17.1. At the time of my inspection, the pumps had been repaired and the ARFF vehicles were in service. This meant that full disassembly and examination of the pump gearboxes could not be conducted.
- 17.2. However, with assistance from the maintenance team, I was able to conduct an endoscopic inspection of the replacement eccentrics fitted to each of the ARFF vehicles, which provided partial visual access to the eccentrics.
- 17.3. This was done by draining the oil from the gearbox of each of the ARFF vehicles, and inserting an endoscope into the gearbox oil drain plug.
- 17.4. With the endoscope camera viewing the eccentric, the PTO shaft was then manually rotated, allowing a full circumferential inspection of the eccentric.
- 17.5. However, it is important to note that this inspection only allowed visual access to the larger diameter end of the eccentric, since the metal collar was situated over the smaller diameter end. Nevertheless, even though only providing visual access to one end of the eccentric, it was considered that this would likely be indicative of the overall condition of the remainder of the component.
- 17.6. On this basis, this cursory in-service inspection provided an up-to-date assessment of the condition of each of the eccentrics.
- 17.7. Inspection of the full circumference of the larger diameter end of the eccentric from each ARFF vehicle showed that the eccentrics appeared to be intact, with no visible damage, defect, abrasion, cracking or the like.
- 17.8. At the time of this endoscopic inspection, the eccentrics had been in service for between five and six months.
- 17.9. Images of the eccentrics from each ARFF vehicle are provided in Figure 96, overleaf, to Figure 101, on page 74.



Figure 96: Eccentric of R1 (in situ) (1)



Figure 97: Eccentric of R1 (in situ) (2)



Figure 98: Eccentric of R2 (in situ) (1)



Figure 99: Eccentric of R2 (in situ) (2)



Figure 100: Eccentric of R3 (in situ) (1)



Figure 101: Eccentric of R3 (in situ) (2)

18. PRELIMINARY TESTING

- 18.1. During my time at SHAL, I conducted a preliminary, rudimentary experiment to assess any potential effects of exposure of the elastomer to different fluids, and in particular, on the integrity of the material.
- 18.2. This involved removing small samples from one of the eccentrics and placing each in one of four fluids: virgin (i.e. previously unused) SAE 10 oil; virgin 10W40 oil, SAE 10 oil deliberately contaminated with approximately 10% water, and pure tap water.
- 18.3. To ensure similarities between the samples, they were all removed from the original R2 eccentric, and as best as could be achieved with the equipment available, each of the samples were of similar size and shape.
- 18.4. The samples were then stored in a container of each fluid for a period of three days.
- 18.5. After three days exposure, each of the samples was visually inspected and then placed between metal plates and a force was applied using a mechanical press.
- 18.6. It is important to note that during my time at the airport, I did not have access to any high-precision laboratory equipment, and I only had access to limited workshop facilities. As such, I was unable to quantify the precise loading applied to the samples; however, to ensure consistency, the same loading was applied to each sample. To this end, it is to be understood that this experiment was intended only as an illustrative demonstration of any potential effect of exposure to each fluid, done on a comparative basis between each sample, rather than as a high-precision and quantifiable laboratory test.
- 18.7. It is also noted that there is a possibility that the already damaged condition of the elastomer could affect the outcomes of further exposure, and as such, virgin (i.e. unused) elastomer material may offer a more accurate assessment of exposure to the fluids. However, it is important to note that no virgin elastomer material was available for testing. Nevertheless, since this testing is done on a comparative basis between samples from the same original eccentric, any such effect is negated.
- 18.8. Considering the two samples that were stored in oil, there was no detectable change to the properties of the sample (for example, tactile feel, hardness, colour etc.) between pre and post-exposure. Light pressure to the sample with a tool did not appear to cause any permanent deformation, indentation or damage to the surface.
- 18.9. When the samples were compressed using the mechanical press, they formed generally circular discs of broadly homogeneous texture. The discs held their shape and could be removed from the metal plates with ease and without sustaining further damage.

- 18.10. The sample stored in contaminated oil appeared to have softer tactile properties, and light pressure with a tool caused minor permanent deformation and surface indentation. The colour was also slightly lighter in hue than the oil-exposed samples.
- 18.11. When the sample was compressed in the mechanical press, it appeared to be more brittle than the oil-exposed samples, and broke into a number of fragments. The sample had adhered slightly to the metal plate and it fractured further upon removal.
- 18.12. The sample stored in tap water appeared to have significantly softer tactile properties, and the sample began to crumble in my fingers when removing it from the water. The colour was also even lighter in hue than the oil-contaminated exposed sample.
- 18.13. When the sample was compressed in the mechanical press, it disintegrated even further. It also had adhered to the metal plate to a greater extent and crumbled extensively upon removal.
- 18.14. Photographs of the samples taken following their compression with the mechanical plate are provided in Figure 102, below.

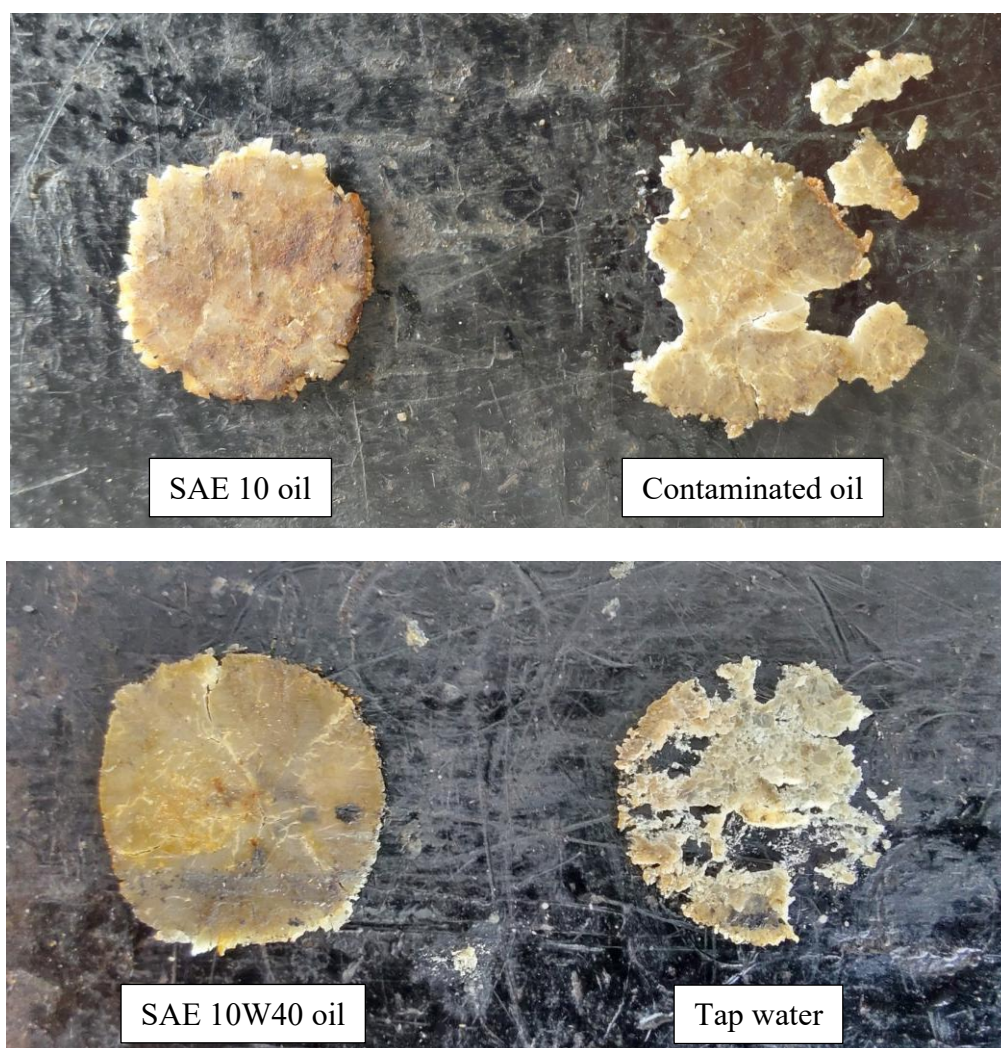


Figure 102: Post-pressure test texture of elastomer samples exposed to different fluids

- 18.15. In light of this preliminary test, it appears that the exposure to both grades of oil did not affect the structure of the elastomer material to any significant extent (at least within a three day exposure period). However, it also suggests that when exposed to water, the composition of the elastomer material was seemingly altered, causing it to become significantly more brittle, and more prone to disintegration.
- 18.16. It is acknowledged that this experiment does not provide the same level of quantifiable accuracy as in a scientific laboratory with access to specialist testing equipment. However, as described previously, such equipment was unavailable to me during my time at St Helena Airport. Nevertheless, this preliminary test serves to illustrate a potential link between water exposure and possible change in the structure and/or properties of the elastomer material, and degradation and/or disintegration of the structure.
- 18.17. This is also consistent with the information provided by the elastomer manufacturer Vulkoprin, which as described previously, states that Vulkollan® is resistant to oils, greases and various chemicals; however it is susceptible to hydrolysis, which is the chemical breakdown and decomposition of polyurethane materials in contact with water, where the individual polymer chains can be damaged, potentially causing the material to lose its strength, become brittle and crack or crumble.
- 18.18. The removed eccentrics have also been retained, and can be used for further, scientific testing if required.
- 18.19. If investigations are to continue, I would suggest that a similar test be repeated, and that quantifiable hardness testing be conducted on the samples under controlled laboratory conditions.

19. OIL ANALYSIS

19.1. Overview

- 19.1.1. Following observation of the damage to the eccentrics, a number of samples of the gearbox oil were retained and sent for laboratory testing. The testing was conducted by 'Wear Check', an international oil analysis company. In this instance, the oil samples were analysed in South Africa. I have been provided with oil test reports conducted by Wear Check.
- 19.1.2. It is important to note that prior to the discovery of the damage to the eccentrics, none of the oil drained from the gearboxes was retained and/or sent for testing. In particular, the oil drained from the gearbox of R1 during its annual service on 29/11/2025 was not retained.
- 19.1.3. The oil analysis reports are provided in Appendix D. However, for ease of reference, a summary of the findings are provided in Table 1 overleaf, to Table 3, on page 80.

- 19.1.4. As described previously, the original manual with the issue year 2014 stipulated the use of SAE 10 oil; however, the manual was subsequently updated in 2021, at which point, it stipulated the use of SAE 10W40 oil. However, this updated manual was not received by SHAL until March 2026. Due to delays in delivery, the new oil did not enter service until May 2026. It is reported that the 10W40 oil went into service on 27 May 2026.
- 19.1.5. The differences between these two oils is described further separately below; however, it is important to note that SAE 10W40 has a significantly greater viscosity than SAE 10 oil. As such, the increase in the viscosity after 27 May 2026 shown in Table 1 to Table 3 relates to the change in the oil used. The tests conducted on 27 May 2026 relate to the previous SAE 10 oil, and the first testing of the new 10W40 oil occurred on 10 June 2026. For ease of reference, the tests of the previous SAE 10 oil are highlighted in green, and the tests of the new 10W40 oil are shown highlighted in blue.

Table 1: Consolidated oil analysis results for R1

Date	Pump Hours	Notes	Viscosity (cSt @40C)
05/02/2026	299	5.5% water present. Viscosity is high for grade of oil. Wear rates increased.	57.4
21/03/2026	305	Wear rates normal, free from unacceptable contamination or degradation. Debris analysis normal	45.2
04/04/2026	306	Wear rates normal, free from unacceptable contamination or degradation. Debris analysis normal	45.1
18/04/2026	307	Wear rates normal, free from unacceptable contamination or degradation. Debris analysis normal	45
29/04/2026	308	Wear rates normal, free from unacceptable contamination or degradation. Debris analysis normal	44.6
27/05/2026	311	Wear rates normal, free from unacceptable contamination or degradation. Debris analysis normal	45.9
10/06/2026	312	Wear rates normal, free from unacceptable contamination or degradation. Debris analysis normal. Trace water present.	103.1
24/06/2026	314	Wear rates normal, free from unacceptable contamination or degradation. Debris analysis normal. Trace water present.	98
08/07/2026	315	Wear rates normal, free from unacceptable contamination or degradation. Debris analysis normal. Trace water present.	94

Table 2: Consolidated oil analysis results for R2

Date	Pump Hours	Notes	Viscosity (cSt @40C)
21/03/2026	352	Wear rates normal, free from unacceptable contamination or degradation. Debris analysis normal	45.3
24/03/2026	352	Wear rates normal, free from unacceptable contamination or degradation. Debris analysis normal	46.5
04/04/2026	354	Wear rates normal, free from unacceptable contamination or degradation. Debris analysis normal	44.7
18/04/2026	355	Wear rates normal, free from unacceptable contamination or degradation. Debris analysis normal	45.1
29/04/2026	355	Wear rates normal, free from unacceptable contamination or degradation. Wear particles present but considered normal	44.3
27/05/2026	359	Wear rates normal. Debris analysis normal.	46.1
10/06/2026	361	Wear rates normal, free from unacceptable contamination or degradation. Debris analysis normal. Trace water present.	102.6
24/06/2026	362	Wear rates normal, free from unacceptable contamination or degradation. Debris analysis normal. Trace water present.	96.6
08/07/2026	364	Wear rates normal, free from unacceptable contamination or degradation. Debris analysis normal. Trace water present.	92.8

Table 3: Consolidated oil analysis results for R3

Date	Pump Hours	Notes	Viscosity (cSt @40C)
11/03/2026	293	Wear rates have increased. Debris analysis normal. Check correct oil level is being maintained. Trace water present.	45.3
13/03/2026	293	Wear rates normal, free from unacceptable contamination or degradation. Debris analysis normal	44.7
26/03/2026	295	Wear rates normal, free from unacceptable contamination or degradation. Debris analysis normal. Trace water present.	45.8
18/04/2026	296	Wear rates normal, free from unacceptable contamination or degradation. Debris analysis normal. Trace water present.	46
29/04/2026	296	Wear rates normal, free from unacceptable contamination or degradation. Debris analysis normal. Trace water present.	45.1
27/05/2026	296	Viscosity is low for grade of oil. Wear rates normal. Debris analysis normal. 1.2% water present.	47.3
10/06/2026	298	Wear rates normal, free from unacceptable contamination or degradation. Debris analysis normal. Trace water present.	98.7
24/06/2026	362	Wear rates normal, free from unacceptable contamination or degradation. Debris analysis normal. Trace water present.	96.6
08/07/2026	364	Wear rates normal, free from unacceptable contamination or degradation. Debris analysis normal. Trace water present.	92.8

19.2. Oil Viscosity

- 19.2.1. Viscosity is a measure of a fluid's resistance to flowing, which, in essence describes its thickness. A fluid of high viscosity is thick and will resist flowing, whereas a fluid of low viscosity is comparatively thin and will flow quickly and easily. Examples of high viscosity fluids include honey and syrup, and examples of low viscosity fluids include water, petroleum and alcohols.
- 19.2.2. When considering an engine or gearbox oil, an oil of higher viscosity will be able to support greater loads than an oil with lower viscosity. However, a higher viscosity oil will flow less readily than a lower viscosity oil. There is therefore a balance to be met between an oil that can support the applied loading, yet flow sufficiently throughout the engine/gearbox, ensuring that all contacting surfaces are sufficiently lubricated.
- 19.2.3. In general, viscosity is inversely proportional to temperature, meaning that viscosity of a fluid will reduce with increasing temperature, i.e. as the temperature increases, the fluid will become less thick, and more runny.

- 19.2.4. To this end, for an engine or gearbox, the viscosity of the oil will vary as the temperature of the engine/gearbox varies, i.e. as the temperature increases during use, and then subsequently decreases after use.
- 19.2.5. SAE 10 oil is referred to as a monograde oil as it has a single viscosity rating, meaning that it works best within a narrow temperature range.
- 19.2.6. However, SAE 10W40 is referred to as a multigrade oil as it includes additives that allow it to operate over a wider range of temperatures.
- 19.2.7. The original SAE 10 oil used in the ARFF pump gearboxes is “*Castrol CRB Monograde 10W*”. Consultation with the manufacturer’s product data sheet states that this oil has a kinematic viscosity at 40°C of 41 centistokes (cSt), and at 100°C of 6.7 cSt.
- 19.2.8. The replacement SAE 10W40 oil used in the pump gearboxes is “*TotalEnergies Quartz 7000S 10W-40*”. Consultation with the manufacturer’s product data sheet states that this oil has a kinematic viscosity 40°C of 103 cSt, and at 100°C of 14.6 cSt.
- 19.2.9. On this basis, it can be seen that the viscosity of 10W40 oil is over double that of SAE 10 oil.
- 19.2.10. The product data sheets for both oils are provided in Appendix E.
- 19.2.11. It is also important to note that the presence of water contamination within an oil will cause its viscosity to increase.

19.3. Viscosity of Oil Used in ARFF Vehicles

- 19.3.1. As shown in the Oil Test reports and in Table 1 to Table 3, the non-contaminated oil samples of SAE 10 oil from R1 had a viscosity of 44.6 to 45.2 cSt. However, when water contamination of 5.5% was detected, the viscosity was 57.4 cSt.
- 19.3.2. The SAE 10 oil from the gearbox of R2 had a viscosity of 44.3 cSt to 46.5 cSt.
- 19.3.3. The non-contaminated samples of oil from R3 had viscosity of 44.7 cSt to 46.0 cSt. However, when water contamination of 1.2% was detected, the viscosity increased slightly to 47.3 cSt.
- 19.3.4. As described previously, the presence of water contamination will cause the viscosity of an oil to increase; as such, the observed increases in viscosity for the water contaminated samples is not unexpected.
- 19.3.5. The 10W40 oil from the gearbox of R1 had a viscosity of 94 cSt to 103.1 cSt, the oil from the gearbox of R2 had a viscosity of 92.8 cSt to 102.6 cSt, and the oil from the gearbox of R3 had a viscosity of 98.7 cSt. The 10W40 oil from R3 tested on 08/07/2026 had a water contamination of 1.6%, causing the viscosity to increase slightly to 99.8 cSt.

19.3.6. On this basis, as can be seen, the viscosity of the non-contaminated samples are broadly in line with the manufacturer's product data sheets for each respective oil.

19.4. Possible Cause for Change of Oil

19.4.1. The reason why the manufacturer changed the stipulated oil from SAE 10 oil to 10W40 is not known.

19.4.2. If investigations are to continue, I would recommend that Ziegler be consulted to enquire why the stipulated oil was changed.

19.4.3. However, I have also consulted a UK based oil laboratory to enquire why a manufacturer might change the stipulated oil from SAE10 oil to 10W40. They advised that the manufacturer might change from one oil to another oil that had a significantly increased viscosity (for example from SAE10 to 10W40 oil) if it is discovered that the original oil did not provide sufficient lubrication properties, resulting in excessive wear of the gearbox components. In such a scenario, the oil could be changed to one with increased viscosity in an attempt to reduce wear on the components.

19.4.4. While the precise reason for the change in oil in this instance is not known and cannot be confirmed at this stage, such a scenario cannot be precluded, for example, that it was discovered that SAE10 oil did not provide sufficient lubrication properties for the gearboxes.

19.5. Volume of Oil Samples

19.5.1. For completeness, I measured the volume of the retained oil samples. To avoid potential contamination of the samples, I did not decant the oil, but rather considered the range of oil levels of each of the oil containers, and then measured the corresponding volume of an identical container.

19.5.2. Using this approach, I measured that the retained oil samples ranged between approximately 1.25l and 1.35l. As described previously, the gearbox has a capacity of 1.5l.

19.5.3. However, it is important to note that for each of the samples provided to me, a smaller separate sample had already been removed and sent for testing. As such, the samples available to me were not the full sample originally removed from the gearbox.

19.5.4. On this basis, accounting for the sample sent for testing, as well as any other potential losses during the extraction (for example some oil being retained within the gearbox due to its viscosity), the oil samples that I inspected appear to be broadly consistent with the capacity of the gearbox, and do not necessarily indicate that the quantity of oil was less than the 1.5l stipulated in the operating manual.

19.6. Potential Cause of Water Contamination

- 19.6.1. It is reported that the oil samples were stored in plastic containers that previously contained water. On this basis, it has been suggested that the water contamination of the oil could have been due to remnants of water within the container. However, as shown above, the oil sample taken from R1 on 05/02/2026 had 5.5% water present, and the oil sample taken from R3 on 27/05/2026 had 1.2% water present.
- 19.6.2. The samples taken were 1.5 litres; as such, a water content of 5.5% would constitute 82.5ml, and 1.2% would constitute 18ml. Even if the volume of oil within the gearbox was as low as 1.25l (as measured in the sample container), 5.5% would constitute 69ml of water, and 1.2% would constitute 15ml of water.
- 19.6.3. To my mind, these quantities of water are significantly greater than what would be expected from mere remnants of water left inside the container. To this end, I do not consider that the water detected in these samples would have been solely due to any remnants of water left inside the container in which the oil was collected.
- 19.6.4. Rather, the presence of water would indicate some other water leak within the gearbox system. However, I understand that at this stage, the source of the leak has not been identified.

20. **ARFF ROUTINE OPERATION**

20.1. Overview

- 20.1.1. During my time at St Helena Airport, I witnessed the daily, monthly and quarterly testing conducted on the ARFF vehicles by the RFFS team. This allowed me to gain insight into the routine operations conducted on the ARFF vehicles, and in particular, the water pump and gearbox, and consider the loading and environmental conditions that the vehicles could be exposed to during routine testing and use of the pumps.
- 20.1.2. The routine testing and inspections consider a broad range of aspects relating to the fire tenders, including a number that extend beyond the realm of the operation of the water pumps, for example testing of the radio, inspection of ancillary tools, first-aid equipment, personal protective equipment (PPE), lights, ladders, wheel chocks and the like. While the routine checks test/inspect these aspects, it is important to note that for the purposes of my investigation, I have only considered the testing relevant to the water pumps, their use, pumping operation, storage and the like. To this end, this section only discusses the testing relating to the water pumps, and does not describe any other unrelated matters. However, it is to be understood that the aspects discussed here are not an exhaustive list of the actions conducted by the RFFS team during their routine testing/inspection.

20.2. Daily Testing

- 20.2.1. The daily testing of the water pumps comprises operating each of the vehicle's water jets/outlets using both the low pressure pump and the high pressure pump. The low pressure pump operates the front turret, roof-mounted turret and low pressure rear-mounted hoses, and the high pressure pump operates the high pressure rear-mounted hoses. Both low and high pressure pumps are also tested using both manual and automatic pressure regulation controls.
- 20.2.2. These tests only use the water stored in the on-board water tank, i.e. not from an external supply, and do not use any foam-based fire retardants.
- 20.2.3. Whenever the pump is operating, but water is not being discharged, the 'pump to tank' mode is activated, which recirculates water around the pump to provide cooling, and prevent the pump from overheating.
- 20.2.4. Once the testing is complete, the on-board water tank is replenished from the mains-water supply via a hydrant. When doing so, the tank is refilled until the overflow outlet begins to visibly dispel water, indicating that the tank is completely full.
- 20.2.5. The vehicles are then stored in the hangar until their next use, either the next daily test, or for an emergency fire-fighting response.

20.3. Monthly Testing

- 20.3.1. The monthly testing of the water pumps comprises the aforementioned daily test actions, as well as separate testing of the suction of the pump. This is done by closing the isolator valve between the on-board water tank and the pump, but leaving the sealing cap engaged with the drafting inlet, and then operating the pump.
- 20.3.2. Closing the isolator valves and the drafting inlet in this way creates a sealed system, and when the pump is operated, if the system is operating correctly, a vacuum should be generated. As such, operating the pump in this manner tests the ability of the pump to generate a vacuum, as well as the efficacy of the seals within the pump. This test is done without pumping water, and as such is referred to as a 'dry vacuum test'.
- 20.3.3. More specifically, with the system sealed, the pump is operated, and the pressure gauge is monitored. If the system is working correctly, the gauge should begin to register a negative pressure (or vacuum) within approximately 20 seconds. The operation of the pump is then maintained until the gauge reads approximately -0.8 bar, which typically takes up to approximately one minute, at which point the pump is switched off. Monitoring of the pressure gauge is then continued for a period of one minute, and if the vacuum of -0.8 bar is maintained for one minute, the system is considered to be working correctly and sealed adequately.
- 20.3.4. However, if a vacuum cannot be generated, or if no negative pressure is detected within 20 seconds to register, and/or if the pump cannot hold a vacuum for one minute,

it would suggest a leak within the system. In which case, the test would be terminated, and all valves/seals checked, before restarting the test.

- 20.3.5. During the test that I witnessed, a negative pressure was first detected after the pump had been running for approximately 15 seconds, and a reading of -0.8 bar was achieved after approximately 30 seconds. The negative pressure of -0.8 bar was then sustained for in excess of 1 minute, at which point the test was stopped as it was deemed satisfactory. Images from the dry-vacuum test are provided in Figure 103, below, and Figure 104, overleaf. Instructions for this test are also outlined in the pump operating manual, and this is shown in Figure 105, also overleaf.

