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TNO report

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Black Box application on board Shrimper

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Het project 'Pilot blackbox – logistiek en infrastructuur' is een initiatief van de Stichting Verduurzaming Garnalenvisserij. Dit onderzoek is uitgevoerd en gefinancierd in opdracht van het Ministerie van Economische Zaken en is mede mogelijk gemaakt door het Europees Visserij Fonds (EVF), ter investering in duurzame visserij.

Ministerie van Economische Zaken

Europees Visserijfonds:
Investering in duurzame visserij

Summary

The Netherlands shrimper fishing community considers applying a black box data system on board all their ships to demonstrate they comply with the requirements with regard to:

1. not fishing in areas where fishing is not allowed and
2. the maximum allowable ship propulsion power while shrimp fishing not exceeds 221 kW (300 hp).

This document reports the results of an investigation into the viability of such a system. The main conclusion is that a black box concept is viable.

Determining the ship's condition (sailing or fishing) can be done from measured RPM of the propeller shaft in combination with the measured torque or the measured charging air pressure.
However determining the ship's condition (sailing or fishing) from charging air pressure has been found to be sensitive for manipulation.

Contents

1 Introduction

The ‘Stichting Verduurzaming Garnalenvisserrij’ (Foundation for sustainable shrimp fishing) has secured a subsidy from the European fisheries fund for conducting a pilot project in which the viability of a black box is investigated. The purpose of the black box is to detect if a shrimper;

1 fishes with propulsion power exceeding 221 kW (300 hp).
2 fishes in closed areas.

A pilot study was carried out which demonstrated this viability as reported by TNO [2], [3], [4] and [5]. It was stated that power can only be determined in an unambiguous fashion through a torque sensor on the propeller shaft in conjunction with a rpm sensor.

Following these findings questions were raised related to the analysis of long term data, i.e. weeks rather than hours. Moreover it was argued that the actual power which is delivered by the main engine can also be derived in a reliable and unambiguous fashion from charging air pressure measurements, which however is not supported by TNO.

TNO was requested to further investigate these issues.

Two actions were taken;

1. During a longer period the data generated by the installed black box system was analysed.
2. An attempt was made to manipulate the measured charging air pressure without detection by the black box system.

For the first action black box recordings covering four weeks of ship operation of one of the ships also used in the pilot tests (TX33), have been analysed.
For the second action the same fishing ship has been equipped with a torque meter and subjected to a charging air manipulation exercise while at sea.

As said, with this vessel trials were run in the past (reported in [3]). Since then a new engine has been installed and new trials were done. It is noted that the propeller was not changed. The measured data with the new engine is compared with the previously obtained data with the old engine.

The findings are reported in this document.

2 Trial test results

The TX33 has been equipped with a black box system, RPM sensor, GPS sensor, charge air pressure sensor, and torque meter.

The installed torque meter on the propeller shaft is shown in figure 1.

Figure 1 Torque meter (strain gauges underneath the black tape).

Figure 2 shows the actual ships speed over ground during the trial, measured with GPS.

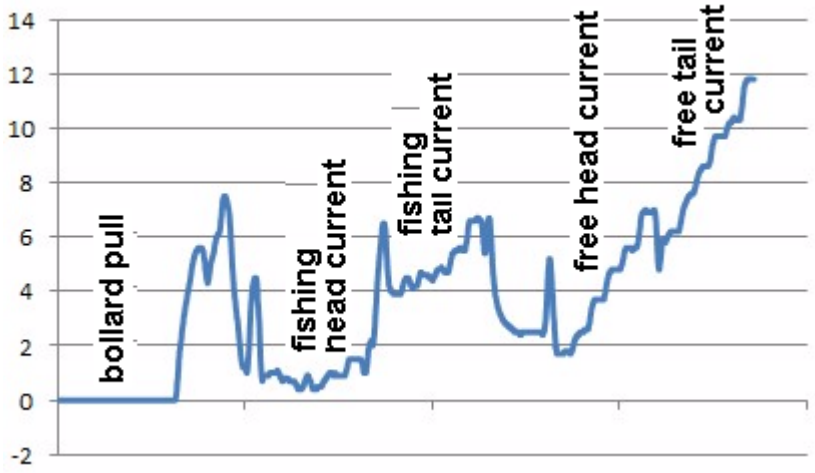

Figure 2 Speed over ground in knots against time.

Figure 3 shows the propeller shaft rotation rates which were chosen during the trial tests.

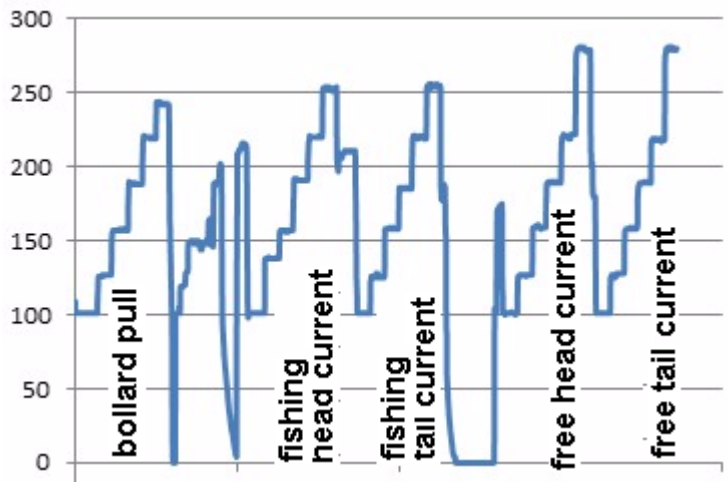

Figure 3 RPM of propeller shaft against time.

Figure 4 shows the power versus rpm of propeller shaft curves as measured during the trial tests.
In this figure some curves from the earlier trial tests with the previous engine have been added.

