Report on failure of No 5 lifeboat winch

on ***P&OSL Calais***

on 25 June 1999,

and related investigation

into self-lifting sprag clutch behaviour

Marine Accident Investigation Branch
First Floor, Carlton House
Carlton Place
Southampton
SO15 2DZ

Report No 13/2001

Extract from

The Merchant Shipping

(Accident Reporting and Investigation)

Regulations 1999

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

CONTENTS

GLOSSARY OF ABBREVIATIONS

BST	-	British summer time
m	-	metre
MCA	-	Maritime and Coastguard Agency. Formerly Marine Safety Agency (MSA), formerly Department of Transport
MGN	-	Marine Guidance Notice (of MCA)
mm	-	millimetre
rad/s^2	-	radians per second per second. Units of angular acceleration.
Ro-Ro	-	Roll on-Roll off
SOLAS	-	Safety of Life at Sea (Convention)

SYNOPSIS

During a routine crew training exercise on board the ro-ro passenger ferry, *P&OSL Calais*, the empty No 5 lifeboat was being raised. Once the lifeboat was in position, the winch operator stopped the motor. The winch then went into reverse involuntarily, allowing the boat to lower until the bowsing gear took its weight. There was no loss of life or injuries.

This incident occurred in Dover on 25 June 1999. The Marine Accident Investigation Branch (MAIB) received a report from the vessel's owners on 1 July. Following receipt of further information requested by the MAIB, an investigation was opened on 2 September.

The manufacturers of the winch identified the loss of control as being caused by the failure of the one-way clutch on the winch's drive motor. Although unable to offer supporting data, they also offered the opinion that this failure was because the clutch had been filled with oil of too great a viscosity.

MAIB's records showed that similar failures had occurred on other vessels having winches fitted with clutches of similar design, fortunately without serious consequences. In light of these failures, the MAIB decided that its investigation should cover the likely effects of incorrect lubricant on the performance of this type of clutch.

On behalf of the MAIB, Frazer-Nash Consultancy, Dorking, undertook two phases of experimental work. Its work assessed the in-situ behaviour of a winch/clutch installation, followed by a laboratory-based investigation of the effects of clutch acceleration, oil level and oil viscosity. During the laboratory work no clutch failures occurred when the specified oil was used, but there were several failures when a higher viscosity gear oil was used. Failures also appeared to be dependent on the depth of oil, but again only when the higher viscosity oil was used. These results support the initial opinion of the winch manufacturers.

Merchant Shipping Notice M.1186 contains advice on the use of light oil or grease, without also clarifying which type of clutch is considered. The Maritime and Coastguard Agency (MCA) is recommended to amend this M Notice by setting out the importance of using only the specified grade of lubricant in winches using one-way clutches of the self-lifting sprag type. Guidance should also be given to assist in the identification of self-lifting sprag clutches.

P&O Stena Line modified on-board lubrication instructions so that they are unambiguous and specific to the lifeboat winches on board *P&OSL Calais*.

SECTION 1 - FACTUAL INFORMATION

1.1 VESSEL AND INCIDENT PARTICULARS

Vessel name	:	*P&OSL Calais*
Port of registry	:	Dover
Type	:	Ro-Ro passenger, Class II
Official number	:	709074
Gross tonnage	:	26,433
Length	:	169.6m
Built	:	Schichau-Unterweser AG Bremen Germany
Date built	:	1987
Lifeboat numbers	:	6 x 135 persons partially enclosed lifeboats 2 x rescue boats
Owner	:	P&O Stena Line Ltd Channel House Channel View Road Dover Kent CT17 9TJ
Position of incident	:	Eastern Dock, Port of Dover
Date and time	:	22 June 1999, 0045
Injuries	:	None

P&OSL Calais

The failed self-lifting sprag clutch from *P&OSL Calais*

1.2 NARRATIVE

At about 0230 BST on 22 June 1999, No 5 lifeboat on *P&OSL Calais* was being used for a crew exercise. The vessel was in the Eastern Docks of Dover Harbour.

The lifeboat, with no one in it, was at embarkation level with the bowsing gear attached to the lower blocks.

The winch motor was then started, to raise the boat towards its stowed position. When the motor stopped the winch ran free. This allowed the boat to hit the side of the ship and fall until the bowsing gear took its weight. There were no injuries.

Service staff from Umoe-Schat-Harding, the manufacturers, examined the winch. They suggested that winch failure had been due to slipping of the one-way clutch due, in turn, to the use of incorrect lubricant.

1.3 INTRODUCTION

Other cases of winches running away have been reported to the MAIB. None has caused loss of life, although one resulted in a lifeboat being lost at sea. Not all reports have included sufficient information to positively identify the causes. However, most have been due to one-way clutch failure; although the type of clutch affected has rarely been identified.

This investigation was opened as a result of the one-way clutch failure in No 5 lifeboat winch on board *P&OSL Calais*. However, early work quickly identified common features with similar failures on *Pride of Burgundy* and *Arcadia.* Each failure involved the same type of one-way clutch, the self-lifting sprag type, fitted to the same type of winch. The investigation, therefore, concentrated largely on the characteristics of the particular type of self-lifting clutches fitted to these winches.

1.4 LIFEBOATS AND DAVITS

P&OSL Calais is equipped with six lifeboats and two rescue boats. Each lifeboat is of 137 person capacity and launched by hydraulically actuated swinging-arm davits. Total mass of each boat loaded with its full complement of persons is 17.1 tonnes.

The installation was approved by the MCA as complying with the Merchant Shipping (Life Saving Appliances) Regulations 1986 and the 1983 amendments to Chapter III of the Safety of Life at Sea Convention 1974 (SOLAS 1974), which came into force on 1 July 1986. As the vessel's keel was laid before July 1986, compliance was voluntary on the part of the owners.

1.5 ARRANGEMENTS OF DAVITS AND WINCHES

Each lifeboat is supported in hydraulically-operated swinging-arm type davits manufactured by Umoe-Schat-Harding Ltd.

They are lowered on 22mm diameter fall wires. Each fall is separate, one serving each lower block forward and aft, running over a number of sheaves to the 521mm diameter drum of a winch, Umoe-Schat-Harding type 2-38-10.

Some winch control is from a local console unit on which are also mounted controls for the hydraulic system for the davit's arms. Lowering of the boat is controlled by a brake lever on the winch's brake housing. Release of the lever allows gravity to re-apply the brake automatically.

Within the same housing as the gravity-operated brake is a centrifugal brake that limits the speed of lowering. Both brakes operate on a common shaft, coupled to the annulus of the primary reduction gear train by a roller chain and sprockets.

For ease of embarkation, the lifeboats can be held to the side of the vessel by a bowsing system employing an independent winch at each set of davits. Wires run from these winches, over several sheaves to the lower block at each end of each lifeboat. No tricing pendants are fitted.

1.6 MAINTENANCE AND REPAIR

During January 1999 the vessel underwent an annual survey and repair period in Southampton during which, among much other work, the one-way clutches on Nos 1,3 and 5 lifeboat winches were renewed. Service staff from the winches' manufacturers carried out the work.

1.7 MAINTENANCE DATA

Separate instruction manuals for the lifeboat and rescue boat davits and winches are carried on board *P&OSL Calais*. These cover both operation and maintenance of the equipment.

Associated with the instruction manuals are engineering drawings giving details of the equipment installed. However, the manuals describe several models of winches, and users are required to extract the information relevant to their installation.

Lubrication data is contained in a general-purpose table covering a range of applications and lubricant suppliers. Effective use of this table requires knowledge of the type of gearing used in the winch being serviced.

The owners also followed advice given by the lubricant suppliers.

1.8 WINCH LUBRICATION

Lubrication of the primary gear train, one-way clutch and roller chain is from an oil bath fitted with level and drain plugs. The secondary gear train, within the rope drum, is fitted with its own filling and drain plugs, and is independent of the primary train's oil bath.

To allow oil from the oil bath to enter the enclosed annulus of the primary gear train, plugs in the annulus are removed during assembly of the winch at the manufacturer's works. Oil from the oil bath is able to enter the primary gear train through these openings.

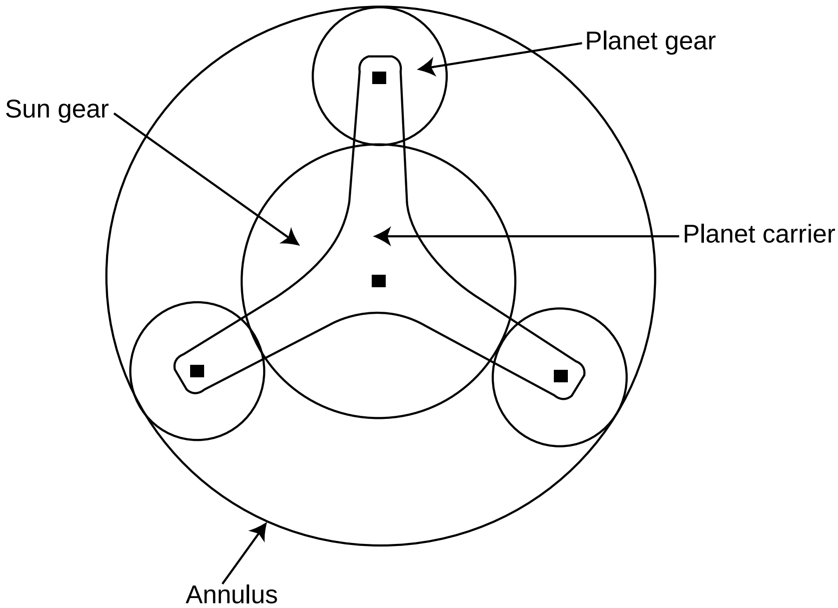
The primary and secondary gear trains are bought-in items purchased from a specialist manufacturer.

1.9 PLANETARY GEAR TRAINS

All reduction gearing in each lifeboat davit winch on *P&OSL Calais* is of the planetary type. Two sets are used in each winch **(Figure 1)**.

A planetary gear train is one in which the axis of one or more of the gears within the train may be allowed to rotate about the axis of other gears within the same train. A typical gear train consists of three elements: a sun gear, a planet gear or gears, and an annulus gear. The annulus and sun gears have a common axis of rotation. The planet gear(s), which mesh with the sun and annulus, rotate about their own axis and may also rotate about the common sun/annulus axis by allowing the planet carrier to rotate. Whether or not the planet carrier rotates is dependent on the application of the train.

Figure 1



1.10 WINCH GEARING AND BRAKING

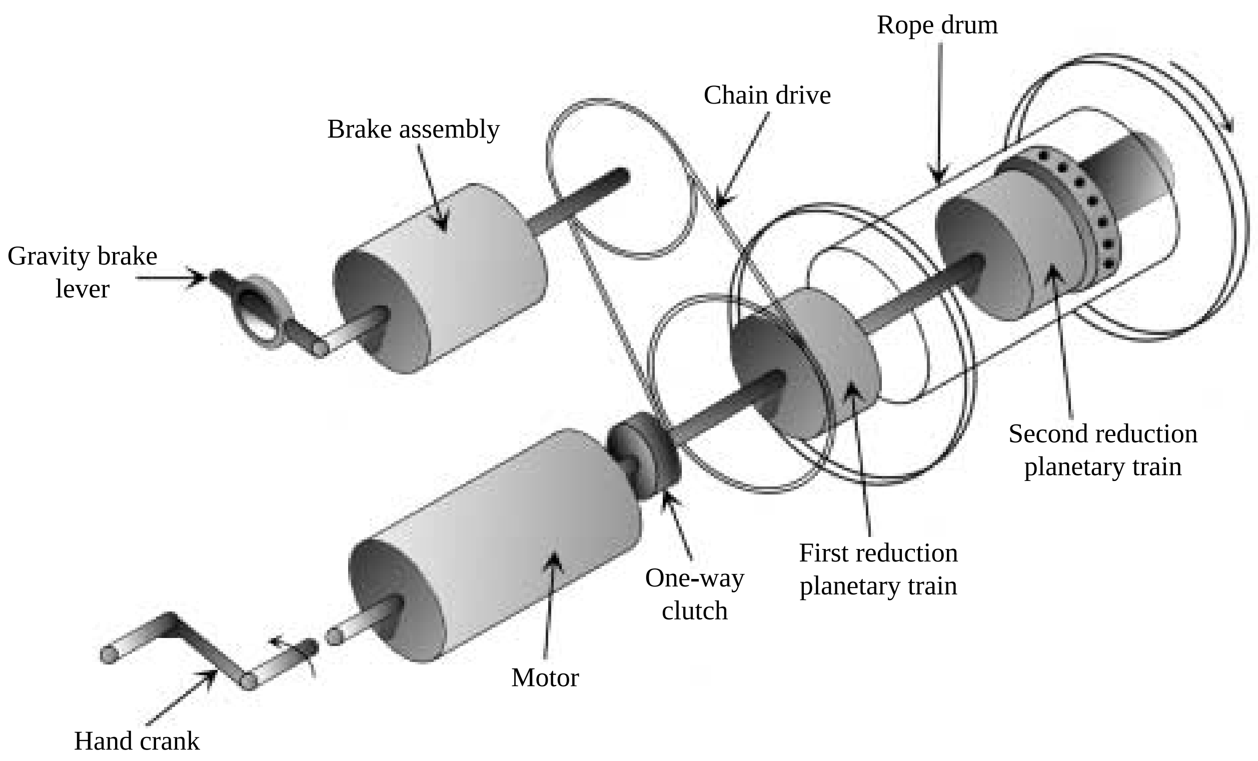
Power transmission between the hoisting motor and wire drum is through the two planetary gear trains arranged in series **(Figure 2)**.

During hoisting, the motor drives the sun gear of the first planetary train. The annulus element is prevented from turning by the roller chain and sprocket connection to the friction brake assembly. Reduced speed output is taken from the planet gear carrier to become the input to the sun gear of the second planetary train.

The second stage planetary train is mounted within the wire drum by a bolted connection between the annulus and drum. The planet carrier of this train is fixed to, and prevented from rotating by, the drum end bearing support. Thus, when the sun gear is driven the annulus rotates and drives the drum directly.