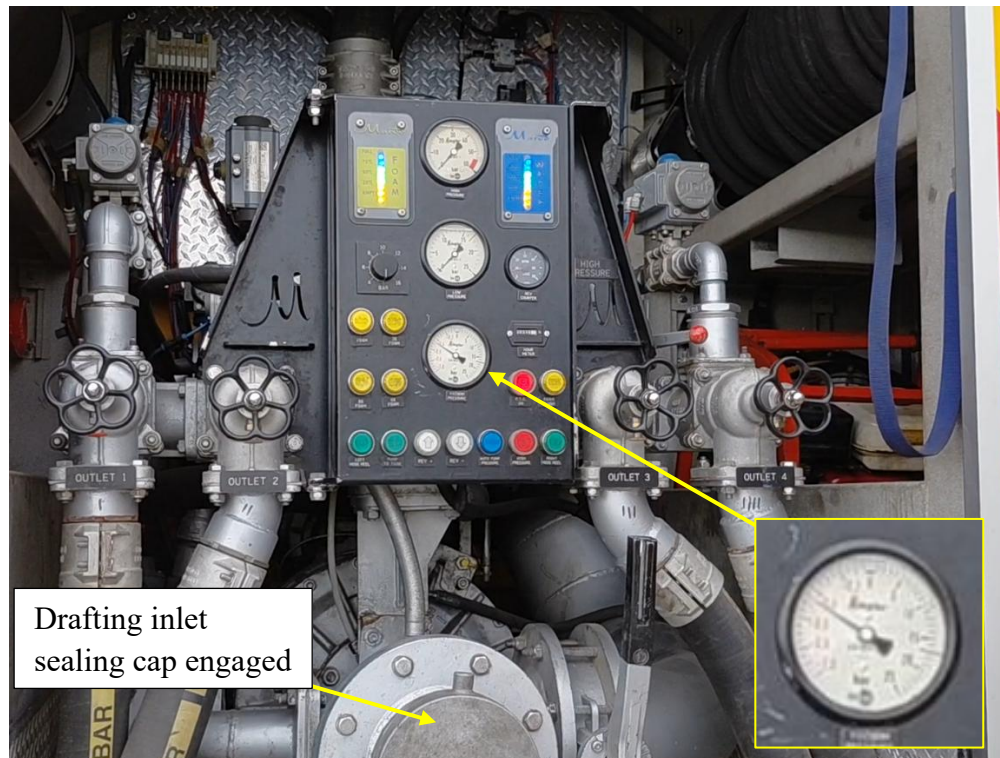


Figure 103: Dry vacuum test: negative pressure detected after ~15s

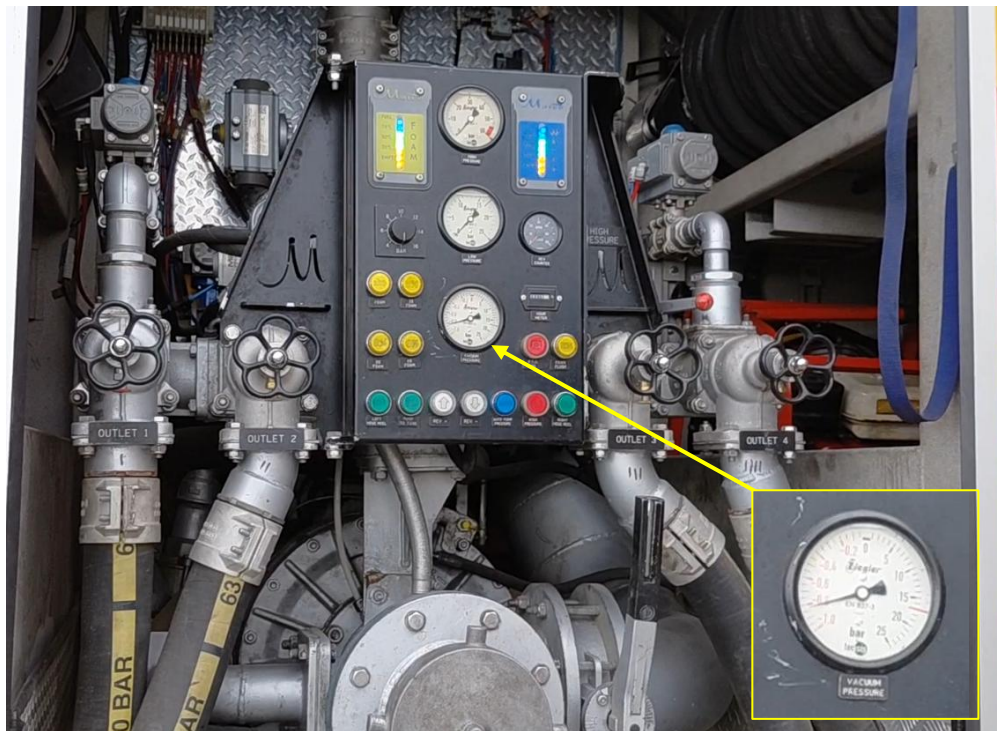


Figure 104: Dry vacuum test: negative pressure of -0.8bar achieved after ~30s

Vacuum Test

Operation

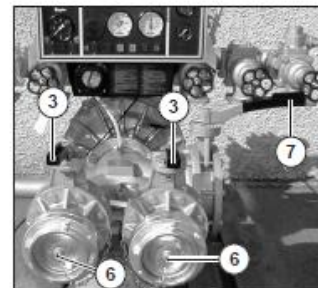
Procedure

After each time the pump is operated, however at least once a month, a vacuum test is to be performed.

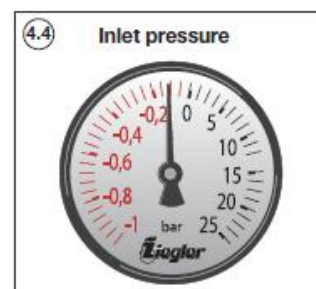
- Drain pump:
See "Draining fire centrifugal pump".

Preparation

- Seal A-suction inlet (6) using blanking coupling.
- Set the pump to the "suction operation" operating mode:
 - Close valve (7)
 - Open valve(s) (3).
- Close all drain valves on the pump.
- Close all outlet valves.
- Switch on pump:
see "Switching on fire centrifugal pump".



The pointer on the pressure gauge/vacuum gauge (4.4) must be in the red area at the latest after 20 s.



- Switch off pump when a partial vacuum of approx. 0.8 bar is reached.
- Observe indication of the pressure gauge/vacuum gauge (4.4):
The partial vacuum is allowed to drop by a maximum of 0.1 bar within 1 minute!



If the partial vacuum drops more, the pump is leaking. This means that air is entering the pump and the pump can no longer draw correctly!

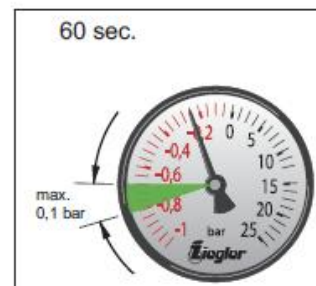


Figure 105: Instructions for dry-vacuum test of pump

20.4. Quarterly Testing

- 20.4.1. The quarterly testing of the water pumps comprises the aforementioned daily and monthly test actions, as well as a drafting test, where water is pumped from an external water supply via the drafting inlet (i.e. rather than using the on-board water supply).
- 20.4.2. This is achieved by closing the isolator valve between the on-board water tank and the pump, removing the sealing cap from the drafting inlet, and connecting a feed hose to the drafting inlet.
- 20.4.3. A small container is then filled with water, and the feed hose is inserted into the container. The pump is then operated, which begins to draw water from the external supply, and discharges it from the hose outlets.
- 20.4.4. In a similar manner to the monthly dry vacuum test, this drafting test assesses the suction of the pump and the efficacy of the seals; however, this test is more comprehensive test than the dry vacuum test, and one that is more akin to the potential operating conditions during an emergency response.
- 20.4.5. This test also more thoroughly assesses the operation and efficacy of the Trokomat primer. In the daily tests using the on-board water supply, the water level is situated above the level of the pump, thereby creating a positive pressure head, meaning that the water within the tank will gravity-feed into the pump. This in turn means that the pump can potentially self-prime, without the need of the Trokomat primer to dispel any air within the pump.
- 20.4.6. However, when drafting water from an external source in this way, the water level is below the level of the pump. This means that the pump will not be gravity-fed, and as such is reliant on the Trokomat primer to remove any air from the system. If any air remains within the pump, an air-lock would be generated, in turn preventing the flow of water. Consequently, testing the drafting function in this manner also tests the operation of the Trokomat primer.
- 20.4.7. Images of the quarterly drafting testing are shown in Figure 106, overleaf, to Figure 108, on page 89.

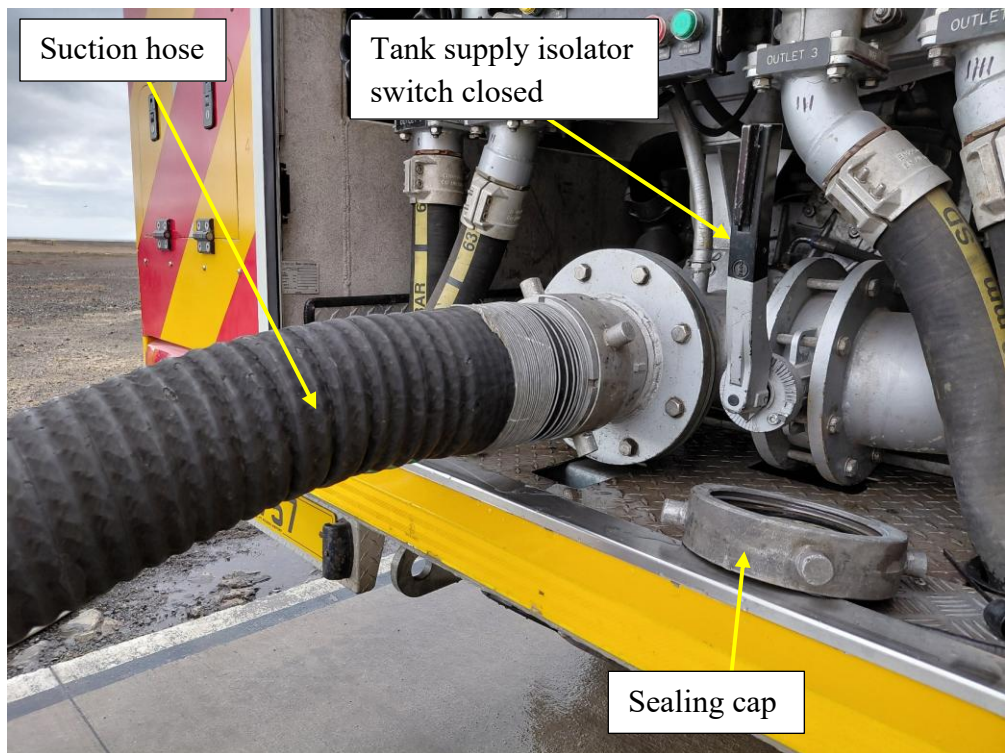


Figure 106: Suction hose connected to drafting inlet



Figure 107: Opposing end of suction hose inserted into external water supply



Figure 108: Water pumped from external supply

20.5. Annual Testing

- 20.5.1. The scheduled annual testing of the ARFF vehicles did not coincide with my time at St Helena Airport. However, consultation with the RFFS team suggests that the annual test includes the daily, monthly and quarterly tests; however, operation of the pumps using the foam dispense is also tested.
- 20.5.2. Following testing of the foam, a complete flush of the system is required to remove any remnants of the foam, and this is specified in the operating manual, as shown in Figure 109, below.



WARNING!

Soiling of the pump!

- **The pump is never allowed to be operated without the inlet filter!**
- Each time after operation with foam, thoroughly flush the related parts of the pump system and the fittings used.

Figure 109: Instructions for pump flush following use of foam

20.6. Summary of Routine Testing

- 20.6.1. Comparison of the daily, monthly and quarterly testing that I observed first-hand, the comments made by the RFFS team, and the instructions set out in the operating manual suggest that all of the actions conducted during these tests were in direct accordance with the manual. In particular, I did not observe any evidence to suggest that any of the actions undertaken contravened the manufacturer's instructions.

- 20.6.2. As described previously, I have not witnessed the annual test first-hand; however, taking the comments of the RFFS team at face value would suggest that the actions conducted during the annual test are also in accordance with the operating manual.
- 20.6.3. During an interview of the RFFS team manager, he also stated that all of the team are highly trained in the operation of the pumps, and all are fully aware of how to operate the pumps, any restrictions/limitations imposed upon the pumps, and how to troubleshoot common unforeseen operational issues.

21. MAINTENANCE & SERVICING

- 21.1. The routine maintenance and servicing of the pump gearboxes as stipulated in the operating manuals comprise a monthly check of the oil, and an annual oil change.
- 21.2. 2014 Issue Operating Manual
- 21.2.1. The 2014 issue manual stipulates that “*every 10 operating hours, at least once a month*” the oil level is checked via the dipstick, and that “*every 50 operating hours, at least once a year*” the oil is changed.
- 21.2.2. As described previously, the 2014 manual stipulates the use of SAE 10 oil.
- 21.2.3. The 2014 manual also stipulates that “*after 20 operating hours, however at least once a year*” the pump is lubricated with grease via the grease nipple.
- 21.2.4. The lubrication and grease schedule, and specific stipulated oil as per the 2014 issue manual are shown in Figure 110, overleaf, to Figure 112, on page 92.
- 21.3. 2021 Issue Operating Manual
- 21.3.1. The 2021 issue manual stipulates the same oil servicing schedule as the 2014 manual and that “*every 10 operating hours, at least once a month*” the oil level is checked via the dipstick, and that “*every 50 operating hours, at least once a year*” the oil is changed.
- 21.3.2. However, as described previously, the 2021 manual stipulates the use of SAE 10W40 oil, rather than SAE 10 oil as stipulated in the 2014 manual.
- 21.3.3. The 2021 manual does not stipulate any requirements for the application of grease to the gearbox.
- 21.3.4. The lubrication schedule, and specific stipulated oil as per the 2021 issue manual are shown in Figure 113 and Figure 114, both on page 93.
- 21.3.5. Both manuals also state that “The pump’s high pressure unit is maintenance-free!”.
- 21.3.6. The only other servicing requirements appear to be an annual cleaning of the high pressure filter, which is stipulated in both issues of the manual. However, neither

manual stipulate any other routine servicing. In particular, they do not appear to stipulate any requirement to disassemble any parts of the pump and/or gearbox, or inspect the eccentric, metal collar, or Trokomat pistons.

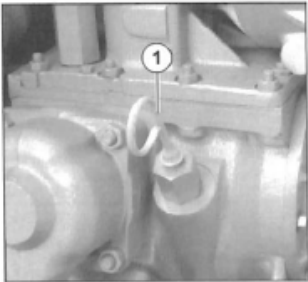
Lubrication schedule, pump system	Servicing / maintenance
Pump gearbox	
Checking oil level	
Servicing interval	Every 10 operating hours, at least once month. ● Position pump so it is level. ● Unscrew dipstick (1), pull out and wipe with a cloth. ● Insert dipstick (1) and tighten. ● Unscrew dipstick (1) again and pull out.
Changing oil	
Servicing interval	Every 50 operating hours, at least once a year. Capacity: see lubrication schedule See lubrication schedule. Only use high quality oil with a suitable viscosity!
Lubricant quality	● Position pump so it is level. ● Place collecting container under the oil drain plug. ● Pull out dipstick (1) and unscrew oil drain plug. ● Completely drain gearbox oil. ● Clean oil drain plug, check sealing ring. Replace faulty sealing ring. ● Screw in oil drain plug and tighten. Tightening torque 15 Nm ● Top-up with suitable gearbox oil via the filler opening (2).
 WARNING!	
Damage!	
The exact oil level in the pump gearbox after the oil change is defined by the mark on the dipstick! ➤ Do not fill above the top mark!	
● Insert dipstick (1). ● Close filler opening (2). ● Correctly dispose of waste oil with due care for protecting the environment!	

Figure 110: Pump lubrication schedule (gearbox oil) - 2014 issue manual

Lubrication schedule, pump system

Lubricating radial sealing rings The grease nipple (1) is, for example, on the pump housing.

Servicing interval After 20 operating hours, however at least once a year.

- With approx. 3 strokes from the grease gun, lubricate via the grease gun (1).

Oil quality Use only high quality grease, e.g.
special pump grease Divinol Multitherm 2,
Texaco grease F 020
or equivalent pump grease



The special pump grease Divinol Multitherm 2 is available from ZIEGLER under article no. 098 810 (400 g can) or article no. 216 096 (25 kg container).

Servicing / maintenance

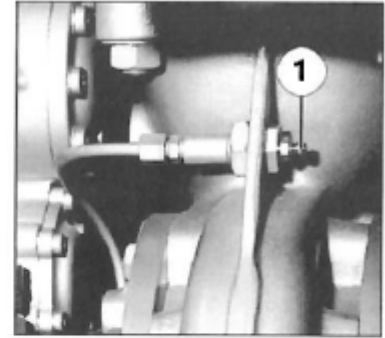


Figure 111: Pump lubrication schedule (grease) - 2014 issue manual

Item	Lubrication point	Quantity	Lubricant	Servicing interval
1	Pump gearbox	1	Gearbox oil SAE 10 capacity 1.5 l ¹⁾	Check after 10 operating hours, oil change after 50 operating hours, at least once a year
2	Pump shaft sealing	1	Special pump grease Divinol Multitherm 2	Lubricate after 20 operating hours, at least once a year
3	Universal joint	Dependent on superstructure	Special pump grease Divinol Multitherm 2	Lubricate after 20 operating hours, at least once a year (not required in case of lubrication for life)

The special pump grease Divinol Multitherm 2 is available from ZIEGLER under article no. 098 810 (400 g can) or article no. 216 096 (25 kg container).

The pump's high pressure unit is maintenance-free!

¹⁾ The mark on the dipstick defines the exact oil level!

Figure 112: Oil use as stipulated in 2014 operating manual

Lubrication schedule, pump system

Pump gearbox

Checking oil level

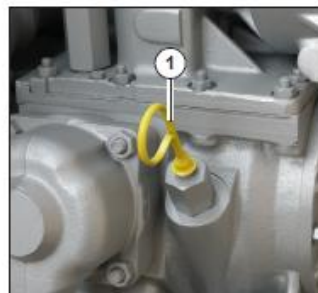
Servicing interval

Every 10 operating hours,
at least once month.

- Position pump so it is level.
- Unscrew dipstick (1), pull out and wipe with a cloth.
- Insert dipstick (1) and tighten.
- Unscrew dipstick (1) again and pull out.

The top edge of the visible oil film must be between the two marks MIN-MAX on the dipstick.

Servicing / maintenance



Changing oil

Servicing interval

Every 50 operating hours,
at least once a year.

Capacity: see lubrication schedule

Lubricant quality

See lubrication schedule.
Only use high quality oil with a suitable viscosity!

- Position pump so it is level.
- Place collecting container under the oil drain plug.
- Pull out dipstick (1) and unscrew oil drain plug.
- Completely drain gearbox oil.
- Clean oil drain plug, check sealing ring. Replace faulty sealing ring.
- Screw in oil drain plug and tighten.
Tightening torque 15 Nm
- Top-up with suitable gearbox oil via the filler opening (2).



WARNING!

Damage!

The exact oil level in the pump gearbox after the oil change is defined by the mark on the dipstick!

➤ Do not fill above the top mark!

- Insert dipstick (1).
- Close filler opening (2).
- Correctly dispose of waste oil with due care for protecting the environment!



Figure 113: Pump lubrication schedule (gearbox oil) - 2021 issue manual

Item	Lubrication point	Quantity	Lubricant	Servicing interval
1	Pump gearbox	1	Gearbox oil SAE 10W40 capacity 1.5 l ¹⁾	Check after 10 operating hours, oil change after 50 operating hours, at least once a year

The pump's high pressure unit is maintenance-free!

¹⁾ The mark on the dipstick defines the exact oil level!

Figure 114: Oil use as stipulated in 2021 operating manual

21.4. Interviewing Maintenance Team

- 21.4.1. In addition to reviewing the operating manual, I also independently interviewed the maintenance team to verify the routine maintenance and servicing that they perform on the ARFF vehicles. Taking the comments made by the maintenance team at face value indicates that the servicing that they performed on the vehicles prior to the incident matches the requirements as stipulated in the 2014 operating manual.
- 21.4.2. More specifically, they advised that they checked the oil level via the dipstick every month, and changed the oil and applied additional grease every year.
- 21.4.3. It is important to note that due to the low usage of the pumps, the stipulated time interval occurred before the maximum operating hours interval. As such, the oil was checked once per month even though the monthly operating hours had not reached 10 hours, and the oil was changed once per year, even though the annual operating hours had not reached 50 hours.
- 21.4.4. As described previously, following the incident, the oil has been replaced more frequently than once per year; as such, the servicing schedule since the incident has been more frequent than the minimum stipulated requirements.

22. **WATER SOURCE**

22.1. Water Source

- 22.1.1. As described previously, the ARFF vehicles currently use potable, mains water for fire-fighting and training purposes. This water is supplied to the airport by means of fire-hydrants located at the airport.
- 22.1.2. However, prior to 17 July 2020, a borehole water supply was used as a water source for the ARFF vehicles.

22.2. Water Analysis

- 22.2.1. I have been provided with water test reports of both the borehole water, as well as the mains water. This testing was conducted in 2016, and I have not been provided with any more recent analysis reports relating to the water supply.
- 22.2.2. Nevertheless, the testing found that the borehole water supply had high levels of salts, dissolved solids, and chlorides.
- 22.2.3. While not to the same extent as the borehole water supply, the tap water also had high levels of salts and chlorides. Both water supplies are also described as highly corrosive.
- 22.2.4. The complete water analysis report is provided in Appendix F. However, for ease of reference, Table 4, overleaf, shows a summary of these results. For ease of comparison, I have also presented water analysis results for tap water from a North-

West England based mains supply (dated August 2026), and the corresponding regulatory limits. As can be seen, the sodium, magnesium, sulphate, chloride and nitrate levels of the borehole supply are significantly greater than those of the North West England supply, and the sodium, magnesium, and chloride levels of the airport tap water are significantly greater than the North West England supply.

22.2.5. The chloride and nitrate levels of the borehole water supply are also in excess of the North West England regulatory limits. All other levels, while higher than the North West England tap water, are still within the regulatory limits. For further ease of reference, the levels that are in excess of the North West England water supply are shown highlighted in light red, and the levels that are in excess of the regulatory limits are shown highlighted in dark red.

Table 4: Summary of water analysis results

Analysis	Unit	Borehole 5	Airport Tap Water	N. West England Tap Water	N. West England Regulatory limit
Potassium as K dissolved	mg/l	6.6	1.8		
Sodium as Na dissolved	mg/l	155	41	15.7	200
Calcium as Ca dissolved	mg/l	35	8.1	38.1	-
Magnesium as Mg dissolved	mg/l	34	7.2	3.89	-
Sulphate as SO4 dissolved	mg/l	49	9.8	21.9	250
Chloride as Cl	mg/l	314	61	20.5	250
Alkalinity as CaCO3	mg/l	62	47	66.1	-
Nitrate + Nitrite as N	mg/l	3.9	0.2	0.406	1
Electrical Conductivity	mS/m	120	31	272	2500
pH		7.8	7.7	7.36	9.5
Total dissolved solids	mg/l	768	198		
Hardness as CaCO3	mg/l	227	50	111	-
Ryznar Index		8.8	10.3		
Indication (Ryznar 1942)		Heavy Corrosion	Corrosion intolerable		
Bicarbonate as HCO3 Dissolved	mg/l	36	28		

22.3. Potential Impact of Water Chemistry

- 22.3.1. A full analysis of the water chemistry is beyond the remit of this investigation; however, of potential relevance are the high levels of chlorides in the water. In particular, it is important to note that chlorides in a water supply will increase its electrical conductivity, which in turn will significantly accelerate metal corrosion.
- 22.3.2. It is therefore possible that the observed corrosion of the pump components could have been caused or exacerbated by the nature of the water supply used and pumped by the ARFF vehicles, particularly during the time that the borehole water supply was used.
- 22.3.3. I note that the pump operating manual states that *“If salt-laden or heavily soiled water has been pumped using the fire centrifugal pump, the pump must be cleaned.”* This is shown in Figure 115, below.
- 22.3.4. However, no quantification of the term ‘salt-laden’ is provided, and in particular, the level of salt content that would warrant cleaning post-use. Consequently, I am unable to comment as to whether or not the salt levels found in the borehole water supply, and the airport tap water would constitute ‘salt-laden’ and therefore if the pumps would require post-use cleaning.

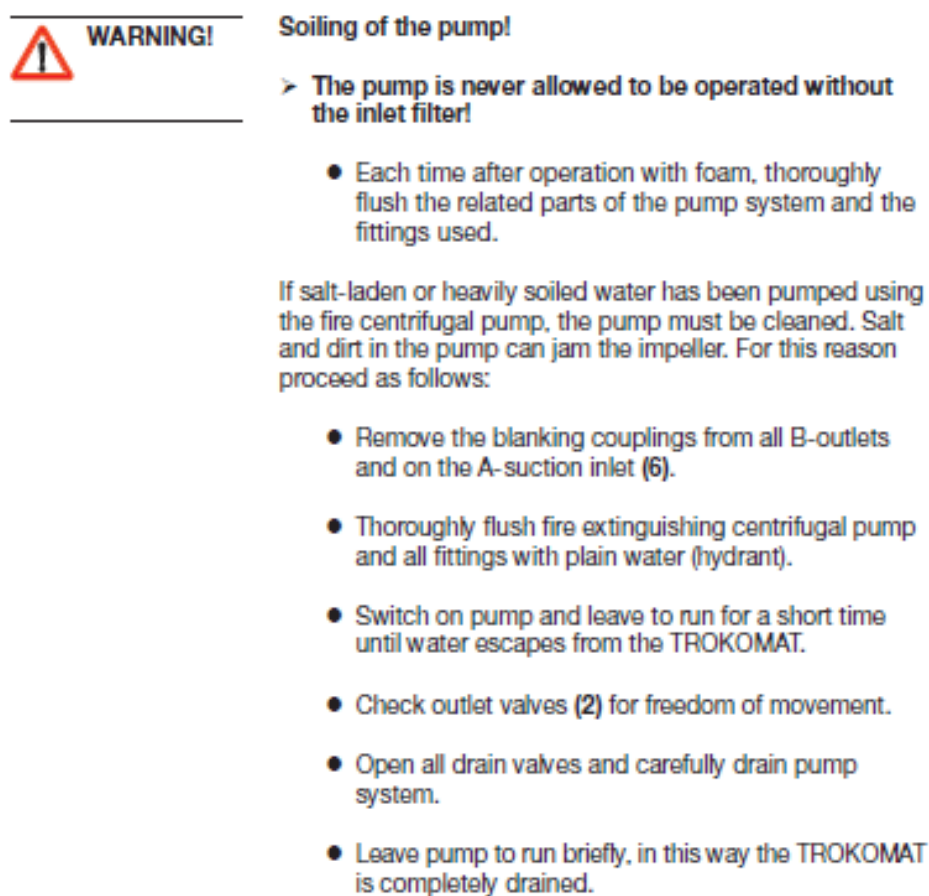


Figure 115: Instruction for requirement to clean pump after discharging salt-laden water

ANALYSIS

23. OVERVIEW

- 23.1. My assessment of the failure of the eccentrics is based upon all aforementioned aspects of my investigation, including my inspection of the failed eccentrics, review of photographs taken during the disassembly of the gearboxes, consultation with the operating manual, and interviewing the management, maintenance and RFFS teams.
- 23.2. This has allowed me to assess the eccentric components, their function, their interaction with other components within the gearbox, the manner in which they have failed, and possible causative and/or contributory factors that led to their failure.