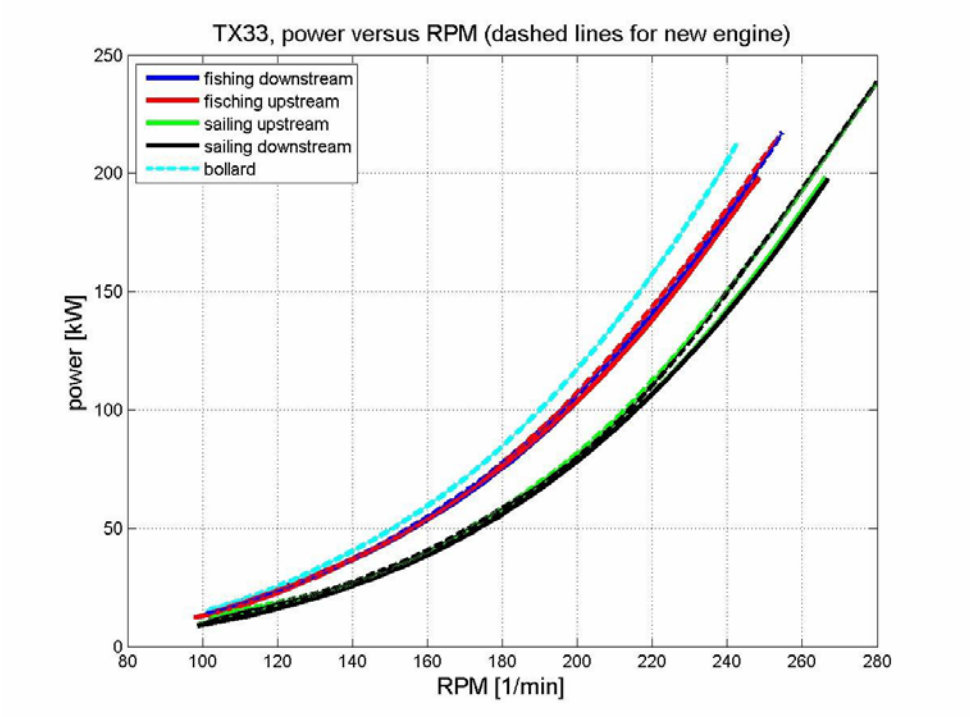

Figure 4 Power versus RPM of propeller shaft

As expected lines from the old engine and lines from the new engine are comparable and the bollard pull takes more power at the same rpm than fishing and fishing again more than free sailing.

Figure 5 shows the charging air pressure versus rpm of propeller shaft curves as measured during the trial tests. Curves from the earlier trial tests with the previous engine have been added.

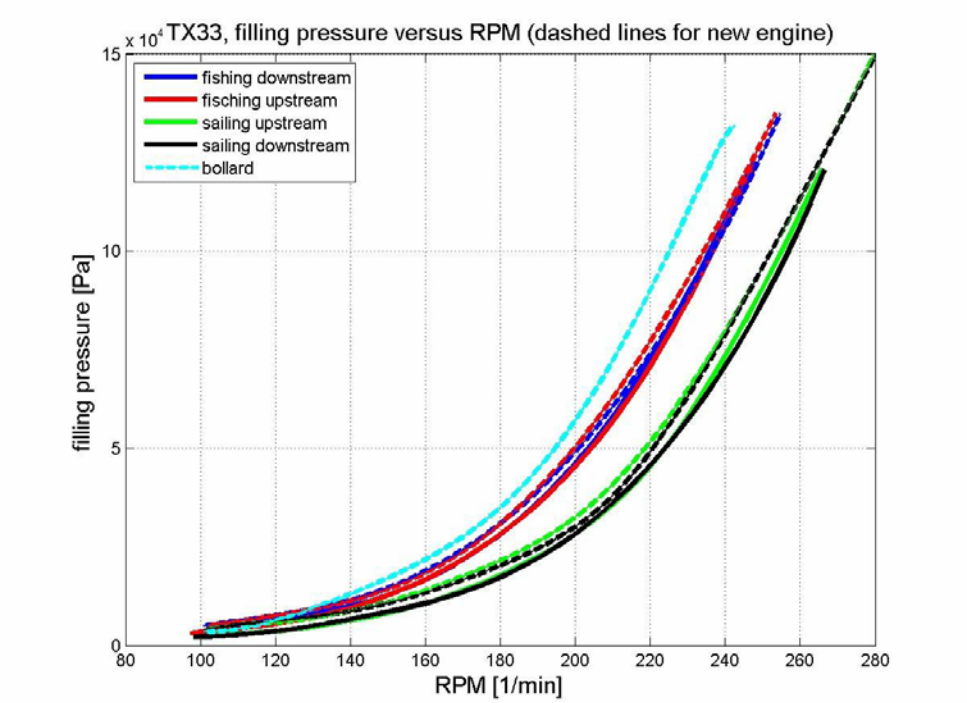

Figure 5 Charging air pressure versus RPM of propeller shaft

Figure 6 shows the power versus charging air pressure curves as measured during the trial tests. Curves from the earlier trial tests with the previous engine have been added.

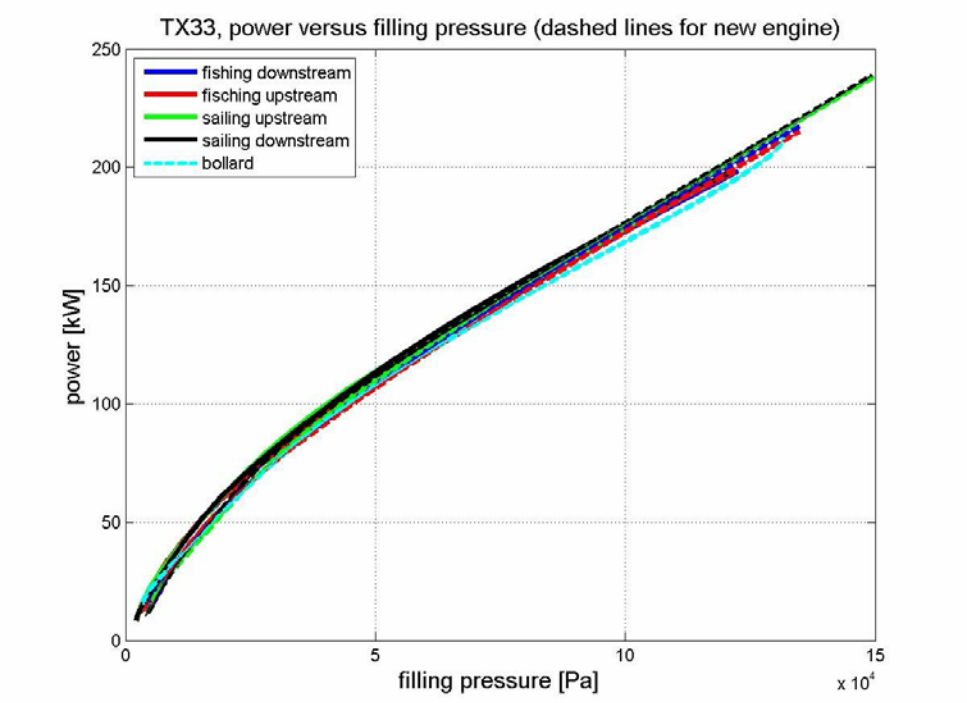

Figure 6 Power versus Charging air pressure

Curves of power versus charging air pressure are the same for all conditions as well as for the previous and current engine.

