Technical Sciences
Van Mourik Broekmanweg 6
2628 XE Delft
P.O. Box 49
2600 AA Delft
The Netherlands

www.tno.nl

T +31 88 866 30 00
F +31 88 866 30 10

TNO report

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Black Box Shrimper

Date	19 November 2014
Author(s)	Bosman B. Vredeveldt A.W.
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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.

Europees Visserijfonds: Investering in duurzame visserij

Ministerie van Economische Zaken

Summary

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

1. not entering areas where no fishing is allowed and
2. the maximum allowable ship propulsion power while shrimp fishing not exceeding 221 kW (300 hp).

This document reports the results of an investigation into the viability of such a system. An actual system, designed and manufactured by a Dutch company[1], has been tested on board two typical shrimpers. The main conclusion is that a black box concept is viable.

1 DCI Electronics

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. sails/ fishes with propulsion power exceeding a given maximum,
2. sails in prohibited areas.

Both aspects are important for controlling ecologically sustainable shrimp fishing, which is acceptable from a societal point of view. In this context it is considered vital that entrepreneurs abide the rules. Therefore there exists a need for a reliable system which can be used to verify whether this is the case.

Technologies are currently available for such verifications. A Dutch company[2] has developed a system which can be used for this purpose. The system consists of a data acquisition unit, a data storage unit and a data communications unit in conjunction with a Global Positioning System and at least two additional sensors. Two additional sensors are required because power is always a multiplication of two signals, i.e. a ‘driving force’ by a ‘’velocity’,e.g. pressure drop by fluid velocity, electric potential drop by electric current or torque by rpm.

Trial tests have been held with two typical fishing vessels, in order to verify the functionality of the system.

An attempt was made to determine propulsion power from propeller shaft rotation rate in conjunction with ship speed over ground and at a later stage also charge air pressure.

The findings are reported in this document.

2 DCI Electronics

2 Functional Specifications

The functional specifications can sub-divided into:

1. Data to be recorded,
2. Safeguards against data manipulating,
3. Environmental specifications.

2.1 Data to be recorded

The purpose of the black box is clearly stated;
1. Detect and record whether the shrimper sails in prohibited areas,
2. Detect and record whether the shrimper sails with a power exceeding the 300 hp (221 kW) limit.

A reliable way of detecting whether the shrimper sails in a prohibited area is through the use of data from a global position system. United States Government states on their website[3] an accuracy of 3.5 m in the horizontal plane. This is a fraction of the ship length which is considered sufficient.
It is recommended to use this system only because it is controlled solely by the US government and therefore well protected against unauthorised manipulation. Moreover receiver systems are very cheap and accessible to a large public.

The second purpose of the black box is to detect whether the 300 hp limit is exceeded. The pilot, reported in chapters 3, 4 and 5, has shown that the only undisputable way of measuring the propulsion power on board a ship is through measuring the torque on the propeller shaft and the shafts rotation rate (revolution per minute, rpm). A very simple calculation with torque and rpm as input yields the shaft power. It is recommended that torque and rpm are logged and sent ashore.

2.2 Safeguards against data manipulating

Since the system is used for law enforcement it is important that manipulation by non-authorised persons is not possible. This requirement can be met relatively easily by complying with the following;

1. An alarm must be generated when the black box is opened,
2. It must be possible to detect a disconnected sensor,
3. An alarm must be generated when the electrical power is disconnected,
4. The black box should have an internal power supply and should be able to function during at least 14 days when the external power supply is not present,
5. The black box should have sufficient memory on board for data storage during at least 14 days, at a recording interval of 60 seconds,
6. The sensors must directly be connected with the black box, using a cable in one part without any junction box.

[3] http://www.gps.gov/systems/gps/performance/accuracy/

When an alarm is generated, a message must be transmitted ashore as soon as the system is within gsm range. Additional alarms of the same ship, within the same calendar day need not be transmitted ashore, however they should be logged by the black box.

2.3 Environmental specifications

The equipment must comply with requirements for application on board ships, confirmation with at least the CE-mark must be demonstrated.

3 Installation Black Box and Sensors

Two ships have been equipped with a typical black box[4];

1. HD 16,
2. TX 33.

The black boxes were installed by the vendor. Vendor also installed the rpm sensors including the signal cable between sensor and black box. Figure 1 shows the rpm sensor. This sensor is sensitive to a changing magnetic field. This change occurs at each passage of the steel strip (see figure) which is mounted on one of the retaining bolts of propeller shaft flange.

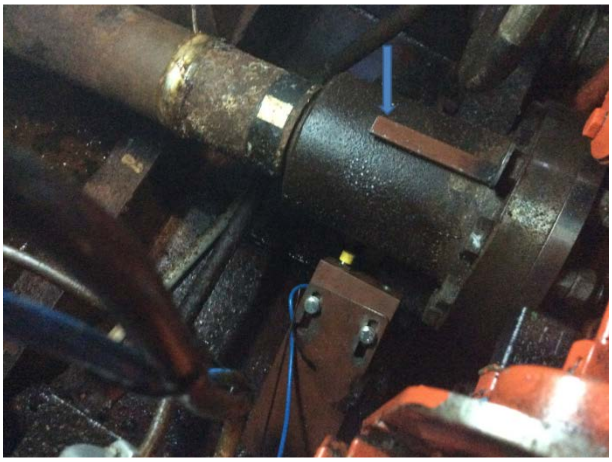

Figure 1 Typical rpm sensor (yellow) with steel strip (arrow) (HD16)

Vendor also installed a GPS antenna as shown in Figure 2.

Figure 2 GPS antenna (TX33)

Also the existing charge air pressure sensor was connected to the black box.

4 Make: DCI Electronics

The sensor signal cable(s) are led to a junction box as shown in Figure 3.

Figure 3 Typical electrical signal cable junction box (left HD16, right TX 33)

Typical mountings of the black box are shown in Figure 4 (arrow) and Figure 5.