24. EXTENT OF FAILURE OF ECCENTRICS

- 24.1. The provided photographs taken during the disassembly of each of the pumps shows that while each of the eccentrics were damaged, they appeared to be broadly intact within the gearbox, and the metal collars remained in place surrounding the smaller diameter end of each of the eccentrics.
- 24.2. As I understand the construction of the Trokomat, the metal collar is secured in position on the eccentric via a friction fit, i.e. held in position solely by the eccentric.
- 24.3. On the basis of the construction of the Trokomat primer, and in particular, the interaction between the metal collar and the pistons, this means that if the eccentric had failed completely and catastrophically, there would be nothing to secure the metal collar in place. This in turn would mean that the metal collar would not be able to actuate the pistons.
- 24.4. Consequently, if the eccentric failed completely and catastrophically, the Trokomat primer would suddenly and entirely lose its functionality, in turn meaning that it would not be possible to prime the pump and dispel any air from the system. As such, any time the primer pump was required for operation, it would have been detectable by a loss of priming function.
- 24.5. Furthermore, if the eccentric had failed completely, the metal collar would be loose and free to vibrate on the shaft, which would likely cause significant noise as the PTO shaft rotated. It is also likely that this vibration would cause damage to other adjacent components of the gearbox. However, no such noise during routine testing has been reported by the RFFS team, and the maintenance team reported that no such damage was observed during the disassembly of the gearboxes. Furthermore, no damage to adjacent components was visible in the provided photographs.
- 24.6. On the basis of the provided photographs, and taking the comments of the RFFS and maintenance teams at face value would suggest that at the time that the gearboxes

were first disassembled, the eccentrics were broadly intact, and were able to support the metal collar in position.

- 24.7. Furthermore, from my understanding of the routine testing of the ARFF vehicles by the RFFS team, I have been able to gain an understanding of the specific operation of the pumps, and in particular, the Trokomat primer, during each of the routine tests.
- 24.8. As described previously, the daily tests only discharge water from the on-board tank. Due to the arrangement and relative positions of the tank and the pump, there would be a positive pressure head between the tank and the pump, meaning that the pump would likely be self-primed, i.e. the pressure head would feed water into the pump due to gravity, and automatically and passively dispel any air within the system, potentially obviating the need for active priming via the Trokomat. This means that any loss of the Trokomat's priming function may not necessarily have been detectable during the daily tests.
- 24.9. However, the quarterly tests include drafting, in which water is pumped from an external water source below the level of the pump. In this instance there would be no positive pressure head to automatically and passively prime the pump, and any air within the pump could form an airlock. Consequently, priming of the pump via the Trokomat is essential to allow pumping and discharge of the water. This would mean that if the eccentric failed catastrophically, it would likely have at least been detectable during the quarterly tests, if not before.
- 24.10. In light of the above, the provided photographs, comments made by the RFFS and maintenance teams, and successful routine testing prior to the incident would all indicate that despite the damage to the eccentrics, they remained at least partially intact to the extent that they were able to hold the metal collar in position, and perform the priming function.

25. POTENTIAL INEFFICIENCIES OF TROKOMAT PRIMER

- 25.1. While the evidence suggests that despite the damage to the eccentrics, they were still at least partially performing their function, it is possible that the damage to the eccentrics could have affected the efficiency of the actuation of the Trokomat pistons.
- 25.2. For example, if the damage to the eccentric allowed some relative movement between the metal collar and the PTO shaft (even if the metal collar were retained sufficiently in its position on the eccentric so as not to work loose), it is possible that the eccentric may not have been able to push the pistons to their maximum positions, in turn partially reducing the pumping capacity of the Trokomat.
- 25.3. In such a scenario, while the Trokomat would still operate, it may not operate at maximum efficiency. On this basis, there is a potential link between the condition of the eccentric and the primer efficiency.

- 25.4. I note that the work order 12564 states that on 04/03/2025, the pump was tested where it was not able to generate a vacuum; however, after pumping water through the pump, it was able to pull a vacuum.
- 25.5. The fact that the pump was initially unable to pull a vacuum but was subsequently able to pull a vacuum once the pump had been filled with water could suggest inefficient or incomplete priming by the Trokomat on that occasion.
- 25.6. The reason for this is unknown; however, I cannot preclude the possibility that it could have been in some way related to damage to the eccentric.
- 25.7. However, further testing on 21/03/2025 shown in work order 12769 found that the primer was operating normally when pumping against a closed valve, and that all was deemed to be satisfactory. Furthermore, no other issues relating to the efficacy and/or efficiency of the pump have been reported since.
- 25.8. On this basis, even if the initial issues generating a vacuum observed on 04/03/2026 were in some way related to the eccentric, the apparent full working order of the pump in subsequent tests could either suggest that the issue was a single occurrence, and/or that it was unrelated to the condition of the eccentrics. At this stage, it is not possible to provide any further comment in this regard.
- 25.9. Nevertheless, it is important to emphasise that the apparent working order of the pump and the Trokomat primer in all other testing would have meant that there would have been no reason to suspect any issue with the gearbox, or its components. As such, even in light of this reported issue, I do not consider there would have been any perceivable correlation between the observed issue on that single occasion, and any potential damage to the eccentric.
- 25.10. Furthermore, as described previously, there is no apparent requirement as stipulated in the operating manual to inspect the eccentric during its life.

26. MODE OF FAILURE OF ECCENTRICS

- 26.1. Inspection of the eccentrics shows differential staining to different regions, which was likely due to the exposure to the oil. If caused by the oil, the different extent of staining is likely related to the length of time of exposure to the oil, where the darker areas were exposed for a longer period of time than the lighter coloured areas. Consequently, this would indicate that different regions of the eccentric were exposed to the oil at different times, with the lighter areas exposed to the oil comparatively more recently than the darker areas.
- 26.2. There was also localised staining that had penetrated into some of the cracks, thereby increasing their visual contrast. The presence of staining within the cracks would suggest that these cracks had been developing for an extended period of time, and long enough for the oil to have penetrated the crack and cause the observed staining.

- 26.3. To further investigate this, I deliberately force-fractured some of the partially developed cracks. This showed that the newly exposed fracture surfaces were light brown/tan in colour, and similar to the colour of the undamaged exemplar eccentrics. However, regions of the previously partially initiated cracks were stained darker brown in colour.
- 26.4. The differential colouring again indicates that the cracks had propagated (exposing the resulting fracture surfaces) at different times. Consequently, this indicates that at least some of the cracks had been developing for an extended period of time.
- 26.5. The eccentrics were severely cracked, with a multitude of fractures throughout the entire structure. The eccentrics had also fractured into a large number of fragments of varying sizes.
- 26.6. There were some cracks that emanated from the corners of the keyway slots. The sharp corners of these slots would likely act as stress-raisers, and as such it was not unexpected to observe cracks in this region of the structure. However, there also numerous other cracks within the structure that were present across all planes of the component, including in longitudinal, radial and circumferential directions. The fracture surfaces were also multi-faceted.
- 26.7. The multiplanar directionality and multiple positions of these cracks did not appear to coincide with any one loading direction. To my mind, this would suggest that the cracks were not solely caused by the applied mechanical loading.
- 26.8. Rather, to my mind, the multi-planar, and multi-faceted fracture surfaces, as well as the large number of fragments that the eccentric had fractured into, appears more consistent with an almost complete disintegration of the structure.
- 26.9. The eccentrics also appeared hard and brittle, and markedly different to the tactile properties of the exemplar eccentric.
- 26.10. To my mind, this would suggest that the failure was at least in part related to a breakdown of the structure and changes to the material properties, rather than solely due to the mechanical loading applied upon the eccentrics. This may have been caused or contributed to as a result of the combination of the chemical composition of the material, and the environmental conditions to which the eccentrics were exposed.

27. SCORING TO METAL COLLAR

- 27.1. I note that in addition to the damage to the eccentric, some of the images taken during the disassembly of the gearboxes also appear to show scoring/abrasion marks to the outer circumference of the metal collar surrounding the eccentric, and within the area in contact with the Trokomat pistons when in use.
- 27.2. As described previously, due to the arrangement of the Trokomat, once water commences pumping, the water pressure within the pump will overcome the force of

the retaining springs, in turn pushing the pistons away from the eccentric and metal collar. This means that if working correctly, the Trokomat will only function, and the pistons will only remain in contact with the metal collar whilst there is air within the pump.

- 27.3. Furthermore, as also described previously, the tips of the pistons appeared to have been formed of brass, which would likely be softer than the metal collar, which appears to be of stainless steel construction.
- 27.4. Nevertheless, due to the contact between the pistons and the metal collar, some localised surface polishing at the contact area is not unexpected. However, to my mind, the localised scoring is more significant than I would have expected to observe if the gearbox was sufficiently lubricated.
- 27.5. It is not possible to determine when the scoring occurred, and/or for how long it has been present and/or developing.
- 27.6. It is also important to note that at this stage, I have not inspected the pistons, or any photographs showing the tips of the pistons. As such, I am unable to determine whether there is any corresponding damage to the tips of the pistons that could have caused, or been caused, by the observed scoring to the metal collar.
- 27.7. Nevertheless, the presence of scoring could suggest insufficient lubrication, for example, insufficient quantity, and/or insufficient viscosity. This is described further below.

28. OIL ANALYSIS

28.1. Type of Oil

- 28.1.1. As described previously, the 2014 issue pump operating manual stipulated the use of SAE 10 oil within the gearbox; however, the 2021 issue manual stipulated the use of 10W40 oil.
- 28.1.2. Also as described previously, 10W40 oil has a viscosity reading in excess of double the viscosity of SAE 10 oil. In general, an oil of greater viscosity will be able to support greater loads than an oil with lower viscosity, but it will be able to flow less readily than a lower viscosity oil.
- 28.1.3. On this basis, all other aspects being equal, and provided that the 10W40 was able to flow sufficiently throughout the gearbox, the use of 10W40 oil would likely provide greater lubrication properties, and make the components of the gearbox less prone to wear, than with the use of SAE 10 oil.
- 28.1.4. As described previously, the observed scoring to the metal collar could potentially have been caused (or partially caused) by insufficient lubrication. However, at this stage, this cannot be confirmed.

28.1.5. Nevertheless, while the reason for the change in oil is not known, the possibility that it was done to reduce wear within the gearbox cannot be precluded.

28.2. Quantity of Oil

28.2.1. The capacity of the gearbox is 1.5l. I have measured the remaining oil samples to be within approximately 1.25l to 1.35l.

28.2.2. As described previously, these oil samples had already had some quantity removed that was sent for testing.

28.2.3. On this basis, accounting for the removed oil specimens sent for testing, as well as other potential losses during withdrawal from the gearbox (e.g. on account of the oil's viscosity), the volume of oil appears to have been broadly in line with the capacity of the gearbox (i.e. 1.5l). On this basis, this would suggest that insufficient volume of oil was unlikely to have been a factor.

28.3. Contamination of Oil

28.3.1. The oil analysis shows that there was 5.5% water contamination of the pump oil of R1 on 5 February 2026. Routine testing between 21 March and 27 May showed that the oil was free from contamination, and with normal wear rates and debris analysis. Since commencement of the new oil on 10 June 2026, the oil has again been free from contamination, and with normal wear rates and debris analysis; however, there has been trace water present.

28.3.2. The pump oil from the gearbox of R2 showed that the oil was free from contamination, and with normal wear rates and debris analysis. There were wear particles present on 29 April 2026; however, these were considered normal. Since commencement of the new oil on 10 June 2026, the oil has again been free from contamination, and with normal wear rates and debris analysis; however, there has been trace water present.

28.3.3. The pump oil from the gearbox of R3 showed that on 11 March 2026, the wear rates had increased, and there was trace water present. On 13 March 2026, the oil was free from contamination, and with normal wear rates and debris analysis. Since 26 March 2026, the oil has remained free from contamination, with normal wear rates and debris analysis; however, there has been continued water present. On 27 May 2026, the water contamination reached a maximum of 1.2%, but in all other tests there was only trace water present.

28.3.4. Nevertheless, this indicates that the pump oil from each ARFF vehicle has at least at one stage contained water.

28.3.5. Furthermore, the pump oil from R1 and R2 has contained water in all tests conducted since 10 June 2026, and the pump oil from R3 has contained water in all tests conducted since 26 March 2026. This would suggest that each of the pumps have ongoing water ingress to varying extents.

- 28.3.6. The presence of water within the oil may have a detrimental effect on the composition of the elastomer material used for the eccentrics. This is described further below.
- 28.3.7. I understand that to date, the source of the leak has not been identified. However, it is reported that there are minimal access points into the gearbox through which water could enter the gearbox: namely the shaft seals where the PTO shaft enters the gearbox, the Trokomat pistons, and the gasket between the gearbox and the high pressure pump.
- 28.3.8. It is reported that during disassembly of the gearbox of R2, the seals were considered to be intact and free from damage. However, the other pumps have not been disassembled, and as such, the condition of the seals of these pumps is not known.
- 28.3.9. Nevertheless, it is important to note that visual inspection of the seals may not be sufficient to fully assess their condition, and their sealing ability, since even minor damage that may not be visible to the naked eye, could result in water ingress.
- 28.3.10. It is important to note that it is also possible that a crack(s) in the casing of the gearbox could allow water ingress. Such a crack may also not be readily visible to the naked-eye.
- 28.3.11. To my mind, the efficacy of the seals, and possible cracks/leaks in the casing could only be fully investigated by conducting detailed testing, for example, pressure testing of the gearbox and/or dye-penetrant testing.
- 28.3.12. In the absence of any further information, at this stage I am unable to make any comment as to the potential source(s) of any water leaks into the gearbox.

29. RESILIENCE OF ELASTOMER MATERIAL

- 29.1. As described previously, the elastomer material used in the eccentrics is reported to be Vulkollan® 90 Shore A, a polyurethane based elastomer.
- 29.2. While the product data sheet suggests that this material is highly resistant to oils and greases, it also suggests that it is susceptible to hydrolysis, which is the chemical breakdown and decomposition of the material in contact with water, where the individual polymer chains can be damaged, potentially causing the material to lose its strength, become brittle and crack or crumble.
- 29.3. Having inspected the remnants of the eccentrics, the nature of the material appeared brittle, and the components had visibly crumbled/fractured into numerous fragments. On this basis, the nature of the failure appears consistent with the reported consequences of hydrolysis degradation of Vulkollan® as stated by the manufacturer.
- 29.4. I have also performed a rudimentary experiment whereby specimens of the elastomer were exposed to different fluids (SAE 10 oil, 10W40 oil, contaminated SAE 10 oil, and tap water) for a period of three days. In this test, exposure to both grades of oil

did not appear to affect the structure of the elastomer material to any significant extent. However, when exposed to water, the composition of the elastomer material was seemingly altered, causing it to become significantly more brittle, and more prone to disintegration. This preliminary test serves to illustrate a potential link between water exposure and a possible change in the structure and/or properties of the elastomer material, and degradation and/or disintegration of the structure.

- 29.5. This is also consistent with the aforementioned properties and limitations of Vulkollan® as specified by the manufacturer, Vulkoprin.
- 29.6. As described previously, the oil test reports indicate that water contamination of the oil has (at varying times) occurred in the gearboxes of R1 and R3 since testing commenced. Unfortunately, no oil from prior to the incident was retained, and no testing was conducted. Furthermore, no oil tests relating to R2 are available prior to 12 March 2026. Consequently, it is not possible to determine whether or not there was any water contamination of the gearbox oil of each of the ARFF vehicles prior to the incident.
- 29.7. However, if there was water ingress at any time prior to the incident, it is possible the presence of water could have affected the integrity of the elastomer material, and possibly caused or exacerbated the observed degradation and failure of the eccentrics.

30. DAMAGE TO BEARING

- 30.1. The damage to the bearing comprised fracturing of the inner ring, and deformation to the bearing cage.
- 30.2. As described previously, to my mind, the nature of the fracture surfaces of the broken fragments of the bearing appeared consistent with brittle fracture as a result of a single, over-load type failure, and there was no observable evidence of any progressive degradation mechanisms such as fatigue loading and/or corrosion.
- 30.3. Based on the currently available evidence, it is not possible to confirm the precise cause of the failure; however, it is reported to have been caused by Marcé engineers during reassembly of the gearbox of R2 after the eccentric had been replaced.
- 30.4. I note that in Work Order 17449, the engineer's sign off notes entry dated 10/02/26 states "*Assist engineers with fitting gear box, found bearing broken.*". However, no further details are provided.
- 30.5. While I have not been provided with any evidence to support this allegation, to my mind, the nature of the failure could be consistent with these reported circumstances.
- 30.6. I will also add that had the bearing fractured in this manner whilst in use and within the gearbox, it is likely that had the gearbox been operated whilst the bearing was damaged, it would have been immediately evident. For example, the damage to the bearing could potentially cause imbalance of the shaft, in turn possibly causing

vibrations and/or noise from within the structure, and/or any loose fragments of the bearing could have caused damage within the gearbox during its operation. However, no such issues were reported.

- 30.7. On this basis, to my mind, it is unlikely that the bearing was fractured during service.
- 30.8. Consequently, in light of the above, to my mind, the damage to the bearing is likely to be unrelated to the degradation and damage to the eccentrics.
- 30.9. While the fracture is likely unrelated, the lack of information provided in the work order relating to the cause of the fracture highlights a potential requirement for more transparent reporting when such damage is observed, or caused. This is described further below.

31. PRESENCE OF PITTING DAMAGE

- 31.1. To my mind, the nature and appearance of the pitting to the impeller blades, and the interior of the casing of the pump of R2 appears consistent with cavitation.
- 31.2. As described previously, cavitation is a mechanism that occurs when the local pressure within a fluid reduces below the vaporisation pressure of the fluid, causing small vapour bubbles to be produced, which then subsequently collapse. The process of the bubbles collapsing creates shock waves that over time can cause degradation to the surface of the material.
- 31.3. Due to the nature of this mechanism, cavitation can occur at or in the vicinity of any device that reduces the local pressure of a fluid, and propellers or impellers are common places where this mechanism can be observed.
- 31.4. On this basis, the presence of the observed pitting on the impeller blades is not entirely unexpected.
- 31.5. As described previously, it is not possible to determine when the pitting first developed, and/or how long it had been developing.
- 31.6. In particular, it is reported that prior to the disassembly of the pump of R2, none of the pump casings had been opened. As such, the interior of the pump housing would not otherwise have been visible, and the full extent of pitting damage would not have been detectable. Furthermore, the interior of the pump casings of R1 and R3 have to date not been inspected, and as such, the full extent of any pitting damage to these pumps is not currently known. Consequently, it is possible that the pitting damage has been developing for a number of years, and possibly throughout the life-time of the pump.
- 31.7. The impeller blades and any pitting damage thereon are partially visible via the drafting inlet. However, I will add that when I inspected the impellers, illumination of the drafting inlet was required. As such, inspection of the impellers requires conscious

effort, and they would not otherwise be readily visible, unless an operator/mechanic was actively illuminating the area. To this end, without a specific requirement to visually inspect the impellers in this way (for example as stipulated routine maintenance), it is unlikely that any pitting damage would be readily apparent. However, I am not aware of any requirement for routine inspection of the drafting inlet and impeller blades to assess the presence of any developing pitting damage.

- 31.8. As such, to my mind, unless the pitting was noticed during routine use, testing and/or servicing of the vehicles, any developing damage could easily have gone unnoticed.
- 31.9. Nevertheless, the presence of pitting on the pump casing could indicate that cavitation has occurred over the life-time of the pump, which itself would indicate that the pressure at these regions of the pump were/have been below the vaporisation pressure.
- 31.10. However, at this stage, there is no evidence to allow the precise cause of the cavitation to be determined. Furthermore, I have not had sight of any evidence that links the occurrence of the pitting damage to the degradation damage to the eccentrics. On this basis, I cannot preclude the possibility that these two damage mechanisms are unrelated.

32. CORROSION DAMAGE

- 32.1. There was corrosion present on the interior casing of the pump of R2 as visible in the provided photographs, as well as on the drafting inlets during my inspection of each vehicle.
- 32.2. Furthermore, as described previously, it is reported that when the pump of R2 was removed, the casing had fused together, and that continued application of heat and impact forces were required in order to separate the casing.
- 32.3. If developed to a sufficient extent, corrosion on the mating surfaces of the casing could provide a fusing effect, in essence adhering the casing together. This could explain the difficulty the team had in separating the casing.
- 32.4. Taking the comments of the maintenance team at face value would suggest that the level of corrosion was significant, and such a level of corrosion that required such means to separate the casing would indicate that the corrosion had been developing over an extended period of time.
- 32.5. Since the pump casing had not been opened prior to this disassembly, it is not possible to determine when the corrosion first developed. However, it is possible that the corrosion had been developing over a number of years, and/or possibly over the entire life-time of the pump.
- 32.6. Any pump used for water over an extended period of time will likely sustain at least some corrosion over its lifetime.

- 32.7. However, in this instance, the water testing reports indicate that the borehole water supply used prior to 2020 had very high levels of dissolved solids, and in particular, high levels of salt and chlorides, as well as high electrical conductivity. The tap water supply used since 2020 has reduced levels compared to the borehole supply, but still has a relatively high salt content.
- 32.8. As described previously, the presence of salts and chlorides within a water supply will exacerbate and accelerate the development of any corrosion. To this end, it is likely that the water supply used by the ARFF vehicles would have at least contributed or accelerated the development of corrosion found within the pump and drafting inlets, particularly during the time that the borehole water supply was used.
- 32.9. While corrosion was observed at both of these regions of the ARFF vehicles, it is likely that other such corrosion will be present on other components.
- 32.10. Nevertheless, I consider that the presence of the observed corrosion is likely to be unrelated to the damage and degradation of the eccentrics.

33. POTENTIAL EARLY-DETECTION OF FAILURE

33.1. Means of Early Detection

- 33.1.1. On the basis of the nature, location, and function of the eccentrics within the gearbox, the only means in which any damage to the eccentric could have been detected is via visual inspection, and/or as a result of a loss or reduction in the priming function of the Trokomat. I am unaware of any other means by which the damage to the eccentrics could have been detected.
- 33.1.2. There has been no reported loss or reduction of function of the Trokomat primer, which would at least have been detectable during the routine quarterly testing of the pumps conducted by the RFFS team.
- 33.1.3. Further, the evidence indicates that the eccentric of each ARFF vehicle was broadly intact and able to support the metal collars, actuate the pistons, and operate the Trokomat to prime the pumps with water.
- 33.1.4. This means that irrespective of the progressive degradation and fracturing of the eccentrics, for as long as the eccentrics were sufficiently intact to perform their function, any damage or degradation would not have been detectable through the routine testing of the pumps via a loss of function.
- 33.1.5. The only stipulated routine maintenance for the pump gearboxes are monthly oil level checks, and annual oil replacement, and grease application. There is no other documented requirement for routine servicing and/or inspection of internal components. More specifically, there is no apparent requirement for the gearbox to be opened during servicing.

- 33.1.6. This means that whilst conducting servicing as per the manufacturer's instruction manual, there would have been no visual way that any developing damage and degradation of the eccentrics could have been detected.
- 33.1.7. As such, it is not possible to determine when the damage to each eccentric first commenced, and it cannot be precluded that the damage may have been present for an extended period of time.
- 33.1.8. Through the course of my investigation, it has come to light that endoscopic examination of the gearbox and eccentric could potentially identify any developing damage to the eccentrics; however, this type of inspection was not stipulated or suggested by the manufacturer.

33.2. Ability to Predict Damage/Failure

- 33.2.1. In light of the above, there appears prima facie to have been no prior indication of any developing damage, or any impending failure of the eccentrics.
- 33.2.2. Furthermore, on the basis of my understanding of the construction and assembly of the gearbox and Trokomat system, operation of the pumps, and routine testing and maintenance schedules done in accordance with the operating manual, I can see no way in which any prior indication of the developing failure could have been gained whilst working within the remit of the OEM operating manual.
- 33.2.3. For these reasons, while the eccentrics remained at least partially intact at the point that the damage was first observed, I also do not consider it is possible to predict or determine the remaining working life of the eccentrics, or the point at which catastrophic failure could occur. For instance, the eccentrics could have failed catastrophically and completely within hours/days of first observation of the damage, or alternatively they could have remained broadly intact for months or years. Based on the available information, it is not possible to determine the remaining working life, and it is not possible to preclude either scenario, or even comment that the likelihood of one scenario would be greater than the other. To my mind, the only way in which such lifetime could be predicted would be through comprehensive laboratory based lifetime testing of the components under the same operating and environmental conditions.
- 33.2.4. Consequently, on the basis of the information available to SHAL prior to and at the point of first observation of the failure, I consider that there would have been no conceivable way to determine or predict the remaining working life of the eccentrics, and thus the duration that the pumps could continue to be operated without sustaining a complete and catastrophic failure of the eccentrics.
- 33.2.5. Had the eccentrics failed completely, the Trokomats would have sustained a complete loss of function, which would in turn likely mean that any airlocks within the system could not be removed. In such a scenario, an airlock in the system could potentially completely prevent, or severely restrict the flow of water.