From measured data the relation between power and shaft RPM and the relation between charging air pressure and shaft RPM could be derived.

Units used:

- for power [kW]
- for charging air pressure (fp) [bar]
- for RPM [1/min]

For power the following relations were found:
Fishing: $power = 3.4540E\text{-}6*(rpm)^3 + 0.0051*(rpm)^2 - 0.8465*(rpm) + 45.1264$
Sailing: $power = 2.2366E\text{-}5*(rpm)^3 - 0.0052*(rpm)^2 + 0.6952*(rpm) - 29.8353$

For charging air pressure the following relations were found:
Fishing: $charging\ air\ pressure = 1.7647E\text{-}7*(rpm)^3 - 2.4902E\text{-}5*(rpm)^2 - 4.0641E\text{-}4*(rpm) + 0.1754$
Sailing: $charging\ air\ pressure = 3.4482E\text{-}7*(rpm)^3 - 1.3167E\text{-}4*(rpm)^2 + 0.0179*(rpm) - 0.7865$

Relation between power and charging air pressure is the same for all situations.
$power = -57.3738*(fp)^4 + 254.0819*(fp)^3 - 385.3110*(fp)^2 + 360.4459*(fp) - 2.0347$

These regression curves are presented in figures 7 to 9.

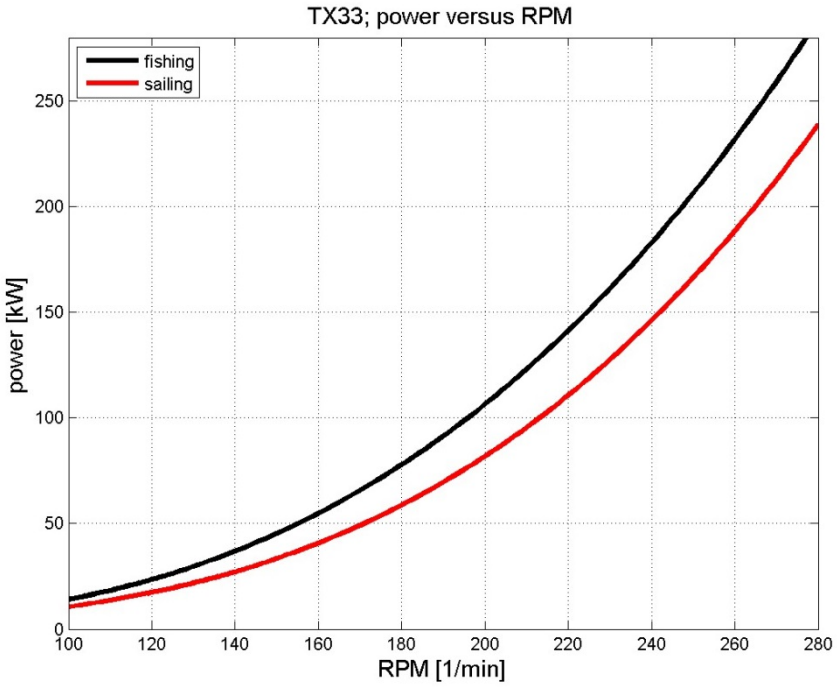

Figure 7 Relation found between Power and RPM of propeller shaft

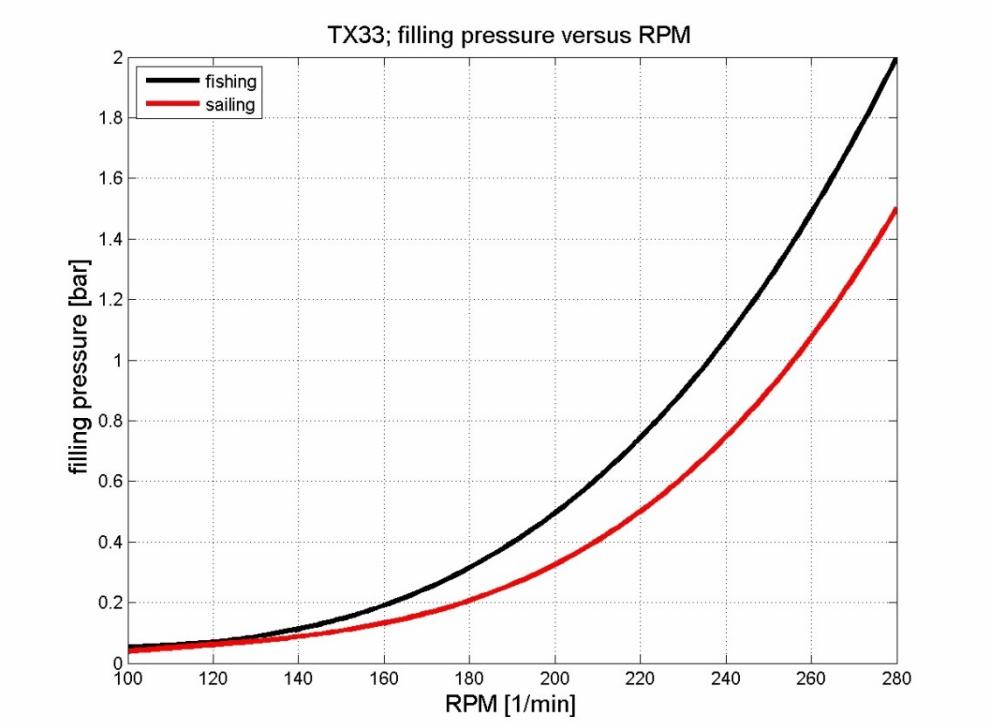

Figure 8 Relation found between Charging air pressure and RPM of propeller shaft

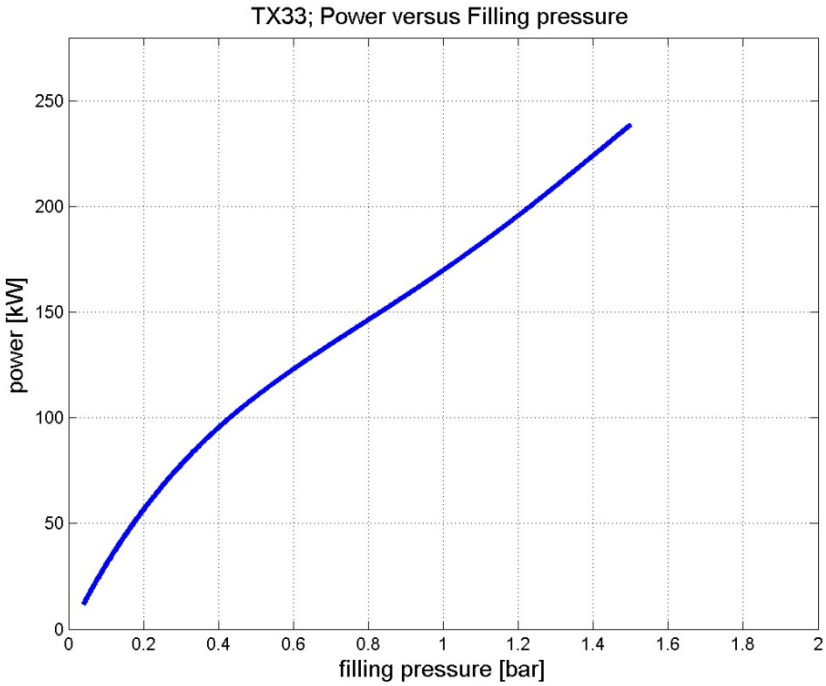

Figure 9 Relation found between Power and Charging air pressure

3 Long term data acquisition