When motor power is shut off, the motor's armature is prevented from rotating in reverse by a one-way clutch. While the gravity brake remains applied, the winch drum remains stationary. Lifting the gravity brake's lever releases the brake allowing the brake shaft, roller chain and hence winch drum to run, in the lowering direction, under the influence of gravity. Speed of lowering is then controlled automatically by the centrifugal brake acting through the roller chain onto the primary gear train's annulus.

Figure 2



1.11 FUNCTION OF ONE-WAY CLUTCHES

The one-way clutch is fitted to allow rotation of the motor’s armature during hoisting operations and to lock immediately the motor stops, when power is shut off. Should it fail to lock, the sun gear and the planet carrier of the primary planetary gear train are free to rotate under the influence of the lifeboat’s weight. The annulus is still held stationary by its roller chain connection to the gravity brake, but this will not influence the motion of the planet carrier and output shaft. In this condition, all control of the wire drum is lost, and it is free to run in the lowering direction under the influence of the boat’s weight.

1.12 OTHER WINCH ARRANGEMENTS

Over many years the design of lifeboat winches has developed in line with requirements of SOLAS and shipowners.

These developments have resulted in a number of different arrangements of gearing, brakes and clutches fitted to the winches serving the davits on many vessels. However, with many of these there is a common requirement that one element of the gear or brake train is locked when the winch is not hoisting; the motor shaft, hand crank or brake shaft. Although some winch manufacturers employ alternative solutions, this is a common application for the one-way clutch within winches.

1.13 TYPES OF ONE-WAY CLUTCHES

Many winches in use at sea are fitted with mechanisms that perform the function of a one-way clutch. Although serving a common function, details of their design and construction vary significantly between manufacturers and applications.

Three common types are: roller, sprag and self-lifting sprag. However, whichever the type the end user (the seafarer) usually uses one of several generic descriptions:

- roller clutches;
- roller ratchet clutches;
- ratchets;
- sprag clutches;
- free-wheels;
- back stops;
- cam clutches;
- one-way clutches.

This report will use the term *one-way clutch* to describe any type of mechanism serving this function. When a particular design is being considered, the description which best suits the design will be used.

Recognising that other types of mechanisms may be commercially available to serve the function of a one-way clutch, the types that will be discussed are:

- roller clutches;
- sprag clutches;
- self-lifting sprag clutches.

These types are described in order to ease identification.

1.14 DESIGN FEATURES OF ONE-WAY CLUTCHES

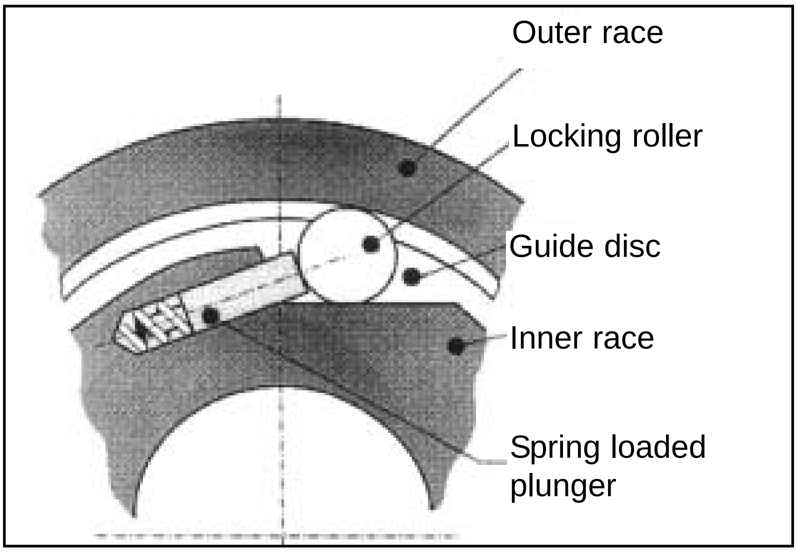
- **Roller clutches (Figure 3)**

A cylindrical roller is placed in each of several cavities around the periphery of the inner element and surrounded by an outer track. There are normally several cavities in each clutch. Acting on each roller is a spring, or springs, which maintain the roller in contact with both outer track and inner element. The geometry of the rollers' cavities ensures that the springs tend to push each roller into the converging channel between the inner element and the outer track.

When rotating in the unlocked direction, friction between the outer element and rollers tends to move the rollers away from the narrow ends of the cavities against spring forces. This friction force, being proportional only to the spring forces, has a very small magnitude and is insufficient in most applications, to give any significant torque transmission.

Rotation in the opposite direction causes these small friction forces to have the effect of pushing the rollers towards the narrow end of the cavities. The resultant 'wedge' action increases the radial forces between rollers and other two elements, producing a corresponding large increase in the friction between them. The torque transmitted is increased correspondingly and, within design limits, the inner and outer elements are effectively locked.

Figure 3



Roller Clutch

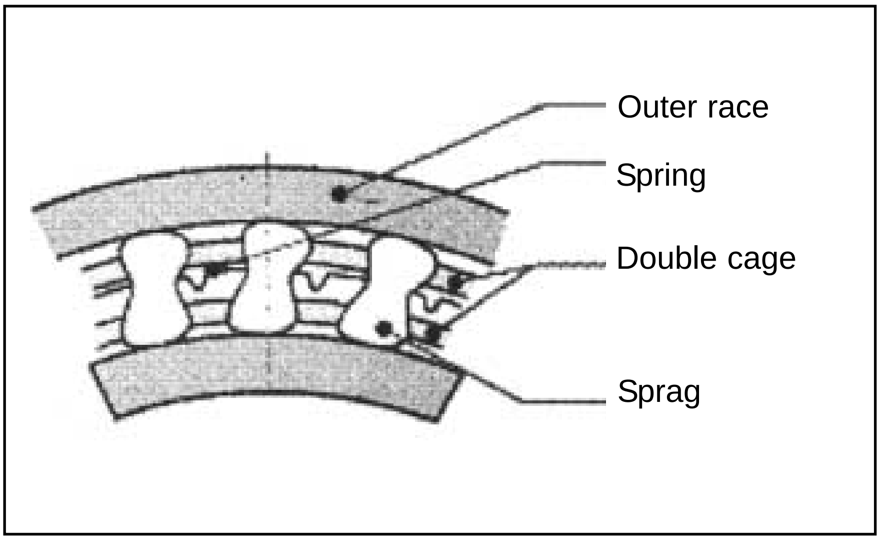
- **Sprag clutches (Figure 4)**

Both inner and outer elements are of cylindrical form. In the annular space between the two is a series of sprags having a cross-section of critical geometry. A spring, or springs, maintains each sprag in light contact with inner and outer elements.

When turning in the unlocked direction, friction forces on the extremities of the sprags tends to slightly rotate the sprags against spring forces, leading to a reduction in the radial forces between sprags and the other two elements. The resultant friction forces, and corresponding torque transmission, is small.

Opposite rotation causes the sprags to rotate slightly in the direction of the spring's forces. Radial forces between sprags and the other elements are increased, with a corresponding increase in friction force. The effect grows, within design limits of the unit, and the two elements are locked together.

Figure 4



Sprag Clutch

- **Self-lifting sprag clutches (Figures 5, 5a & 5b)**

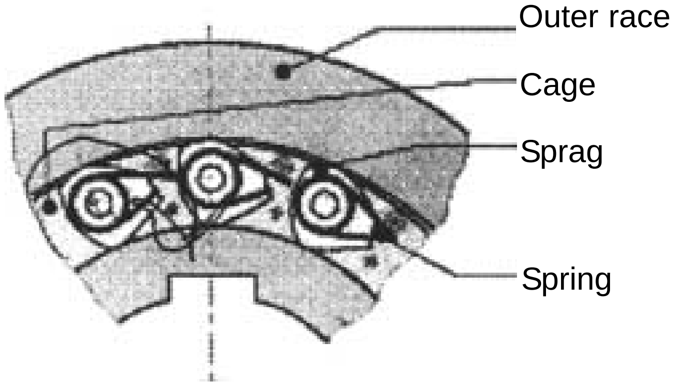
Again both inner and outer elements are of cylindrical form with a series of spring-loaded sprags in the annular space between them. Cross-section of each sprag is of complex geometry. Spring forces are small, and tend to rotate the sprags into the engaged position.

Sprags are mounted on, and free to rotate about, pins which are fitted to a cage. The cage and sprags rotate with one race of the unit. When the unit is used in lifeboat winches, the cage is commonly fitted to, and rotates with, the inner race.

When rotated in the free-wheel direction, the unit initially operates in the fashion of a sprag clutch and slips. However, when the free running speed reaches a pre-determined figure, centripetal and centrifugal forces on each sprag rotates it against its spring and contact between sprags and other elements is lost. This type of unit is thus able to run in the free-wheel direction with minimal friction force and torque.

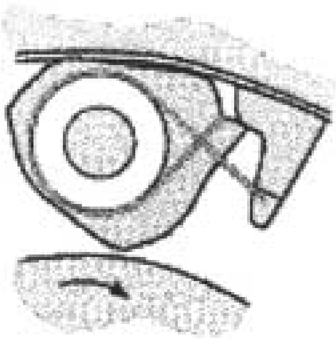
Rotation in the opposite direction causes the sprags to behave in a similar fashion to a sprag clutch, and the unit locks.

Figure 5



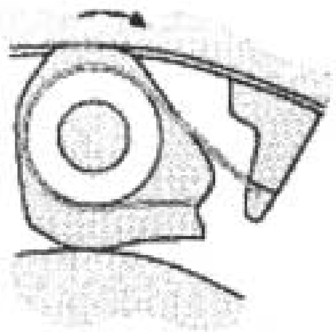
Self-lifting sprag clutch

Figure 5a



Running free

Figure 5b



Locked

1.15 CLUTCH LUBRICATION

Any of these types of clutches require that the rollers or sprags can break the lubricant film as the unit comes to a stop. Failure to do so will prevent the generation of sufficient friction to produce the necessary locking action.

Conversely, when running free some lubrication is necessary on the roller and sprag types of clutch. The self-lifting sprag type is less reliant on lubrication in this mode as there is no contact between the sprags and stationary element. However, even this type requires some lubrication for those transient conditions when the clutch is slowing and sprags start to make contact with the stationary element.

1.16 OTHER ONE-WAY CLUTCH FAILURES

During a routine lifeboat exercise on *Arcadia* on 9 December 1998, a lifeboat was being recovered following an in-water test. After the boat was reconnected to the falls and lifted from the water, the winch was stopped. The winch immediately and unintentionally ran free until the lifeboat, still attached to the falls, again entered the water. Although one person was hurt during the subsequent recovery operation, there were no injuries as a direct result of the winch running free.

Arcadia's lifeboat winches were fitted with one-way clutches of the self-lifting sprag type. It was concluded that they had been filled with oil having viscosity higher than specification, and that this was the cause of this unit failing to lock.

A similar incident occurred on *Pride of Burgundy* on 20 April 1995, except that the bowsing tackles were attached at the time of failure. The lifeboat ran back until its weight was taken on the bowsing tackles, allowing the five crew to climb to safety. There were no injuries.

Pride of Burgundy's lifeboat winches were fitted with one-way clutches of the self-lifting sprag type. Their manufacturer concluded that they had been filled with oil having a viscosity higher than specification and that this was the cause of this unit failing to lock.

The winches on *P&OSL Calais* are also fitted with one-way clutches of the self-lifting sprag type. Again the winch manufacturers suggested that failure had been caused by the use of an incorrect lubricant. As the three most recent failures reported to the MAIB involved this type, this investigation concentrates on the behaviour of the self-lifting sprag clutch.

Several other winch failures have been reported to the MAIB, the symptoms of which have suggested one-way clutch failure. However, from the information supplied it has proven impossible to identify the type of clutch involved.

1.17 MERCHANT SHIPPING NOTICE

During 1981 a seafarer was injured while assisting in the recovery of a lifeboat/passenger launch on a cruise ship. When the boat reached boat deck level the launching crew began fitting tricing pendants as the winch operator stopped the winch. The brake apparently failed to hold the boat, and although one of the tricing pendants had been connected to the lower block, it could not hold the boat in position. The pendant parted, causing the boat to swing violently and drop on the falls into the sea. The seafarer was thrown into the sea and injured.

When the winch was opened up for examination, the brake and the one-way clutch were both found to be in good condition. Further investigations resulted in tests being carried out. On their completion, it was concluded that the most probable cause of this and other similar winch failures was the weakening of the springs used to retain the rollers in position within the one-way clutches. This weakening was judged to have been caused by the frequent use of these particular winches on passenger cruise ships.

Consequently, in August 1985, the Department of Transport issued a Merchant Shipping Notice M.1186, making strong recommendations to shipowners, masters and safety officers aimed at ensuring winches are checked regularly.

In particular, it recommends that:

The ratchet mechanisms (one-way clutches) *should never be packed with grease; a light non-solidifying grease or light oil should be smeared on the mechanism to assist easy movement and to prevent the onset of corrosion.*

This Merchant Shipping Notice was still in force at the time of the accident on board *P&OSL Calais* on 25 June 1999.

SECTION 2 - ANALYSIS

2.1 SYMPTOMS OF ONE-WAY CLUTCH FAILURE

During the known incidents of one-way clutch failure, slip has always occurred immediately after the power to the winch motor has been shut off after raising the lifeboat. There is no recorded incident of a one-way clutch failing spontaneously, ie once locked no unit has subsequently slipped.

The common factor in all the known failures has been the failure of the clutch to lock after running in the free direction. The period of free running has been from a few seconds, while adjusting a lifeboat's position, to a minute or more when recovering a lifeboat from the water. There appears to be no connection between the time spent in the free running mode, and the likelihood of failure.

Once a lifeboat has been raised to the stowed position, a winch's one-way clutch will demonstrate that it has locked by preventing the lifeboat from lowering involuntarily. The one-way clutch should not need to be operated in the free condition again until the hoist motor is next operated. Normally this would not occur until the lifeboat is next recovered, usually following a crew exercise.