DISCUSSION

34. SUGGESTED CAUSES OF THE FAILURE

34.1. Following the first observation of the damage to the eccentric of R2, SHAL made enquiries with Marcé and Ziegler as to any potential causes for the failure.

34.2. It is reported that in response, between them, Marcé and Ziegler presented the following hypothetical potential causes:

- Excessively high rotational speed of the pumps;
- Operating the pumps whilst dry;
- Overheating of the pumps;
- Incorrect oil and/or low oil level;
- Annual services not conducted.

34.3. In response to these hypothetical scenarios, I make the following comments.

34.4. Excessive Rotational Speed of the Pump

34.4.1. There is no evidence to confirm the precise operational history of the pumps, and in particular, the speeds at which the pumps have been operated over the course of their lifetime. The pumps are also not equipped with rev-limiters or the like, and the gauges do not comprise ‘red-lines’ to indicate the maximum recommended pump speed. The operating manual also does not specify what would constitute ‘excessive speed’. As such, it is not possible to determine whether or not the pumps have been operated at ‘excessive speed’.

34.4.2. However, the RFFS team advised that during routine testing of the pumps, there would be no need to operate the pump at an excessive speed. For instance, in the dry-vacuum and drafting tests, the inability to generate a vacuum (e.g. as a result of a leak) would be evident very quickly (within approximately 20 seconds), and an increase in pump speed, and/or continued operation of the pump would not result in a vacuum being generated. In such a scenario, it is reported that the RFFS team are trained to stop the test and recheck the seals before restarting the test.

34.4.3. The RFFS team also report that during routine operation, the pump will generally not exceed 20,000 rpm, and that all personnel are trained to avoid overspeed of the pump.

34.4.4. It is also reported that operating the pump at excessive speeds would result in significant noise. As such, any inadvertent operation of the pump at excessive speed would be evident to the operator.

34.4.5. On this basis, while there is no evidence to confirm the operational history of the pumps, provided that the RFFS team have operated the pumps in accordance with

their training, and with the operating manual, there would likely have been no need for the pumps to be operated at 'excessive speed'.

34.5. Operating the Pump Whilst Dry Leading to Overheating

- 34.5.1. As above, there is no evidence to confirm the precise operational history of the pumps, and in particular, whether the pump had been run dry and/or overheated.
- 34.5.2. I understand that the pump is run dry during the monthly dry vacuum tests; however, the RFFS team state that there would be no other operational reason to run the pump dry, for example, during other tests. Furthermore, the RFFS team also reported that all staff are trained not to operate the pump whilst dry, save for the monthly dry vacuum test (described below).
- 34.5.3. It is reported that there is no automatic pump cut-off if the tank runs dry, but rather it is the responsibility of the operator to cease operation of the pump if the water supply is exhausted. However, the RFFS team also report that during routine testing, the tank will generally never be drained below approximately 50% of the tank capacity, and that there would be no operational need to use more than 50% of the water supply during the routine testing. Taking these comments at face value would suggest that it is unlikely that the full tank volume would be completely discharged.
- 34.5.4. During the drafting tests, if the water supply became exhausted and/or the hose lifted out of the external water supply (i.e. cutting off the water supply), this too would be readily evident to the operators.
- 34.5.5. As witnessed during my observation of the routine tests, all actions appear to have been done in accordance with the OEM operating manual. Furthermore, when using the on-board supply, the tests were completed prior to the tank becoming depleted. During the drafting test, one operator held the hose below the surface of the water for the entire duration of the test, whilst the other operator actuated the pump controls, thereby preventing any risk of the hose lifting out of the water container, cutting off the water supply, and causing the pump to run dry.
- 34.5.6. During the daily tests using the on-board tank water supply, if the isolation valve was inadvertently left closed, this would be evident to the operator by water not being ejected from the hoses. As such, there would be no need for the operator to maintain use of the pump with the valve closed (except for the dry vacuum and drafting tests).
- 34.5.7. While the dry vacuum test requires the pump to be operated in the absence of a water supply (i.e. with the isolator valve closed), this is set out by the manufacturer in the operating manual. As such, if operating the pump in a dry manner during the dry vacuum tests caused or contributed to the observed damage, this would suggest that the operating manual stipulates actions that are not appropriate for the integrity of the pump and/or its components.

34.5.8. In light of the above, while there is no evidence to confirm the operational history of the pumps, provided that the RFFS team have operated the pumps in accordance with their training, and with the operating manual, there would have been no need for the pumps to be run dry, save for conducting the dry vacuum test in accordance with the operating manual.

34.6. Pump Overheating

34.6.1. As above, there is no evidence to confirm the precise operational history of the pumps, and in particular, whether the pump had been allowed to overheat.

34.6.2. There is also no quantification as to what would constitute 'overheating'. I have also not been advised as to whether the gearboxes are fitted with heat tabs that could indicate whether or not the gearbox had overheated and/or indicate the temperatures achieved by the gearbox casing.

34.6.3. However, I will add that as witnessed during my observation of the routine tests, all actions appear to have been done in accordance with the OEM operating manual.

34.6.4. A possible hypothesised reason for the pump overheating is that the pump was operated with the tank to pump isolator valve closed. However, as described above, there would be no operational need to operate the pump with the isolator closed, except for during the dry vacuum test. If the isolation valve was inadvertently left closed, this would be evident to the operator by water not being ejected from the hoses. As such, there would be no need for the operator to maintain use of the pump with the valve closed.

34.6.5. The RFFS team also report that all staff are trained to inspect the pump controls, and recognise any apparent issues, for example water not flowing due to the tank to pump isolator being inadvertently closed.

34.6.6. Furthermore, the staff are trained to engage the pump to tank recirculation at any time that the pump is operating but water is not being discharged in order to provide cooling to the pump and prevent overheating.

34.6.7. On this basis, provided that the RFFS team have operated the pumps in accordance with their training, and with the operating manual, there would have been no need for the pumps to be run with the tank to pump isolator valve in a closed position, save for the dry vacuum test, or without the pump to tank recirculation being engaged when required.

34.7. Low Oil Level and Wrong Oil

34.7.1. The capacity of the gearbox is 1.5l, and I have measured the remaining oil samples to be within approximately 1.25l to 1.35l.

- 34.7.2. Accounting for the losses sustained by the removed oil specimen sent for testing, as well as a possible incomplete withdrawal from the gearbox on account of the oil's viscosity, the volume of oil appears to have been broadly in line with the capacity of the gearbox (i.e. 1.5l). On this basis, this would suggest that insufficient volumes of oil were unlikely to have been a factor.
- 34.7.3. As described previously, the 2014 issue operating manual stipulates the use of SAE 10 and the 2021 issue operating manual stipulates the use of 10W40 oil. However, the 2021 operating manual was not provided to St Helena Airport until 2026. On this basis, SAE 10 oil was used in the gearboxes for a period of approximately five years after the manufacturer changed the stipulated oil to 10W40.
- 34.7.4. However, at all times leading up to the incident, St Helena Airport were using the gearbox oil as stipulated in the manual provided to them by Marcé.
- 34.8. Yearly Services Not Done
- 34.8.1. I have had sight of the annual service history relating to each of the ARFF vehicles between 2016 and 2026.
- 34.8.2. During this time period, all servicing was conducted by Marcé, except for 2020 (due to travel restrictions due to the Covid-19 pandemic), and 2025. In 2020 and 2025, the annual service was completed in-house.
- 34.8.3. It is important to note that the OEM operating manual does not stipulate that the servicing can only be conducted by an approved service provider, and rather only stipulates that *"Servicing and repair work is only allowed to be undertaken by personnel who are familiar with these tasks, have the related specialised knowledge and are familiar with the health and safety regulations."* For ease of reference, this is shown in Figure 116, overleaf.
- 34.8.4. As such, there are no apparent stipulations to state that servicing cannot be conducted in-house.
- 34.8.5. Nevertheless, the service records indicate that comprehensive annual servicing has been completed throughout the lifetime of the vehicles.
- 34.8.6. The full service history is not included in this report; however, SHAL have documented records of the entire service history for each of the three ARFF vehicles.

Safety measures

Servicing / maintenance

General

Servicing and repair work is only allowed to be undertaken by personnel who are familiar with these tasks, have the related specialist knowledge and are familiar with the health and safety regulations.

Shut down fire service vehicle's engine during servicing work!

Position the fire service vehicle so that it is secure!



Figure 116: Excerpt from operating manual relating to servicing requirements

35. OTHER CASES OF ECCENTRIC FAILURE

- 35.1. As described previously, the Marcé engineers alleged that similar failures had occurred to the eccentrics in similar vehicles in Botswana; however, there is no evidence to support this allegation.
- 35.2. However, during the course of my investigation, internet research has identified a number of other cases where the eccentrics of Ziegler pumps have seemingly failed in a similar manner to that observed in this instance, where the elastomer component has disintegrated. These are presented below.
- 35.3. Groß-Schweinbarth Firestation, Austria
 - 35.3.1. The first example is of a rescue and fire-fighting vehicle operated at Groß-Schweinbarth Firestation, Austria.
 - 35.3.2. In this instance, it is reported that the issue was first detected in 2016, when the pump had a sudden loss of suction, and a noise was heard emanating from the pump during operation.
 - 35.3.3. Disassembly of the pump, and in particular the Trokomat primer, identified that the eccentric driving the Trokomat pistons had disintegrated, and only the outer metal ring remained attached to the shaft. The metal ring was discovered to be the source of the unusual noises heard emanating from the pump. A number of pieces of the eccentric were reportedly removed from the bottom of the pump housing.
 - 35.3.4. Further details of this instance are described on the Groß-Schweinbarth Firestation website at the following links:

<https://www.feuerwehr-gross-schweinbarth.at/details.php?id=301>

<https://www.feuerwehr-gross-schweinbarth.at/Schaukasten/2017Einbaupumpe.pdf>

35.3.5. It is important to note that these articles are written in German, and my understanding of this matter has relied on internet-based English translations, the accuracy of which cannot be verified.

35.3.6. Nevertheless, this failure prima facie appears broadly similar to that sustained at the ARFF vehicles at St Helena Airport, although to a more significant extent.

35.4. Online Eccentric Repair Tutorial

35.4.1. Another identified example of similar failures of the eccentric is shown on an online video tutorial by a German mechanic providing guidance on how to replace the eccentric component of the gearbox of Ziegler pumps. While in this instance the pump is a different model to those fitted to R1, R2 and R3, the replacement eccentric can be seen to appear to be identical to those of this investigation.

35.4.2. In the video tutorial, the mechanic can be seen to remove the outer casing of the eccentric housing, where the eccentric can be seen to have disintegrated. The mechanic then removes some of the fragments of the eccentric, and compares these to a new replacement eccentric.

35.4.3. This video tutorial can be accessed at the link below, and the relevant sections are shown at a timestamp of approximately 7:15.

<https://www.youtube.com/watch?v=XECFggaW3FA>

35.4.4. For ease of reference, still images taken from the video footage are also provided in Figure 117, below, to Figure 119, overleaf.

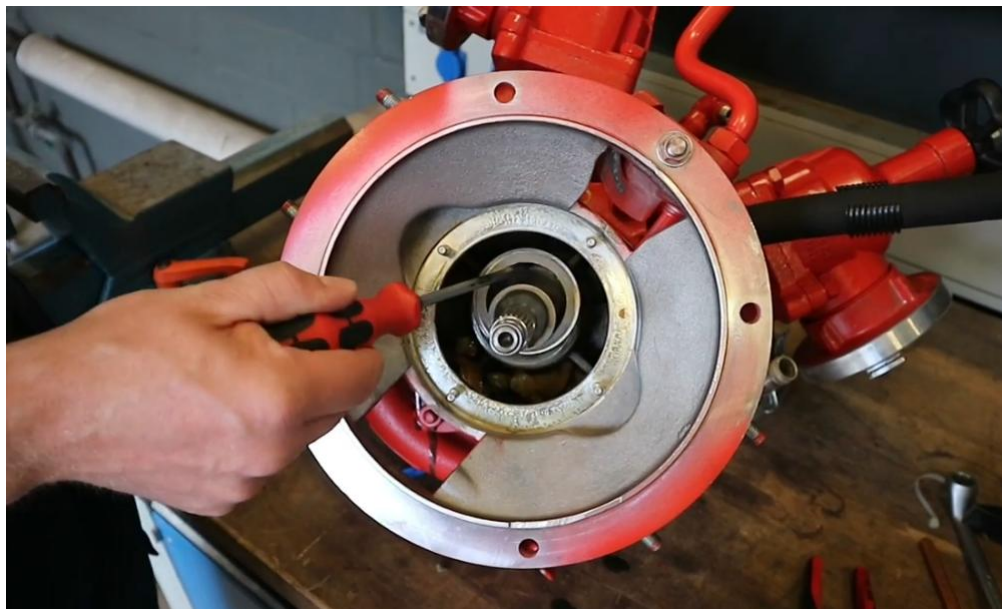


Figure 117: Online video tutorial showing disintegrated eccentric (1) © ‘Scotty’s Maschinisten Channel’ (<https://www.youtube.com/watch?v=XECFggaW3FA>) [accessed August 2026]



Figure 118: Online video tutorial showing disintegrated eccentric (2) © 'Scotty's Maschinisten Channel' (<https://www.youtube.com/watch?v=XECFggaW3FA>) [accessed August 2026]



Figure 119: Online video tutorial showing disintegrated eccentric (3) © 'Scotty's Maschinisten Channel' (<https://www.youtube.com/watch?v=XECFggaW3FA>) [accessed August 2026]

36. EXPECTANCY OF THE FAILURE

- 36.1. The evidence indicates that at the time that the failures were first observed, the eccentrics were still at least partially performing their function. This means that the damage to the eccentrics would not have been detectable during routine use of the pumps.
- 36.2. Furthermore, in light of the routine maintenance and servicing as stipulated in the operating manual, there would have been no way in which the full extent of damage to the eccentrics could have been detected.
- 36.3. In light of the above, I do not consider that there would have been any prior indication of the developing damage to the eccentrics, and thus no prior expectancy of the failure.
- 36.4. Even once the failure was first detected, there would have been no way to determine when complete failure of the eccentrics would/could occur. As such, at that point, there would have been no guarantee that the ARFF vehicles could continue to be used without causing further damage to (and potentially the complete and catastrophic failure of) the eccentrics.

37. POTENTIAL CONSEQUENCES OF FAILURE

- 37.1. In this instance, at the time of first detection, the eccentrics had not at that point failed catastrophically and completely.
- 37.2. If the eccentrics had failed completely, there would have been no mechanism in which any air within the system could have been actively removed from the pump.
- 37.3. It is possible that a gravity feed of water from the on-board storage tank may have self-primed the pump; however, this is not guaranteed.
- 37.4. If self-priming was not possible/effective, and/or if the ARFF vehicles were required to pump water from an external source (e.g. via drafting), the failure of the eccentrics would mean that any air-locks within the system could not have been removed.
- 37.5. Consequently, the presence of any air-locks within the pump system that could not be removed would likely significantly limit, or even completely prevent, the flow of water through the pump.
- 37.6. To this end, complete and catastrophic failure of the eccentrics has the potential to render the ARFF vehicle(s) incapable of discharging any water.

38. QUESTIONS RAISED

38.1. During my time at the Airport, and through the course of my investigation, a number of questions have come to light that, to date, have been unable to address.

38.2. Some of these questions also extend beyond the remit of my mechanical investigation; however, I still consider them to be pertinent to the case.

38.3. Consequently, for the investigation to continue, I raise the following questions:

(1) Should the extent and nature of the service level agreement with Marcé have included the provision of updated manuals from Ziegler, and was the onus on Marcé to provide the updated operating manual from Ziegler after it was reissued in 2021?

(2) Why did Ziegler change the stipulated oil from SAE 10 to 10W40, and what did/do Ziegler consider to be the potential consequences of not using 10W40 oil but rather continuing to use SAE 10 oil?

(3) Was the Vulkollan® used in the eccentrics hydrolysis stabilised? If not, what mitigations are/have been made to reduce any potential effect of exposure to water on the integrity of the material?

39. FURTHER INVESTIGATION

39.1. This initial investigation has explored the failures of each of the eccentrics, and the potential impacts of the mechanical and environmental loading conditions applied upon the components.

39.2. However, it has also highlighted the need for additional work to progress the investigation further, if required.

39.3. Laboratory Testing

39.3.1. The cursory, rudimentary experiment conducted during my time at the Airport explored the potential effects of exposure of the elastomer material to different fluids, and highlighted a potential link between exposure to water and a chemical decomposition of the elastomer.

39.3.2. As addressed previously, this initial experiment lacked quantifiable scientific accuracy; however, the damaged eccentrics removed from the ARFF vehicles have been retained.

39.3.3. To this end, if investigations are to continue, I would recommend that this experiment be repeated under laboratory conditions. In particular, since the hardness of the original material is known, hardness testing could be conducted on each of the samples to quantifiably assess any potential effect of each of the fluids (and water in particular) on the material's hardness.

39.4. Other Examples of Eccentric Failure

- 39.4.1. A number of other occurrences have been identified where the same eccentrics have failed in a seemingly similar/identical manner. One of which was documented in a report written in German. While I have used internet-based translation tools, if investigations are to continue, it may be necessary to have this professionally translated to ensure accuracy.
- 39.4.2. It may then also be beneficial to make enquiries with those involved in these other instances to gain an understanding of the failures that their eccentrics sustained, and any similarities there may have been between these cases and the failures of the eccentrics at St Helena Airport.

40. **FUTURE RECOMMENDATIONS**

40.1. Routine Inspection/Service

- 40.1.1. In this instance, the main reason why it is not possible to determine the precise point at which the degradation of the eccentrics first commenced is that no routine inspection of the eccentrics has been performed. While this is within the specification of the operator's manual, to my mind, more comprehensive and routine inspection would provide ongoing assessment of the condition and integrity of the eccentrics (as well as other components).
- 40.1.2. For instance, conducting endoscopic inspection of the gearbox and eccentrics via the oil drain plug has been found to provide a simple and time efficient means of gaining insight into the in-service condition of the eccentrics. As such, incorporating this method of inspection into the routine maintenance schedule would provide an ongoing assessment of the condition of the eccentrics, and any developing damage throughout their lifetime.
- 40.1.3. This inspection only requires the oil to be drained from the gearbox, and minimal time investment. As such, this could be done during the annual service and scheduled oil change. However, for a more comprehensive assessment, in the first instance I would recommend that this type of inspection could be conducted every six months, with the option to reduce the frequency to once per year if necessary.
- 40.1.4. For a more comprehensive examination, partial disassembly of the gearbox could be conducted on less frequent intervals, for example, every two to five years. While a significantly more labour intensive task, this would provide first-hand sight of the gearbox components (including the eccentric) and thus allow a more in-depth assessment of the developing condition of the eccentrics when compared to the endoscopic inspection alone.

40.2. Request for Updated Manuals

- 40.2.1. As described previously, this investigation has raised the question as to whether Marcé have a duty to provide updated operating manuals, as and when they are issued.
- 40.2.2. Irrespective of Marcé's obligations, I would also recommend that going forward, a more proactive approach is adopted by SHAL with regards to enquiries with Ziegler and/or Marcé as to whether any recent updates to the manuals have been issued.
- 40.2.3. For example, this could be done by contacting Ziegler and/or Marcé every six months to enquire whether the manual that SHAL have is the latest and current version, and if not, if an updated version could be provided. This would allow SHAL to remain apprised of the latest updates to the manual, independent to any obligations on Marcé to provide any relevant updates.

40.3. Transparent Reporting

- 40.3.1. I note that while the damage to the bearing that was sustained during the replacement of the eccentrics by Marcé was recorded in the work order, no specific detail was provided. As such, I was only able to gain more insight into the damage through discussions with the maintenance team.
- 40.3.2. To this end, I consider that this potentially highlights a requirement for more transparent and thorough reporting. For instance, if more information relating to the damage to the bearing, its cause, and any other relevant factors had been recorded, a more comprehensive, historical evidence trail would have been maintained.

40.4. Water Ingress

- 40.4.1. As described previously, there is evidence to suggest that there is ongoing water ingress to each of the pumps, albeit only trace amounts. Nevertheless, given the potential link between the presence of water and chemical degradation of the elastomer, to my mind it is imperative that any sources of leaks are identified, and addressed as soon as possible.
- 40.4.2. Also as described previously, visual inspection alone may not be sufficient to assess the condition of seals, or any other potential sources of water ingress (e.g. cracks in the gearbox casing). Rather, more detailed testing would be required such as pressure testing of the gearbox and/or dye-penetrant testing. Pressure testing of the gearbox could also potentially be incorporated into routine servicing to assess the ongoing integrity of the seals and casing.

40.5. Summary

- 40.5.1. All of the actions conducted by SHAL, the maintenance and RFFS teams in terms of routine operating and servicing appear prima facie to be within the specification as set out in the OEM operating manual.

40.5.2. However, given the environment in which St Helena Airport is based, the potential consequences of failed/damaged components, and the challenges in sourcing replacement components at short notice (e.g. in response to a component failure), to my mind, a more proactive approach to servicing and maintenance could be beneficial, and may help mitigate the risks of similar incidents occurring again in the future. For example, this could involve conducting routine servicing and maintenance actions that are in excess of, more comprehensive than, and more frequent than, the maintenance and servicing schedule as set out in the operating manual.

SUMMARY & CONCLUSIONS

41. SUMMARY

- 41.1. In response to the specific questions raised as part of this investigation, I make the following comments.
- 41.2. *What failed, and what is its function?*
- 41.2.1. The failure was sustained by the eccentric component that drives the Trokomat primer, which in turn dispels any air from the pump and fills (primes) it with water, ready for use. If air is not dispelled from the system, an airlock can be produced, which could impede or completely prevent a flow of water from the pump.
- 41.3. *How did it fail? What were the mode(s) of failure (e.g. fatigue, corrosion, overload, software fault, design defect)?*
- 41.3.1. The eccentric appeared to fail as a result of complete disintegration of its structure. The material properties appeared to have changed, and appeared brittle, and markedly different to an exemplar, unused eccentric, which was comparatively soft and pliable.
- 41.3.2. There were numerous cracks at different locations and within different planes and directions of the eccentric (e.g. radial, longitudinal and circumferential). The multiplanar directionality and multiple locations of these cracks did not appear to coincide with any one loading direction. To my mind, this would suggest that the cracks were not solely caused by the applied mechanical loading, but possibly at least partly due to a breakdown of the structure and changes to the material properties.
- 41.4. *Why did it fail? Were there any underlying causes (engineering, human factors, process, environmental)?*
- 41.4.1. There is evidence to suggest that the elastomer material used for the eccentric can break down in the presence of water, resulting in decomposition of the chemical structure, in turn potentially causing the material to become brittle and crack or crumble.
- 41.4.2. I have conducted a cursory experiment that supports this and highlights a potential link between water exposure and altered material properties.
- 41.5. *When were the failures initiated?*
- 41.5.1. When the failures were identified, the eccentrics had not at that stage sustained a complete and catastrophic failure, and the eccentrics were still performing their function. As such, the damage to the eccentrics was not detectable through use.

- 41.5.2. There were no requirements for visual inspection of the eccentrics within the gearbox, and there would have been no other means by which the damage to the eccentrics could be observed.
- 41.5.3. Consequently, there is no evidence to allow the point at which the failures first commenced to be determined.
- 41.6. *Could the failure have been detected earlier? Were monitoring, inspections, maintenance etc. adequate?*
- 41.6.1. The point at which the failure first commenced cannot to be determined, and the failure was not detectable based on the routine monitoring, inspection and maintenance schedule as stipulated by the manufacturer. Consequently, there would also have been no means by which the failure could have been detected any earlier.
- 41.6.2. It is possible that endoscopic inspection of the gearbox could have provided earlier detection of the developing damage to the eccentrics. However, this was not stipulated or suggested by the manufacturer, and would have been over and above the specific stipulated requirements. Furthermore, based on the information available at that stage, there would have been no prior warning of the developing failure, and thus no apparent requirement or reason to conduct any such endoscopic inspection.
- 41.7. *What are the implications for similar systems or assets at the Airport?*
- 41.7.1. The implications of failure of the eccentrics are that the ARFF vehicles could potentially have lost all water pumping capabilities. The failures were present in all ARFF vehicles, and as such, if catastrophic failure of all three eccentrics had occurred, it could have resulted in a complete loss of water pumping capability across the fleet of three ARFF vehicles.
- 41.7.2. Based on my understanding of the failures of the eccentrics, they are independent of other extraneous systems of the Airport. As such, failure of the eccentrics would likely not have had any other effect on the Airport, other than the aforementioned potential loss of water pumping capability.
- 41.7.3. However, my investigation has highlighted the highly corrosive nature of the borehole water supply, and the potential accelerated rate of corrosion that exposure to this water supply could cause.
- 41.8. *What actions are required to prevent recurrence?*
- 41.8.1. While the routine maintenance schedule is within the specification as stipulated by the manufacturer, given the nature of the location in which the ARFF vehicles are used (i.e. on a remote, isolated island), I consider that routine maintenance and inspection that goes beyond the stipulated schedule would be beneficial in providing an ongoing assessment of the condition of the eccentrics.

- 41.8.2. I have also recommended that a proactive approach be taken in relation to making enquiries with Ziegler and/or Marcé with regards to any recent updates made to the operating manual, for example, making such enquiries every six months. This will ensure that SHAL have access to the most up to date manual(s), independent of any obligations on the part of Marcé to provide such manuals.

42. CONCLUSIONS

- 42.1. My conclusions are based upon my examination of evidence relating to the incident, the consideration of the incident circumstances as provided, the results of my analysis, and my experience.

42.2. Background

- Critical faults were identified in the water pumps of all three of the Airport Rescue and Firefighting (ARFF) vehicles at St Helena Airport (R1, R2, R3) that resulted in closure of the airport.
- Disassembly of the pumps found degradation and cracking to the eccentric of each of the three ARFF vehicles.
- The eccentric is a subcomponent of the gearbox that acts as a cam to drive a secondary primer pump to remove any airlocks from within the main pump.
- The eccentric is formed of a polyurethane based elastomer.