The first reliable torque data was available in week 30 of 2015.

Figure 10 shows power versus RPM of the propeller shaft for data of week 30.
Fishing curve and sailing curve, as found from the trial tests, are included in figure 10.

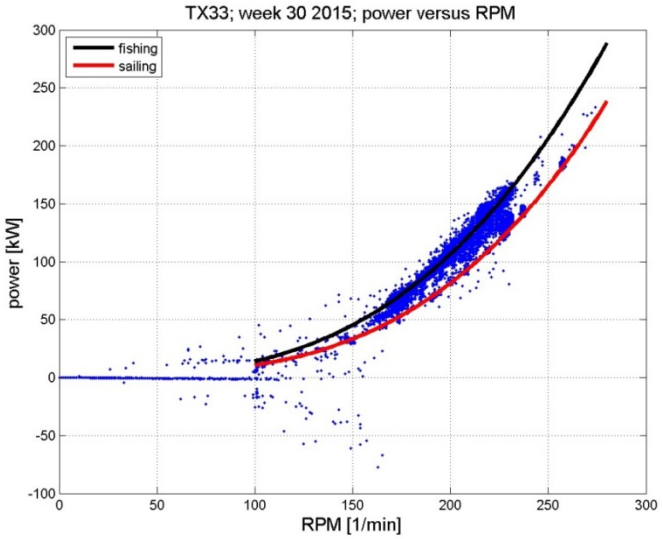

Figure 10 Data of week 30, power versus RPM of the propeller shaft

It is notable that negative values have been found for the power.
These are situations with a reverse rotation of the propeller shaft.

Figure 11 presents power versus RPM of the propeller shaft for data of week 30, 31, 32 and 33 for power higher than zero and RPM higher than 100.
Figure 11 is comparable with figure 10.

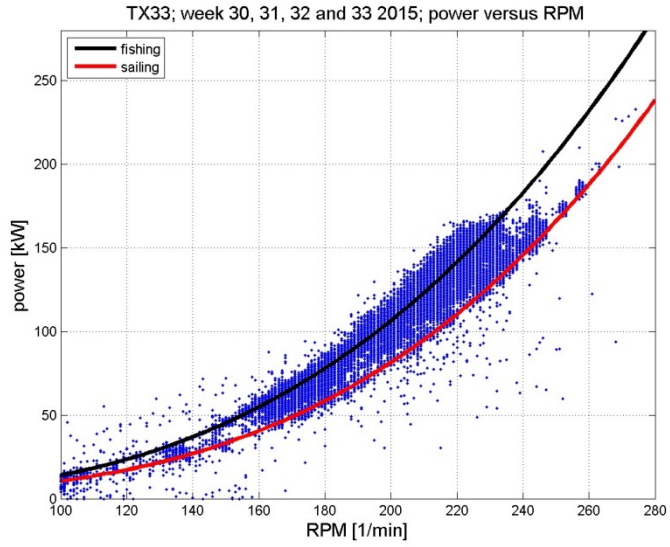

Figure 11 Data of week 30 till 33, power versus RPM of the propeller shaft

In figure 12 charging air pressure versus RPM of the propeller shaft for data of week 30,
31, 32 and 33 for RPM higher than 100 has been presented.

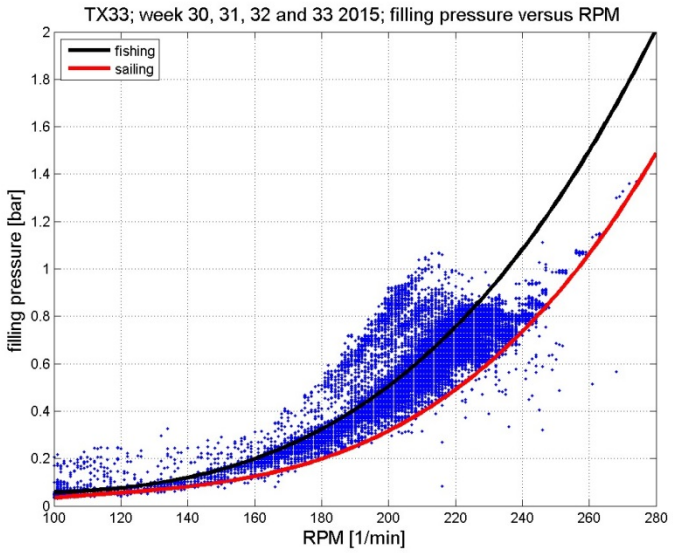

Figure 12 Data of week 30 till 33, charging air pressure versus RPM of the propeller shaft

Obviously, for power as well as charging air pressure, a lot of points are in-between the curves of sailing and fishing.

This presentation of the long term results cannot be used to determine the operational status of the ship, it can be used to determine whether the ship exceed the 221 kW limit.