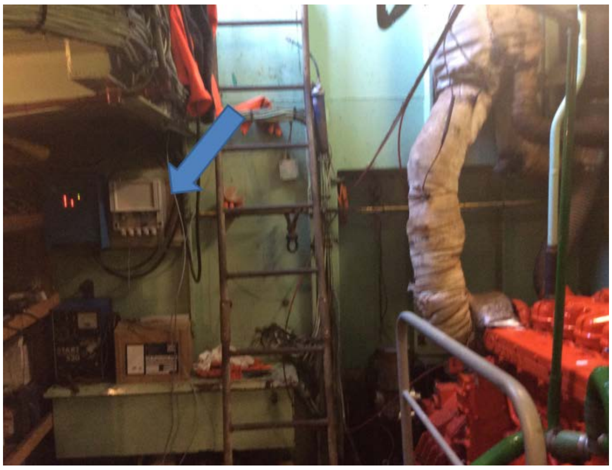

Figure 4 Black box located in engine room (arrow) (HD16)

Figure 5 Black box located on bridge (TX33)

A typical mounting of the charge air pressure sensor is shown in Figure 6. It is noted that the gauge is not directly mounted on the engine but via a pressure hose.

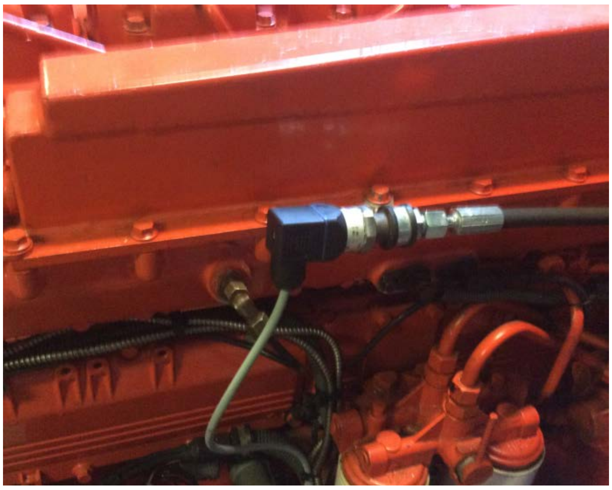

Figure 6 Turbo pressure gauge (HD16)

4 Observations

4.1 Additional measuring equipment

For calibration purposes additional measuring equipment was installed on the ships.

Propeller shaft torque and rpm.
For measuring actual propulsion power, a temporary propeller shaft torque/ rpm measuring device was fitted. The systems consists of electronic strain gauges which are bonded diagonally on the propeller shaft with an adhesive. These gauges measure the torsional strain in the propeller shaft, which is a direct measure for the torque in the shaft. These strains are electronically processed and consecutively transmitted through a wireless transmitter because the shaft rotates, (the box with antenna as shown in Figure 7).

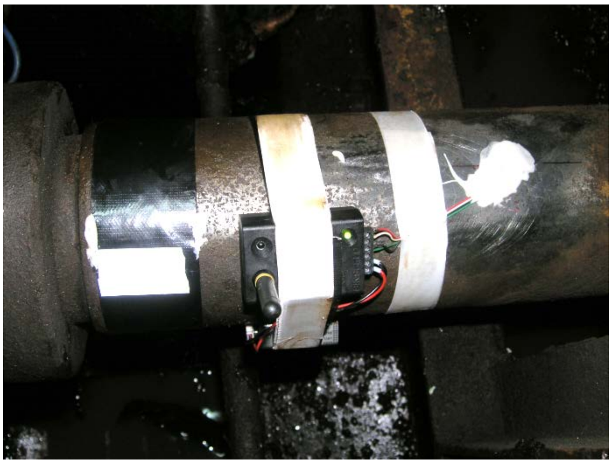

Figure 7 Telemetry emitter on propeller shaft (HD16)

A receiver then picks up the transmitted strain signal which is then led toward a laptop computer.
In addition a laser based transducer is mounted on the ship, near the propeller shaft, pointing to a black (dark) belt with a white patch on it, bonded around the circumference of the shaft. When the white patch passes the laser beam the system detect this as a pulse. The number of pulses per minute is counted by the data acquisition/ analysis system. It equals the rpm of the shaft.

Ship speed through water
A water flow speed impeller was installed in order to measure the speed of the ship through the water. Figure 8 shows the device. The device was rented from the Deltares[5].

[5] http://www.deltares.nl/en

Figure 8 Impeller for ship speed through water

Figure 9 shows how the impeller was mounted on the ship.

Figure 9 Impeller mounted on ship (HD16)

4.2 Trial Tests Results

Figure 10 and Figure 12 show the actual ships speeds measured during the trial tests for HD16 and TX33 respectively.

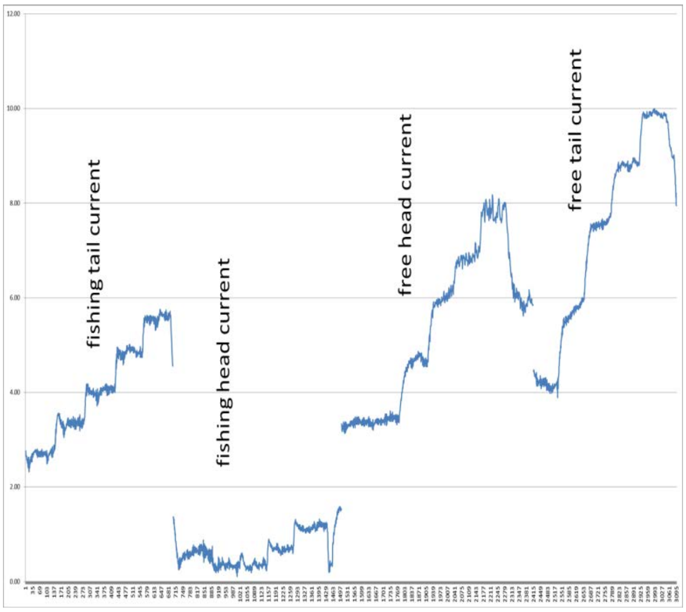

Figure 10 Trial tests HD16, speed over ground in knots (bollard pull not shown)

Figure 11 shows the propeller shaft rotation rates which were set during the trial tests.