42.3. Service Agreement & Oil Use

- The ARFF vehicles were supplied to St Helena Airport by Marcé. The original equipment manufacturer (OEM) of the water pumps is Ziegler.
- St Helena Airport have an ongoing maintenance and service agreement with Marcé.
- When the ARFF vehicles were originally provided to St Helena Airport by Marcé, a Ziegler OEM water pump operating manual was supplied. This had an issue date of 2014.
- The 2014 manual stipulated the use of SAE 10 oil within the gearbox.
- In 2021, Ziegler issued an updated manual in which the specified gearbox oil was changed to SAE 10W40, an oil with over twice the viscosity of SAE 10 oil (i.e. a thicker oil).
- This updated manual was not supplied to St Helena Airport until 2026, when Marcé attended to conduct repair work on the damaged eccentrics.
- Consequently, while St Helena Airport were maintaining the gearboxes in accordance with the manual supplied to them, and one that was believed to be the latest and current version, SAE 10 oil was used within the gearbox for a period of approximately five years after the point that Ziegler changed the specified oil to SAE 10W40.
- The reason for the change of oil is not known, nor is it known why the updated manual was not provided to St Helena Airport following its reissue in 2021.

- This raises questions as to whether there was an obligation on Marcé to provide the updated manual in light of the ongoing service agreement.

42.4. Observation of Damage

- The pump of R2 was removed and disassembled, where extensive corrosion and pitting damage was observed to the pump casing.
- The gearbox of R2 was opened, where extensive fracture damage to the eccentric was observed.
- The gearboxes of R1 and R3 were subsequently removed and opened, where similar fracture damage to the eccentrics was observed.
- There was also visible scoring/abrasion marks to the outer circumference of the metal collar surrounding the eccentric, and within the area in contact with the primer pistons when in use.

42.5. On-Site Investigation

- I attended St Helena Airport between Monday 27 July 2026 and Friday 7 August 2026, where I was assisted by St Helena Airport in all aspects of my investigation.
- My investigation considered mechanical examination and testing of the eccentrics, oil analysis, operational matters of the ARFF vehicles, maintenance and servicing, the water source used by the ARFF vehicles, and the material of the failed component.

42.6. Mechanical Examination

- I inspected the remnants of each of the failed components.
- The eccentrics each appeared to have failed as a result of disintegration of their structure, and the material properties had altered when compared with an unused exemplar eccentric.
- There were numerous cracks throughout the eccentrics, in a multitude of locations and across all planes of the structures. The multiplanar directionality and multiple locations of the cracks did not appear to coincide with any one loading direction.
- The nature of the failure could suggest that the cracks were not solely caused by the applied mechanical loading, but likely at least partly due to a breakdown of the structure and changes to the material properties.
- The exact point at which the damage first commenced could not be determined from the available evidence. However, the evidence would suggest that it had been developing over an extended period of time.
- There was differential staining to different regions of the structure which was likely related to the duration of exposure to the oil, where the darker areas were exposed for a longer period of time than the lighter coloured areas.

- There was also localised staining that had penetrated into some of the cracks, which would suggest that the cracks had been developing for an extended period of time, and long enough for the oil to have penetrated the cracks and cause the observed staining.
- I also performed an endoscopic inspection of the eccentrics currently in service in the ARFF vehicles, which showed no signs of any developing damage.

42.7. Preliminary Testing

- The elastomer is reported to be formed of Vulkollan®, which is resistant to oils and greases; however, it is susceptible to hydrolysis, which is the chemical breakdown and decomposition of the structure in contact with water.
- To test this, I conducted a preliminary experiment whereby samples of the eccentric were exposed to different fluids (oil, water contaminated oil, and water) for a period of three days.
- While not of quantifiable scientific accuracy, the sample exposed to water appeared to have sustained some degradation, and the appearance and textural properties were different to that of the oil-exposed sample.
- This test highlighted a potential link between water exposure and possible change in the structure and/or properties of the elastomer material, and degradation and/or disintegration of the structure.

42.8. Oil Analysis

- I have reviewed oil analysis reports for a number of oil samples taken from the gearboxes of R1, R2 and R3 over a range of dates since the failure of the eccentrics.
- The analysis reports do not show any significant wear rates, debris, contamination, or degradation; however, water contamination has been detected at varying levels within each of the ARFF vehicles.
- This would suggest water ingress and thus a potential leak within the gearbox system.
- The source of the leak(s) are currently unknown. During my investigation, the ARFF vehicles were in service and so full disassembly of the pumps to inspect for signs of leaks was not possible.
- Further investigation would be required to identify the source(s) of any leak(s). It is likely that visual inspection alone would not be sufficient to identify leaks, and more comprehensive testing may be required, such as pressure testing of the gearbox, and/or dye-penetrant testing.
- The remaining volume of the oil samples did not suggest that an insufficient volume of oil had been used in the gearboxes.
- The viscosity of SAE 10W40 oil is over twice that of SAE 10 oil.
- In general, an oil of higher viscosity will be able to support greater loads than an oil with lower viscosity. However, a higher viscosity oil will flow less readily than a lower viscosity oil.

- With regards to the reason for the change of specified gear box oil, I consulted a UK based oil laboratory who advised that a manufacturer may change from one oil to another oil with significantly increased viscosity if it is discovered that the original oil did not provide sufficient lubrication properties, resulting in excessive wear of the gearbox components.
- The reason for the change in oil in this instance is not known; however, the possibility that SAE 10 oil was found to not be providing sufficient lubrication cannot be precluded.
- To my mind, the extent of localised scoring observed on the metal collar was more significant than I would have expected to observe if the gearbox was sufficiently lubricated.
- It is not possible to determine when the scoring occurred, and/or for how long it had been present and/or developing.
- However, the presence of scoring could suggest insufficient lubrication, for example, insufficient quantity, and/or insufficient viscosity.

42.9. Corrosion & Pitting Damage

- There was extensive corrosion and pitting damage present on the R2 pump casing, and the drafting inlets of each ARFF vehicle.
- The presence of pitting damage could indicate that cavitation has occurred, which is a damage mechanism caused by localised pressure differences in a fluid.
- It is not possible to determine when the corrosion and pitting damage first commenced; however, it is possible that they had both been developing over an extended period of time, and possibly over the entire lifetime of the pumps.

42.10. Routine Testing of Pumps

- I witnessed daily, monthly, and quarterly testing of the pumps done by the RFFS team, and consulted the OEM operating manual.
- All routine testing actions conducted by the RFFS team appeared prima facie to be in direct accordance with the OEM operating manual. There was no evidence to suggest that the pumps had been operated in a manner in contravention of the manufacturer's instructions.

42.11. Maintenance & Servicing

- I interviewed the maintenance team and reviewed the servicing schedule as specified in the OEM operating manual.
- All servicing actions conducted on the pumps and gearboxes by the maintenance team appeared prima facie to be in direct accordance with the 2014 issue OEM operating manual.

- While the oil used in the gearboxes was different from that specified in the 2021 OEM operating manual, prior to the incident, St Helena Airport had not at that stage received the updated 2021 manual.

42.12. Water Source

- The ARFF vehicles currently use potable, mains water for fire-fighting and training purposes. Prior to 17 July 2020, a borehole water supply was used as a water source for the ARFF vehicles.
- I have reviewed water analysis reports for both a borehole and airport tap water supplies.
- The borehole water supply had high levels of salts, dissolved solids, and chlorides.
- While not to the same extent as the borehole water supply, the tap water also had high levels of salts and chlorides. Both water supplies were also described as highly corrosive.
- The presence of chlorides in a water supply will increase its electrical conductivity, which in turn will significantly accelerate metal corrosion.
- It is therefore possible that the observed corrosion of the pump components could have been caused or exacerbated by the nature of the water supply used and pumped by the ARFF vehicles, particularly during the time that the borehole water supply was used.

42.13. Detection of Failure

- The evidence indicates that at the point that the damage to the eccentrics was observed, they had not at that point failed completely and catastrophically, and were still performing their function, despite their developing damage.
- A complete failure of the eccentrics would have resulted in a loss of priming function, and would have been detectable at least during the quarterly tests of the pumps, if not before.
- As there was no loss of function, there was no means through the routine testing and use of the ARFF vehicles that any developing damage could have been detected.
- The eccentric components are housed within a sealed gearbox, and as such there was no way in which the routine inspection and servicing as stipulated by the manufacturer could have detected the developing damage.
- Consequently, there appears prima facie to have been no prior indication or expectancy of any developing damage, or any impending failure of the eccentrics.
- At the point that the damage was first observed, there was also no way to predict the remaining working life of the eccentrics, nor the duration that the pumps could continue to be operated without sustaining a complete and catastrophic failure of the eccentrics.

- Had the eccentrics failed completely, the primer pump would have lost all function, meaning that it might not have been possible to remove any airlocks that were within the system. In such a scenario, an airlock could potentially completely prevent, or severely restrict the flow of water through the pump.
- Consequently, a complete and catastrophic failure of the eccentrics has the potential to render the ARFF vehicle(s) incapable of discharging any water.

42.14. Other Occurrences of Failure

- A number of other, independent cases have been identified where the same eccentrics have failed in seemingly identical manners, whereby the structure has disintegrated and crumbled, suggesting that this failure was not an isolated occurrence.

42.15. Further Investigation and Future Recommendations

- A number of questions have been raised that extend beyond the current scope of the investigation, but are considered to be pertinent to the case.
- Actions for further investigation have been identified, including laboratory testing of the elastomer material, and pressure testing/dye penetrant testing of the gearboxes.
- Future recommendations have been made to help mitigate the risks of similar incidents occurring again in the future, particularly in light of the environment in which the ARFF vehicles are operated, and the challenges in sourcing replacement components at short notice.
- This includes enhanced monitoring of the eccentrics (that is more comprehensive and frequent than that set out by the manufacturer), as well as a more proactive management strategy with the service provider.

42.16. Summary

- I am prepared to consider any other further relevant evidence coming to light in respect of this particular incident.
- I reserve the right to amend any of my views if new evidence changes the nature of the collision under review.

43. DECLARATION OF INDEPENDENCE

- 43.1. For the avoidance of doubt, I do not consider that my independence as an investigator has been compromised in any way during my time at St Helena Airport, or on St Helena Island more generally, prior to my arrival, or since my departure from the Island.
- 43.2. My findings are based solely on my own interpretation of the available evidence.

44. STATEMENT OF TRUTH

I confirm that I have made clear which facts and matters referred to in this report are within my own knowledge and which are not. Those that are within my own knowledge I confirm to be true. The opinions I have expressed represent my true and complete professional opinions on the matters to which they refer.



Dr Ross Beesley CEng
22/09/2026

APPENDIX A: QUALIFICATIONS AND EXPERIENCE

Professional Profile

I am a Chartered Engineer with the Engineering Council, and Forensic Engineer with GBB (UK) Ltd, where I specialise in mechanical failure investigation, and collision reconstruction. My professional experience includes detailed examination and analysis of mechanical defects and material failures in a wide range of applications including pedal cycles, passenger cars, commercial and agricultural vehicles, highways maintenance vehicles, and domestic infrastructure. I am also experienced in the investigation and reconstruction of incidents involving motorcars, motorcycles, pedal cycles, electric bikes and e-scooters, pedestrians, heavy goods vehicles and agricultural vehicles.

I hold an Engineering Doctorate in Nuclear Engineering, where my research involved the structural integrity and fracture mechanics of gas turbine components subject to extreme structural and thermal loading conditions, and focussed specifically on material failure, metal fatigue, lifetime assessment, and computational modelling. I also hold a Master's degree in Mechanical Engineering, and am a member of the Institute of Mechanical Engineers (IMechE).

I apply my knowledge of engineering, material failure, structural integrity, and dynamics to the investigation of engineering failures, and reconstruction of vehicle collisions. I joined the Forensic Collision Investigation profession in 2020.

I have been trained in and have developed investigation and reconstruction techniques using computer simulation, laser scanning, computer aided design (CAD) modelling, as well as vehicle examination techniques including forensic seatbelt analysis, and motorcycle and pedal cycle helmet examination. I have also attended professional training courses in techniques for the forensic analysis of CCTV and dashcam video footage, the effects of human factors in vehicle collisions, and motorcycle collision reconstruction.

Academic Credentials

EngD Nuclear Engineering	- University of Strathclyde (2012 - 2017)
MEng Mechanical Engineering	- University of Strathclyde (2008 - 2012)

Professional Affiliations

Chartered Engineer (CEng) with the Engineering Council
Member of the Institute of Mechanical Engineers (IMechE)
Affiliate Member of the Institute of Traffic Accident Investigators (ITAI)

Collision Investigation Related Formal Training

Bosch CDR Technician Course – *EUDarts* 2021
Video Analysis in Collision Reconstruction – *FCIR Ltd* 2021
Human Factors for Traffic Crash Reconstruction – *Crash Safety Solutions LLC* 2022
Motorcycle Collision Reconstruction – *Lightpoint Learning* 2023
Forensic Image & Video Enhancement with Amped5 – *Amped Software* 2024

APPENDIX B: DOCUMENTATION CONSIDERED

I have considered the following documentation in preparing this report:-

- Consolidated timeline of events pre and post-incident including email chains;
- Photographs taken during disassembly of R2 pump, and R1 and R3 gearbox;
- St Helena Airport Quarterly Pump Operation checklist;
- Historical service records and work orders (R1, R2, R3);
- Oil Analysis Reports (R1, R2, R3);
- Borehole & Airport Tap Water Analysis Report (2016);
- Evidence Locker Temper Evident Seal Log;
- 2014 Issue Ziegler Pump Operating Manual (scanned copy);
- 2021 Issue Ziegler Pump Operating Manual (digital copy);
- Ziegler Spare Parts List (2019).

APPENDIX C: VULKOLLAN ® PRODUCT INFORMATION

(overleaf)

(24 pages)



VULKOLLAN®

Vulkollan®

The Ultimate Elastomer





Covestro – a leader in material solutions

With sales of EUR 12.1 billion in fiscal 2017, a global workforce of around 16,200 (calculated as full-time equivalents) and 30 production sites worldwide, Covestro is among the world's largest polymer companies. Covestro's business activities are focused on manufacturing high-tech polymer materials and the development of innovative solutions for products used in many areas of daily life, e.g., in the automotive, construction, wood processing and furniture, electrical and electronics, sports and leisure, cosmetics and health industries.

In the Coatings, Adhesives, Specialties (CAS) segment, Covestro systematically develops and supplies aliphatic and aromatic isocyanates and their derivatives as well as polyurethane dispersions for coatings, adhesives, sealants and specialty products. The main application areas are in the automotive, transportation, infrastructure, construction, wood processing and furniture industries. New applications are also being developed in fields such as cosmetics, medical equipment, textiles, specialty films, elastomers and 3D printing products. Innovations are focused on enhancing efficiency, improving quality, boosting sustainability and environmental aspects such as reducing solvent content.

In the Polyurethanes (PUR) segment, Covestro offers a comprehensive range of raw materials for manufacturing rigid polyurethane foam for insulation purposes, soft polyurethane foam for applications such as upholstered furniture, mattresses and car seats, and high-strength, lightweight composites. Covestro has also developed a new polyurethane infusion resin for wind turbine blades with superior qualities to the widely used epoxy resins.

In the Polycarbonates (PCR) segment, Covestro develops and supplies products that set new standards in energy efficiency and safety, support the lightweighting trend, and allow greater design freedom. Important application areas include weight-saving solutions for the automotive industry, energy-efficient LED lighting, solid and multi-skin polycarbonate sheets for the construction industry, and medical equipment.

Performance where it's needed

Contents

4–5	Vulkollan® engineering material – premium performance that benefits you
6–7	Solid Vulkollan® – pure resistance
8–9	Optimal mechanical properties – top rankings in all disciplines
10–11	High performance – low energy loss during deformation and high thermal stability
12–13	Impressive dynamics – top bench test results
14–15	Solid Vulkollan® – peak performance in every application
16–17	Cellular Vulkollan® – lasting dynamic properties for effective damping and shock absorption
18–19	Cellular Vulkollan® – dimensional stability in all terrains
20–21	Design benefits – less space, less weight



Vulkollan® engineering material – premium performance that benefits you

Vulkollan® is a high-grade polyurethane elastomer based on raw materials from Covestro:

Desmodur® 15 and special polyester polyols.

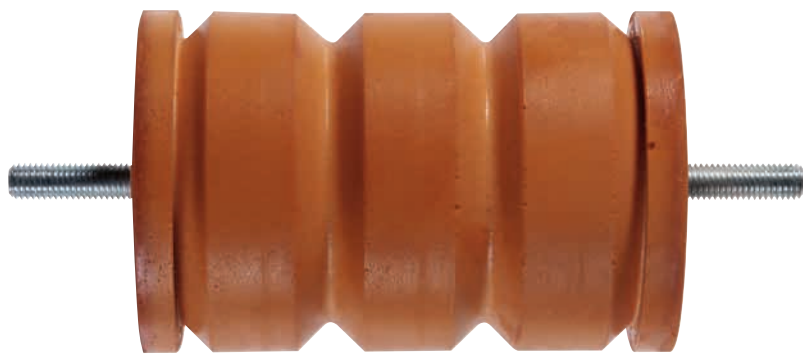
The rubber-elastic material boasts an highest mechanical and dynamic load-bearing capacity.

On the one hand, it's a classic, but on the other, it's one of the world's most modern plastics. First developed in the 1950s as an advancement of polyurethane (PU), invented by Otto Bayer in 1937, Vulkollan® quickly won over the industry. Users today can benefit from a wealth of experience with the hot-cast elastomer and take full advantage of its unique set of properties. Most worthy of mention in this connection are its extremely high mechanical strength and dynamic load-bearing capacity.

The right combination of critical properties makes solid and cellular Vulkollan® the materials of choice wherever numerous other candidates fail to make the grade. Even steel and rubber are increasingly being replaced by the elastomer.

Vulkollan® is produced on the processor's premises: certified manufacturers make molded parts from the raw materials. The formulations and manufacturing process parameters are determined by precise specifications defined in close cooperation with Covestro. This is an important prerequisite for maintaining the uniformly high level of quality of the engineering material, formulated in part on the basis of the isocyanate Desmodur® 15.

A success in many fields of application, Vulkollan® is often the best solution.



Vulkollan® – the ultimate elastomer

- Highest mechanical load-bearing characteristics
- Highest dynamic load-bearing capacity
- Made from Desmodur® 15

Solid Vulkollan® – pure resistance

Solid Vulkollan® really shows its strengths when it comes to heavy-duty tasks with peak loads. It is the engineering material of choice for many users whenever they need exceptionally high wear resistance and high mechanical strength.



From the 2nd subbasement to the 78th floor at the press of a button
... and back down again. Elevators are on the move day and night, some of them running almost constantly. Guide rollers made of solid Vulkollan® guarantee passengers a high level of safety and a comfortable ride. Elevator manufacturers and building owners benefit from lower maintenance costs thanks to the high wear resistance of the rollers.

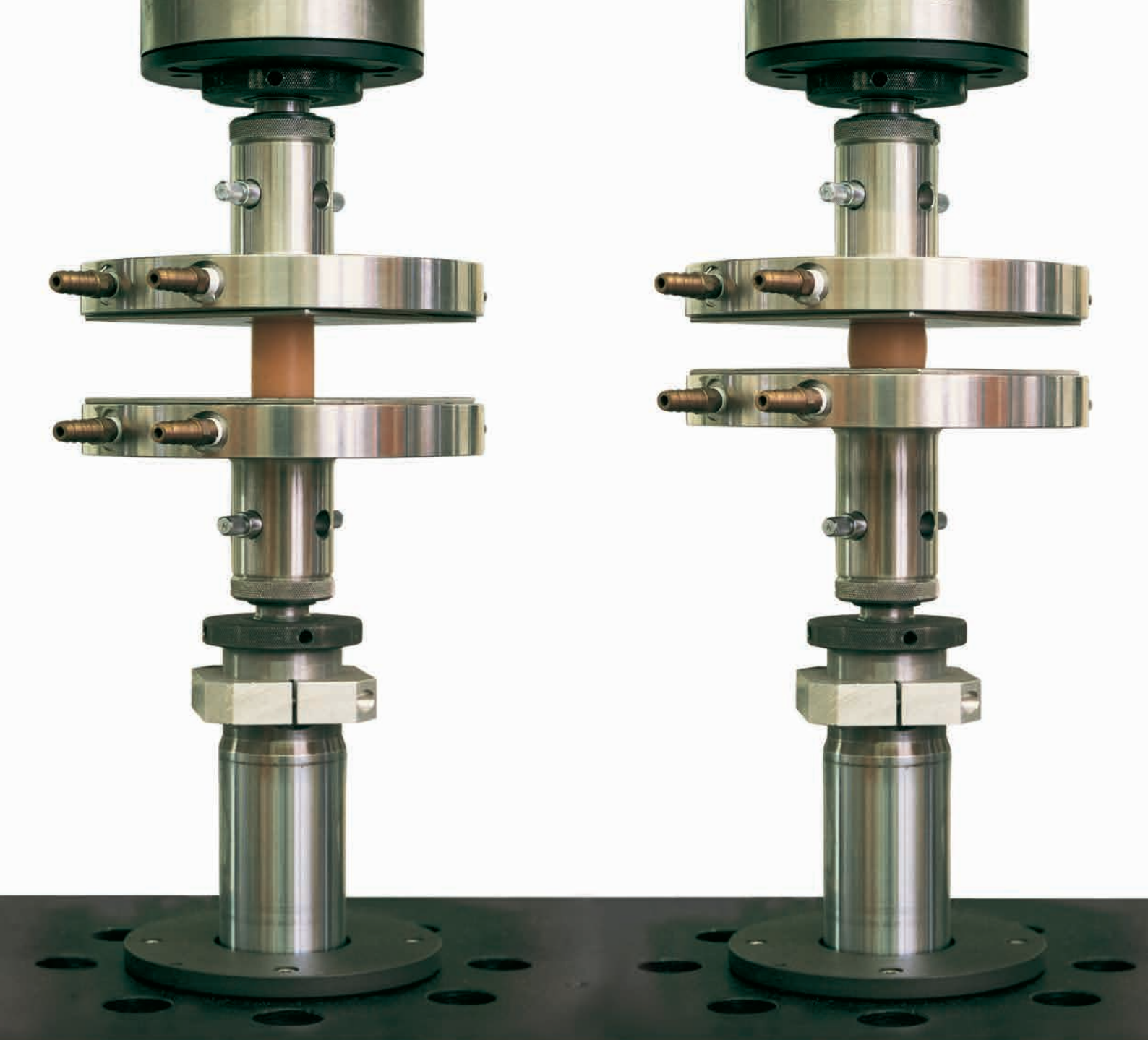


Heavy loads on quiet wheels
Cutting-edge goods supply systems call for increasingly efficient logistics centers, which in turn depend on forklifts and order-picking vehicles that can move heavy items quickly and reliably. Solid Vulkollan® wheel coverings enable such vehicles to achieve high travel speeds, offer a long service life and display outstanding elastic recovery.

Loop-the-loops at maximum G-force

The wheels on roller coasters are subjected to tremendous loads. Very strong forces act on them, some reaching several times gravity in the curves. Vulkollan® wheel coverings ensure long-lasting functional reliability. What's more, the high-tech material's elasticity promotes the quiet, smooth running of the wheels.





Optimal mechanical properties – top rankings in all disciplines

Vulkollan® has outstanding mechanical properties, including low abrasion loss, high tensile strength, excellent tear propagation resistance, as well as outstanding compressive deformation and rebound resilience.

Vulkollan® properties as a function of hardness

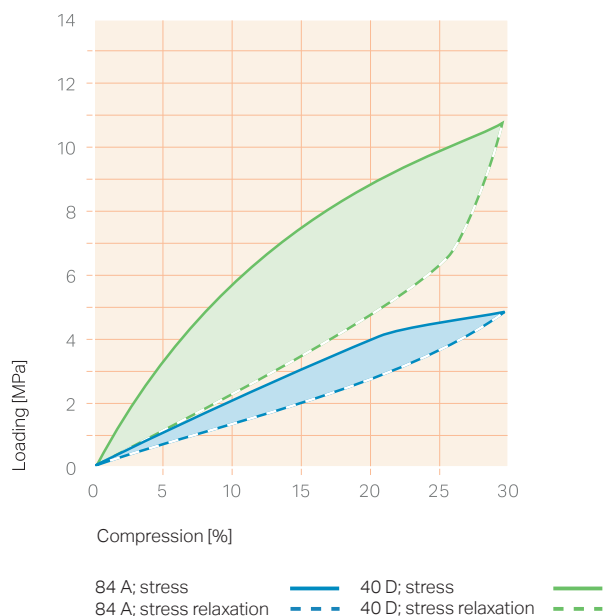
Mechanical properties	ISO test standard	Unit	Shore A/D hardness			
Shore A/D hardness	868		83/29	83/35	92/36	95/40
Density	1183	g/cm ³	1.26	1.26	1.26	1.2
Stress at 100% elongation	37	MPa	4.3	5.9	8.0	10.6
Stress at 300% elongation	37	MPa	7.8	10.4	12.8	15.8
Tensile strength	37	MPa	50	54	53	42
Elongation at break	37	%	660	700	740	692
Tear propagation resistance	34	kN/m	31	38	54	67
Rebound resilience	4662	%	65	64	62	61
Abrasion	4649	mm ³	37	32	28	26
Taber abrasion (S42/4.9 N)	9352	mg	3.5	4.0	6.1	7.5
Compression set	815					
70 h/23°C		%	8	9	10	14
24 h/70°C		%	18	19	19	20

High performance – low energy loss during deformation and high thermal stability

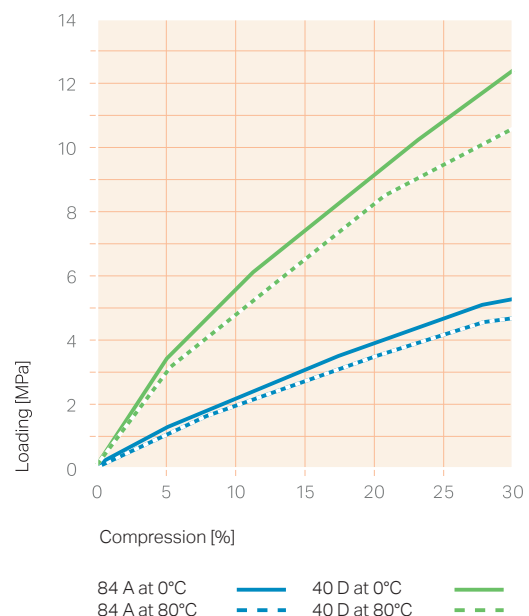
Compressive deformation at various temperatures

In compression testing, the stress application and removal curves for solid Vulkollan® are very close together, indicating very low energy losses. This is particularly advantageous in the case of repetitive and sustained dynamic loading.