Relations, as found in chapter 2, can be used to calculate real time power and charging air pressure for sailing- as well as fishing condition from measured RPM of the propeller shaft.
The calculated values, based on the regression curves, can be compared with the measured values.
In figures 13 and 14 these curves are presented for the first 10 hours on Monday July 20th.

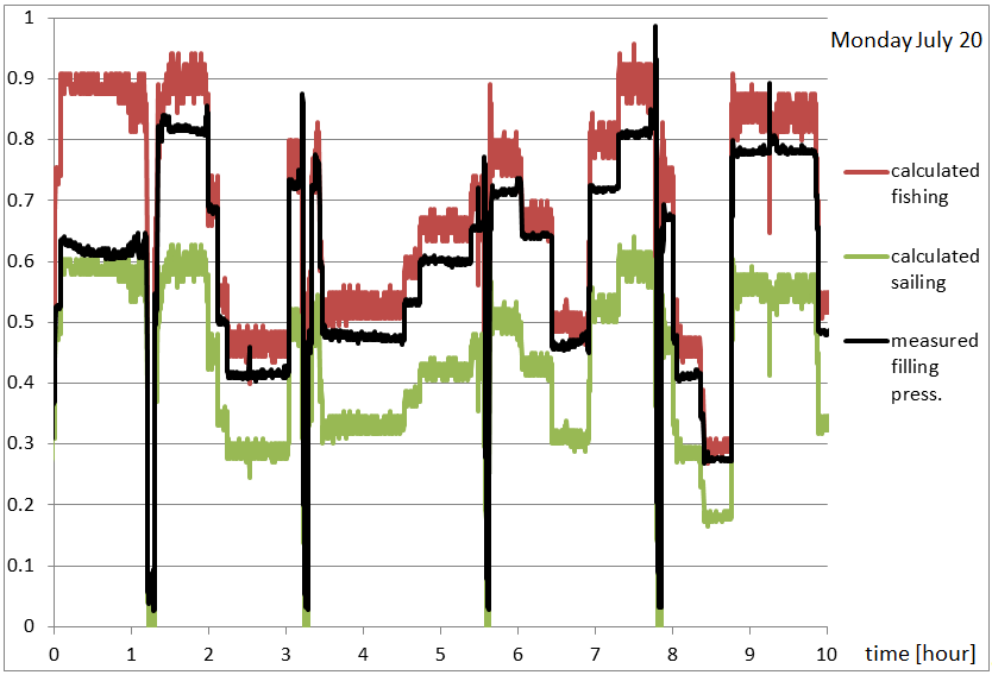

Figure 13 Calculated charging air pressure from measured RPM for fishing and sailing, as well as measured charging air pressure.

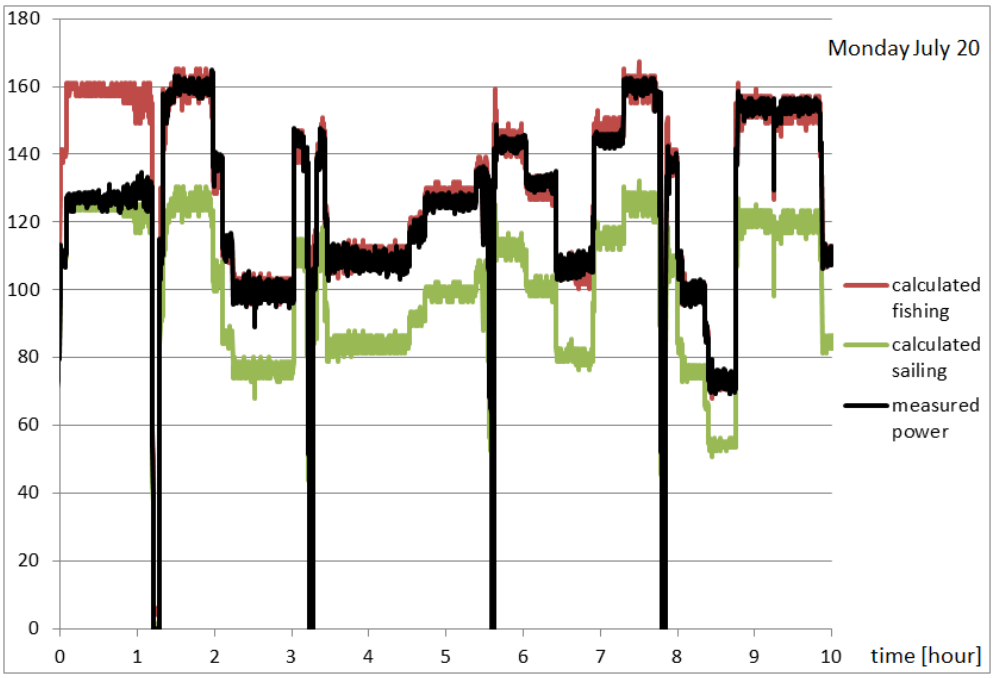

Figure 14 Calculated power from measured RPM for fishing and sailing, as well as measured power.

The ship first starts sailing for over one hour, where the measured (black) line follows the calculated (green) line of sailing.
Consecutively the ship starts fishing, where the measured (black) line follows the calculated (red) line of fishing.
In this way a clear distinction can be made between sailing and fishing.

The authority who manages the data can easily set up a scanning routine which can be used to indicate the ship's activity (sailing or fishing).
Additionally the exceedance of the maximum allowable ship propulsion power, while fishing, can be checked automatically.
From the GPS-data the ship's trajectory can be shown on a sea chart which also shows the areas closed for fishing.
Pending the ship's activity, sailing or fishing, the character of the trajectory-line can be changed, e.g. red for fishing and green for sailing.
The authority can extend the scanning routine with an algorithm which triggers on fishing in closed areas.

Figure 15 presents power lines, as found on Wednesday September 2th from 12:00 till 16:00.

At 12:00 the ship is sailing. Then from 13:22 till 13:42 the ship is not sailing and it is not fishing either. The fishing nets are being flushed, resulting in a line in-between the calculated fishing line and the calculated sailing line. At 13:42 the ship starts fishing again.

