Impacts of Low Load Operations of Modern Four-Stroke Diesel Engines in Generator Configuration

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Introduction

The diesel engine has been the workhorse in marine industry for decades and continuously being developed for higher efficiencies and reduced emissions. Over the years have the engines become smaller and lighter with higher power to weight ratios. Diesel engines have long been the preferred choice for direct-mechanical propulsion systems, but diesel-diesel electric propulsion systems have become increasingly popular over the last decades. These engines are normally medium- to high-speed engines with lower weight and costs than similar rated low-speed engines used for conventional propulsion.

Diesel engines in generator mode are normally optimized for operations at medium to high engine loads. It is suspected that operations at low loads, combined with transient loads, may increase operational problems and thus the engine damage frequency. It is also suspected that the negative effects of low load operations are aggravated by the recent exhaust emission regulations issued by the International Maritime Organisation (IMO). Of particular significance are the standards regarding emission of nitrogen oxides and sulphur oxides.

There has been a number of diesel engine damages over the last years that possibly can be linked to low load operations. The issue concerns relatively new engines from different makers of different designs and sizes. The engine types affected are both in-line and V-engines, with power ranging from 500-2200 kW and engine speeds ranging from 1500 - 1800 rpm. All the damaged engines have operated as genset drives on vessels with diesel-electric propulsion systems and dynamic positioning systems.

Motivation

The motivation for this project is to better understand the mechanisms that may affect the diesel engine during low load operations. The purpose of this thesis is to create a comprehensive overview of the engine damage extent in which may be related to low load operations. This type of documentation is lacking today and thus requested by DNV GL.

Approach

The approach to this problem has been divided into four main parts. The first part reviews relevant theory to better understand the problem. The second part of the thesis presents a damage case study which intends to illustrate mechanisms and damages that may result from extensive low load operations of diesel engines in generator configuration. The third part of the thesis analyses qualitatively diesel engine finding data extracted from DNV's database. The analysis is based on simple frequency measurements of diesel engine findings. The last part of this thesis intends to examine the engine manufacturers' experiences with low load operations of diesel engines in generator configuration. Interesting questions will be related to typical mechanisms occurring at low loads, how these affect the engine, recommended corrective actions and how environmental requirements have influenced on the modern diesel engine.

Framework of the Thesis

The structure of this thesis reflects the approach of the problem and includes eight chapters:

1. Introduction
2. Literature review
3. Case studies
4. Finding analysis
5. Manufacturer experience
6. Discussion
7. Conclusion
8. Summary

Low Load Operations

Low load operations can be defined as load levels lower than 40% of maximum continuous rating. Load levels lower than 25% are defined extreme low load. Definitions for the entire load range are presented in the table below:

Table 1: Definition of low load

0 – 25 %	Extreme low load
25 – 40 %	Low load
40 – 80 %	Regular generator operation
80 – 90 %	High load
90 – 100 %	Extreme high load

From an engine designer's point of view are short periods of low load operations acceptable given that the engine is brought to full load on regular basis. Marine diesel engines in generator configuration may experience long periods of low load operations either because they are left idling as a standby power generating units or serving very low power demands during vessels operation.

Low load operations of diesel engines in generator configuration are typical for offshore operating vessels with dynamic positioning systems, but are not limited to these types of vessels. Offshore operating vessels may experience a large variation in load demand as they divide their time between transit and stationkeeping operations. Statiokeeping operations impose stringent demands to the electrical power generation system which are given by the International Maritime Organization (IMO) and thus the classification societies. According to DNV Rules for Classification of Ships, the traditional industry practice for redundant dynamic position systems is typically based on an approach where the redundancy is based on running machinery and not utilizing stand-by units or change over mechanisms. These power generation systems have very high reliability due to multiple engine redundancy which means that the power available often is much higher than the load demand during operation.

A typical operational profile for gensets on board a platform supply vessel (PSV) is shown in the figure below. The abscissa shows the engine power rating in percentage of maximum continuous power and the vertical axis shows vessel operating time in hours. The diagram shows that the engines are running at extreme low loads for more than 60% of operation time.