If lifeboats are required for an evacuation during an emergency, there may be no power available for the winch motors. Indeed, regulation requires that the lifeboats can be lowered safely without power being available. Lowering the lifeboats requires only that the gravity brake be released. There should be no need for the one-way clutch to be in any state other than locked at any time during evacuation.

However, if lifeboat embarkation arrangements require the lifeboat to be lowered from the stowed position to an embarkation deck, there may be a need to slightly raise the lifeboat if the winch operator allows it to 'overshoot' the embarkation level. With no power available, this may be done with the winch's hand crank handle, the operation of which will move the one-way clutch in the free direction. The one-way clutch will need to re-lock when manual turning effort is removed. Although there have been numerous reports of minor injures to crew when turning a winch's crank handle, there has been no incident reported to the MAIB of a one-way clutch slipping immediately after the release of crank handle effort.

2.2 POTENTIAL DANGERS

Apart from the possible need to correct for 'overshoot' when lowering a lifeboat to the embarkation deck, there is no stage of a launching operation where a winch's one-way clutch needs to run free. In view of the recorded one-way clutch failures occurring only immediately after they had been running free, the likelihood of failure occurring during launching and evacuation appears small. As an evacuation is the only operation during which lifeboats are likely to be carrying their full complement of persons, the probability of one-way clutch failure on a winch serving a fully loaded boat is, from the data held, similarly small.

However, as the reported incidents show, the greatest danger has normally been to the lifeboat's launching crew during an exercise. The critical stages where one-way clutch failure might occur is during recovery of a lifeboat as its winch is stopped, either at disembarkation level or approaching its fully stowed position. Provided neither the tricing pendants nor bowsing tackles are connected, the lifeboat will, in the extreme, lower to the water. The rate of lowering will not be under the control of either of the winch's brakes, centrifugal or gravity. This may result in permanent damage to the one-way clutch, and possibly also to the motor. Recovery of the lifeboat from the water, using its own davits, may then be difficult or even impossible. Other consequences, particularly if the mother ship is making way through the water, may be catastrophic for the lifeboat's crew.

If tricing pendants or bowsing tackles are connected at the time of one-way clutch failure, the consequences may also be serious for any crew in the lifeboat. This is particularly true if only one pennant or tackle is connected, as the lifeboat is likely to tip about the secured end and deposit its crew into the sea.

Clutch failures are thus most likely to prove a hazard to boats' launching crews.

2.3 CAUSES OF ONE-WAY CLUTCH FAILURE

All three types of one-way clutch mentioned in this report rely, to a degree, on springs to ensure initial contact between the elements. Once contact has been made, friction forces predominate and lock the unit.

Clearly, wear on springs can reduce their effect and lead to slip. The same is true if incorrect springs are fitted, or if they have been strained in some fashion, possibly during fitting by an unskilled person.

Although several years ago one shipowner expressed some concern about the quality of some of the springs supplied in these units from an unknown manufacturer, the one-way clutches which have failed during accidents investigated by the MAIB have suffered from neither of these problems. Indeed, the units have given every indication of having been in good condition before their failure and, in at least one case, a comparatively new unit was fitted by the winch manufacturer's staff. This was the case with the one-way clutch that failed on No 5 lifeboat winch on *P&OSL Calais*.

Wear or incorrect installation may, therefore, not be necessary for failure to occur.

Following a number of one-way clutch failures, some units have been reported to have been filled with lubricating oil that did not comply with the winch manufacturer's specification. The incorrect lubricant viscosity has been submitted as the cause of the units' failures. As the locking of these units depends on the lubricant film being forced from contact surfaces of components, and higher viscosity oils have a greater resistance to flow than those of lower viscosity, initial consideration suggests this to be a reasonable explanation for the failures.

However, as no samples of the lubricants had been taken or tested during the manufacturer's investigations of the failures, no data could be supplied to support their conclusions that incorrect lubricant was the cause of failure.

Three points indicate that lubricant grade might not be the only factor of significant influence:

- Satisfactory operation in low winter temperatures before failing in higher summer temperature, without a change in grade of lubricating oil.
- The manufacturers of the clutches specify a range of lubricant types from light oil to grease.
- Satisfactory operation for several months after being refilled with fresh but incorrect lubricant.

2.4 CLUTCH DYNAMICS

Of the three types of one-way clutches mentioned in this report, one type depends on dynamically-generated forces for its proper functioning: the self-lifting sprag type fitted to *P&OSL Calais, Pride of Burgundy* and *Arcadia.* While running in the freewheel direction, the sprags are positively lifted clear of the inner and outer tracks by centripetal force. To ensure that these forces generate a disengaging moment about the sprags' axis, the centre of gravity of each sprag is offset from the axis of its pin.

Although important to the correct functioning of the unit, this arrangement may have the potential to generate undesirable effects due to tangential accelerations, particularly when decelerating. As a result, a self-lifting sprag clutch in good condition, fitted with correctly specified springs and filled with oil of correct specification has a design limiting deceleration of 1250rad/s^2.

2.5 APPLICATION TO WINCHES

When fitted to lifeboat winches, self-lifting sprag clutches are subjected to significant angular deceleration when the power is shut off the hoist motor.

However, as far as the MAIB has been able to establish, no measurements of the dynamic behaviour of the winch/lifeboat system have been taken. The true deceleration of the motor and self-lifting clutches is therefore not known. Indeed, it appears that no consideration was given to any potential dynamic limitations of the clutches when first installed in these winches.

The manufacturer specifies a limiting clutch angular deceleration of 1250rad/sec^2. The winch manufacturer has no data to suggest that this limitation was considered when this clutch was specified for this application. Indeed, they can offer no data setting out the in-service dynamics of the winch motor or gear train.

2.6 TESTS

Initial work of this investigation identified areas of uncertain and even conflicting data, sufficient to generate doubt as to the reliability of the conclusion that clutch failures were due to excessive lubricant viscosity.

The clutch manufacturers indicated that the self-lifting sprag clutches could operate with lubricants having a large range of viscosity. Yet the winch manufacturers had identified excessive lubricant viscosity as the cause of failure in all three cases mentioned in this report.

The design of the winch's oil bath allows for a static oil level well above the optimum specified by the clutch manufacturers. Further, it was considered that exchange of lubricant between the oil bath and the primary gear train might cause a rise of level during operation. The variation was unknown. However, the clutch manufacturers specified optimum lubricant level significantly lower than could result from the position of oil bath level plug. They also suggested that clutch performance might be affected by a rise of lubricant level above the design optimum.

Given this uncertainty, and the absence of in-service data on winch dynamics, the MAIB commissioned Frazer Nash Consultancy to perform a series of tests. This company provides expertise to the transport, defence and aerospace industries. The test objectives were to eliminate these uncertainties and to offer support, or otherwise, for the manufacturer's conclusions on the causes of the failures.

These tests were arranged in two phases:

Phase 1

This aimed to determine the operating conditions of a one-way clutch in a representative davit winch, in terms of maximum clutch decelerations and lubricant levels.

With the generous co-operation of P&O Stena Line, this phase was conducted on board *P&OSL Calais* on 6 September 2000, the vessel on which one clutch failure occurred.

These tests showed that the range of decelerations experienced by the one-way clutch was 872 to 1029 rad/s^2. While winch was running, oil bath level varied several centimetres. The complete results are set out in **Annex I**.

Phase 2

The aim was to identify the limiting angular deceleration of the one-way clutch beyond which it fails to prevent reversal of the shaft. The variable was the level and grade of lubricant. These results were compared with the results of Phase I.

These tests showed that, almost irrespective of deceleration up to the test rig's limit of 6000rad/s^2, the one-way clutch did not fail to lock when lubricant of the specified viscosity was used. Conversely, numerous failures occurred, at decelerations within and without the operational envelope, when a higher viscosity lubricant was used. Failure was also more frequent at higher lubricant levels. The complete results are set out in **Annex II**.

A significant feature of the Phase II tests was the initial satisfactory operation of the clutch with the incorrect, high viscosity gear oil in use. This was then followed by several failures after the experimental rig had been unused for a time. The causes of this initial satisfactory performance, followed by failures, were not investigated. However, these results match the in-service experience of the clutches that have failed only after a satisfactory period in service.

2.7 TESTS' SUMMARY

Testing has shown that with a lubricant of greater viscosity than specification, clutch failure can occur at decelerations similar to those found in a winch in service. Failure has no clear pattern, but appears more likely with elevated lubricant levels.

It would be necessary to carry out a detailed tribological investigation of the contact surfaces/lubricant in order to understand this behaviour. For the purposes of this MAIB investigation, such a study is not considered justifiable.

These test results support the opinion of the winch manufacturer, who has stated that excessive lubricant viscosity has been the initiating factor in these failures. In the light of these results, and owing to the safety implications of clutch failure, the importance of using only specified lubricant should be highlighted to the vessel's owners and to the industry.

2.8 INSTRUCTION MANUALS

A common and understandable perception of many winch users might be that the function of the winch's oil bath is purely that of lubrication; essentially the prevention of wear and corrosion. Without a detailed knowledge of the one-way clutch's requirements, a user might reasonably fill the gearbox oil bath with a gear oil, as was probably done prior to these in-service clutch failures. The winch manufacturers' recommended oil is more commonly referred to as a hydraulic oil; a classification which might not immediately suggest it is suitable for a gearbox.

The present method of presenting maintenance data to shipboard staff on *P&OSL Calais,* and other vessels, uses a multi-purpose instruction manual. This is normal practice for the manufacturer of this type of winch. Although ship specific information is supplied in the format of engineering drawings, on matters of gearbox lubrication, the data is less specific.

As a result, the user is required to read some material which is inapplicable to the winches on his vessel. At best, this results in time being wasted extracting the necessary relevant information. At worst, insufficient time will be expended and incorrect information will be used; possibly leading to improper servicing of equipment.

Requirements for instructions covering on-board maintenance of lifesaving appliances, and particularly for a diagram of lubrication points with recommended lubricants, are set out in at Regulation 52 of Chapter III of SOLAS.

In view of the importance of using a low viscosity oil in these gearboxes, the lubrication instructions should be unambiguous. Simplification of the instructions, possibly providing information in a diagrammatic format specific to the vessel, would reduce the chances of an incorrect lubricant being used.

Many shipowners may have equipment of this type and which is equally prone to failure following the use of incorrect lubricating oil. Some of these owners might be operating outside the manufacturer’s service regime and thus be unaware of any recommendations they may make. As clutch failure has an important implication for safety, these owners should also be made aware of the importance of strictly adhering to manufacturer’s lubrication recommendations. To this end, the MCA should be recommended to offer advice on the importance of correct lubrication of this type of one-way clutch used on lifeboat winches.

2.9 MERCHANT SHIPPING NOTICE

The existing advice from the MCA on the lubrication of one-way clutches fitted to winches is contained in M.1186. It mentions the use of grease or light oil being used in the mechanisms.

Such lubricants might be suitable for the roller type of one-way clutches mentioned in the M Notice. However, in view of the general use of the term ‘roller clutch’ to describe almost any type of one-way clutch, the advice needs to be clarified.

In particular, the use of correct lubricants in self-lifting sprag clutches is critical. The term ‘light oil’ used in the M Notice is insufficiently specific to identify a suitable lubricant.

Within the M Notice there is an apparent interchangeability of terms where it refers to one-way clutches as ratchet mechanisms, and also mentions rollers and springs of the mechanisms. Thus, it is not clear which type of one-way clutch mechanism is being described.

This M Notice should therefore be amended, and new more specific guidance should be offered on the different type of one-way clutches and their lubrication needs.

SECTION 3 - CONCLUSIONS

3.1 FINDINGS

1. In-service deceleration of the one-way clutches is in the order of $1000 rad/s^2$. [2.6]

2. Clutch manufacturers' recommended limiting deceleration is $1250 rad/s^2$. [2.4]

3. Up to the experimental rig's operating limit of $6000\ rad/s^2$, failure to lock could not be replicated when specified oil was used. [2.6]

4. Failure to lock was replicated only when a higher viscosity gear oil was used, and after a number of satisfactory locking cycles. [2.6]

5. Failure to lock occurred at decelerations that were within normal service conditions for a lifeboat winch. [2.6]

6. Failure was more likely at higher lubricant levels. [2.6]

7. The MAIB's test results support the manufacturer's opinion that one-way clutch failures have been caused by the use of incorrect lubricants. [2.7]

8. Presentation of winch lubrication requirements is not vessel specific, and may lead to confusion. [2.8]

9. Present guidance from the MCA, in M.1186, may cause confusion and result in incorrect lubricants being used in self-lifting sprag clutches. [2.9]

3.2 CAUSES

1. One-way clutch failure on No 5 lifeboat winch of P&OSL Calais was probably caused by the use of incorrect lubricant.

2. The ambiguous on-board maintenance instructions with respect to lubricant specifications contributed to the failure.

SECTION 4 - RECOMMENDATIONS

The Maritime and Coastguard Agency is recommended to:

1. Amend Merchant Shipping Notice M.1186 to give more specific guidance on the different types of one-way clutches and their lubrication needs. Particular guidance should also be given to assist in the identification of self-lifting sprag clutches.

P&O Stena Line is recommended to:

2. Modify on-board lubrication instructions so that they are unambiguous and specific to the lifeboat winches on board P&OSL Calais.

Note

P&O Stena Line report that the action recommended above was taken shortly after the accident on *P&OSL Calais*.