Test conditions: Test specimen 29 mm Ø x 12.5 mm high
Deformation rate 10 mm/min
Temperature 23°C, measured after 3rd deformation



Test conditions: Test specimen 29 mm Ø x 12.5 mm high
Deformation rate 10 mm/min

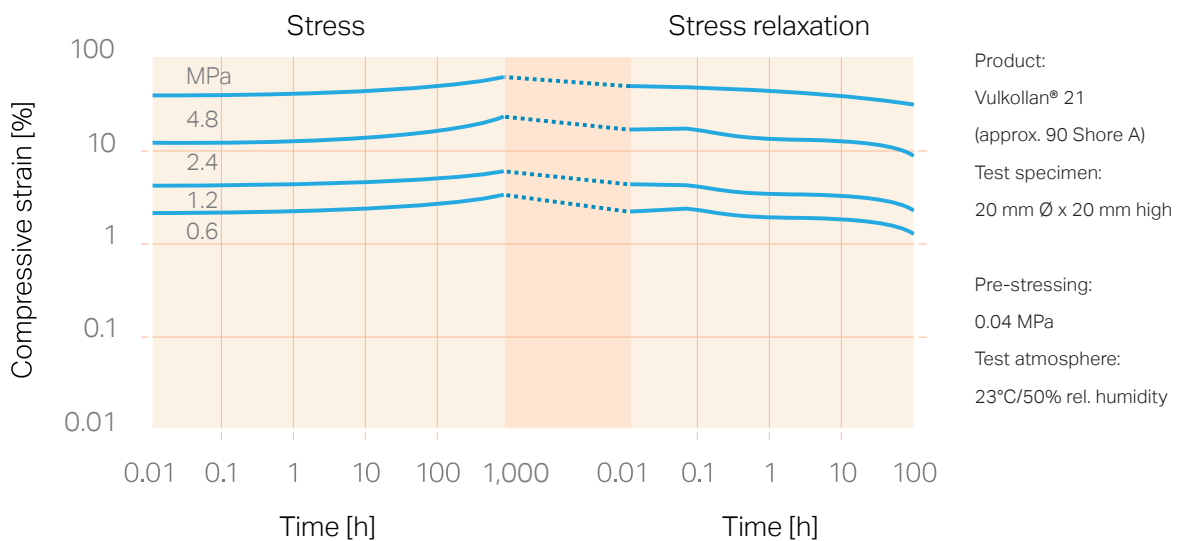


Long-lasting dimensional stability – good for wheels, rollers and seals

At higher deformation levels in elastomers, it is important to look at the material's set behavior as well as its spring characteristics. The compressive deformation performance of solid Vulkollan® exposed to sustained loading can be demonstrated by the compression creep test to DIN 53444.

At constant load, only slight permanent deformation occurs over time.

Therefore rollers and wheels made of Vulkollan® do not go flat even after long periods of inactivity, meaning the associated vehicles function without interruption. Seals made of the elastomer can do their job continuously because their elasticity remains constant over long periods of time.

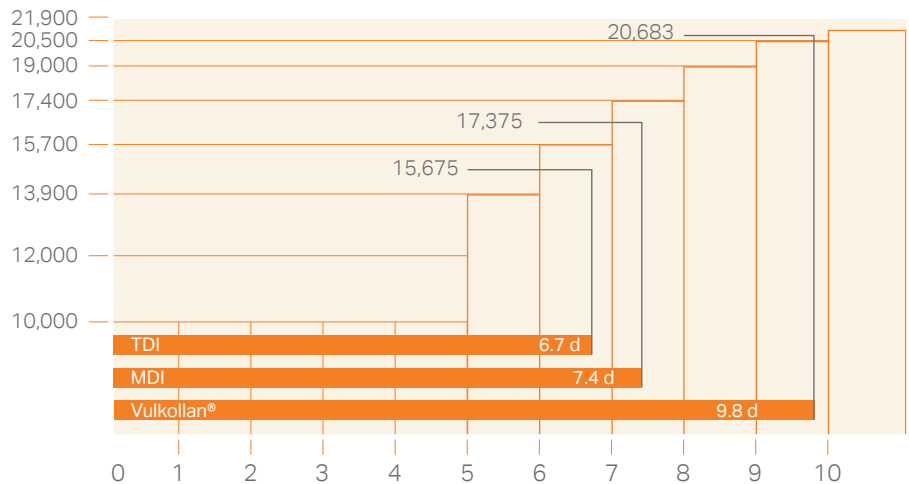


Impressive dynamics – top bench test results

In elastomer components subject to dynamic load, internal friction processes generate heat. This effect is particularly pronounced in the case of loads associated with high deformation or high frequency. Many elastomer materials sustain thermal damage as a result. In contrast, solid Vulkollan® can withstand extraordinarily high dynamic loads. This is the main reason why it is used to manufacture wheel coverings and suspension elements.

Test result (TÜV Munich) as mean failure load/failure time with gradually increasing load; 6 km/h test speed; wheel dimensions 250 x 130 mm

Contact force [N]

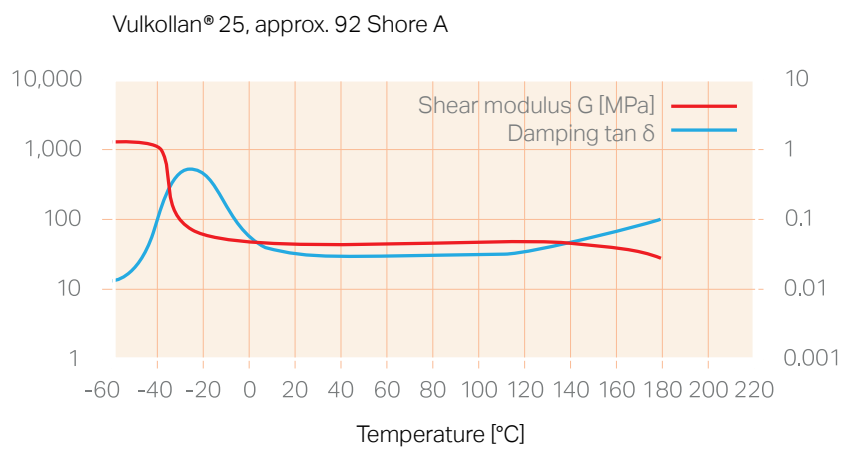


Time [d]

Roller test bench experiments support the quality testing of heavy-duty rollers and provide a wealth of other important data.

The quality of the elastomer itself, and the strength of the bond between the material and the metal, are carefully assessed.

Additionally, possible line loads can be evaluated at different speeds and cross-sectional geometries.



Solid Vulkollan® stiffens as the temperature drops (below -10°C). The glass transition temperature is approximately -40°C , but embrittlement only sets in at much lower temperatures.

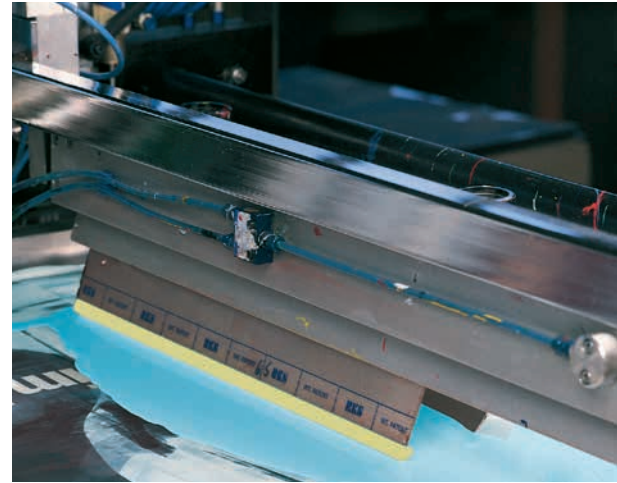
The shear modulus is virtually constant over a temperature range from approx. -10°C to $+120^{\circ}\text{C}$. In other words, consistent deformation behavior is seen across a very wide temperature range.



Solid Vulkollan® – peak performance in every application

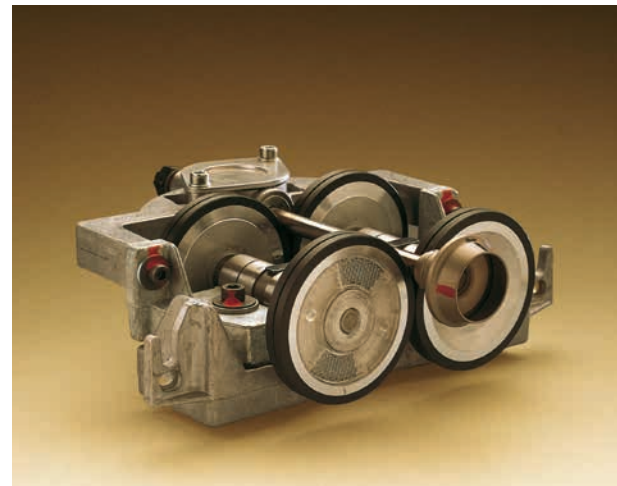
High dimensional stability

A screen printing doctor blade has to withstand quite a lot. It must demonstrate high resistance to solvent-induced swelling and outstanding dimensional stability for consistently superior printing results, even when handling long print runs. Furthermore, it must offer a long service life, so as to reduce blade changes and retouching to a minimum. Solid Vulkollan® is the material of choice for screen printing doctor blades: it contains no fillers or plasticizers, has a high shear modulus and displays only minimal permanent deformation.



High modulus of elasticity

Couplings are required to reliably transfer engine power. To do so, they must withstand high torques and acceleration, and be capable of balancing out axle angles and displacement. Solid Vulkollan® has just the right properties to act as a cushioning element or coupling disc in such applications: a high modulus of elasticity for optimal power transmission, the right degree of damping, high abrasion resistance and good resistance to grease and lubricants.



Handles heavy loads

When forklifts carry heavy loads, all the weight is transferred to the tires, so their coverings must be capable of withstanding high surface pressures over long periods. Solid Vulkollan® can easily handle these extreme conditions. It is characterized by outstanding mechanical load-bearing properties and dynamic load resistance, combined with impressive wear resistance and high tear resistance. Its low compression set prevents tires from flattening out, even after long periods of inactivity.





Cellular Vulkollan® – lasting dynamic properties for effective damping and shock absorption

For greater comfort and safety

The vehicle manufacturing industry faces rising comfort and safety requirements. From bicycles to cars and agricultural machinery, all demand innovative engineering solutions. In these applications, excellent quality and high cost-efficiency need not be contradictory. Cellular Vulkollan® meets all these requirements.

For greater cost-efficiency and a longer service life

Cellular Vulkollan® boasts outstanding dynamic properties and an impressive combination of high-quality and very consistent characteristics. It shows hardly any signs of fatigue under load, meaning that components made of the high-performance elastomer have a long service life and maintain their value. As a result, the consumption of raw materials in their manufacture is at very sustainable levels.

For space-saving designs

Cellular Vulkollan®, with its good mix of high-level material properties, offers an opportunity to design components of significantly smaller dimensions than is possible with other materials. With its good deformation behavior and thermal stability, this material is predestined for use in components that have to remain functional in the long term even in small spaces.

Vulkollan® – the ultimate elastomer

- Highest mechanical load-bearing characteristics
- Highest dynamic load-bearing capacity
- Made from Desmodur® 15

Cellular Vulkollan® – dimensional stability in all terrains

Cellular Vulkollan® is preferred over the solid version in applications requiring higher levels of deformability and lower compression hardness. In day-to-day operations, it is the compressive deformation properties that are of relevance.

The advantages of cellular Vulkollan® make it particularly well-suited to use in motor vehicles. For example, it is used to make auxiliary springs for low-cost linear steel springs, which are an economical alternative to expensive progressive steel springs. As well as being a solution to purely suspension-related problems, our elastomer is increasingly popular in many other fields of application, such as sound insulation, where Vulkollan® is proving to be very effective in decoupling vibrating components while vastly improving vibration damping.

Mechanical properties

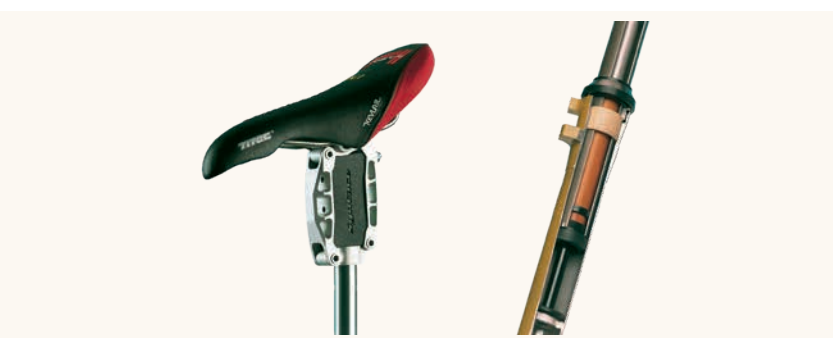
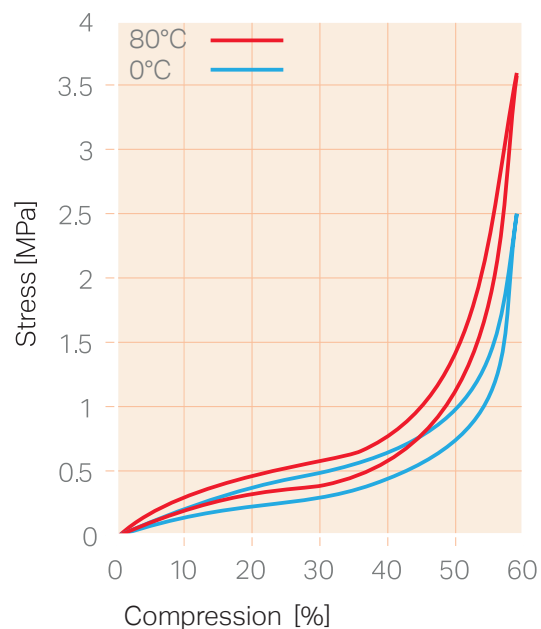
		Test standard				
Density	kg/m ³	ISO 845	350	450	550	650
Tensile strength	MPa	ISO 37	3.0	4.0	5.5	7.7
Elongation at break	%	ISO 37	400	400	400	400
Tear propagation resistance	kN/m	ISO 34	8	12	16	20
Rebound resilience	%	ISO 4662	60	60	60	60
Compression set		ISO 815				
70 h/23°C	%		3.0	3.0	3.0	3.0
24 h/70°C	%		10.0	7.5	8.0	9.0



Cyclists enjoy a particularly comfortable ride when telescopic forks and saddles are dampened with compressible cellular Vulkollan®. The smoothness of the ride is confirmed by the spring characteristics measured in tests of the material's damping behavior at various temperatures.

Determined during the upward and downward deflection phases, the curves describe an area whose size is a measure of the energy loss occurring during deformation. In suspension elements, the heat build-up over repeated load cycles remains very low, be it at 0°C or 80°C, as demonstrated by the low temperature dependence of the damping characteristics of cellular Vulkollan®.

Cellular Vulkollan® hysteresis curves at 0°C and at 80°C, density 505 kg/m³



Design benefits – less space, less weight

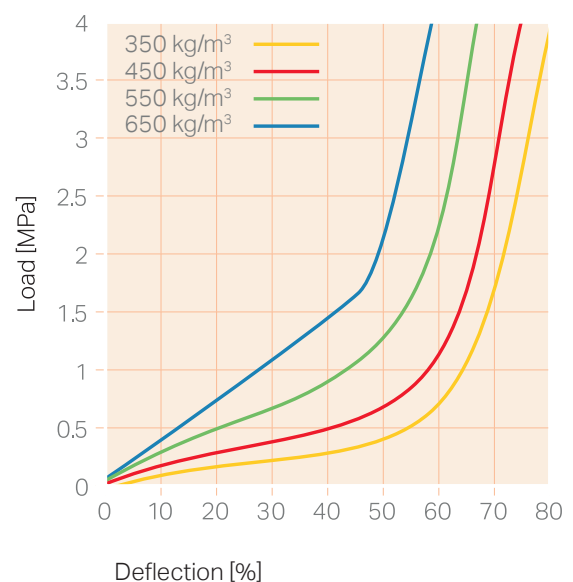


Progressive spring characteristics:

The compressive deformation curves for cellular Vulkollan® demonstrate its typical progressive spring characteristics. Transverse expansion or “spreading” is very minimal.

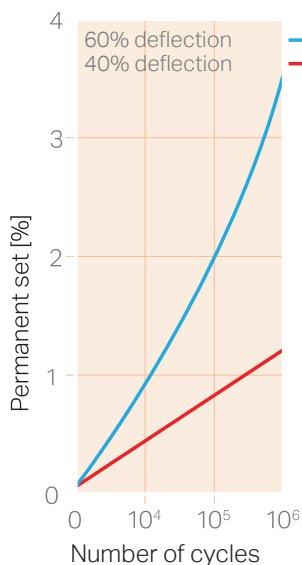
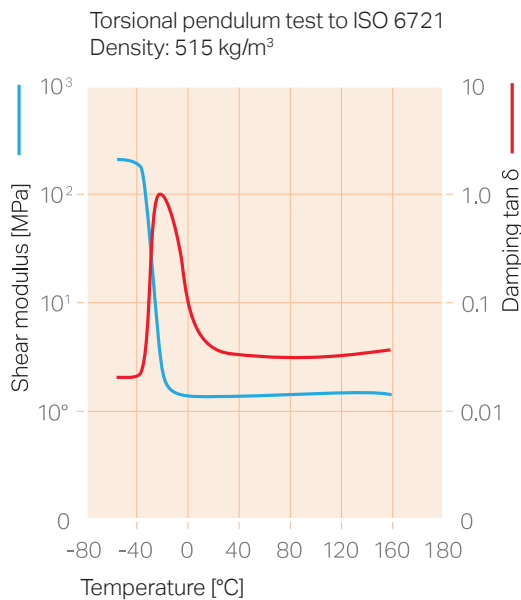
The engineering material therefore combines the high mechanical strength of solid elastomers with the compressibility of foamed plastics.

Load deflection as a function of density



The superior advantages of cellular Vulkollan® prove their worth in innumerable motor vehicles of virtually all makes around the world. One primary application is spring struts. Auxiliary springs made of cellular Vulkollan®, together with the shock absorbers and steel springs, are the main components responsible for ensuring that the struts can do their job continuously even in limited spaces and at such a low weight. The spring characteristics can be altered by varying the density of the auxiliary spring and its geometry.

Demands on vehicle comfort and noise damping likewise are on the rise. One highly effective way of tackling this challenge is to adopt designs that decouple the suspension from the body using damper bearings made of cellular Vulkollan®. The result is well-damped elastic resonance and a reduction in the transmission of structure-borne noise into the body and the vehicle interior.



The shear modulus of cellular Vulkollan® is virtually constant from -10°C to +120°C, meaning its deformation behavior is consistent over a wide range of temperatures, and that is a decisive criterion when it comes to material selection. Another benefit is the extraordinarily good low-temperature flexibility. Hardening does not set in until the temperature drops below -40°C. The maximum permissible working temperature is +80°C.

Brief and temporary exposure to +120°C is also permissible. The properties of cellular Vulkollan® change only gradually under sustained dynamic load. Whether at room temperature or at 80°C, the spring characteristics are always of the same order of magnitude. Even after 1 million compressions by 60%, permanent deformation is still only 3.5%!

Know-how is part of our service

With Vulkollan®, you are also putting our expertise to use. The Covestro Marketing team of highly qualified chemists, business professionals and technical specialists is happy to share their expertise and provide you with any advice or practical information you need. You can contact us at our headquarters in Leverkusen, Germany, and in many countries on all continents.

We look forward to partnering with you!

Frank Muschiol

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Phone: +49 214 6009 2618
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Covestro Deutschland AG

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Edition: 2018-04 · Order No.: COV00083957 · Printed in Germany

APPENDIX D: OIL ANALYSIS REPORTS (R1, R2, R3)

(overleaf)

(12 pages)

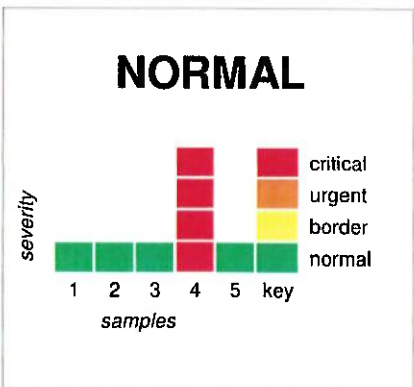
Mr T Chikwenhere [Tavongo]
St Helena Airport Limited
Posperous Bay Plain
St Helena Island
ST HELENA

KWAZULU-NATAL:

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FAX: (031) 700 5471

GAUTENG:

P.O. BOX 284
ISANDO 1600
TEL: (011) 392 6322
FAX: (011) 392 6340



Vehicle : R1
Alt. ID : 4757 -
Model : -
Component : FIRE TRUCK WATER PUMP GEARBOX
Model : "ZIEGLER FIRE CENTRIFUGAL PUMP FPN10-4000-2H/HH"

Code : 5SHHSH
Job No. : -
Site : HLE
Oil : CASTROL CRB MONOGRADE 10W
Queries : PLEASE CONTACT DIAGNOSTIC DEPARTMENT.

DIAGNOSIS

5.) Sample Number D668911 on 29.04.2026 smr 308 HRS
Wear rates are normal and the sample provided appears free from unacceptable contamination or degradation. Debris analysis normal.

PREVIOUS HISTORY

DIAGNOSES

- 1.) Sample Number D668912 on 21.03.2026 smr 305 HRS
Wear rates are normal and the sample provided appears free from unacceptable contamination or degradation. Debris analysis normal.
- 2.) Sample Number D668917 on 04.04.2026 smr 306 HRS
Wear rates are normal and the sample provided appears free from unacceptable contamination or degradation. Debris analysis normal.
- 3.) Sample Number D668903 on 18.04.2026 smr 307 HRS
Wear rates are normal and the sample provided appears free from unacceptable contamination or degradation. Debris analysis normal.
- 4.) Sample Number D668905 on 05.02.2026 smr 299 HRS
Viscosity is high for this grade of oil. Wear rates have increased. Debris analysis normal. 5.5% Water present in the oil - check for point of entry. The oil is not fit for further use due to contamination. Change the oil. Please return feedback.

FEEDBACK

Vehicle: R1 - FIRE TRUCK WATER PUMP GEARBOX - Alt. ID: 4757 -

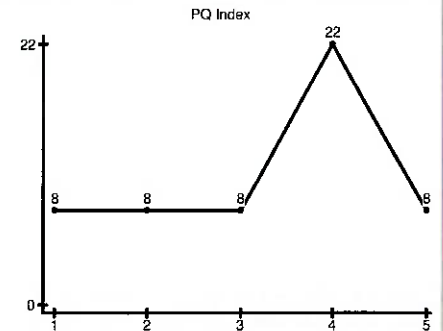
SAMPLE	DATE	LAB	OIL			OIL IN	FILTER	OIL		
NUMBER	SAMPLED	DATE	CONSUMPTION	SMR	UNITS	SERVICE	CHANGE	DRAIN	RRI	
1	D668912	21.03.26	07.05.26	-	305	HRS	-	Yes	Yes	500
2	D668917	04.04.26	07.05.26	-	306	HRS	-	Yes	Yes	500
3	D668903	18.04.26	07.05.26	-	307	HRS	-	Yes	Yes	500
4	D668905	05.02.26	07.05.26	-	299	HRS	-	Yes	No	500
5	D668911	29.04.26	07.05.26	-	308	HRS	-	Yes	Yes	500

WEAR METALS

Sample	Iron	Chromium	Nickel	Aluminium	Copper	Tin	Silver	Lead	Bismuth	PQ Index
1	2	0	0	0	11	0	0	1	0	8
2	3	0	0	0	2	0	0	0	0	8
3	4	0	0	0	2	0	0	1	0	8
4	47	1	0	29	13	2	0	5	0	22
5	4	0	0	0	4	0	0	1	0	8

30 spectrometric analyses are carried out on all samples but only relevant results are reported in parts per million.

PARTICLE QUANTIFIER INDEX

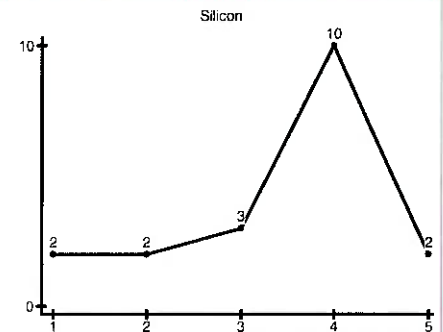


CONTAMINANTS

Sample	Silicon	Sodium	Lithium	Water (%)
1	2	2	0	ND
2	2	3	0	ND
3	3	3	0	ND
4	10	9	14	5.5
5	2	3	0	ND

30 spectrometric analyses are carried out on all samples but only relevant results are reported in parts per million.