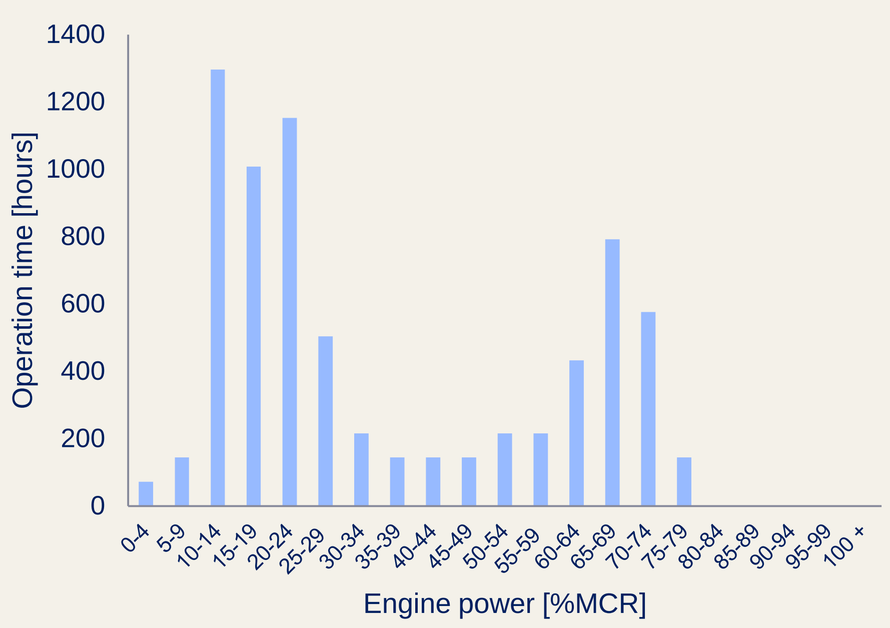

Figure 1: Vessel operational profile

Engine Damage Case Study

This damage case concerns diesel engines on board an IMR, survey and light construction vessel with diesel-electric propulsion and IMO Class 2 dynamic positioning system. The stricken ship has, according to the report, a history of engine trouble and failures. This particular damage case is from 2007 where engine crankcase breakage was the resulting damage. Based on load patterns from past records of the ship and the result of an oil analysis, was the engine breakage assumed to be caused by a series mechanisms resulting from extensive periods of low load operations. The details presented are reviewed from an investigation report composed by representatives from Mitsubishi Heavy Industries.

The resulting damage was breakage of the engine crankcase initially caused by piston scuffing. Scuffing results from mechanical contact when there is a breakdown or absence of lubrication. *Cont.*

Cont. The cause of rapid and sometimes catastrophic failures, as in this case, is adhesion and adhesive wear. The investigation report suggests that the cause of piston scuffing is extensive engine operations at low loads. Incomplete combustion resulting from several hours of operation at low loads has caused oil dilution. This assumption is based on the engine load pattern from past records of the ship and the results from an oil analysis. Oil dilution causes the cylinder liner oil film to deteriorate, which makes the cylinder liner susceptible to carbon polishing from hard carbon. These hard carbon particles are products from the incomplete combustion as well, which worsens the situation over time.

Figure 2: Piston scuffing

Figure 3: Broken cylinder liner

Finding Analysis

Findings have been extracted from Nauticus Production System (NPS), which is the main production support system of DNV Maritime. NPS contains more than 20 million nodes across nearly 6000 vessel product models, most of which is used in the reporting of survey findings during the vessels operational lives.

The quantification and comparison is this analysis based on simple frequency measurements of diesel engine findings. The finding frequency describes the number of findings registered on a component per thousand component year:

$$Finding\ frequency = \frac{Number\ of\ findings}{DNV\ component\ age} \times 1000$$

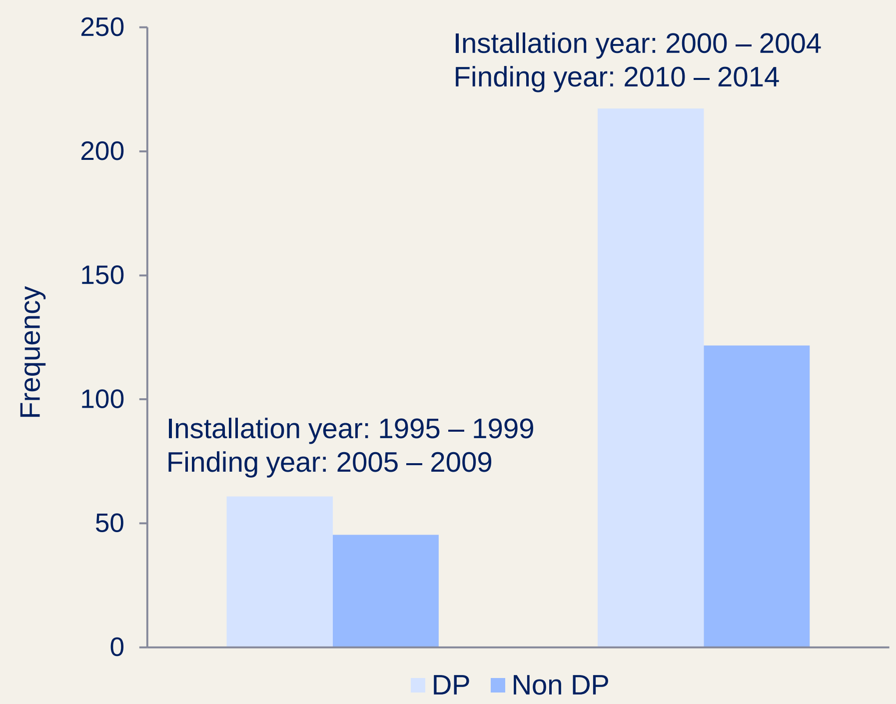

Figure 4: Finding frequency versus installation and finding year

Manufacturer Experience

Engine manufacturers agree that low load operations of diesel engines over time can lead to operational problems if precautions are not taken. None of the manufacturers could tell whether low load operations of diesel engines increase the damage frequency or not, but it was confirmed that extensive periods of low load operations will affect the operation due to more frequent overhaul intervals. An operational problem frequently mentioned is the formation of soot deposits in the cylinder, wet stacking and soot deposits in the turbocharger. Soot formation results from incomplete combustion due to low cylinder pressure and temperature at low loads.

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