Marine Accident Investigation Branch
April 2001

INVESTIGATION INTO FAILURE OF LIFEBOAT WINCH ONE-WAY CLUTCHES

Phase 1 Test Report

FNC 5414/20765R Issue 2

Prepared for

Marine Accident Investigation Branch

DOCUMENT INFORMATION

Project :	Investigation Into Failure Of Lifeboat Winch One-Way Clutches
Report Title :	Phase 1 Test Report
Client :	Marine Accident Investigation Branch
Client Ref. :	
Classification :	Commercial-in-Confidence
Report No. :	FNC 5414/20765R
Issue No. :	2
Date :	September 2000

Compiled By : W.E.C.Wright

P.M. Entwistle

Approved By : P.M.Entwistle

DISTRIBUTION

Copy	Recipient	Organisation
1	J.G.Lee	M.A.I.B.
2	J.G.Lee	M.A.I.B.
3	File	FNC

Copy No. 1

Originating Office: FRAZER-NASH CONSULTANCY LIMITED
Stonebridge House, Dorking Business Park, Dorking, Surrey RH4 1HJ, UK
T: +44 (0)1306 885050 F: +44 (0)1306 886464 E: info@fnc.co.uk W: www.fnc.co.uk

SUMMARY

Frazer-Nash Consultancy (FNC) has been contracted to investigate the cause of several in-service failures of a one-way clutch device used in a lifeboat davit winch mechanism, found on cross-channel ships. The failures have occurred when power to the motor has been turned off during a hoisting operation. The one-way device has failed to lock and allowed the lifeboat to fall uncontrollably.

This document outlines the results of tests carried out on board a sea-borne vessel. The tests encompassed several cycles of the hoisting operation, during which the velocity of the motor shaft and the level of lubricant were monitored and recorded. The analysis and results are presented here.

CONTENTS

1. INTRODUCTION

1.1 BACKGROUND

Davit winches are used to lower and raise lifeboats on large merchant vessels. There have been a number of failures when the power has been switched off during the raising operation. A one-way clutch device is designed to run freely when the motor is raising. At all other times it is designed to lock to prevent reversal of the motor armature. Investigations by the Marine Accident Investigation Branch have concluded that the failures have been a result of the clutch failing to engage when the hoisting operation has been halted. A photograph and a schematic picture of the winch arrangement are shown in figures 1 and 2 respectively.

The one-way device (figure 3) is designed to run freely above speeds of approximately 600 rpm. Centripetal forces cause the sprags to lift clear of the outer race. As shaft speed decreases, the sprags are designed to re-engage in the contact mode and prevent reversal of the shaft. The manufacturers suggest that the device will not lock if the angular deceleration exceeds 1250 rads^{-2}, under an ideal lubricant level of 2mm deep in the outer race. The manufacturers also advise that performance is affected by higher levels of lubricant, viscosity and additives.

The work undertaken by Frazer-Nash Consultancy consists of two phases. The first phase, described here, aimed to determine the operating conditions of the clutch in a representative davit winch, in terms of maximum decelerations and lubrication conditions. The second phase, to be undertaken at FNC premises, will investigate the effect of lubrication conditions on the performance limits of the clutch.

1.2 TEST CONDITIONS

The test were conducted on board the 'Pride of Calais', operated by P&O Stena Line between Dover and Calais, on 6th September 2000. The vessel was berthed in Calais during the tests. A M.A.I.B inspector was present throughout the collection of experimental data.

The test procedure is outlined in the Phase 1 Test Plan (FNC 5414/20647R Issue 1).

2. PROCEDURE

The dynamic behaviour of the motor shaft was monitored using an incremental optical encoder, fixed onto the hand crank attachment. Data from the encoder was logged via data acquisition equipment to a portable computer. The one way clutch device shares an oil bath with the chain drive to the brake shaft and the first epicyclic gearbox. The level of lubricant in the housing was monitored using a sight glass, fed from the drain plug via a flexible hose.

Test runs were carried out in the following sequence:

1. Lifeboat luffed out, lowered to embarkation deck
2. Bowsinghooks released
3. Complete lowering operation from deck to water level
4. 1m hoist and stop (x2)
5. Complete hoist to deck level
6. Lowering to two-thirds deck height
7. 1m hoist at two-thirds deck height (x3)
8. Hoist to deck level
9. Inching operations at deck level (x3)
10. Fill plug removed to vent oil bath
11. Complete lowering operation from deck to water level
12. Complete hoist to deck level, with hesitation
13. Hoist from deck level to davit level
14. Inching operations near davit level (x4)
15. Lowering to two-thirds deck height
16. Hoist to limit
17. Boat Stowed

Angular velocity of the shaft during hoisting was observed to be relatively constant. However, it was estimated from experimental data that the greatest rotational velocity occurred at approximately two-thirds height from water to deck level. Hence, iterations 7 and 8 were conducted at this height.

3. RESULTS

3.1 OIL LEVEL MONITORING

Having fitted the sight glass, the oil level was replenished to 7mm above the centre line of the filling elbow, and the fill plug replaced.

The movement of oil level during testing is summarised in the following table.

Operation	Height relative to fill level (mm)
Static fill level	0
Lowering to water	-58
1m hoist	-23
Hoist to deck level	+7
Lowering to 2/3 height	+23
1m hoist at 2/3 height	+28
Hoist to deck level	+48
Inched at deck level	+60
Fill plug removed	-6
Lowering to water	-34
Raise to deck level	+48

Figure 4 illustrates the lubricant levels relative to the clutch. It shows the initial static fill level, and the minimum and maximum heights of lubricant observed during the tests.

3.2 ANALYSIS OF OIL LEVEL DATA

During the first set of test runs (1-9), the fill plug was in place and therefore the housing was unvented, as it is in normal operation. The oil level was seen to drop significantly during the initial lowering to water level, and then rise with each subsequent operation. It was suspected that the level in the sight glass was being affected by pressurisation effects in the unvented housing. Therefore, the fill plug was removed and the level in the sight glass fell immediately to near the initial static fill level. This confirmed that the sight glass was not indicating the true level in the housing during the first set of tests. With the fill plug removed, both the housing and sight glass were then vented to atmosphere and the test were re-run.

For this reason, the first set of data that was recorded with the fill plug in place can be discounted. Therefore, analysis will concentrate on the effects observed after the fill plug had been removed.

During the lowering operation, the oil level fell by 28 mm. A possible explanation for this is that the chain drive to the brake shaft, which shares the oil bath, is picking up oil on its links and temporarily lowering the surface level.

Conversely, during the hoisting operation, the sight glass level was seen to rise 48mm above the static fill line. This was confirmed by the fact that oil was overflowing from the filling elbow. A speculative explanation for this is that the rotating components in the gearbox housing are displacing the oil when rotating at speeds up to1800 rpm. This level is 29mm above the level of the outer race of the clutch.

3.3 SHAFT ENCODER DATA

The shaft encoder was fitted to the motor shaft at the hand crank attachment point, using the device shown in figure 5.

The data collected from the shaft encoder was analysed to determine the velocities and accelerations of the motor shaft. Figure 6 shows raw data from run 14, a series of four inching operations. Figure 7 shows a line through the data points from which the deceleration is derived. The results are summarised in the table (figure 8) and represented graphically in figure 9.

The results show a steady-state shaft velocity during hoisting of 155 rads^{-1}, which is independent of run time. The average deceleration was 969 rads^{-2}. The data shows a high degree of consistency.

4. CONCLUSION

The test results show that the maximum measured deceleration was 1029 $rads^{-2}$. This was observed during an 'inching up' operation where the lifeboat is close to its upper limit. This is to be compared with the manufacturers stated maximum operational deceleration of 1250 $rads^{-2}$. The manufacturer further states that optimum performance is achieved with a lubricant level of 2mm in the outer race of the clutch and that performance is affected by higher levels of lubricant.

It was observed that the initial static fill level was approximately 19mm below the outer race. However, during a sustained hoisting operation, this level rose by 48mm, resulting in the outer race of the clutch being in a lubricant depth of 29mm.

4.1 FUTURE WORK

Further experimental investigation is planned in order to quantify the effect of lubricant level and condition on performance limits of the device. These tests will take place on a purpose-built rig at FNC premises.