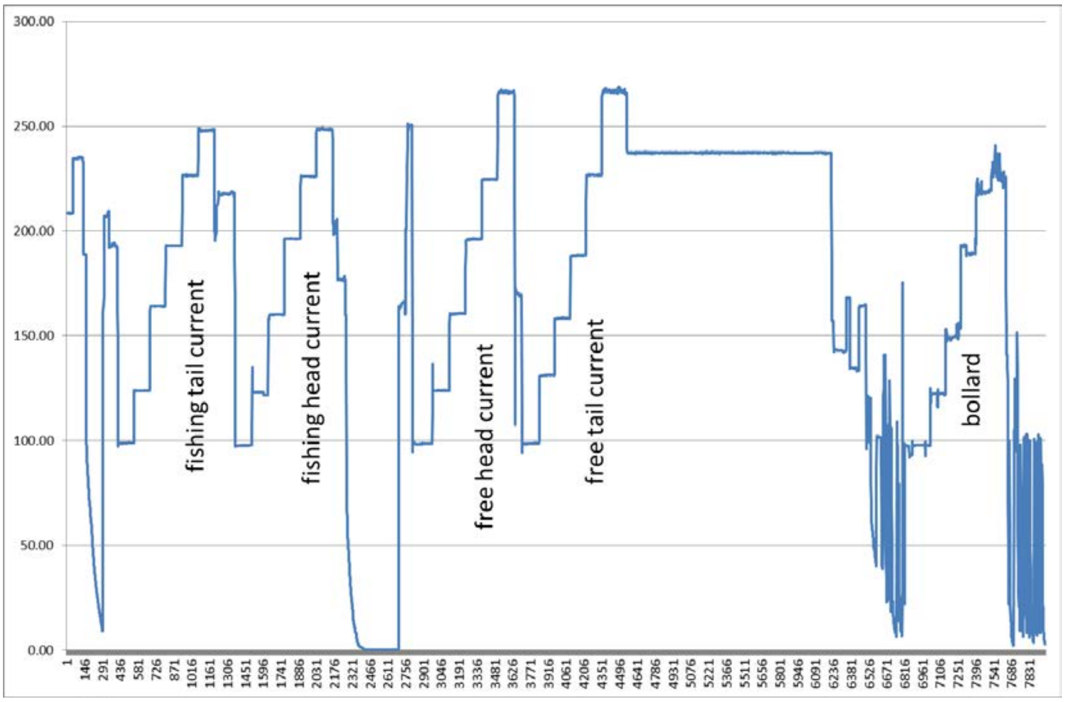

Figure 11 Trial tests TX33, rpm.

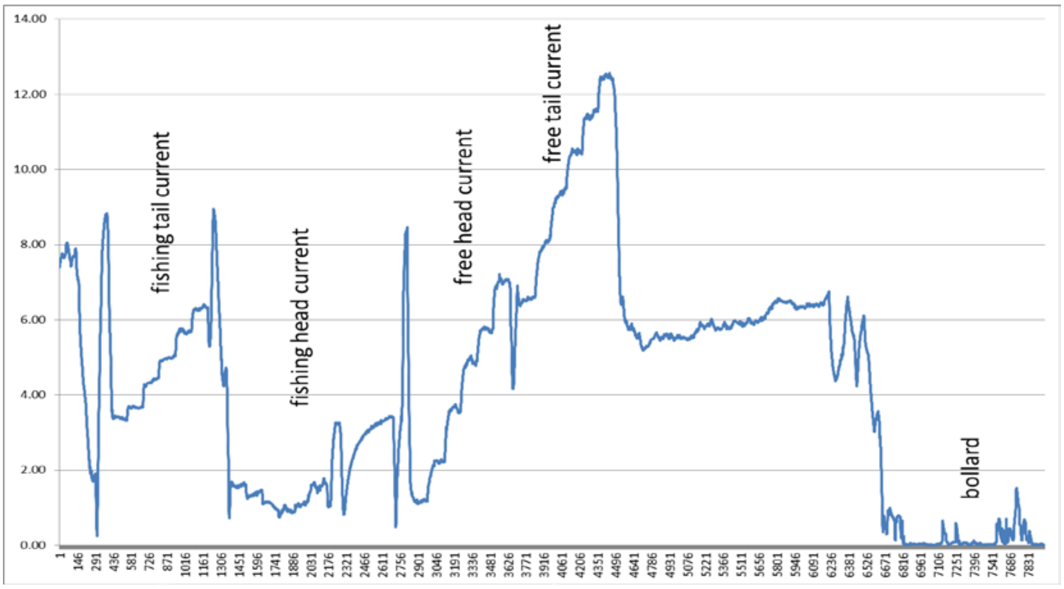

Figure 12 Trial tests TX33, speed over ground in knots

Figure 13 and Figure 14 show the power versus rpm curves as measured during the trial tests, for HD16 and TX33 respectively.