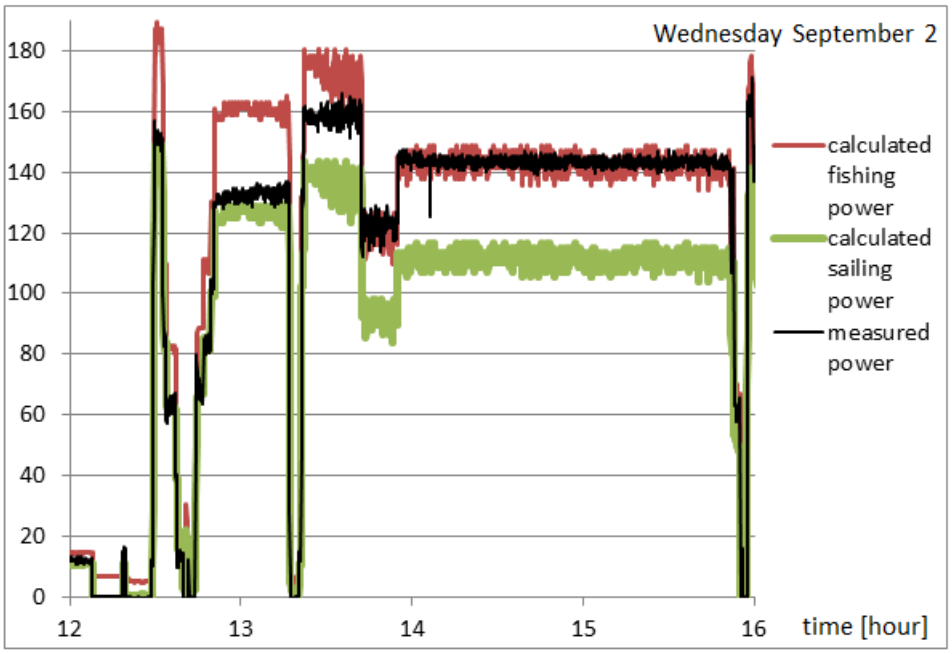

Figure 15 Calculated shaft power [kW] from measured RPM for fishing and sailing, as well as measured power.

4 Manipulation test

For this study we concentrated on manipulation of the system which cannot be determined by the black box registration.
So sabotage of antenna's (GPS-system, torque measurement, RPM measurement) is not included since such an action will be detected by the black box registration.
Also very sophisticated actions, like manipulating the GPS is not included.

Normally, charging air pressure can be used to determine the activity of the ship, sailing or fishing. In earlier discussions it was not clear if charging air pressure can be influenced.
It was decided to install a torque meter on the propeller shaft on board and try to manipulate the charging air pressure.
From measured torque and RPM of the propeller shaft the power can be calculated.

First preparations have been made to be able to manipulate the measured charging air pressure.
Figure 16 shows the original location of the pressure sensor (yellow circle).

Figure 16 Original location of the pressure sensor (yellow circle)

Figure 17 shows a detail of the pressure sensor at its original position, showing the seals.

Figure 18 shows the situation after the preparations. The seal is not broken. The pressure sensor is indicated by the yellow circle.

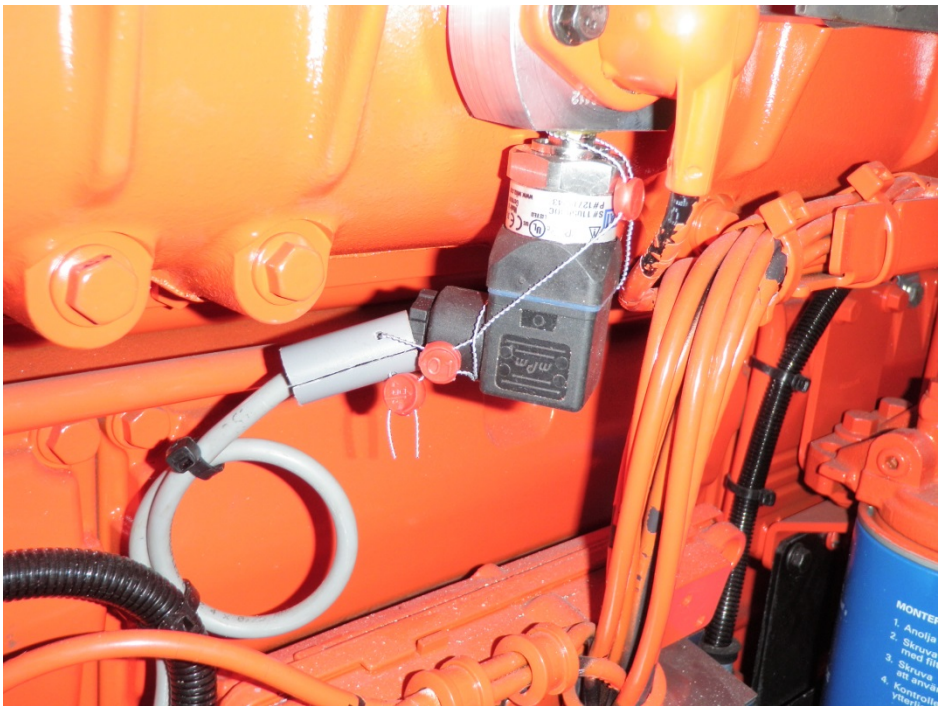

Figure 17 Pressure sensor as originally mounted, including sealing (source DCI Electronics bv)