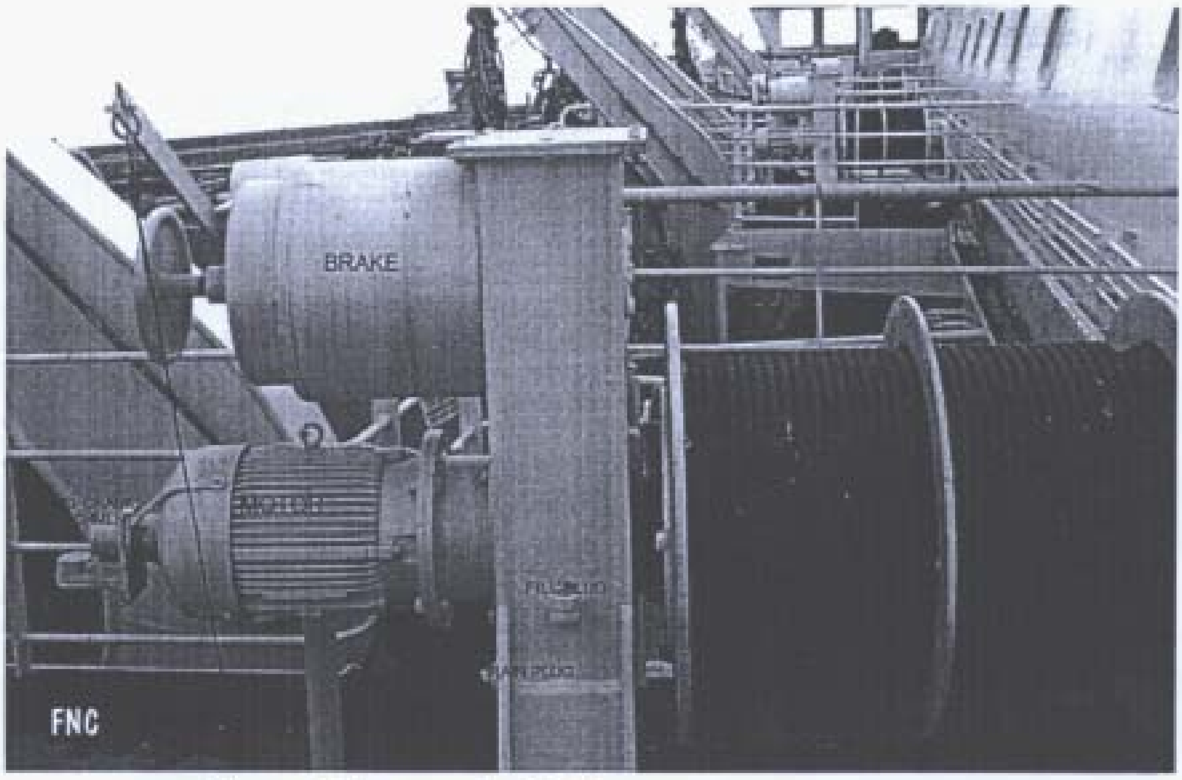


Figure 1 : Photograph of winch arrangement

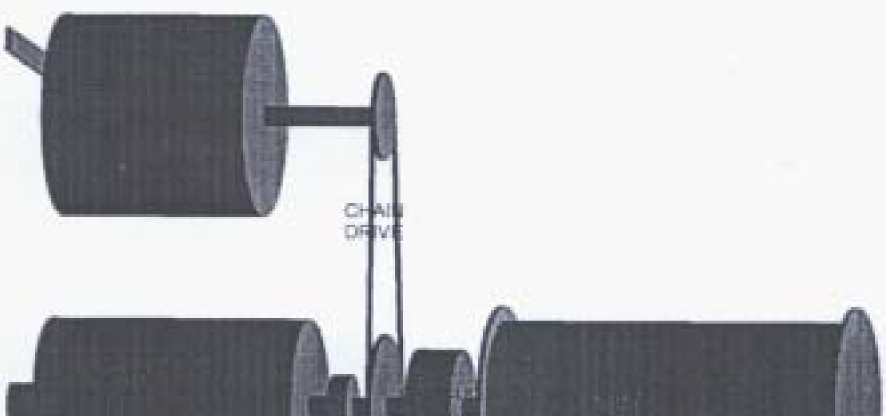


Figure 2 : Schematic of winch arrangement

Figure 3 : RSBI35 one-way clutch device

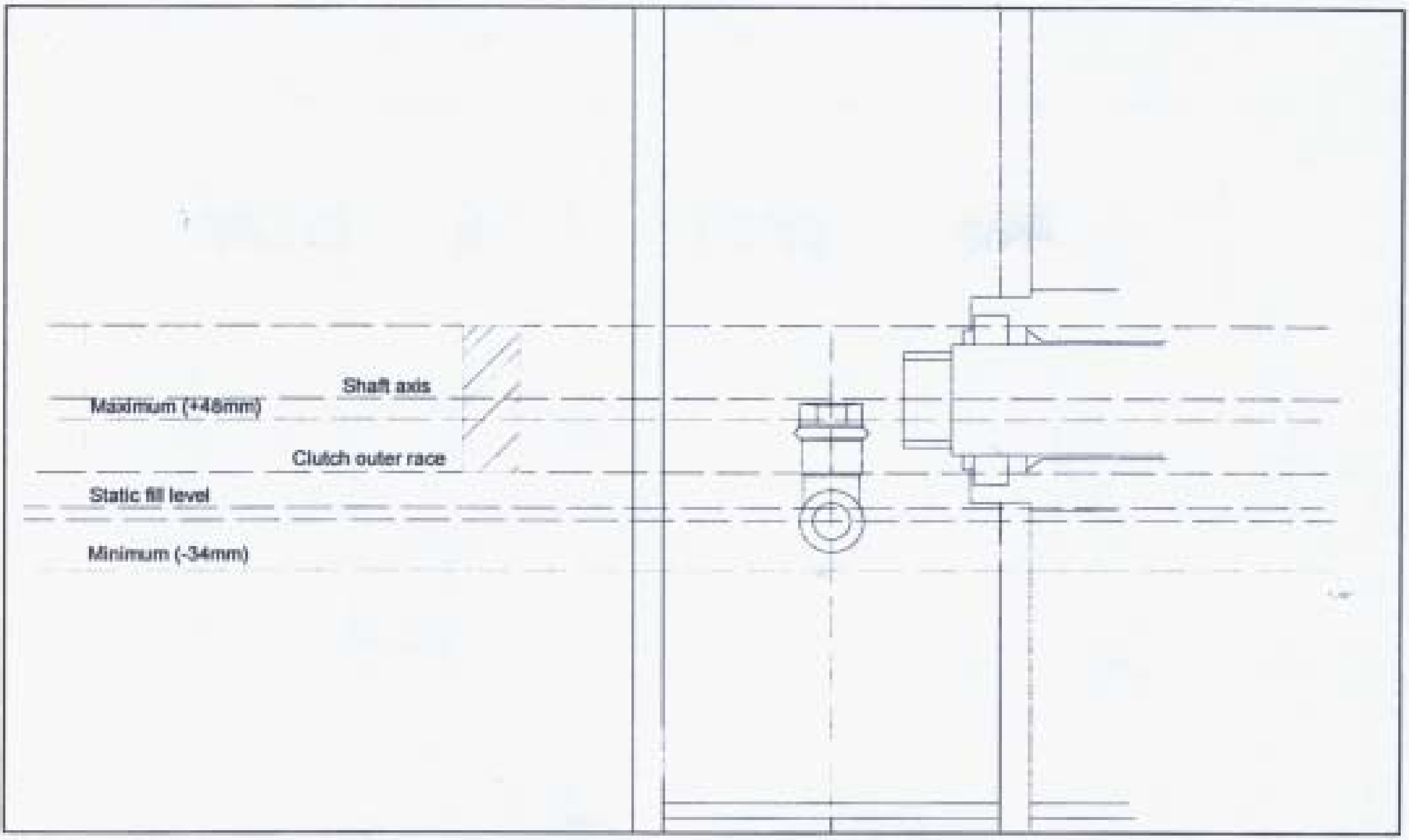


Figure 4 : Lubricant levels, relative to clutch outer race

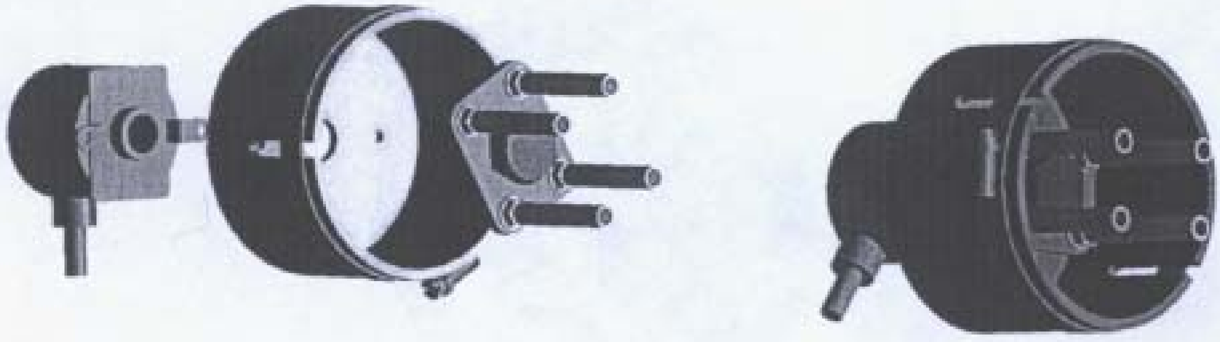


Figure 5 : Shaft encoder attachment assembly

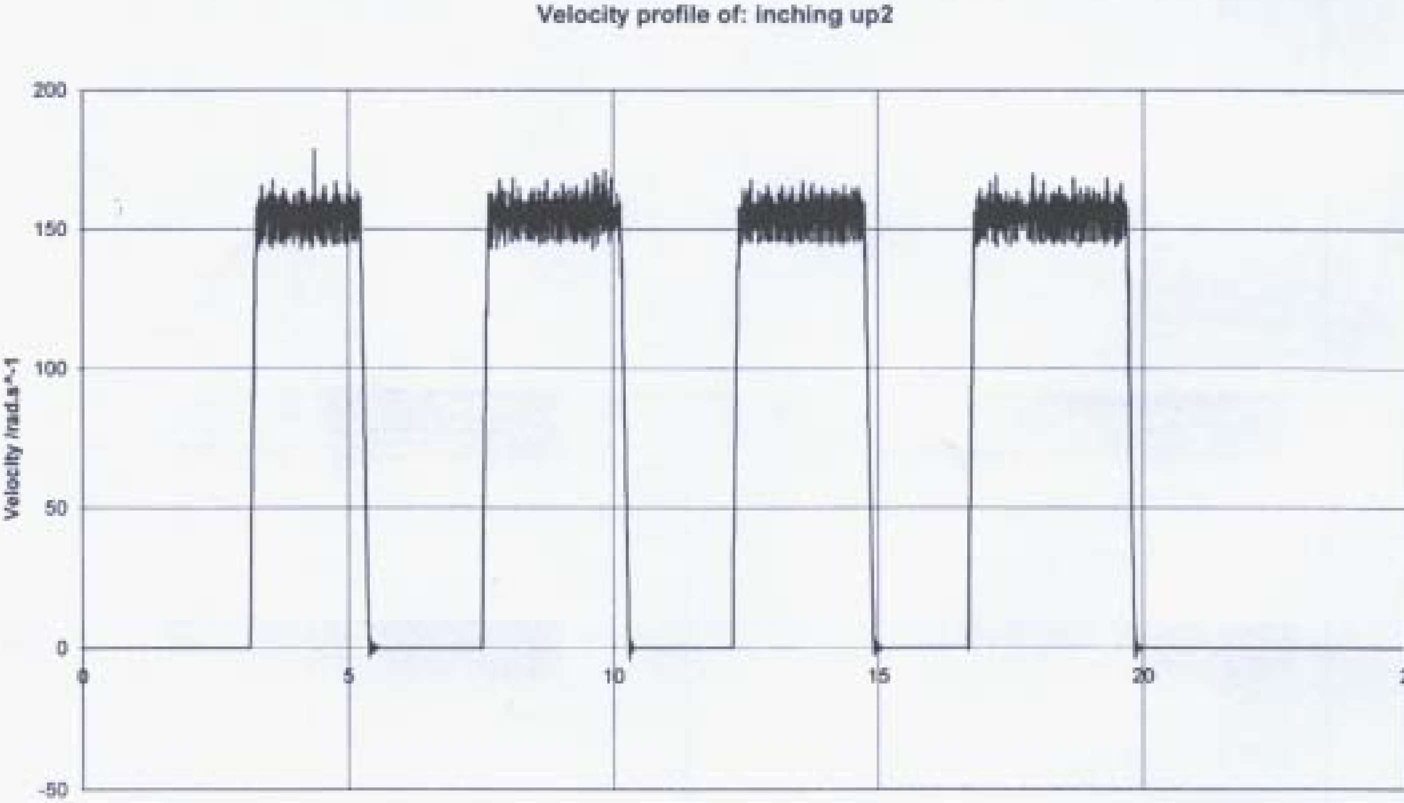


Figure 6 : Raw data – 4 inching operations

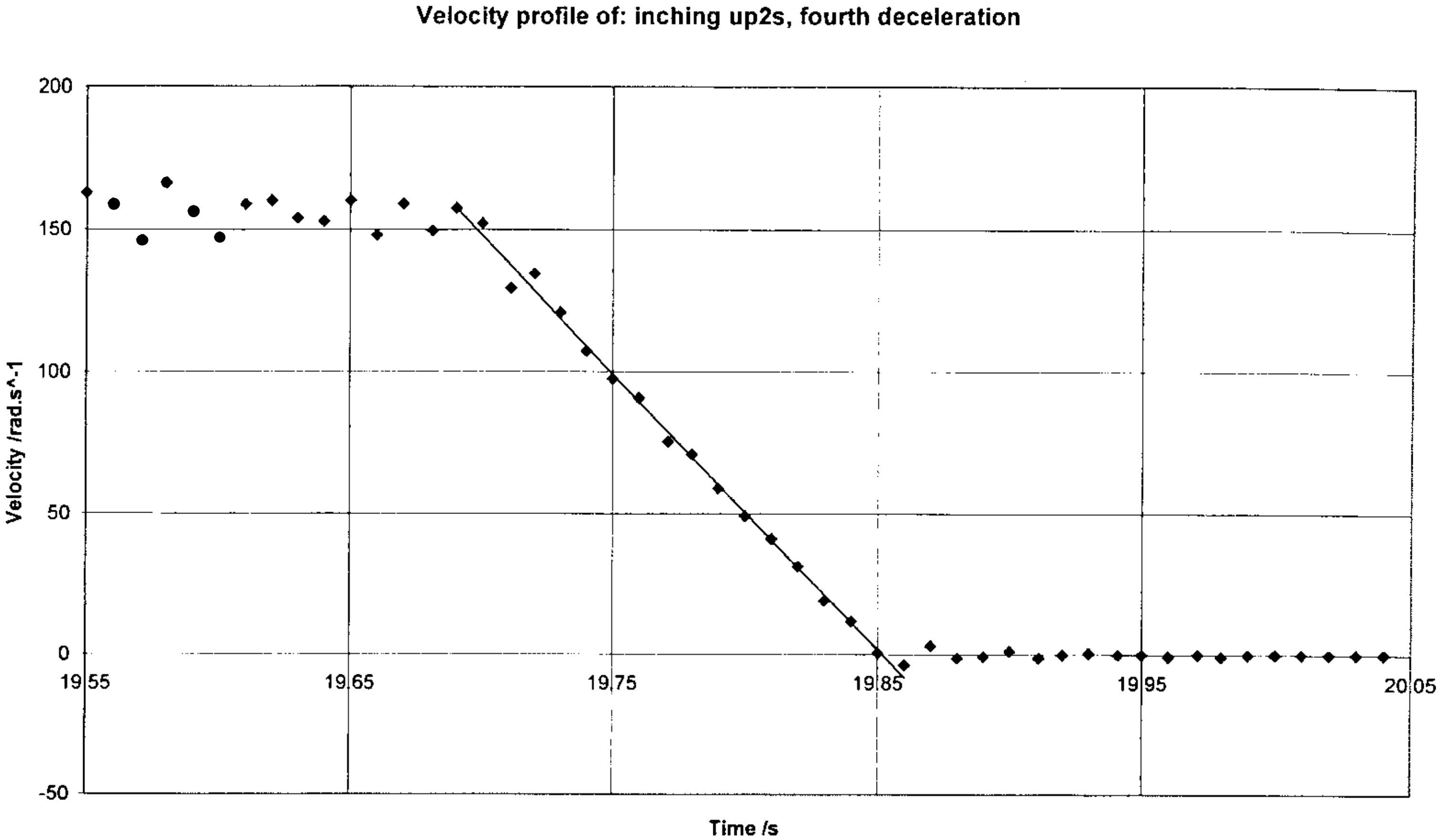


Figure 7 : Line through data points to derive deceleration

Shaft Encoder Data

Run	Operation	Run time (s)	Steady-state velocity ($rads^{-1}$)	Deceleration ($rads^{-2}$)
4	*Near water level:*			
	1m hoist 1	4.51	154.90	975.21
	1m hoist 2	2.90	154.94	1023.70
5	Hoist to deck level	93.85	154.68	1000.80
7	*At 2/3 height:*			
	1m hoist 1	2.65	154.25	1004.80
	1m hoist 2	2.26	154.74	951.42
	1m hoist 3	2.49	154.94	923.42
9	*At deck level:*			
	Inching up 1	1.43	155.10	872.37
	Inching up 2	1.68	155.12	941.97
	Inching up 3	2.51	155.43	973.56
12	Full lift	130.11	154.97	963.60
13	Deck height to davit	35.01	155.42	974.84
14	*At davit height:*			
	Inching up 1	2.23	155.18	1029.00
	Inching up 2	2.82	155.71	973.41
	Inching up 3	2.66	155.45	910.85
	Inching up 4	3.18	155.28	974.27
16	Hoist to limit switch	35.98	155.53	1013.20