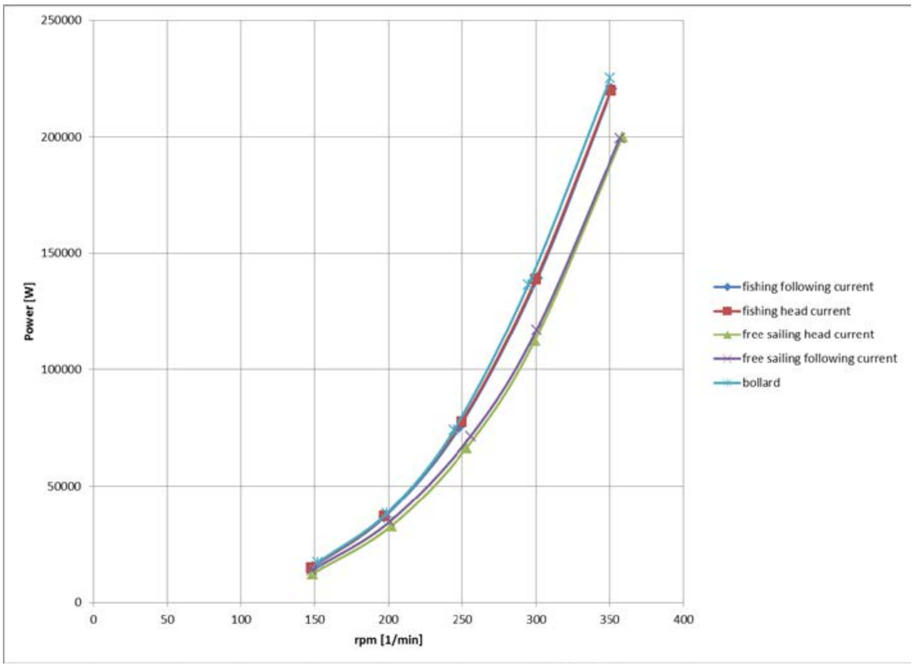

Figure 13 Power versus rpm, HD16

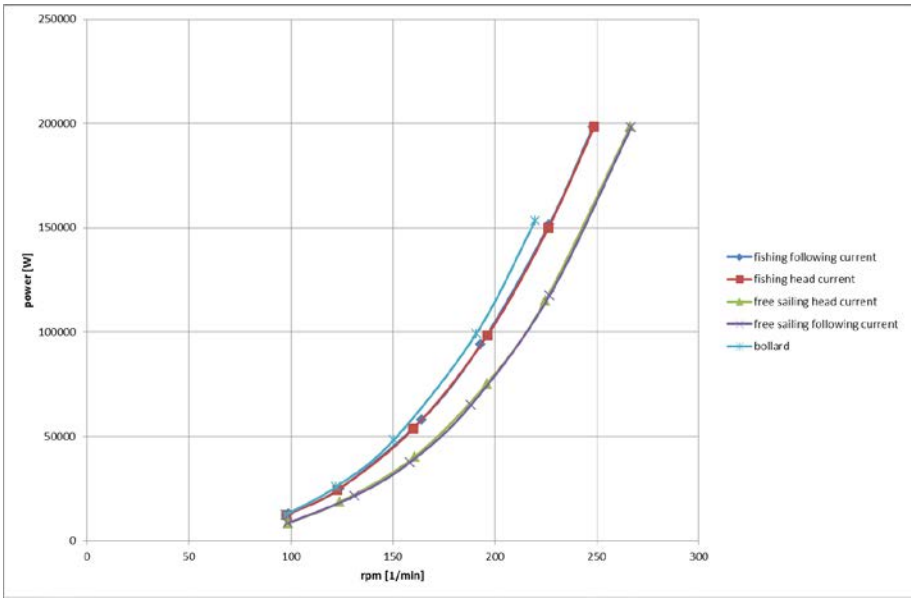

Figure 14 Power versus rpm, TX33

It is entirely within the expectation that bollard pull takes more power at the same rpm than fishing and fishing again more than free sailing.

4.3 Long Term Data Acquisition

Location of ship

Figure 15 shows a one week position track as measured during week 33. The coast line, i.e. the formal border between land and water, is indicated by the yellow line. This data is derived through GPS observations and initially logged in the black box. Since in this case the ship proves to be well within GSM coverage, the data could be retrieved at any time. In exceptional cases the ships may not be within coverage. In such cases the observer needs to wait until the ship is back within reach.