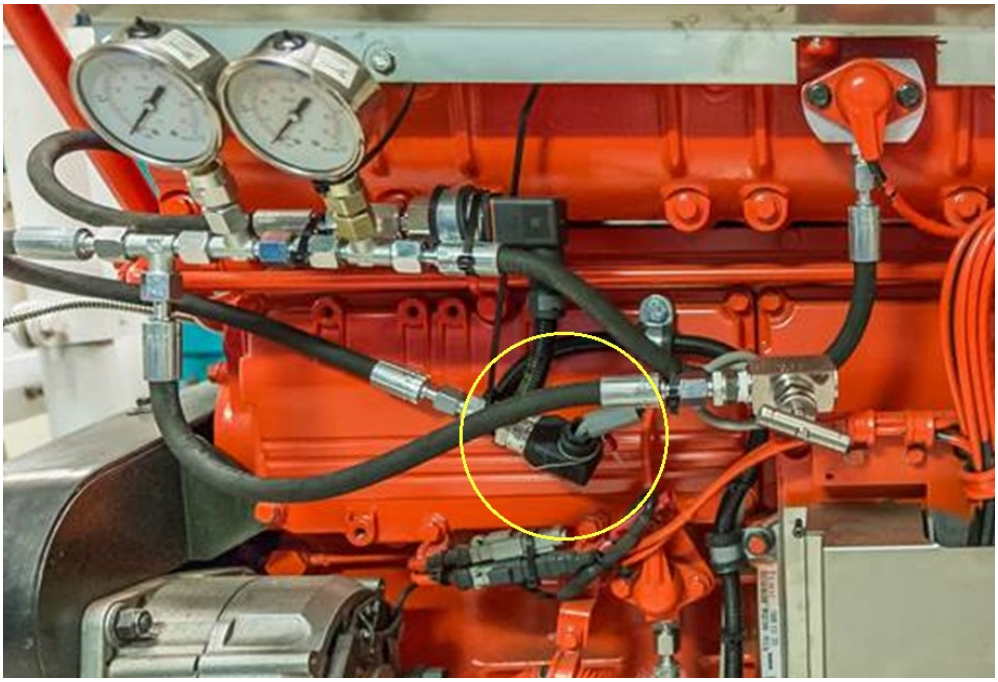

Figure 18 Modified position of the pressure sensor (yellow circle)

On Monday 31th of August TNO came on board to manipulate the charging air pressure.
The ship was fishing.
At 11:30 The pressure at the sensor was reduced from about 0.7 bar to about 0.46 bar and at 12:15 the manipulation was ended.
Figure 19 shows two manometers, the right one indicating the pressure at the engine and the left one indicating the pressure measured by the pressure sensor.

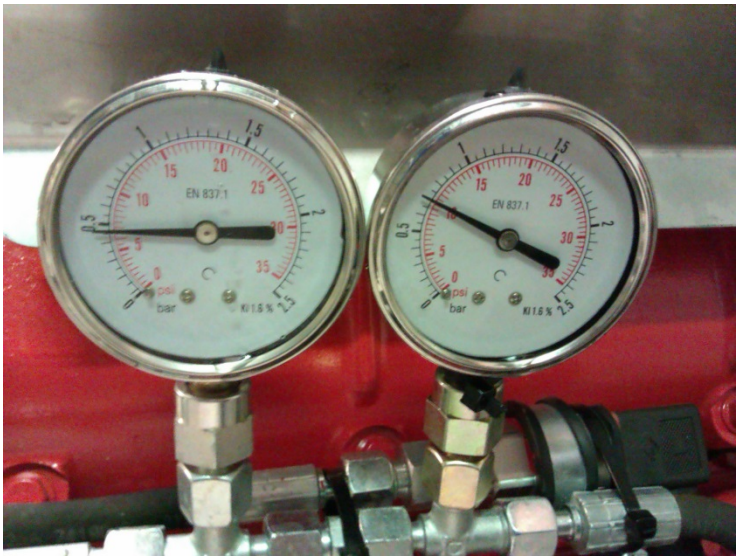

Figure 19 Pressure before restriction (at engine) and after restriction (pressure sensor)

In figure 20 time traces of calculated fishing power, calculated sailing power and measured power from 10:00 till 14:00 are presented.
From this figure it is concluded that the ship is fishing all the time.

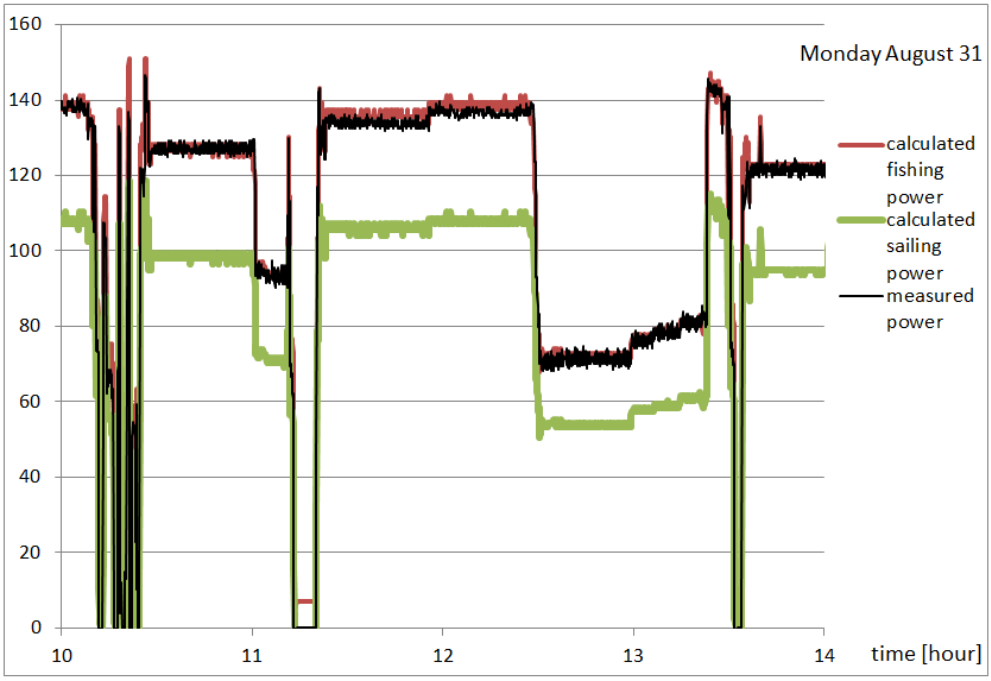

Figure 20 Calculated power from measured RPM for fishing and sailing, as well as measured power.

Figure 21 shows time traces of calculated charging air pressure during fishing, calculated charging air pressure during sailing and measured charging air pressure from 10:00 till 14:00.
From this data the black box system will conclude the ship is sailing between 11:30 and 12:15. However during this time span the measured charging air pressure was

manipulated downwards which suggests the ship is in free sailing mode. This however will not be detected by the black box system.