Figure 8 : Encoder results

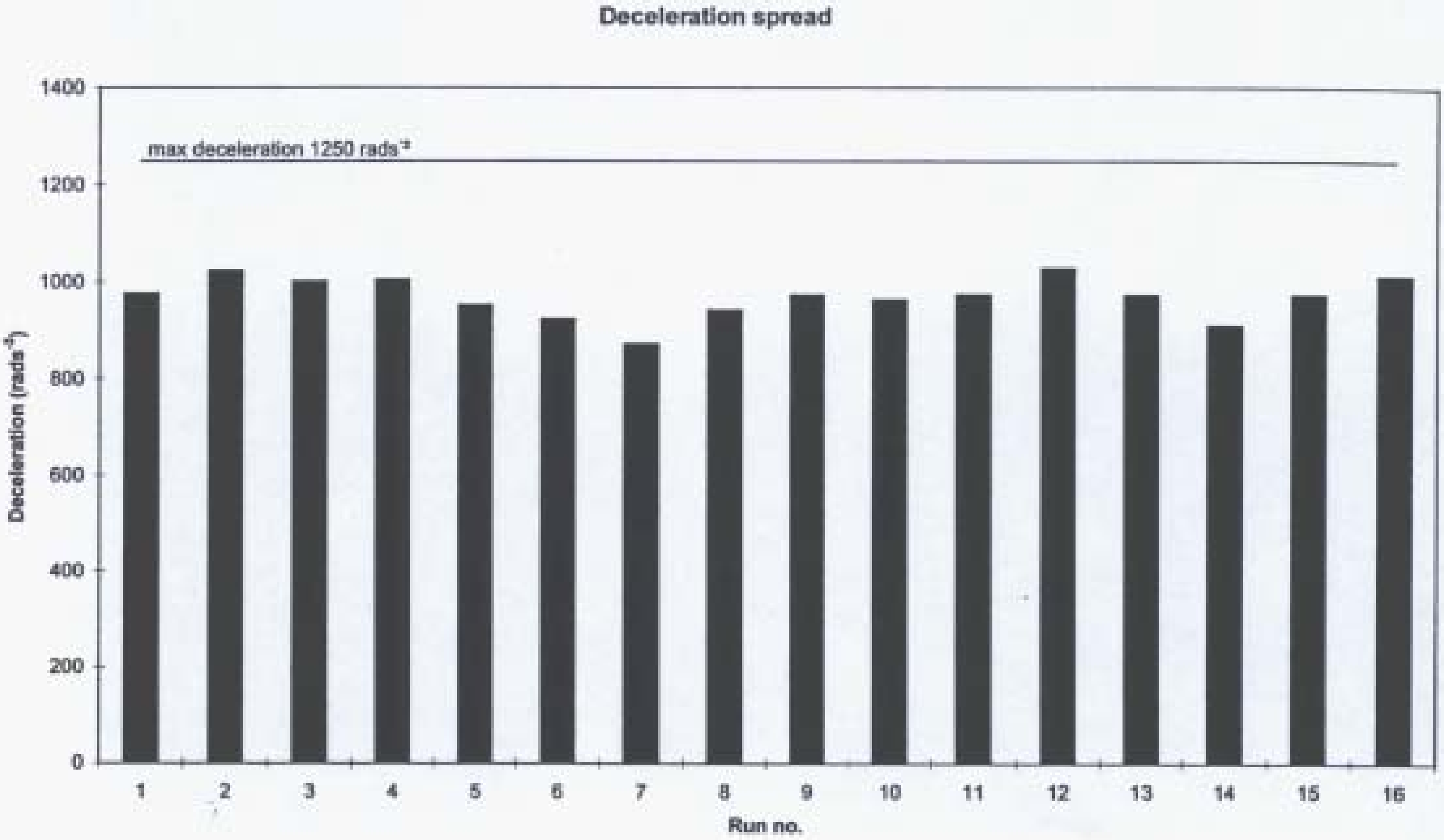


Figure 9 : Graphical representation of encoder results

INVESTIGATION INTO FAILURE OF LIFEBOAT WINCH ONE-WAY CLUTCHES

Phase 2 Test Report

FNC 5414/21094R Issue 2

Prepared for

Marine Accident Investigation Branch

FRAZER-NASH CONSULTANCY

DOCUMENT INFORMATION

Project :	Investigation Into Failure Of Lifeboat Winch One-Way Clutches
Report Title :	Phase 2 Test Report
Client :	Marine Accident Investigation Branch
Client Ref. :	
Classification :	Commercial-in-Confidence
Report No. :	FNC 5414/21094R
Issue No. :	2
Date :	November 2000

Compiled By : W.E.C.Wright

P.M.Entwistle

Approved By : P.M.Entwistle

DISTRIBUTION

Copy	Recipient	Organisation
1	J.G.Lee	M.A.I.B.
2	J.G.Lee	M.A.I.B.
3	File	FNC

Copy No. 1

Originating Office: FRAZER-NASH CONSULTANCY LIMITED
Stonebridge House, Dorking Business Park, Dorking, Surrey RH4 1HJ, UK
T: +44 (0)1306 885050 F: +44 (0)1306 886464 E: info@fnc.co.uk W: www.fnc.co.uk

SUMMARY

Frazer-Nash Consultancy (FNC) has been contracted to investigate the cause of several in-service failures of a one-way clutch device used in a lifeboat davit winch mechanism, found on cross-channel ships. The failures have occurred when power to the motor has been turned off during a hoisting operation. The one-way device has failed to lock and allowed the lifeboat to fall uncontrollably.

During the first phase of the investigation, tests were conducted on a lifeboat winch installation on board a sea-borne vessel in order to determine the in-service operating conditions of the device. The second phase of testing was carried out in a laboratory on a purpose-built rig. The aim of the phase 2 tests was to identify the limiting angular deceleration beyond which the one-way clutch device fails to lock and prevent reversal of the motor, and to investigate the effect of lubricant level and viscosity on that limit. The analysis and results are presented here.

CONTENTS

1. INTRODUCTION

1.1 BACKGROUND

Davit winches are used to lower and raise lifeboats on large merchant vessels. There have been a number of failures when the power has been switched off during the raising operation. A one-way clutch device is designed to run freely when the motor is raising. At all other times it is designed to lock to prevent reversal of the motor armature. Investigations by the Marine Accident Investigation Branch have concluded that the failures have been a result of the clutch failing to engage when the hoisting operation has been halted.

The one-way device is designed to run freely above speeds of approximately 600 rpm. Centripetal forces cause the sprags to lift clear of the outer race. As shaft speed decreases, the sprags are designed to re-engage in the contact mode and prevent reversal of the shaft. The manufacturers suggest that the device will not lock if the angular deceleration exceeds 1250 rads^{-2}, under an ideal lubricant level of 2mm deep in the outer race. The manufacturers also advise that performance is affected by higher levels of lubricant, viscosity and additives.

The work undertaken by Frazer-Nash Consultancy consists of two phases. The second phase, described here, investigates the effect of lubrication conditions on the performance limits of the clutch.

1.2 TEST CONDITIONS

The tests were conducted on a purpose-built rig. The one-way device was mounted into a steel housing with the inner race mounted onto a shaft. The concentricity required by the device (0.18mm) was observed and verified by the rig manufacturer.

The shaft was coupled to brushless D.C. motor, which was controlled from a PC via a servo-amplifier. A shaft encoder was mounted on the shaft and the data logged on a separate PC. For the purposes of experimental control, the shaft encoder data acquisition equipment was identical to that used during the phase 1 ship testing.

The rig was designed such that the one-way device was lubricated from an oil bath, in which the level could be monitored using a sight glass mounted on the side of the housing. The assembled rig is shown in figure 1.

2. PROCEDURE

The purpose of the phase 2 testing was to identify the limiting angular deceleration of the one-way clutch beyond which it fails to prevent reversal of the shaft. The variable was the level and grade of lubricant.

Tests were conducted using two different lubricants. The first, Shell Tellus R10, is similar to that recommended by the winch manufacturers. The second is a more viscous grade of gear oil, MobilGear 629. The level of lubricant was varied between the clutch manufacturers recommended level of 2mm in the inner race and the maximum level observed during phase 1 onboard testing (29mm deep in the inner race). Tests were also conducted with the rig filled completely with lubricant, in order to investigate the bounding condition.

For each run, the inner race was accelerated to normal running speed (155 rads^{-1}) for approximately five seconds. It was then decelerated from this steady state through zero and driven in the reverse direction. In the case of the one-way device functioning correctly, the motor shaft was prevented from reversing and the motor stalled after approximately 2 seconds. Prior to testing, the rig was run without the outer race of the device installed, in order to verify the reversing function of the motor. The results showed that deceleration was constant from normal running speed down through zero to the reversed running speed.

Initially, tests were run with oil levels between 0 and 30mm above the manufacturer's recommended level, and at decelerations between approximately 900 and 2500 rads^{-2}. Under all conditions and with either lubricant, the device continued to operate without a single failure.

The rig was then left for a period of six days, after which similar tests were conducted and a number of failures were observed. These failures occurred in MobilGear 629 oil at levels of 0 and 18 mm above the manufacturer's recommended level. This prompted speculation that, since no variable changed between the two sets of tests, the factor of time between testing may have been influential.

The rig was flushed and refilled with Shell Tellus R10. Tests were run at 0 and 18mm of oil above the recommended level and with the rig completely filled. At each level, 30 iterations were run at decelerations of between 1000 and 2500 rads^{-2}. No failures were observed with Shell Tellus R10.

An identical set of tests was repeated with MobilGear 629 and two failures were observed, both with the rig filled completely and at decelerations of approximately 2100 rads^{-2}.

The rig was then left for a period of four days and a further set of tests was run with the same sample of MobilGear 629. At the manufacturers recommended level of oil, two failures were observed in twenty runs. At 30mm above the recommended, five failures were observed in twenty runs. All failures occurred at approximately 2000 rads^{-2}.

Details of these results are included below.

3. RESULTS

The table below summarises the tests.

Test	Oil	Result
1	Shell Tellus R10	No failures in 47 runs
2	MobilGear 629	No failures in 72 runs
3	MobilGear 629	24 failures in 61 runs
4	Shell Tellus R10	No failures in 90 runs
5	MobilGear 629	2 failures in 90 runs
6	MobilGear 629	7 failures in 40 runs

The results of tests 1, 2, 3 and 6 are tabulated and graphed in Appendix 1.

Samples of raw data are included in the figures:

Figure 2 shows the device locking up under a deceleration of 1265 rads^{-2}.

Figure 3 shows the device failing to lock under a deceleration of 1191 rads^{-2}. The deceleration is calculated by putting a line of best fit through the appropriate data points, as shown in figure 4. This method calculates a mean over the entire period of deceleration. It can be seen from figure 4 that around the point of reversal, the deceleration is much less than this mean deceleration. This observation was common to all failures. Since the reversing function of the motor was verified prior to testing and the deceleration found to be constant, it can be concluded that this effect is a characteristic of the one-way clutch device and not of the test apparatus.

3.1 ANALYSIS & INTERPRETATION

During tests 1 and 2, no failures were observed. These tests were run with a new test piece in fresh oil.

The rig was then left for six days with MobilGear 629, after which a similar set of tests was run and several failures were observed. At the manufacturer's recommended level of lubricant, mean deceleration at failure was found to be approximately 1760 rads^{-2}. The majority of failures occurred at decelerations of between 1900 to 2000 rads^{-2}, although failures also occurred at 986 and 1191 rads^{-2}. At the higher level of lubricant, the mean deceleration at failure was approximately 1090 rads^{-2}.

During test 4, with fresh Shell Tellus R10 oil, no failures were observed. The tests included runs at very high decelerations (>6000 rads^{-2}), as well as inputs designed to simulate the 'inching up' operations observed during phase 1 testing.

Test 5, with fresh MobilGear 629 oil, revealed only two failures in ninety runs, both at approximately 2100 rads^{-2} and with the rig completely full of oil.

Test 6 was conducted four days later with the same batch of MobilGear 629 oil. At the manufacturer's recommended level, two failures were occurred in 20 runs. With 30mm more oil, the failure rate increased to five in twenty runs.

In summary:

- The device was observed to fail only when lubricated with the more viscous MobilGear 629 oil.
- Higher levels of oil appeared to increase the rate of failure.
- The device appeared to fail more consistently and at lower decelerations after the rig had been left for some time with the same batch of lubricant.
- The measured deceleration varied between runs in each test for nominally constant input to the servo-amplifier.
- The modal deceleration at failure of the device in MobilGear 629 Oil was observed to be approximately 1200 $rads^{-2}$.
- The limiting deceleration of the device in Shell Tellus R10 was not determined. The device was subjected to decelerations of up to five times the maximum value observed during the phase 1 on-board ship testing without failure.
- When lubricated with MobilGear 629, failures of the device were observed at decelerations lower than those observed during the phase 1 on-board testing.

4. CONCLUSIONS

The results of the tests outlined here would suggest that the performance of the one-way clutch device is sensitive to the level and grade of lubricant. It was observed that, under test conditions and with the winch manufacturer's recommended grade of oil, the device did not fail to lock when the direction of the motor was reversed. This was true for all levels of lubricant and all decelerations, up to the capacity of the test rig (approximately 6000 rads^{-2}).

When the device was lubricated with a more viscous oil, it was observed that the device failed to lock on several occasions when subjected to decelerations less than the manufacturers stated limit, and less than that observed during phase 1 testing.

Furthermore, it was observed that higher levels of the more viscous lubricant adversely affected the performance of the device. There was also some evidence that the performance degraded when the rig was left with the same batch of lubricant for a relatively short time period, although further testing would be required to validate this finding.