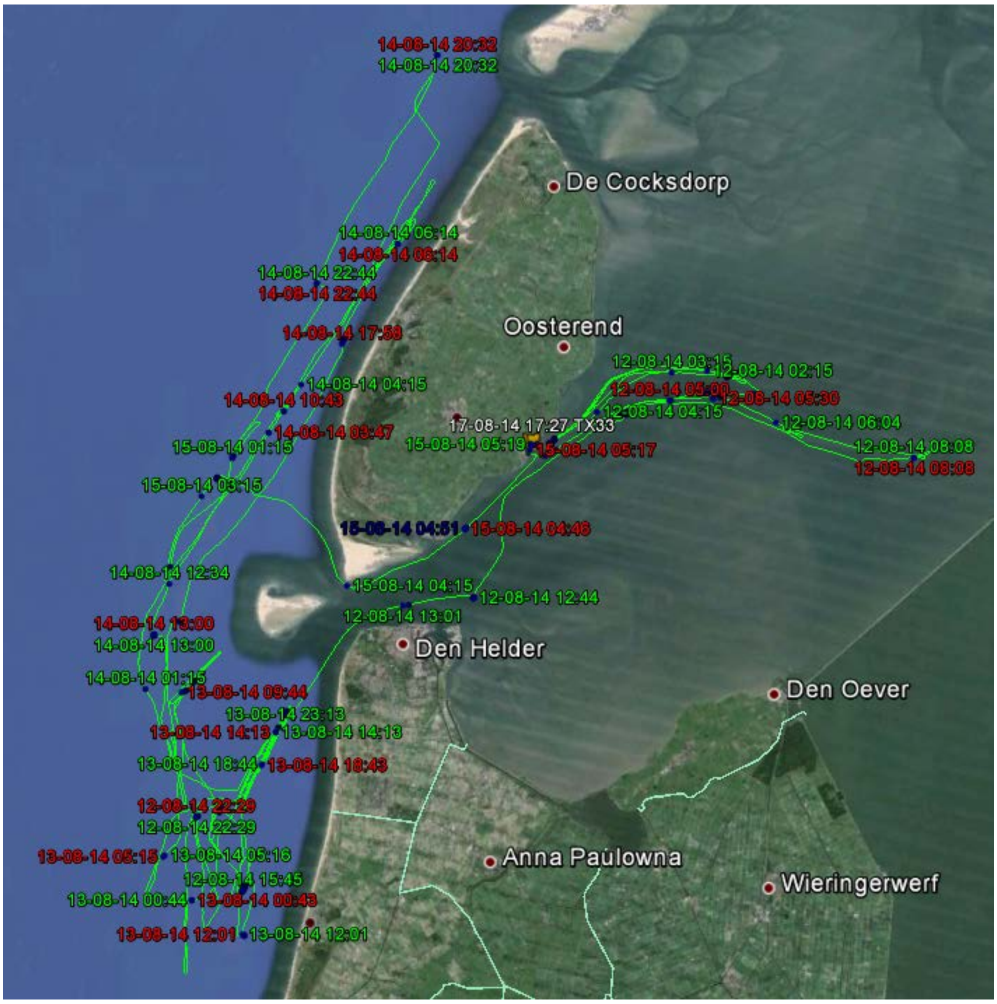

Figure 15 Typical week time track (TX33, week 33) (source DCI Electronics).

The position of the ship is stored digitally, i.e. as data files. The general accuracy of GPS without any additional devices is generally 3.5 m horizontally[6]. This accuracy is suitable for law enforcement with respect to sailing/ fishing in prohibited areas. It is important to note that no on board access to the GPS records is possible.

6 http://www.gps.gov/systems/gps/performance/accuracy/

Operational modes
Since it is quite feasible to log data during extended periods of time at rather short time intervals, it is possible to detect trends in the data.

From long term observations on both the TX33 and the HD16 the manufacturer of the black box[7], used in the pilot, has been able to determine in which mode the ships operate, albeit in 90% of their total operational time (either fishing or free sailing). A typical recording of a fishing week, which is used for this purpose, as shown in Figure 15, is shown in Figure 16 and Figure 17. Only in 10% of the operational time, i.e. not moored, it is unclear what the ship does; e.g. just idling or handling the nets. This observation is based on the recordings of the charge air pressure in conjunction with the ship position.

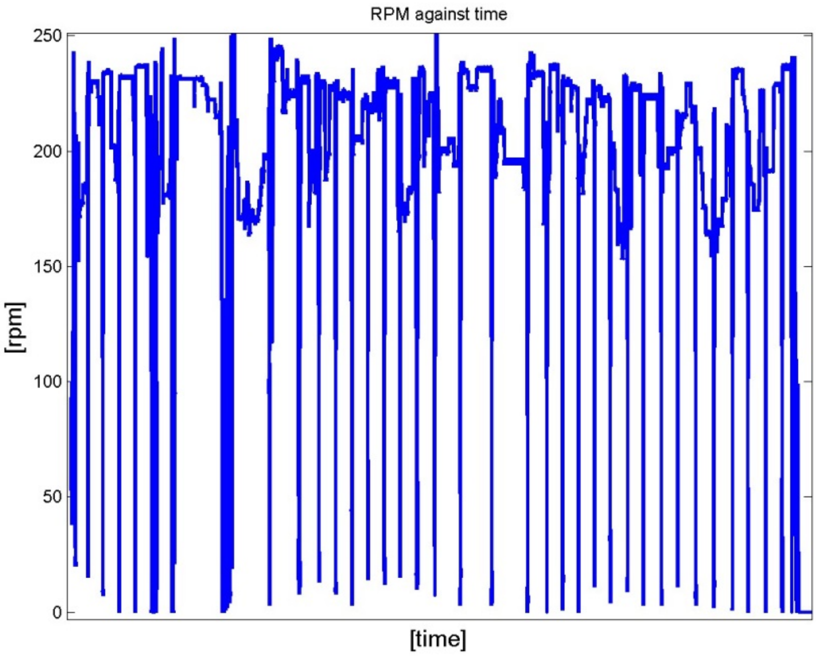

Figure 16 typical time trace propeller shaft rpm (TX33, wk 33)

[7] DCI Electronics

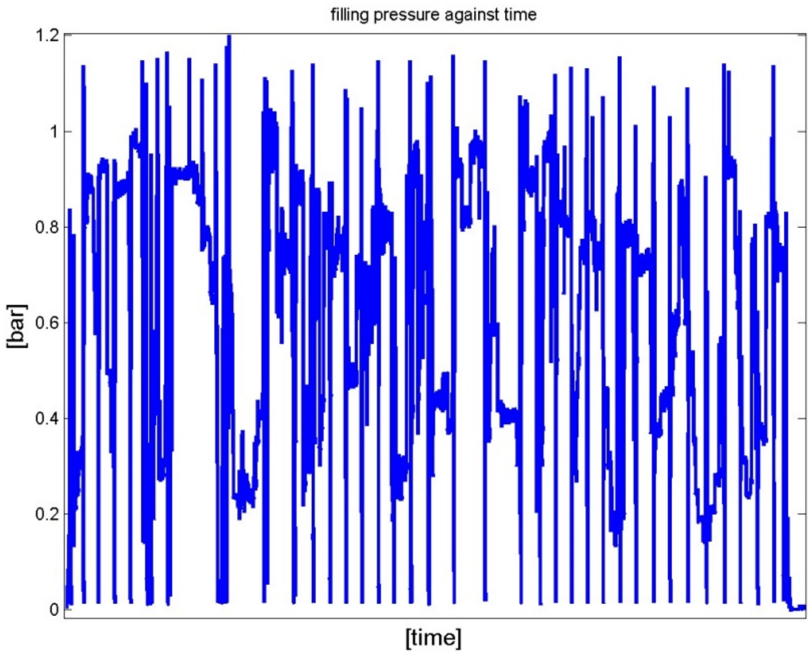

Figure 17 typical time trace charge air pressure (TX33, wk 33)

The question was raised whether this observation can be used in any statistically meaningful way. It was suggested that knowing the operational conditions of the ship during 90% of its time, given the logged data has a 100% reliability, implies a 90% accuracy.
However from a methodological point of view this idea is hard to defend. Although a 90% time coverage with respect to the operational mode of the ship is very useful from a enforcement point of view, it does not imply anything about accuracies.
It is interesting to observe the correlation between the air charge pressure and shaft rpm, based on the measurements during a full fishing week. Figure 18 shows this correlation.