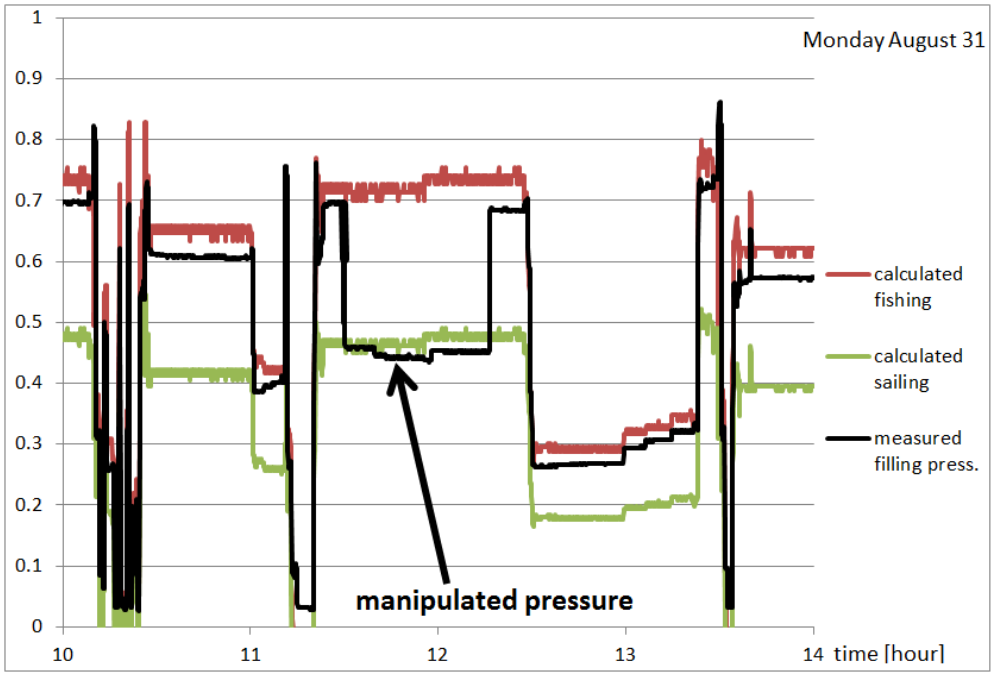

Figure 21 Calculated power from measured RPM for fishing and sailing, as well as measured power.

After the manipulation the pressure sensor has been mounted at its original position without breaking the seal.
In order to show some difference from the original situation and prove the sensor has been moved without breaking the seal some piping has been included when mounting the sensor at its original position again.

Figures 22 and 23 show the pressure sensor after being re-installed at its original position.

Figure 22 Pressure sensor after manipulation tests (seal not broken)

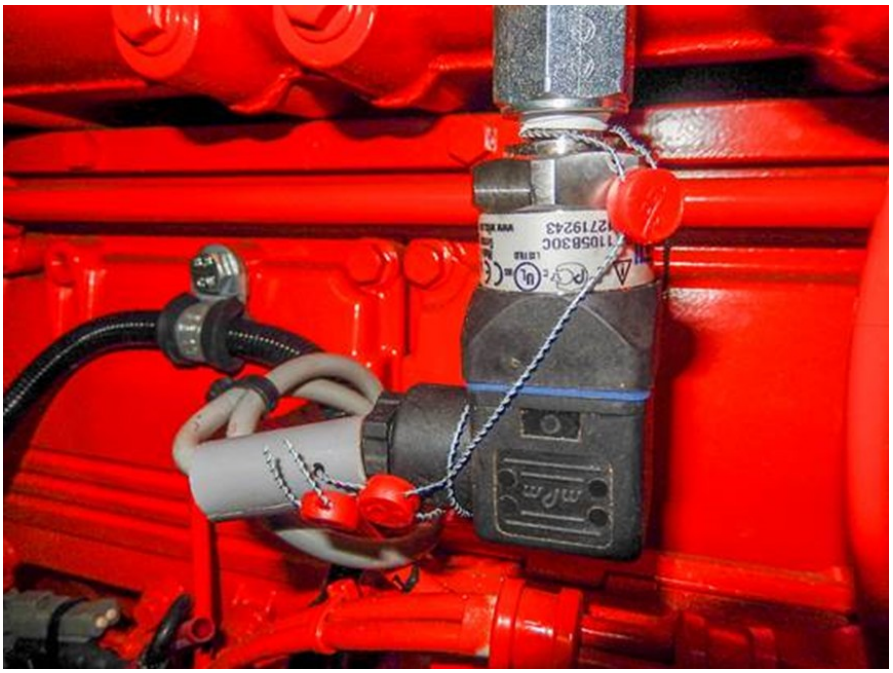

Figure 23 Pressure sensor after manipulation tests (seal not broken)

For manipulating the measured charging air pressure the most easy way was chosen. It is noted that several other options for manipulating the measured charging air pressure exist.

5 Conclusions

Long term data on ship position, propeller RPM, propeller torque and/or charging air pressure, acquired, recorded and transferred to a shore station, can be used to determine the operational status of a fishing vessel and the mechanical power absorbed by the propeller.

There is a clear relation between charging air pressure and power delivered by the engine.
There is a clear relation between power and RPM, which depends on the operational status of the ship, i.e. fishing or sailing.
There is a clear relation between charging air pressure and RPM, which depends on the operational status of the ship, i.e. fishing or sailing.

Plotting power levels or charging air pressure levels measured under operational conditions versus RPM shows a large scatter and can therefore not be used to determine the operational status of the ship.

Analysing measured power or charging air pressure data, measured under operational conditions in the time domain can be used to determine the operational status of the ship. This can be done by calculating the ‘theoretical’ values based on the sailing curve or fishing curve respectively from measured RPM and consecutively comparing these values with measured values.

Measured charging air pressure can be manipulated in such a way that the ship seems to be sailing while in fact she is fishing, without detection by the black box system.

The authority who manages the black box data can easily set up an assessment criterion which can be used to automatically indicate the ship’s activity (sailing or fishing).
Additionally the exceedance of the maximum allowable ship propulsion power, while fishing, can be checked automatically.
The ship’s activity, in conjunction with the GPS data, can be depicted by coloured lines on a map on which also prohibited fishing areas are indicated.

For manipulating the charging air pressure the most easy way has been chosen. However several other options for manipulating the charging air pressure exist.

References

[1] Projectplan Pilot Blackbox – logistiek en infrastructuur, bijlage bij brief Dienst regelingen, Ministerie van Economische Zaken, d.d. 7 augustus 2013, betreffende Beslissing op uw aanvraag EVF vis beschikkingen
[2] Black Box Shrimper; TNO report TNO-2014-R11509; B. Bosman and A.W.Vredeveldt
[3] Blackboxproefvaarten TX 33 en HD16; TNO memo TNO-2015-M-0100187799; A.W. Vredeveldt and B. Bosman
[4] Specificaties blackbox; TNO memo TNO-2015-M-0100281412; B. Bosman and A.W. Vredeveldt
[5] Black box specificatie; TNO memo TNO-2015-M-0100282337; A.W. Vredeveldt

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