Figure 1: Test Rig Assembly

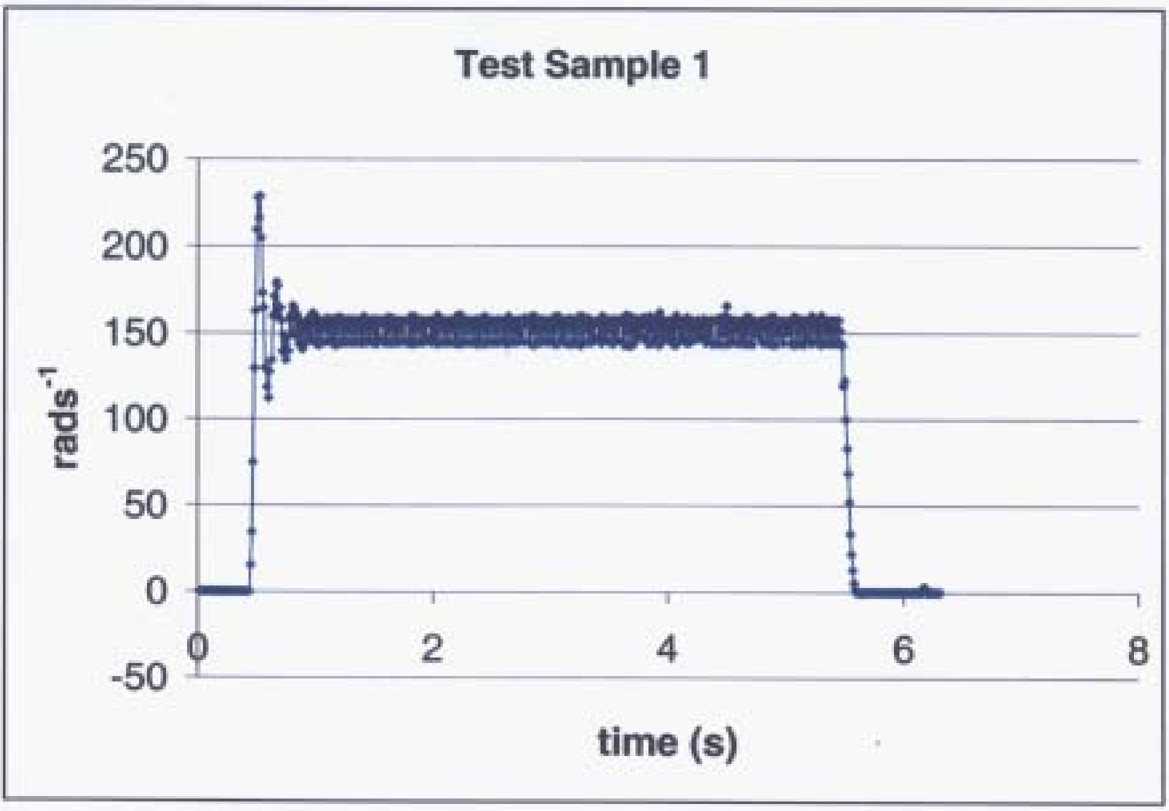


Figure 2: Test Sample 1 – velocity trace of correct function

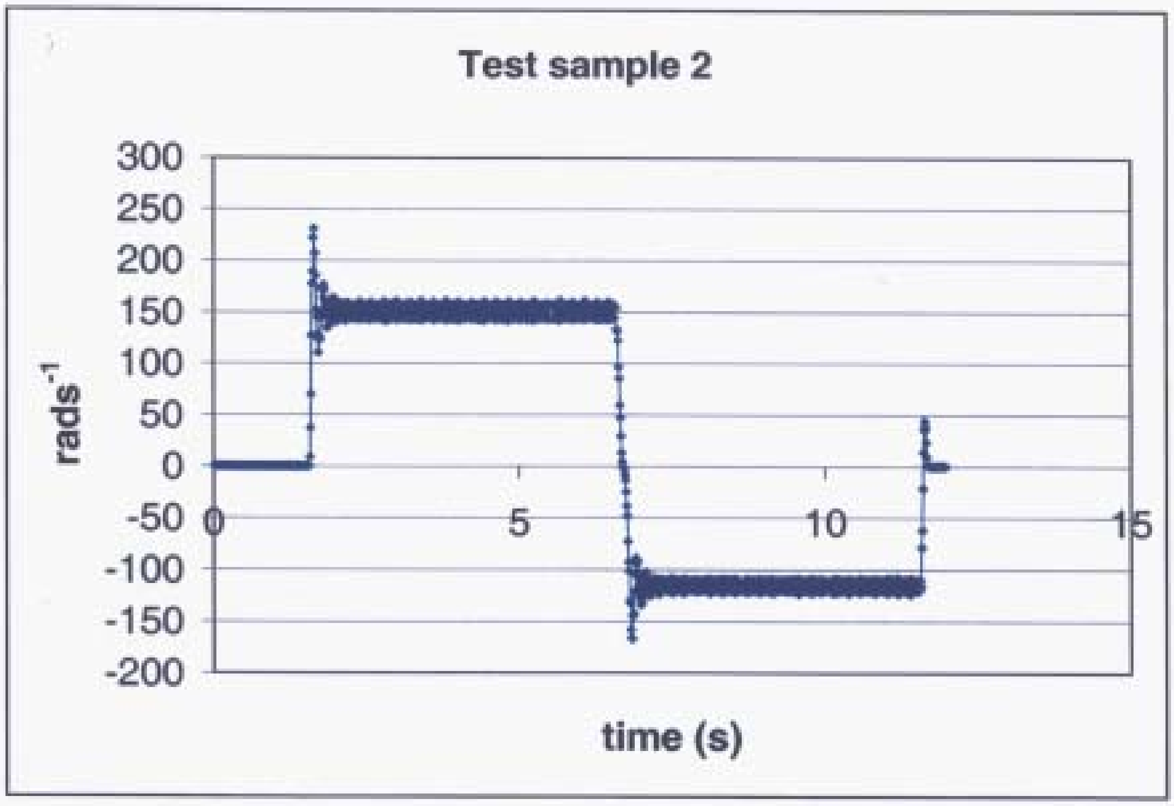


Figure 3: Test Sample 2 – velocity trace of failure

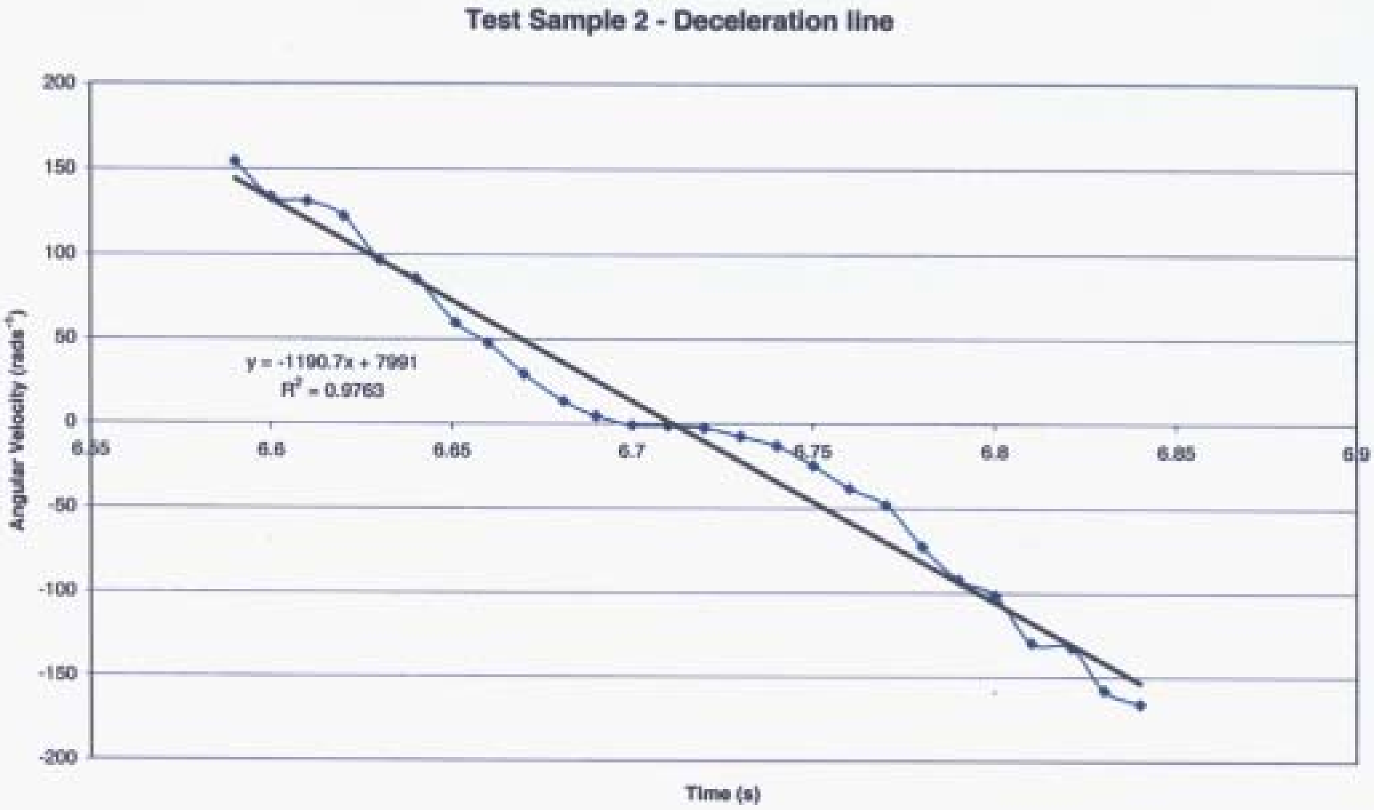


Figure 4: Deceleration trace of sample 2

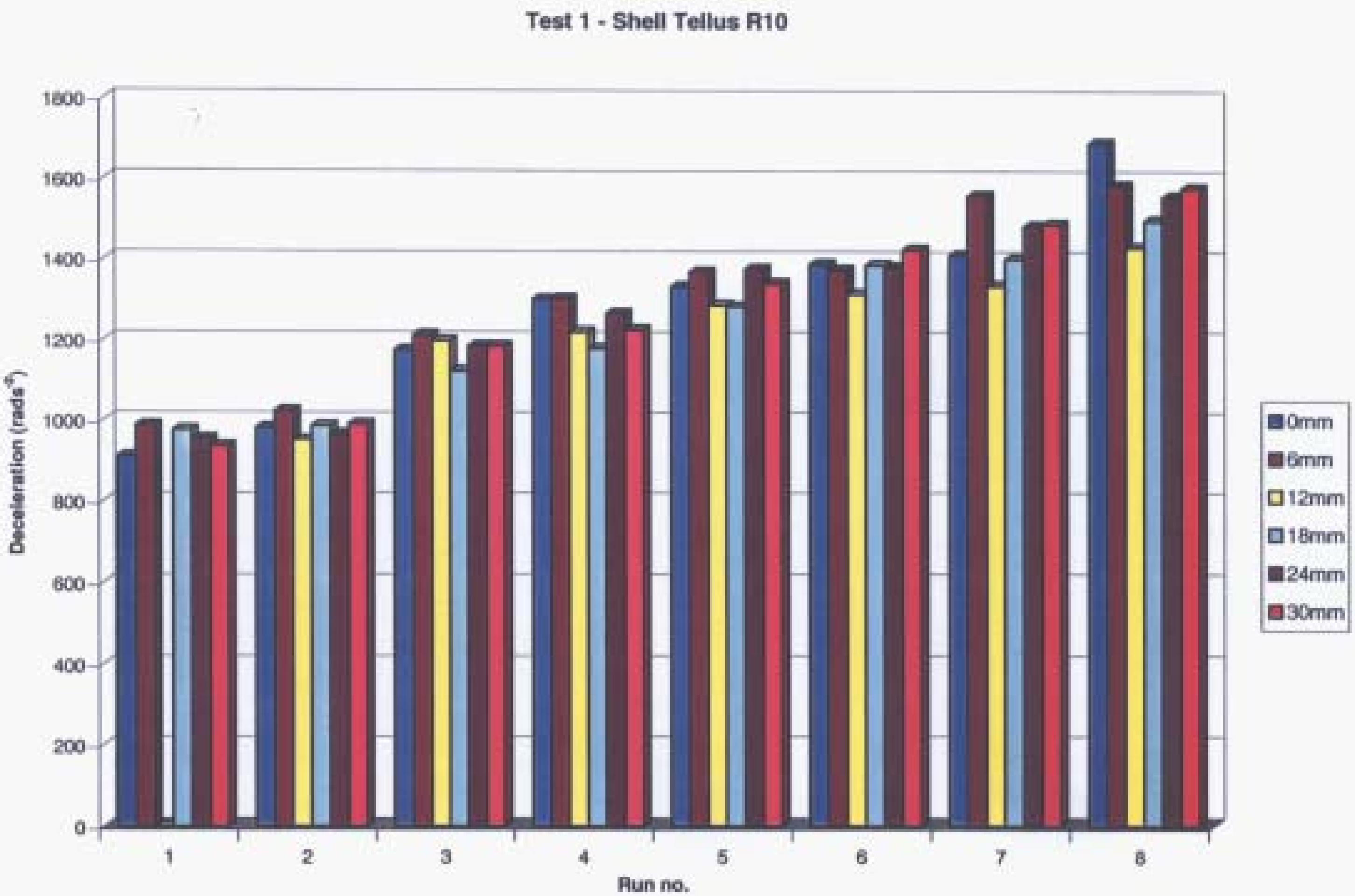
APPENDIX 1

SUMMARY OF TEST RESULTS

Tables and Graphs

Test 1 - Shell Tellus R10

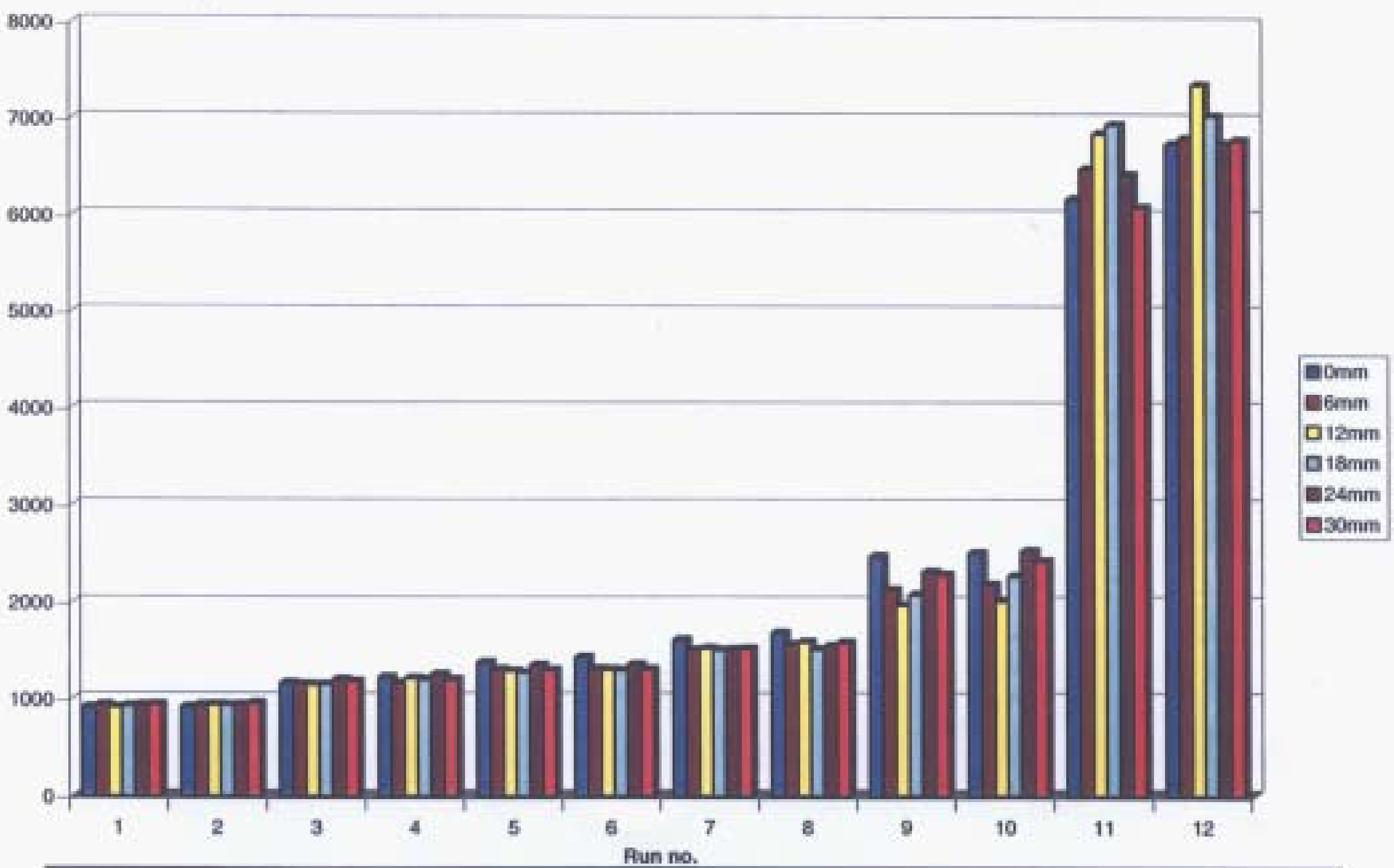
Oil Level (mm)	0	6	12	18	24	30
Run no.	Deceleration (rads^{-2})					
1	911	988	void	976	954	937
2	982	1024	952	986	965	991
3	1175	1213	1198	1123	1185	1185
4	1301	1303	1220	1179	1266	1226
5	1333	1369	1287	1283	1376	1341
6	1389	1374	1314	1386	1381	1425
7	1411	1559	1335	1401	1484	1488
8	1691	1585	1430	1497	1557	1578