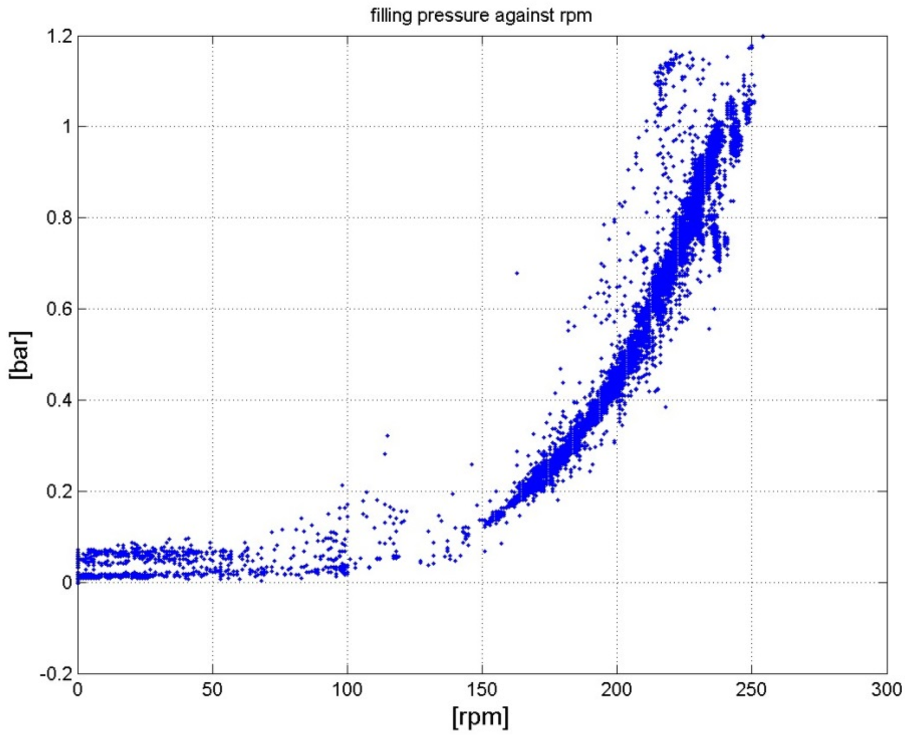

Figure 18 typical trend plot charge air pressure vs propeller shaft rpm (TX33, wk33)

A clear trend is visible, however a clear scatter is visible as well, especially at higher shaft rpm.
Long term measurements may be useful for detecting a systematic overpowering. However overpowering on an incidental basis will not be detected.
The manufacturer of the black box which was used in this pilot, is dedicted to write a separate report on the long term measurements theme.

4.4 Data Analyses

4.4.1 Power based on shaft rpm and ship speed

There exists a clear relation between propeller shaft torque, propeller shaft rpm and advance speed of the propeller, which is entirely determined by the propeller characteristic, in literature known as the K_t K_q J diagrams (see ref. [3]). An example is shown in Figure 19.

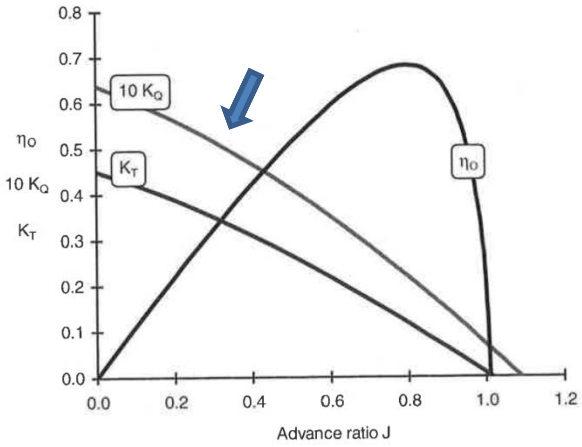

Figure 19 Typical propeller characteristic[8]

K_q and J are non-dimensional parameters;

$$Kq = \frac{Q}{\rho\, n^2\, D^5}$$

$$J = \frac{V}{n\, D}$$

With K_q torque coefficient [ ],
J advance coefficient [ ],
Q torque in propeller shaft [Nm],
ρ mass density water [kg/m3],
n rotation rate propeller [1/sec],
D propeller diameter [m],
V water inflow speed propeller [m/s].

Only the K_q - J curve is relevant within the context of this report. K_t and η_0 can therefore be ignored. As said, the K_q - J curve is a propeller characteristic which can only be changed by physically changing the propeller. It is not influenced by changing propulsion engine settings.
This curve can be determined experimentally by conducting trial tests while measuring propeller shaft rpm, propeller shaft torque and propeller advance speed, which is basically the ship speed through the water.

[8] Source: ref [3]

This analysis has been done on the trial test data obtained for the TX 33. Five sailing conditions have been investigated;

1. Fishing with tail current ,
2. Fishing with head current,
3. Free sailing with head current,
4. Free sailing with tail current,
5. Bollard pull.