SILICON



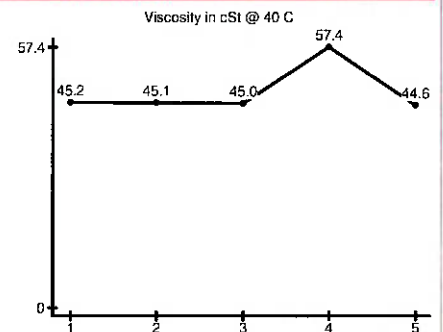
ADDITIVES & LUBRICANT CONDITION

Sample	Magnesium	Calcium	Molybdenum	Zinc	Phosphorous	Potassium	Boron	Sulphur
1	10	2349	84	823	806	4	2	2462
2	9	2275	82	801	795	2	1	2388
3	10	2343	84	835	829	4	2	2420
4	21	1857	69	946	942	2	38	3093
5	10	2170	79	747	747	0	0	2118

30 spectrometric analyses are carried out on all samples but only relevant results are reported in parts per million.

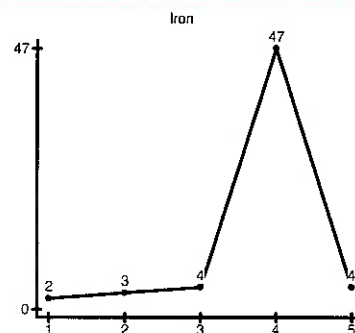
VISCOSITY

Viscosity in cSt @ 40 C

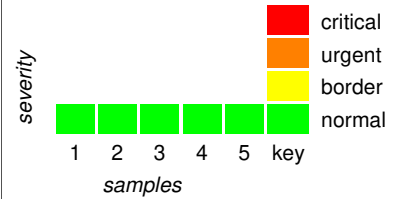


GRAPHICAL REPRESENTATION OF KEY DATA

Too few values to plot Oil in Service



NORMAL



KWAZULU-NATAL:

P.O. BOX 15108
WESTMEAD 3608
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GAUTENG:

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FAX: (011) 392 6340

Ms F Green [Suelaine]
St Helena Airport Limited
Prosperous Bay Plain
St Helena Island
ST HELENA

Vehicle : R1
Alt. ID : 4757 -
Model : -
Component : FIRE TRUCK WATER PUMP GEARBOX
Model : "ZIEGLER FIRE CENTRIFUGAL PUMP FPN10-4000-2H/HH"

Code : 5SHHSH
Job No. : -
Site : HLE
Oil : TOTAL QUARTZ 10W40
Queries : PLEASE CONTACT DIAGNOSTIC DEPARTMENT.

DIAGNOSIS

5.) Sample Number H116434 on 08.07.2026 smr 315 HRS
Wear rates are normal and the sample provided appears free from unacceptable contamination or degradation. A trace of water present in the oil. Debris analysis normal.

PREVIOUS HISTORY

DIAGNOSES

- 1.) Sample Number D668911 on 29.04.2026 smr 308 HRS
Wear rates are normal and the sample provided appears free from unacceptable contamination or degradation. Debris analysis normal.
- 2.) Sample Number DH14971 on 27.05.2026 smr 311 HRS
Laboratory tests indicate that the oil in use is an SAE 10W oil. Wear rates are normal and the sample provided appears free from unacceptable contamination or degradation. Debris analysis normal.
- 3.) Sample Number H116437 on 24.06.2026 smr 314 HRS
Wear rates are normal and the sample provided appears free from unacceptable contamination or degradation. Debris analysis normal. A trace of water present in the oil.
- 4.) Sample Number H116438 on 10.06.2026 smr 312 HRS
Wear rates are normal and the sample provided appears free from unacceptable contamination or degradation. Debris analysis normal. A trace of water present in the oil.

FEEDBACK

Vehicle: R1 - FIRE TRUCK WATER PUMP GEARBOX - Alt. ID: 4757 -

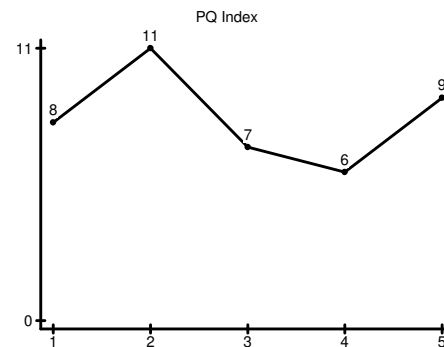
	SAMPLE NUMBER	DATE SAMPLED	LAB DATE	OIL CONSUMPTION	SMR	UNITS	OIL IN SERVICE	FILTER CHANGE	OIL DRAIN	RRI
1	D668911	29.04.26	07.05.26	-	308	HRS	-	Yes	Yes	500
2	DH14971	27.05.26	04.08.26	-	311	HRS	2	Yes	Yes	500
3	H116437	24.06.26	04.08.26	-	314	HRS	2	Yes	Yes	500
4	H116438	10.06.26	04.08.26	-	312	HRS	2	Yes	Yes	500
5	H116434	08.07.26	04.08.26	-	315	HRS	2	Yes	Yes	500

WEAR METALS

Sample	Iron	Chromium	Nickel	Aluminium	Copper	Tin	Silver	Lead	Bismuth	PQ Index
1	4	0	0	0	4	0	0	1	0	8
2	8	0	0	1	3	0	0	0	0	11
3	3	0	0	0	2	2	0	0	2	7
4	2	0	0	0	0	0	0	0	0	6
5	5	0	0	0	2	0	0	0	0	9

30 spectrometric analyses are carried out on all samples but only relevant results are reported in parts per million.

PARTICLE QUANTIFIER INDEX

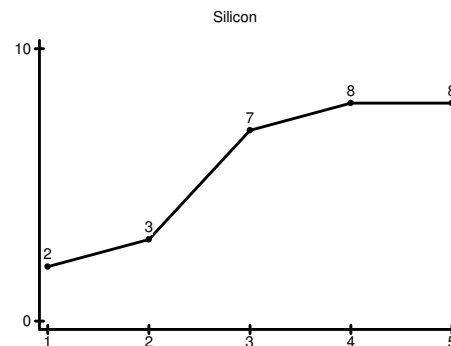


CONTAMINANTS

Sample	Silicon	Sodium	Water (%)
1	2	3	ND
2	3	3	ND
3	7	0	0.1
4	8	0	0.1
5	8	0	0.1

30 spectrometric analyses are carried out on all samples but only relevant results are reported in parts per million.

SILICON



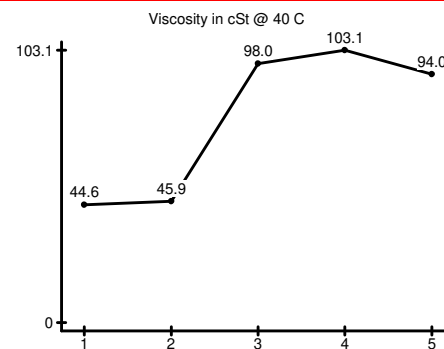
ADDITIVES & LUBRICANT CONDITION

Sample	Magnesium	Calcium	Molybdenum	Zinc	Phosphorous	Boron	Sulphur
1	10	2170	79	747	747	0	2118
2	9	2282	80	809	788	1	2584
3	10	2831	91	957	925	45	2779
4	10	2801	95	989	934	46	2861
5	10	2760	95	991	931	44	2848

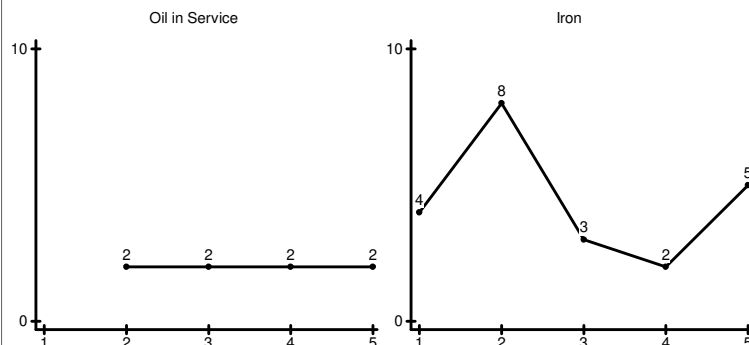
30 spectrometric analyses are carried out on all samples but only relevant results are reported in parts per million.

VISCOSITY

Viscosity in cSt @ 40 C



GRAPHICAL REPRESENTATION OF KEY DATA



Mr T Chikwenhere [Tavongo]
St Helena Airport Limited
Posperous Bay Plain
St Helena Island
ST HELENA

Vehicle : R2
Alt. ID : 4758 -
Model : -
Component : FIRE TRUCK WATER PUMP GEARBOX
Model : "ZIEGLER FIRE CENTRIFUGAL PUMP FPN10-4000-2H/HH"

KWAZULU-NATAL:

P.O. BOX 15108
WESTMEAD 3608
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FAX: (031) 700 5471

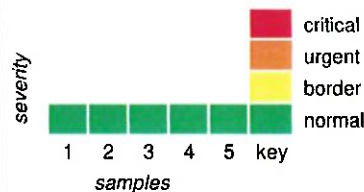
GAUTENG:

P.O. BOX 284
ISANDO 1600
TEL: (011) 392 6322
FAX: (011) 392 6340

Code : 5SHHSH
Job No. : -
Site : HLE
Oil : CASTROL CRB MONOGRADE 10W
Queries : PLEASE CONTACT DIAGNOSTIC DEPARTMENT.

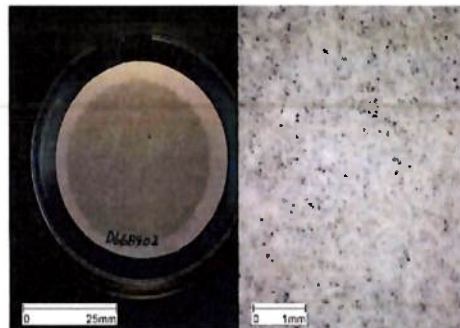
PROBLEM SEVERITY

NORMAL



DIAGNOSIS

5.) Sample Number D668902 on 29.04.2026 smr 355 HRS
Wear rates are normal and the sample provided appears free from unacceptable contamination or degradation. Debris analysis revealed wear particles present which can be considered normal for this system.



PREVIOUS HISTORY

DIAGNOSES

- 1.) Sample Number D668913 on 04.04.2026 smr 354 HRS
The period oil has been in use is unknown. Wear rates are normal and the sample provided appears free from unacceptable contamination or degradation. Debris analysis normal.
- 2.) Sample Number D668910 on 21.03.2026 smr 352 HRS
Wear rates are normal and the sample provided appears free from unacceptable contamination or degradation. Debris analysis normal.
- 3.) Sample Number D668914 on 18.04.2026 smr 355 HRS
Wear rates are normal and the sample provided appears free from unacceptable contamination or degradation. Debris analysis normal.
- 4.) Sample Number D668915 on 24.03.2026 smr 352 HRS
Wear rates are normal and the sample provided appears free from unacceptable contamination or degradation. Debris analysis normal.

FEEDBACK

Vehicle: R2 - FIRE TRUCK WATER PUMP GEARBOX - Alt. ID: 4758 -

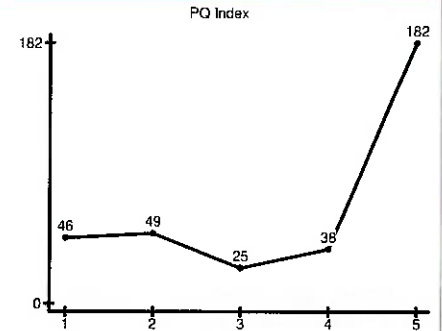
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	NUMBER	SAMPLED	DATE	CONSUMPTION	SMR	UNITS	SERVICE	CHANGE	DRAIN	RRI
1	D668913	04.04.26	07.05.26	-	354	HRS	-	Yes	Yes	500
2	D668910	21.03.26	07.05.26	-	352	HRS	-	Yes	Yes	500
3	D668914	18.04.26	07.05.26	-	355	HRS	-	Yes	Yes	500
4	D668915	24.03.26	07.05.26	-	352	HRS	-	Yes	No	500
5	D668902	29.04.26	07.05.26	-	355	HRS	-	Yes	Yes	500

WEAR METALS

Sample	Iron	Chromium	Nickel	Aluminium	Copper	Tin	Silver	Lead	Bismuth	PQ Index
1	33	0	0	2	4	0	0	0	0	46
2	40	0	0	5	19	1	0	2	0	49
3	55	0	0	2	5	0	0	1	0	25
4	36	0	0	4	10	0	0	0	0	38
5	44	0	0	2	8	0	0	1	0	182

30 spectrometric analyses are carried out on all samples but only relevant results are reported in parts per million.

PARTICLE QUANTIFIER INDEX

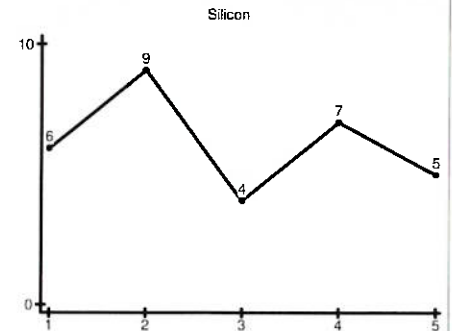


CONTAMINANTS

Sample	Silicon	Sodium	Water (%)
1	6	3	ND
2	9	5	ND
3	4	4	ND
4	7	5	ND
5	5	3	ND

30 spectrometric analyses are carried out on all samples but only relevant results are reported in parts per million.

SILICON



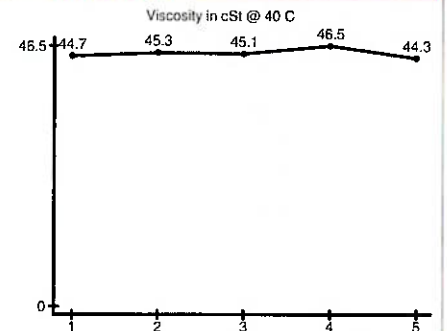
ADDITIVES & LUBRICANT CONDITION

Sample	Magnesium	Calcium	Molybdenum	Zinc	Phosphorous	Potassium	Boron	Sulphur
1	10	2198	84	747	741	1	0	2135
2	11	2396	83	830	815	0	0	2411
3	11	2434	87	844	827	0	0	2345
4	11	2405	77	861	859	2	5	2460
5	9	2300	83	796	800	2	0	2541

30 spectrometric analyses are carried out on all samples but only relevant results are reported in parts per million.

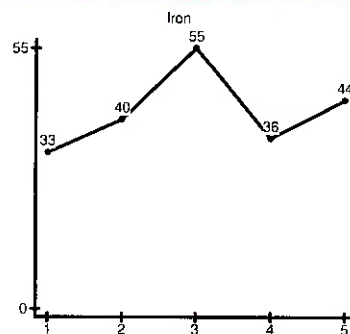
VISCOSITY

Viscosity in cSt @ 40 C

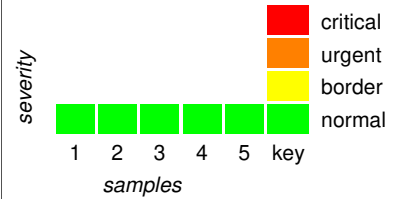


GRAPHICAL REPRESENTATION OF KEY DATA

Too few values to plot Oil in Service



NORMAL



KWAZULU-NATAL:

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Prosperous Bay Plain
St Helena Island
ST HELENA

Vehicle : R2
Alt. ID : 4758 -
Model : -
Component : FIRE TRUCK WATER PUMP GEARBOX
Model : "ZIEGLER FIRE CENTRIFUGAL PUMP FPN 10-4000-2H-HH"

Code : 5SHHSH
Job No. : -
Site : HLE
Oil : TOTAL ENERGIES QUARTZ 7000-10W40
Queries : PLEASE CONTACT DIAGNOSTIC DEPARTMENT.

DIAGNOSIS

5.) Sample Number H116439 on 10.06.2026 smr 361 HRS
Wear rates are normal and the sample provided appears free from unacceptable contamination or degradation. Debris analysis normal. A trace of water present in the oil.

PREVIOUS HISTORY

DIAGNOSES

- 1.) Sample Number D668902 on 29.04.2026 smr 355 HRS
Wear rates are normal and the sample provided appears free from unacceptable contamination or degradation. Debris analysis revealed wear particles present which can be considered normal for this system.
- 2.) Sample Number H116433 on 08.07.2026 smr 364 HRS
Wear rates are normal and the sample provided appears free from unacceptable contamination or degradation. Debris analysis normal. A trace of water present in the oil.
- 3.) Sample Number DH14972 on 27.05.2026 smr 359 HRS
Laboratory tests indicate that the oil in use is an SAE 10W oil. Please confirm oil grade. Wear rates are normal. Debris analysis normal.
- 4.) Sample Number H116436 on 24.06.2026 smr 362 HRS
Wear rates are normal and the sample provided appears free from unacceptable contamination or degradation. Debris analysis normal. A trace of water present in the oil.

FEEDBACK

Vehicle: R2 - FIRE TRUCK WATER PUMP GEARBOX - Alt. ID: 4758 -

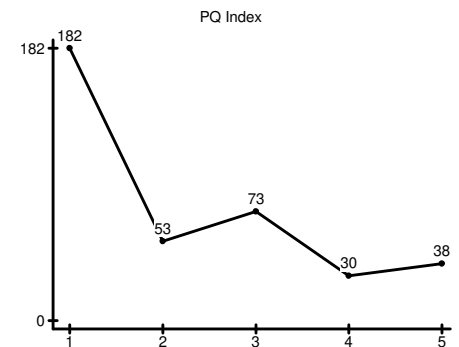
	SAMPLE NUMBER	DATE SAMPLED	LAB DATE	OIL CONSUMPTION	SMR	UNITS	OIL IN SERVICE	FILTER CHANGE	OIL DRAIN	RRI
1	D668902	29.04.26	07.05.26	-	355	HRS	-	Yes	Yes	500
2	H116433	08.07.26	04.08.26	-	364	HRS	2	Yes	Yes	500
3	DH14972	27.05.26	04.08.26	-	359	HRS	2	Yes	Yes	500
4	H116436	24.06.26	04.08.26	-	362	HRS	2	Yes	Yes	500
5	H116439	10.06.26	04.08.26	-	361	HRS	2	Yes	No	500

WEAR METALS

Sample	Iron	Chromium	Nickel	Aluminium	Copper	Tin	Silver	Lead	Bismuth	PQ Index
1	44	0	0	2	8	0	0	1	0	182
2	16	0	0	1	2	0	0	0	0	53
3	59	0	0	2	4	0	0	0	0	73
4	14	0	0	0	2	0	0	0	0	30
5	8	0	0	0	2	0	0	0	0	38

30 spectrometric analyses are carried out on all samples but only relevant results are reported in parts per million.

PARTICLE QUANTIFIER INDEX

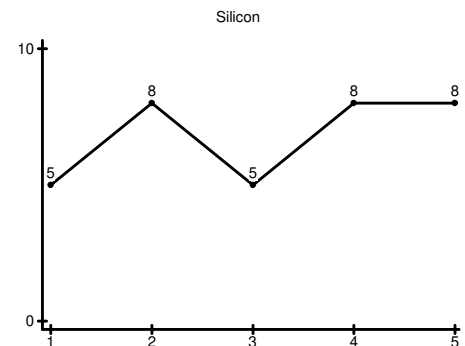


CONTAMINANTS

Sample	Silicon	Sodium	Water (%)
1	5	3	ND
2	8	0	0.1
3	5	5	ND
4	8	0	0.1
5	8	0	0.1

30 spectrometric analyses are carried out on all samples but only relevant results are reported in parts per million.

SILICON



ADDITIVES & LUBRICANT CONDITION

Sample	Magnesium	Calcium	Molybdenum	Zinc	Phosphorous	Potassium	Boron	Sulphur
1	9	2300	83	796	800	2	0	2541
2	9	2883	93	975	951	0	46	2879
3	11	2285	83	825	780	0	3	2386
4	9	2805	94	982	927	0	44	2851
5	9	2823	99	1012	949	0	47	2902

30 spectrometric analyses are carried out on all samples but only relevant results are reported in parts per million.

VISCOSITY

Viscosity in cSt @ 40 C

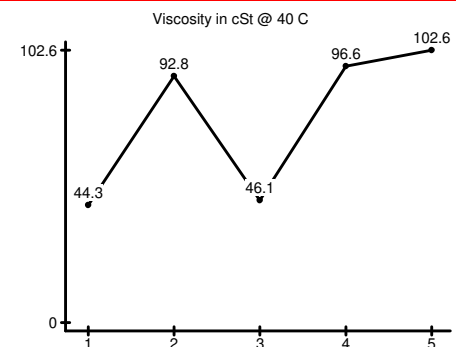
44.3

92.8

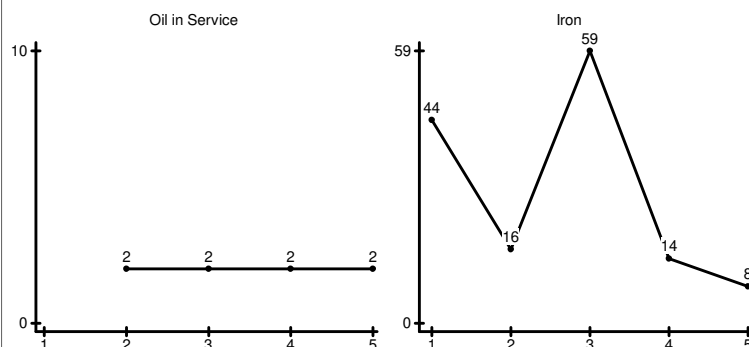
46.1

96.6

102.6



GRAPHICAL REPRESENTATION OF KEY DATA



Mr T Chikwenhere [Tavongo]
St Helena Airport Limited
Posperous Bay Plain
St Helena Island
ST HELENA

Vehicle : R3
Alt. ID : 4759 -
Model : -
Component : FIRE TRUCK WATER PUMP GEARBOX
Model : "ZIEGLER FIRE CENTRIFUGAL PUMP FPN10-4000-2 H/HH"

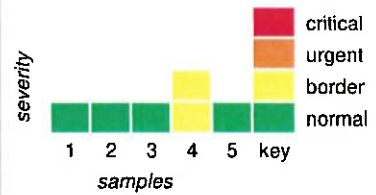
KWAZULU-NATAL:
P.O. BOX 15108
WESTMEAD 3608
TEL: (031) 700 5460
FAX: (031) 700 5471

GAUTENG:
P.O. BOX 284
ISANDO 1600
TEL: (011) 392 6322
FAX: (011) 392 6340

Code : 5SHHSH
Job No. : -
Site : HLE
Oil : CASTROL CRB MOONOGRADE 10W
Queries : PLEASE CONTACT DIAGNOSTIC DEPARTMENT.

PROBLEM SEVERITY

NORMAL



DIAGNOSIS

5.) Sample Number D668919 on 26.03.2026 smr 295 HRS
Wear rates are normal and the sample provided appears free from unacceptable contamination or degradation. Debris analysis normal. A trace of water present in the oil.

PREVIOUS HISTORY

DIAGNOSES

- 1.) Sample Number D668909 on 18.04.2026 smr 296 HRS
The period oil has been in use is unknown. Wear rates are normal and the sample provided appears free from unacceptable contamination or degradation. Debris analysis normal. A trace of water present in the oil.
- 2.) Sample Number D668906 on 29.04.2026 smr 296 HRS
The period oil has been in use is unknown. Wear rates are normal and the sample provided appears free from unacceptable contamination or degradation. Debris analysis normal. A trace of water present in the oil.
- 3.) Sample Number D668908 on 13.03.2026 smr 293 HRS
Wear rates are normal and the sample provided appears free from unacceptable contamination or degradation. Debris analysis normal.
- 4.) Sample Number D668918 on 11.03.2026 smr 293 HRS
Wear rates have increased. Debris analysis normal. Check correct oil level is being maintained. A trace of water present in the oil. Please return feedback.

FEEDBACK

Vehicle: R3 - FIRE TRUCK WATER PUMP GEARBOX - Alt. ID: 4759 -

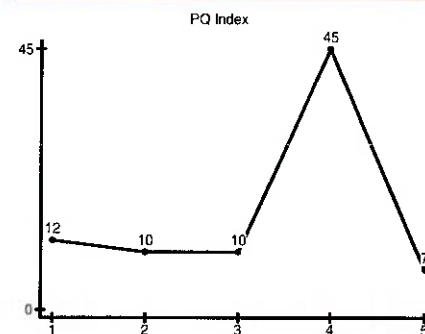
	SAMPLE NUMBER	DATE SAMPLED	LAB DATE	OIL CONSUMPTION	SMR	UNITS	OIL IN SERVICE	FILTER CHANGE	OIL DRAIN	RRI
1	D668909	18.04.26	07.05.26	-	296	HRS	-	Yes	Yes	500
2	D668906	29.04.26	07.05.26	-	296	HRS	-	Yes	Yes	500
3	D668908	13.03.26	07.05.26	-	293	HRS	-	Yes	No	500
4	D668918	11.03.26	07.05.26	-	293	HRS	-	Yes	No	500
5	D668919	26.03.26	07.05.26	-	295	HRS	-	Yes	Yes	500

WEAR METALS

Sample	Iron	Chromium	Nickel	Aluminium	Copper	Tin	Silver	Lead	Bismuth	PQ Index
1	9	0	0	3	10	1	0	1	0	12
2	11	0	0	3	20	0	0	1	0	10
3	3	0	0	0	0	0	0	0	0	10
4	28	0	0	4	5	0	0	0	0	45
5	5	0	0	2	10	0	0	1	0	7

30 spectrometric analyses are carried out on all samples but only relevant results are reported in parts per million.