Test 2 - MobilGear 629

Oil Level (mm)	0	6	12	18	24	30
Run no.	Deceleration (rads^{-2})					
1	912	936	911	925	935	941
2	914	936	939	934	937	953
3	1162	1150	1145	1149	1199	1181
4	1225	1164	1213	1199	1254	1200
5	1374	1301	1285	1270	1346	1293
6	1429	1307	1301	1295	1352	1303
7	1609	1503	1520	1501	1510	1517
8	1680	1557	1585	1510	1542	1581
9	2472	2126	1965	2077	2312	2283
10	2506	2179	2009	2268	2529	2424
11	6173	6486	6852	6945	6429	6087
12	6748	6807	7361	7038	6756	6786

Test 2 - MobilGear 629

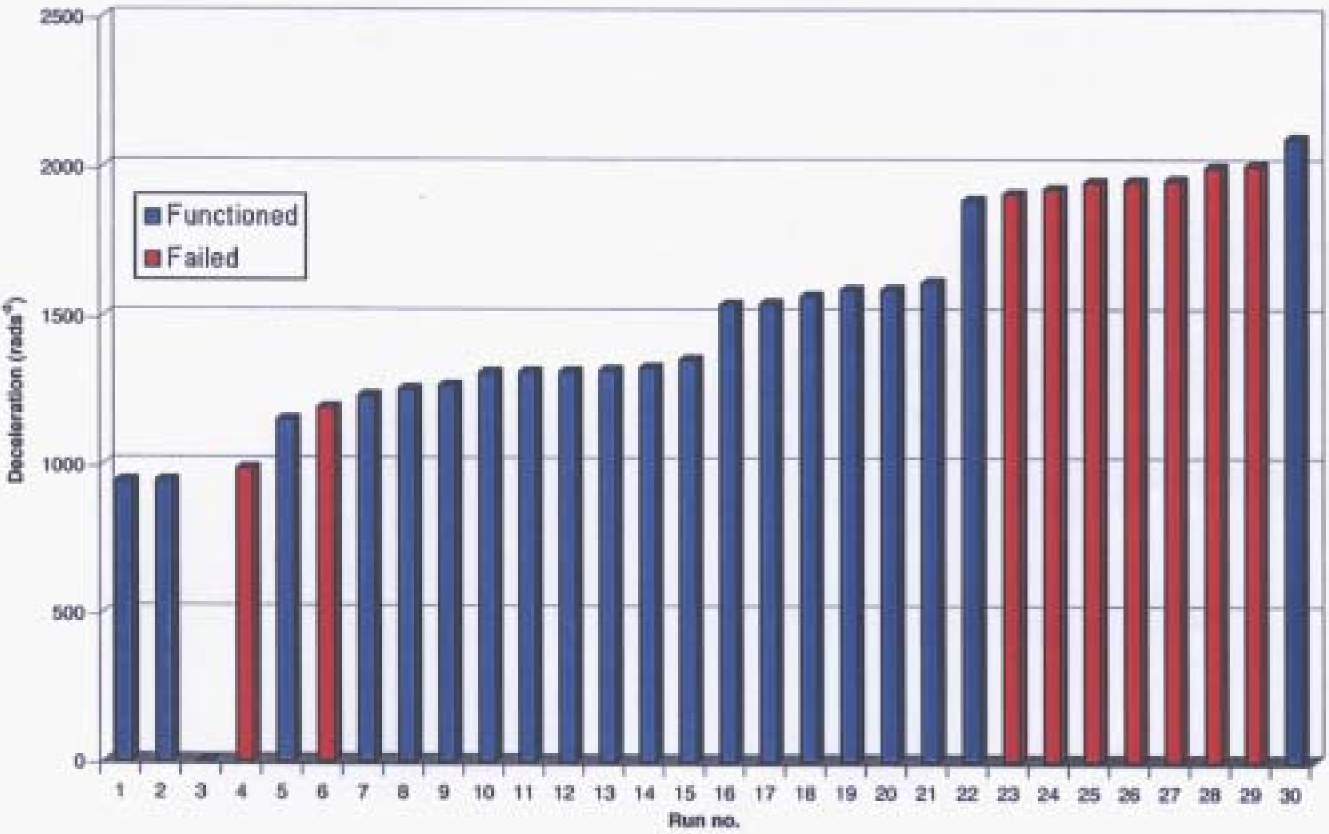


Test 3 - MobilGear 629

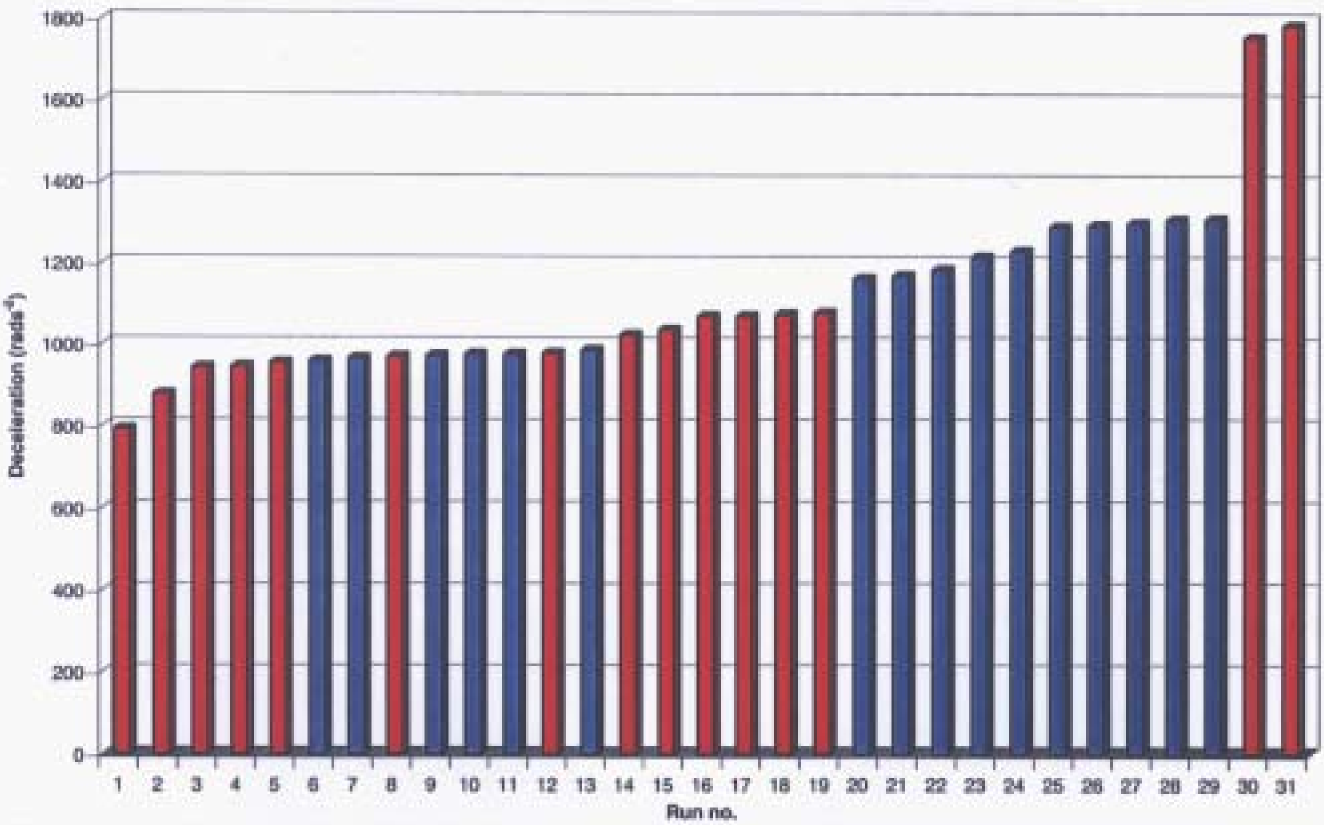
Oil Level (mm)	0	6	12	18	24	30
Run no.	Deceleration (rads^{-2})					
1	944			792		
2	945			878		
3	void			944		
4	986			946		
5	1150			955		
6	1191			960		
7	1231			966		
8	1253			970		
9	1265			973		
10	1309			976		
11	1311			976		
12	1312			978		
13	1317			986		
14	1326			1024		
15	1353			1036		
16	1538			1069		
17	1541			1069		
18	1565			1074		
19	1587			1077		
20	1588			1162		
21	1612			1169		
22	1888			1184		
23	1909			1215		
24	1925			1229		
25	1948			1290		
26	1951			1294		
27	1955			1299		
28	1997			1308		
29	2004			1309		
30	2094			1757		
31	6985			1787		

Red text denotes failure

Test 3 - MobilGear 629 0mm



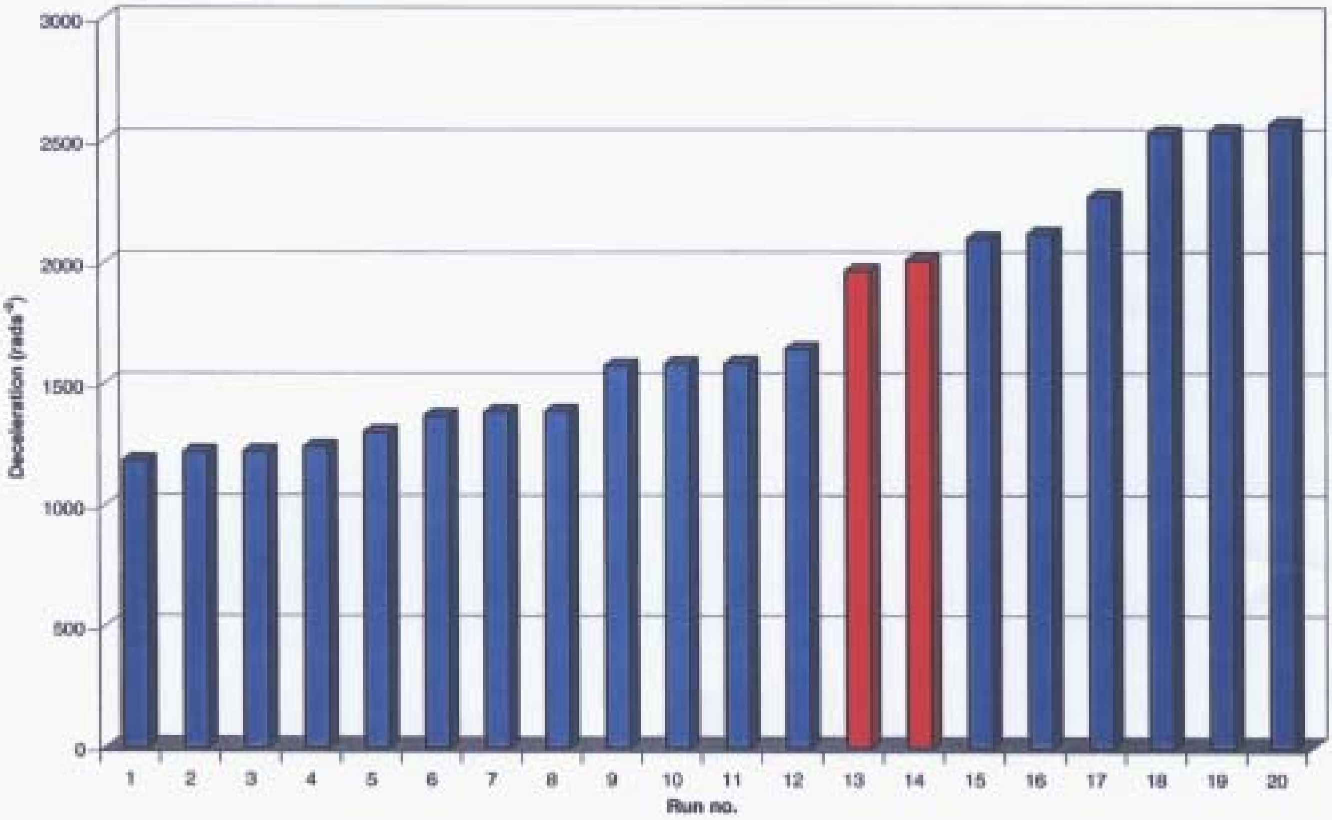
Test 3 - MobilGear 629 18mm



Test 6 - MobilGear 629

Oil Level (mm)	0	6	12	18	24	30
Run no.	Deceleration (rads^{-2})					
1	1185					1135
2	1221					1186
3	1223					1214
4	1243					1229
5	1304					1303
6	1371					1340
7	1387					1344
8	1388					1391
9	1576					1601
10	1583					1616
11	1586					1633
12	1644					1635
13	1966					1961
14	2010					1979
15	2099					1985
16	2119					1986
17	2270					2007
18	2529					2212
19	2535					2355
20	2565					2378

Test 6 - MobilGear 629 0mm



Test 6 - MobilGear 629 30mm