Each condition was run at five consecutive rpm. At each condition, rpm speed and ship speed were measured. Ship speed was measured both as speed over ground (sog, from GPS) and speed through water (log, from impeller[9]). Thus for both parameters 5 data points were obtained for each sailing condition.
Using the formulas for K_q and J, these can be plotted in the K_q – J diagram, as shown in Figure 20.

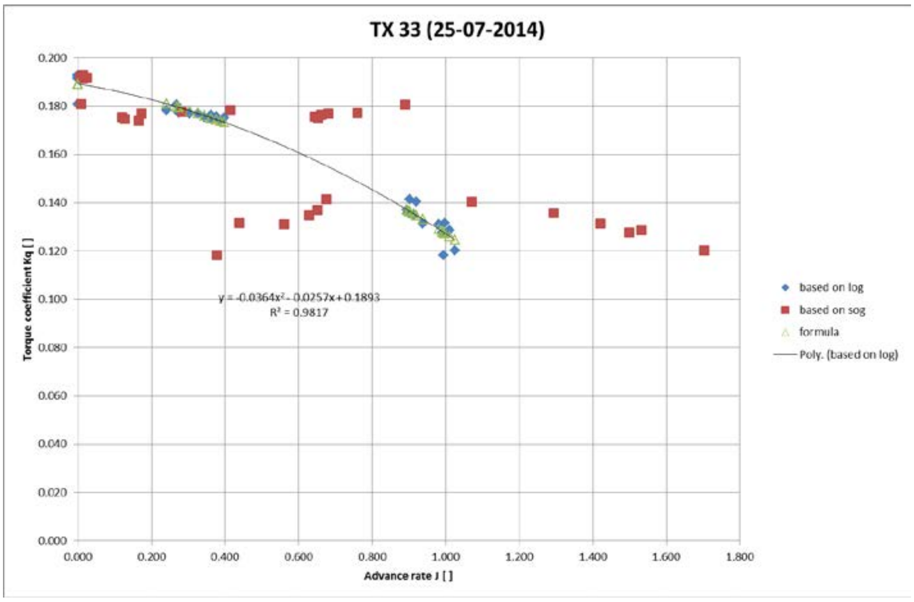

Figure 20 Propeller characteristic TX 33

The inclined cubicles (◊) depict the results obtained from shaft rpm, shaft torque and ship speed through water. A trend line fitted to these data is also shown (Δ). As can be seen the R-squared value, the value reflecting the error (100% is no error), lies at a satisfactory level of slightly over 98 %.
When ship speed over ground (sog) is used as input the data points indicated by the lying cubicles are obtained (□). Clearly this result does not show a satisfactory correlation and is therefore not useful.

4.4.2 *Power based on shaft rpm and charge air pressure*

The trial test data also included charge air pressure time traces. From this data, for each of the five sailing conditions and each of the five propeller shaft rpm, averages have been calculated. These values are plotted in Figure 21 and Figure 22 for the HD16.

9 See Figure 8 and Figure 9

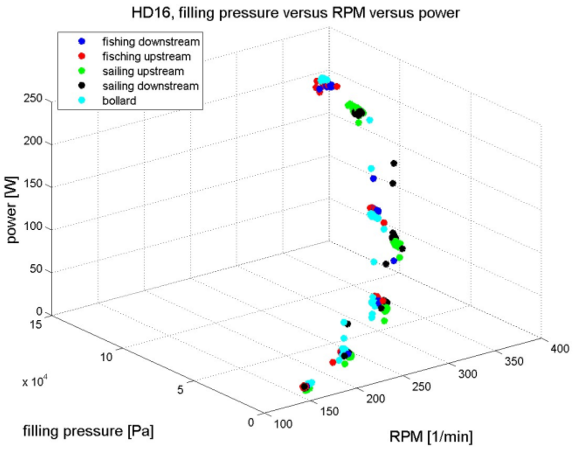

Figure 21 Power vs charge air pressure (turbo pressure) and rpm (HD16)

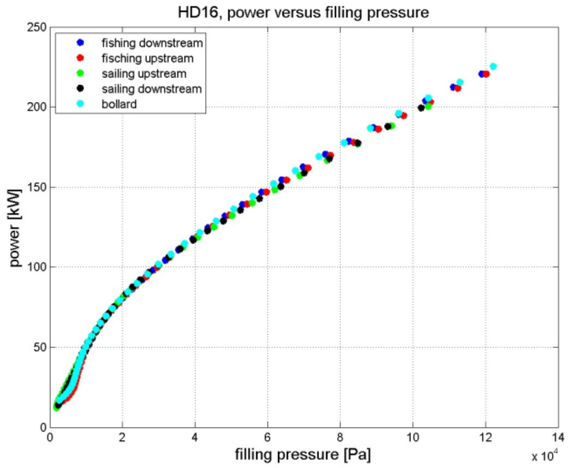

Figure 22 Power vs charge air pressure (turbo pressure) (HD16)

Figure 23 and Figure 24 show the results for the TX 33.

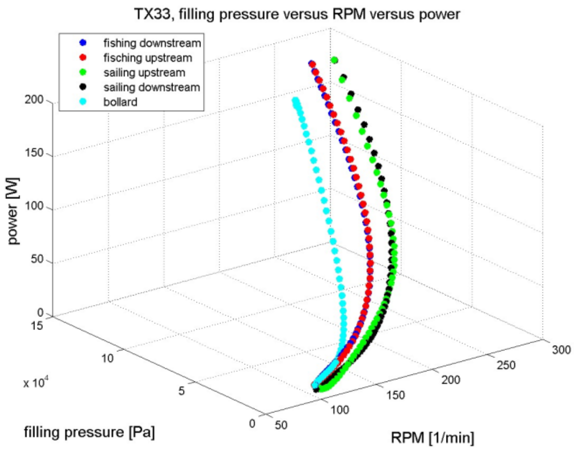

Figure 23 Power vs charge air pressure (turbo pressure) and rpm (TX33)