PARTICLE QUANTIFIER INDEX

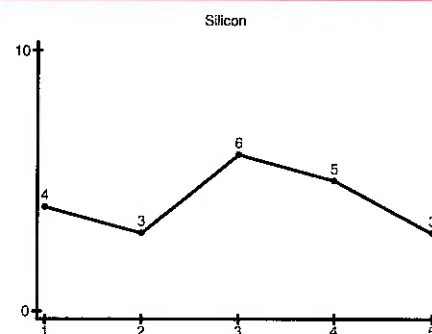


CONTAMINANTS

Sample	Silicon	Sodium	Lithium	Water (%)
1	4	4	2	0.6
2	3	3	2	0.4
3	6	3	0	ND
4	5	4	2	0.6
5	3	3	1	0.5

30 spectrometric analyses are carried out on all samples but only relevant results are reported in parts per million.

SILICON



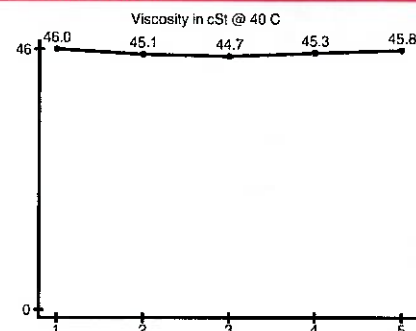
ADDITIVES & LUBRICANT CONDITION

Sample	Magnesium	Calcium	Molybdenum	Zinc	Phosphorous	Potassium	Boron	Sulphur
1	13	2255	78	795	816	2	9	2844
2	10	2157	77	735	750	0	0	2163
3	10	2348	84	815	821	4	4	2420
4	12	2369	83	837	815	2	0	2436
5	9	2309	79	801	796	0	0	2496

30 spectrometric analyses are carried out on all samples but only relevant results are reported in parts per million.

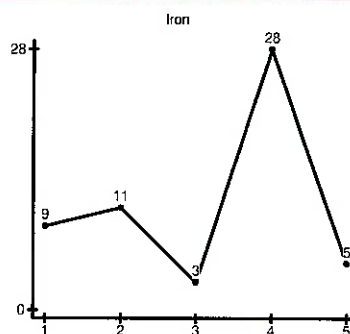
VISCOSITY

Viscosity in cSt @ 40 C

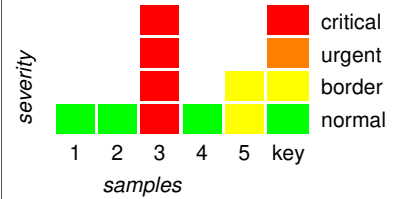


GRAPHICAL REPRESENTATION OF KEY DATA

Too few values to plot Oil in Service



BORDERLINE



KWAZULU-NATAL:

P.O. BOX 15108
WESTMEAD 3608
TEL: (031) 700 5460
FAX: (031) 700 5471

GAUTENG:

P.O. BOX 284
ISANDO 1600
TEL: (011) 392 6322
FAX: (011) 392 6340

Ms F Green [Suelaine]
St Helena Airport Limited
Prosperous Bay Plain
St Helena Island
ST HELENA

Vehicle : R3
Alt. ID : 4759 -
Model : -
Component : FIRE TRUCK WATER PUMP GEARBOX
Model : "ZIEGLER FIRE CENTRIFUGAL"

Code : 5SHHSH
Job No. : -
Site : HLE
Oil : TOTAL QUARTZ 10W40
Queries : PLEASE CONTACT DIAGNOSTIC DEPARTMENT.

DIAGNOSIS

5.) Sample Number H116432 on 08.07.2026 smr 298 HRS
Wear rates are normal. Debris analysis normal. 1.6% Water present in the oil - check for point of entry.
Water contamination made the oil unfit for further use. Oil already changed do not drain again. Please return feedback.

PREVIOUS HISTORY

DIAGNOSES

- 1.) Sample Number D668919 on 26.03.2026 smr 295 HRS
Wear rates are normal and the sample provided appears free from unacceptable contamination or degradation. Debris analysis normal. A trace of water present in the oil.
- 2.) Sample Number H116440 on 10.06.2026 smr 298 HRS
Wear rates are normal and the sample provided appears free from unacceptable contamination or degradation. Debris analysis normal. A trace of water present in the oil.
- 3.) Sample Number DH14977 on 27.05.2026 smr 296 HRS
Viscosity measurement carried out in duplicate. Viscosity is low for this grade of oil. Wear rates are normal. Debris analysis normal. 1.2% Water present in the oil - check for point of entry. The oil was not fit for further use due to contamination. Oil already changed do not drain again. Please return feedback.
- 4.) Sample Number H116431 on 24.06.2026 smr 298 HRS
Wear rates are normal and the sample provided appears free from unacceptable contamination or degradation. Debris analysis normal. A trace of water present in the oil.

FEEDBACK

Vehicle: R3 - FIRE TRUCK WATER PUMP GEARBOX - Alt. ID: 4759 -

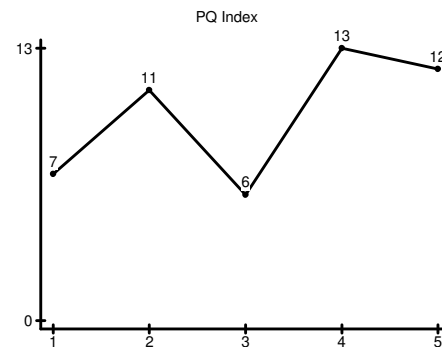
	SAMPLE NUMBER	DATE SAMPLED	LAB DATE	OIL CONSUMPTION	SMR	UNITS	OIL IN SERVICE	FILTER CHANGE	OIL DRAIN	RRI
1	D668919	26.03.26	07.05.26	-	295	HRS	-	Yes	Yes	500
2	H116440	10.06.26	04.08.26	-	298	HRS	2	Yes	Yes	500
3	DH14977	27.05.26	04.08.26	-	296	HRS	2	Yes	Yes	500
4	H116431	24.06.26	04.08.26	-	298	HRS	2	Yes	Yes	500
5	H116432	08.07.26	04.08.26	-	298	HRS	2	Yes	Yes	500

WEAR METALS

Sample	Iron	Chromium	Nickel	Aluminium	Copper	Tin	Silver	Lead	Bismuth	PQ Index
1	5	0	0	2	10	0	0	1	0	7
2	7	0	0	0	4	0	0	0	0	11
3	8	0	0	3	16	0	0	0	0	6
4	6	0	0	2	11	0	0	0	0	13
5	8	0	0	2	14	0	0	0	0	12

30 spectrometric analyses are carried out on all samples but only relevant results are reported in parts per million.

PARTICLE QUANTIFIER INDEX

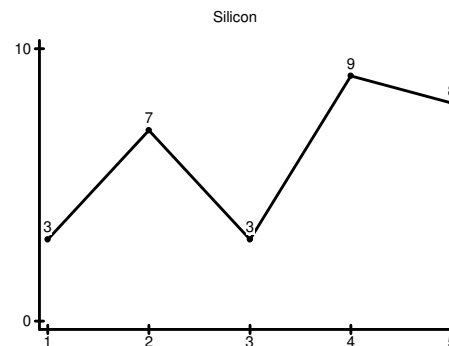


CONTAMINANTS

Sample	Silicon	Sodium	Lithium	Water (%)
1	3	3	1	0.5
2	7	0	0	0.7
3	3	3	1	1.2
4	9	0	0	0.9
5	8	0	0	1.6

30 spectrometric analyses are carried out on all samples but only relevant results are reported in parts per million.

SILICON

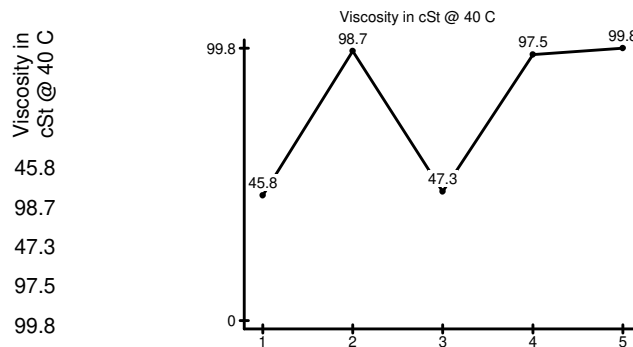


ADDITIVES & LUBRICANT CONDITION

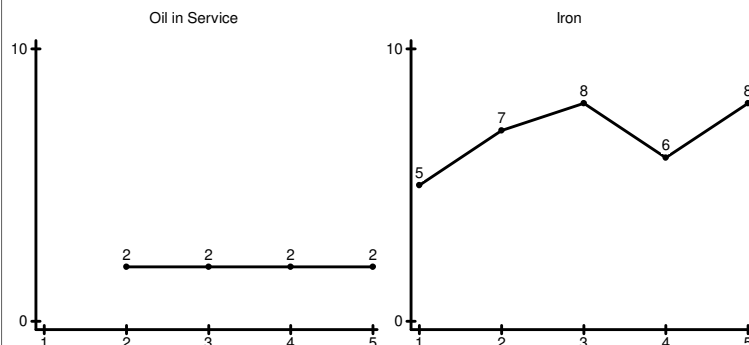
Sample	Magnesium	Calcium	Molybdenum	Zinc	Phosphorous	Potassium	Boron	Sulphur
1	9	2309	79	801	796	0	0	2496
2	10	2765	90	933	916	0	43	3162
3	12	2222	75	844	822	1	6	2759
4	11	2818	100	1032	970	0	44	2971
5	10	2793	95	984	924	0	43	2942

30 spectrometric analyses are carried out on all samples but only relevant results are reported in parts per million.

VISCOSITY



GRAPHICAL REPRESENTATION OF KEY DATA



APPENDIX E: OIL DATA SHEETS (SAE10 & SAE 10W40)

(overleaf)

(4 pages)



Product Data Sheet

CRB Monograde 10W CF

For long and healthy engine life

Description

Castrol CRB Monograde 10W CF is a diesel engine oil designed for use in heavy duty diesel engines, hydraulic systems and transmissions that specify the use of monograde diesel engine oil.

Advantages

During its working life, your engine faces challenges from combustion by-products that can form deposits, and thicken the oil. Castrol CRB Monograde 10W CF helps combat these issues in two ways:

1. It contains cleaning agents which help to displace particles that may otherwise build up on your engine surfaces reducing deposits.
2. It also contains anti-oxidants which help to disrupt the chemical reactions that can lead to oil thickening.

Castrol CRB Monograde 10W CF helps provide protection across multiple applications to encourage long and healthy engine life

Typical Characteristics

Name	Method	Units	CRB Monograde 10W CF
Density @ 15C	ASTM D4052	g/ml	0.866
Viscosity, Kinematic 100C	ASTM D445	mm ² /s	6.7
Viscosity, CCS -25C (10W)	ASTM D5293	mPa.s (cP)	4300
Viscosity, Kinematic 40C	ASTM D445	mm ² /s	41
Viscosity Index	ASTM D2270	None	117
Ash, Sulphated	ASTM D874	% w t	0.80
Total Base Number, TBN	ASTM D2896	mg KOH/g	5.4
Pour Point	ASTM D97	°C	-45
Flash Point, PMCC	ASTM D93	°C	212

Product Performance Claims

API CF

Storage

All packages should be stored under cover. Where outside storage is unavoidable drums should be laid horizontally to avoid the possible ingress of water and damage to drum markings. Products should not be stored above 60°C, exposed to hot sun or freezing conditions.

CRB Monograde 10W CF

04 Aug 2023

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Castrol Singapore Pte. Limited (202034037D), 7 Straits View, Marina One East Tower, #26-01, Singapore 018936

Phone No : 800-120-7082

www.castrol.com

Quartz 7000 S 10W-40

Engine oil

KEY DATA



LIGHT VEHICLE RANGE

GASOLINE & DIESEL ENGINE OIL

SAE 10W-40

SYNTHETIC TECHNOLOGY

INTERNATIONAL STANDARDS

- ACEA A3/B4
- API SN/CF

MANUFACTURER APPROVALS ¹

- VW 501.01/505.00
- Meets the requirements of FIAT 9.55535-G2
- Meets the requirements of MB 229.1
- Suitable for PSA B71 2300
- Suitable for RENAULT RN 0700/0710

¹ Please refer to car owner's manual

TECHNOLOGY

Clean-Shield technology

The effective engine cleaning technology.

Thanks to advanced detergent molecules designed to capture and isolate dirt such as sludge and soots, Clean Shield technology keeps engines clean in the long term.

Fighting against this major cause of breakdowns, Quartz with Clean Shield technology is the oil of choice across the globe to guarantee engine cleanliness during the entire drain interval and after oil change.



APPLICATIONS

Quartz 7000 S 10W-40 is a synthetic based engine oil that has been developed to cover the most stringent requirements of both gasoline and diesel engine.

Quartz 7000 S 10W-40 is particularly suited to turbocharged and multi-valve engines.

This engine oil is perfectly adapted to vehicles equipped with catalysts and using unleaded fuel or liquefied petroleum gas.

Quartz 7000 S 10W-40 is perfectly suited to normal driving conditions.

CUSTOMERS BENEFITS

- 💧 Manufacturers Standards: Quartz 7000 S 10W-40 satisfies rigorous manufacturers' standards (see above), while guaranteeing perfect and constant quality.
- 💧 Resistance to Oxidation: Thanks to the good quality of its base oils and additives, Quartz 7000 S 10W-40 provides a specific resistance to oxidation.
- 💧 Engine protection and cleanliness: This oil ensures good engine cleanliness, reducing particle accumulation in the motor via efficient dispersant power.
- 💧 Long-term wear Protection: Long-term wear protection of engine parts (distribution, ring, plunger and liner) increasing engine life.

CHARACTERISTICS²

TEST	UNIT	TEST METHOD	RESULT
Viscosity grade	-	SAE J300	10W-40
Kinematic viscosity at 40°C	mm²/s	ASTM D445	103
Kinematic viscosity at 100°C	mm²/s	ASTM D445	14.6
Density at 15°C	kg/m³	ASTM D1298	863
Viscosity index	-	ASTM D2270	147
Pour point	°C	ASTM D97	-30
OC Flash point	°C	ASTM D92	234

² The characteristics given above are obtained with a standard tolerance threshold during production and may not be considered specifications.

RECOMMENDATIONS FOR USE

Before using the product, the vehicle's maintenance guide should be checked. Oil changes should be carried out in accordance with the manufacturer's recommendations.

The product should not be stored at temperatures over 60°C. It should be kept away from sunlight, intense cold and extreme temperature fluctuations. If possible, the packaging should not be exposed to the elements. Otherwise, the drums should be laid horizontally in order to avoid any contamination from water and to prevent the product's label from rubbing off.

HEALTH, SAFETY AND THE ENVIRONMENT

Based on the toxicological information available, this product should not cause any adverse health effects, provided it is used for its intended purpose and in accordance with the recommendations laid out in the Safety Data Sheet (SDS).

This can be obtained on request from your local reseller and is available for consultation at <https://ms-sds.totalenergies.com>.

This product should not be used for any purposes other than the ones for which it is intended.



TotalEnergies Lubricants / Last update of this datasheet: June 22 / Quartz 7000 S 10W-40

Some variations can be expected under normal production conditions, but these should not affect the product's expected performance irrespective of the site. The information contained in this document is subject to change without notice. Our products can be viewed on our website at www.lubricants.totalenergies.com.

APPENDIX F: WATER ANALYSIS REPORT

(overleaf)

(2 pages)

Certificate of Analysis

Report NO: SAL-2016-09457	Sample Description: Water samples in 2*500ml plastic bottles with blue caps
Customer: Basil Read	
Address: 7 Romeo Street Hughes ext Boksburg Gauteng	No of Samples: 2
	Sample Condition: Chilled
Contact: Richard Miller	Date Received: 07-Sep-2016
Phone: 011 4186566 Fax:	Date Completed: 20-Sep-16
Email: rmiller@basilread.co.za	Order No: TBA

Sample Disposal	a) Liquid Sample One Month - After issuing of final Certificate of Analysis	b) Solid Sample Three Months - After issuing of final Certificate of Analysis
-----------------	--	--

Lab No	1609457-66229FW	1609457-66230FW
Sample Date	01-Sep-2016	01-Sep-2016
Sample ID	Borehole 5	Airport tap water

Analysis	Unit		
Potassium as K Dissolved	mg/l	6.6	1.8
Sodium as Na Dissolved	mg/l	155	41
Calcium as Ca Dissolved	mg/l	35	8.1
Magnesium as Mg Dissolved	mg/l	34	7.2
Sulphate as SO4 Dissolved	mg/l	49	9.8
Chloride as Cl	mg/l	314	61
Alkalinity as CaCO3	mg/l	62	47
Nitrate + Nitrite as N *	mg/l	3.9	0.2
Nitrate as Nitrogen *	mg/l	3.8	0.1
Nitrite as N *	mg/L	<0.1	<0.1
Fluoride as F *	mg/l	0.1	<0.1
Electrical Conductivity	mS/m (25°C)	120	31
pH (Lab) (20°C)		7.8	7.7
Saturation pH (pHs) (20°C) *		8.3	9.0
Total dissolved solids (Calc) *	mg/l	768	198
Hardness as CaCO3 *	mg/l	227	50
Sod Ad Ratio - (SAR) *		4.5	2.5
Ryznar Index *		8.8	10.3
Indication (Ryznar 1942)		7,5 - 9,0 Heavy corrosion	>9,0 Corrosion intolerable
% Difference (Standard Method) *		0.2	0.9
CATIONS meq/L *		11.5	2.8

This report relates only to the samples actually supplied to and tested at CSIR, Implementation Unit. The operation unit does not accept responsibility for any matters arising from the further use of these results. This certificate shall not be reproduced, except in full, without the written approval of the Laboratory Manager. No reference may be made to the CSIR or any of its operation units or officers in advertisements or for sale or publicity purposes without the CSIR's prior approval. All work is undertaken according to the CSIR general conditions of contract. Samples are discarded after 30 days from issue date of certificate.

Remarks: * Method is not SANAS accredited and is not included in the SANAS Schedule of accreditation for this laboratory.
Opinions and interpretations expressed herein are outside the scope of SANAS accreditation.



Efraim Fieland - Technical Signatory



Sebastian Brown - Technical Manager

Date Printed

20-Sep-2016

Page 1 of 2

Certificate of Analysis

Report NO: SAL-2016-09457	Sample Description: Water samples in 2*500ml plastic bottles with blue caps
Customer: Basil Read	
Address: 7 Romeo Street Hughes ext Boksburg Gauteng	No of Samples 2
	Sample Condition: Chilled
Contact: Richard Miller	Date Received: 07-Sep-2016
Phone: 011 4186566 Fax:	Date Completed: 20-Sep-16
Email: rmiller@basilread.co.za	Order No: TBA

	1609457-66229FW	1609457-66230FW
	01-Sep-2016	01-Sep-2016
	Borehole 5	Airport tap water
ANIONS meq/L *	11.4	2.9
Abs Difference *	-0.05	0.05
Iron as Fe Dissolved mg/l	<0.01	0.09
Bicarbonate as HCO ₃ Dissolved (Calc) in μ mol/L *	596	456
Bicarbonate as HCO ₃ Dissolved (Calc) mg/L *	36	28

This report relates only to the samples actually supplied to and tested at CSIR, Implementation Unit. The operation unit does not accept responsibility for any matters arising from the further use of these results. This certificate shall not be reproduced, except in full, without the written approval of the Laboratory Manager. No reference may be made to the CSIR or any of its operation units or officers in advertisements or for sale or publicity purposes without the CSIR's prior approval. All work is undertaken according to the CSIR general conditions of contract. Samples are discarded after 30 days from issue date of certificate.

Remarks: * Method is not SANAS accredited and is not included in the SANAS Schedule of accreditation for this laboratory.

Opinions and interpretations expressed herein are outside the scope of SANAS accreditation.



Efraim Fieland - Technical Signatory



Sebastian Brown - Technical Manager

Date Printed

20-Sep-2016

Page 2 of 2

EXHIBIT RB/1: INDEPENDENT SUMMARY REPORT

(overleaf)

(4 pages)

MECHANICAL INVESTIGATION INTO THE FAILURES OF WATER PUMP GEARBOXES FITTED TO FIRE TENDERS OPERATED AT ST HELENA AIRPORT

BACKGROUND

GBB were instructed by the St Helena Government to consider mechanical failures observed in the water pump gearboxes fitted to three Airport Rescue and Firefighting (ARFF) vehicles operated at St Helena Airport that resulted in the closure of the airport and suspension of routine commercial operations between 6 and 15 February 2026.

The failure related to the ‘eccentric’, a subcomponent of the water pump gearbox that drives a secondary ‘primer’ pump that ejects any air from within the pump system and fills (primes) it with water, removing any airlocks that could prevent or impede the discharge of water. Consequently, the primer pump and its constituent components are critical for correct operation of the ARFF water pumps.

Dr Ross Beesley CEng, a Forensic Engineer at GBB, attended St Helena Airport between Monday 27 July 2026 and Friday 7 August 2026 to conduct his investigation. During this time, he was assisted by St Helena Airport in all aspects of his investigation.

The investigation considered mechanical examination and testing, oil analysis, operational matters of the ARFF vehicles, maintenance and servicing, the water source used by the ARFF vehicles, and the material of the failed component.

CONCLUSIONS

This investigation has made the following conclusions.

The eccentrics each appeared to have failed as a result of disintegration of their structure, and the material properties had altered when compared to an unused exemplar eccentric.

There were numerous cracks throughout the eccentrics, in a multitude of locations and across all planes of the structures. The multiplanar directionality and multiple locations of these cracks did not appear to coincide with any one loading direction. This would suggest that the cracks were not solely caused by the applied mechanical loading, but likely at least partly due to a breakdown of the structure and changes to the material properties.

There was differential staining affecting different regions of the structure that was likely caused by the presence of the oil. The different extent of staining is likely related to the duration of exposure to the oil, where the darker areas were exposed for a longer period of time than the lighter coloured areas. There was also localised staining that had penetrated into some of the cracks, thereby increasing their visual contrast. The presence of staining within the cracks

would suggest that these cracks had been developing for an extended period of time, and long enough for the oil to have penetrated the cracks and have caused the observed staining.

There was also scoring damage to a metal collar that fits around the outer circumference of the eccentrics, which could suggest insufficient lubrication, for example, insufficient viscosity.

The exact point at which the damage first commenced could not be determined from the available evidence. However, the evidence would suggest that it had been developing over an extended period of time.

The eccentric is formed of an elastomer, that while resistant to oils and greases, is susceptible to hydrolysis, a chemical breakdown and decomposition of the structure in contact with water.

Analysis of the oil used in the gearboxes of each of the ARFF vehicles has indicated water contamination at different points in time since the incident. However, no oil samples from prior to the incident were retained or sent for testing. As such, the extent of any previous water ingress is not known. Nevertheless, a potential link has been identified between water exposure and a possible change in the structure and/or properties of the elastomer material, and degradation and/or disintegration of the structure.

At the point that the damage to the eccentrics was observed, they had not yet failed completely and catastrophically, and were still performing their function, despite their developing damage. This meant that there was no means through the routine testing and use of the ARFF vehicles that any developing damage could have been detected.

The eccentric components are housed within a sealed gearbox, and as such there was no way in which the routine inspection and servicing as stipulated by the manufacturer could have detected the developing damage.

In light of the continued functionality of the eccentrics (at the point that the damage was first observed) and the lack of inspection of the eccentrics (as per the operating manual), there would have been no prior indication of any developing failure.

At the point that the damage was first observed, there would also have been no way to predict the remaining working life of the eccentrics, or the duration that the pumps could continue to be operated without sustaining a complete and catastrophic failure of the eccentrics.

Had the eccentrics failed completely, the primer pump would have immediately lost all functionality, meaning that it might not have been capable of removing any airlocks that were within the system. In such a scenario, an airlock could potentially completely prevent, or severely restrict the flow of water through the pump.

Consequently, a complete and catastrophic failure of the eccentrics has the potential to render the ARFF vehicle(s) incapable of discharging any water.

OTHER RELEVANT FACTORS

The original equipment manufacturer (OEM) operating manual for the pump provided to St Helena Airport with the ARFF vehicles stipulated the use of a particular oil within the gearbox (SAE 10 oil). This manual had an issue date of 2014.

In 2021, the pump manufacturer issued an updated manual that stipulated a different oil (SAE 10W40), the viscosity of which is over twice that of the original oil, i.e. a significantly thicker oil. However, the updated 2021 manual was not supplied to St Helena Airport by the service partner following its reissue.

In general, an oil of higher viscosity will be able to support greater loads than an oil with lower viscosity, and as such, can in some circumstances provide greater lubrication properties, and make components less prone to wear than a thinner oil. However, a higher viscosity oil will flow less readily than a lower viscosity oil.

The updated manual was not provided to St Helena Airport until 2026, when the service partner attended to conduct repairs on the gearboxes and replace the damaged eccentrics. This meant that St Helena Airport was using a different oil to that stipulated by the pump manufacturer for a period of approximately five years before they took receipt of the updated manual. On receipt of the updated manual, St Helena Airport subsequently adopted the use of 10W40 oil.

This then raises questions as to why the specified oil was changed by the pump manufacturer, and why the updated manual was not provided to St Helena Airport by the service partner.

Aside from the different oil used in the gearboxes, review of the maintenance and servicing, and routine testing of the pumps *prima facie* suggest that all actions were conducted in accordance with the operating manual.

There is no evidence to suggest that prior to the failure of the eccentrics, St Helena Airport have operated, maintained, serviced, or otherwise managed the ARFF vehicles in any way other than that stipulated by the manufacturer and as set out in the operating manual that had been provided to them.

OTHER OCCURRENCES OF FAILURES

This investigation has identified a number of other, independent cases where the same eccentrics have failed in seemingly identical manners, whereby the structure has disintegrated and crumbled, suggesting that this failure was not an isolated occurrence.

FUTURE RECOMMENDATIONS

While the routine maintenance schedule, and operating and testing procedures for the ARFF vehicle water pumps as conducted by St Helena Airport all appear to be within the specification as stipulated by the manufacturer, a number of actions relating to enhanced monitoring of the eccentrics, as well as a more proactive management strategy with the service provider, have been recommended to help mitigate the risks of similar incidents occurring again in the future.