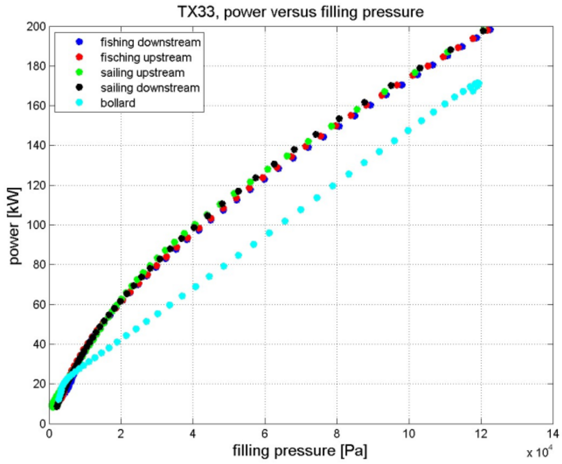

Figure 24 Power vs charge air pressure (turbo pressure) (TX33)

The correlation between power and air charge pressure is good. It is however not clear why the bollard pull curve deviates from the other curves in case of the TX33.

5 Discussion

Shaft rpm and speed over ground (GPS)
The idea of using simple and robust sensors to determine where a ship sails and with what propulsion power it sails is very attractive. Clearly a simple GPS receiver and a rpm sensor, e.g. a proximeter or a laser sensor, comply with the requirement of simplicity and robustness. Since these sensors give ship speed and propeller shaft rpm it is, at least in principle, possible to determine with what power the ship sails. For this to work it is crucial to determine the propeller characteristics, which requires a dedicated trial test, where shaft torque and speed through water are measured. It is noted that propeller characteristics are very difficult to change because it requires physical changes to the propeller which implies the need for dry docking. The validity of this idea has actually been demonstrated in section 4.4.1. However this concept only works in case of the ship speed measured through the water. GPS gives speed over ground, which is equal to the speed through water when there is no current. Obviously, in coastal areas there is always current. Simply ignoring the effect of current and using speed over ground yields data point as shown in Figure 20 by the red boxes (based on sog), which demonstrates the lack of reliability.
A disadvantage of this concept is the need for a ship speed through water sensor. The simple impeller based sensors are not expensive but very vulnerable. The more robust systems, usually based on ultrasonic Doppler effect, tend to be relatively expensive, i.e. hardware costs are around € 6000,=[10], without installation and dry docking.

Charge air pressure
Another possibility to determine with what propulsion power a ship sails might be by measuring the charge air pressure. In section 4.4.2 it is shown that indeed a clear correlation exists between propulsion power and charge air pressure, which is confirmed in section in 4.3. In case of the TX33 the bollard pull case does not follow the free sailing and fishing curves. However the charge air compressor (usually the turbo charger), is a device which is mounted on the engine. It is fitted with means to adjust to optimal settings, e.g. the waste gate. Hence it is also easy to manipulate the power - charge air pressure curve which makes the curve measured during a dedicated sea-trial invalid. However long term observation may be useful to detect changes in the trend.

Direct shaft torque/ rpm measurements
The pilot study relies on a temporary shaft torque measuring system for determining propulsion power and rpm. The question was raised whether a similar system could be mounted on a permanent bases. This proves to be the case. In fact recently one fishing boat was equipped with such a system (Figure 25).

[10] Source: E-mail exchange TNO-Eijkelkamp (https://en.eijkelkamp.com/)

Figure 25 Typical permanent arrangement propeller shaft torque-rpm measurement system[11]

Typical hardware costs are around € 4000,=[12]. Installation costs would take typically 8 man hours. There is no need for any dry docking or a trial test.
GPS data would still be required for checking whether a ship sails in prohibited areas.
This approach is seen as a reliable, robust and cost effective option.

11 Source: Ingenieurbüro m+m schlott

12 Source: E-mail exchange TNO-Ingenieurbüro m+m schlott (www.mmschlott.de)

6 Conclusions

Shaft rpm and ship speed
In general the concept of deriving propulsion power from propeller shaft rotation rate (rpm) and ship speed is sound. However the approach is reliable only when ship speed through water is used as input parameter.
It is crucial to determine the propeller characteristics through a dedicated trial test.
It is very difficult to manipulate the propeller characteristics.

Deriving propulsion power from propeller shaft rotation rate (rpm) and ship speed over ground, i.e. when based on GPS data, is unreliable.

Measuring ship speed through water in a reliable and robust fashion, is feasible. However such measurements require relatively expensive equipment and may therefore be unattractive.

Turbo pressure
There is technical evidence available which indicates that a clear relation exists between charge air pressure and propulsion power. However the actual curve depends on the settings of the turbo charger, most notably the setting of the waste gate.
It is easy to manipulate charge air pressure measurements.
However, long term observation may be useful in detecting changes of main correlation between charge air pressure and shaft rpm and hence shaft power. A report on this issue has been announced by the manufacturer of the black box[13] which was used in the pilot.

Shaft rpm and torque
A permanent system which measures propeller shaft torque and rpm, in conjunction with a GPS and a black box, is seen as the most viable option to fulfil the requirements related to detecting if a shrimper;

1. sails/ fishes with propulsion power exceeding a given maximum,
2. sails in prohibited areas.

When measuring permanently propeller shaft torque and rpm there is no need for any dry docking or a trial test.

[13] DCI electronics

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Signatures

Customer:
Stichting Verduurzaming Garnalenvisserij
P.O. Box 64
83OO AB Emmeloord
The Netherlands

Project team:
A.W. Vredeveldt
B. Bosman
H.T. Pronk

Dates in which the work was carried out:
March 2014 – November 2014

Authors:

A.W. Vredeveldt
Author

B.Bosman
Author

Approval:

H.T. Pronk
Reviewer

Visa:

S.H.J.A. Vossen
Manager Structural Dynamics