Development of a portable measurement system for the investigation of the engine power at sea by supervision personnel

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List of participants and their allocated tasks

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Summary I

Recent EU Regulations have established zones of fishing closed to certain classes of fishing vessels. However, special licenses are granted for vessels with less than a specified engine power. Thus the enforcement of these regulations requires the ability of inspectors to routinely check the propulsion power of vessels fishing in the designated areas. This project was intended to develop the equipment for them to do so.

The RWTH-Aachen proposed and developed a portable system for measuring fishing vessels main engine power at sea („Torque Control" system) measuring the twist of the propeller shaft. Two divisible gearwheels are mounted on the propeller shaft at a distance of 100 to 300mm from each other. The torque is calculated by measured values of the displacement between every pair of facing teeth of both gearwheels. The values of displacement are averaged by software on a portable PC and the propulsion power is calculated according to values of displacement, number of revolutions, and mechanical constants and dimensions of the propeller shaft.

Tests conducted on commercial fishing vessels last year revealed great problems with this system. Fishing vessels with propeller shafts designed for more than 221 kW require a greater distance between the two gearwheels to guarantee a minimum accuracy of 10%. Tests in November 1996 on fishing vessels with no bearing between the gear box and the stern gland have showed that sea motion and manoeuvres strongly influence the measured torque values. Sometimes the erroneous readings of the measured engine power was more than 200 kW at a range of 300 kW. The reason for this was the movement of the propeller shaft in the stern gland caused by a 0.5mm clearance of the gland, a value common to a lot of vessels. Taking into account the grave errors and the limited applicability of this system it is not suitable for monitoring of the engine power of vessels fishing in the plaice box at sea.

Tests were conducted on a simple system for measuring displacement. Utilising a micrometer gauge it measures the displacement between to supports rigidly connected around the circumference of two planes of the propeller shaft at a distance of 100mm from each other. The supports are mounted on the propeller shaft with chains. Readout of the rotating gauge display is possible taking advantage of stroboscopic effect. For this purpose a mark on the propeller shaft is used to trigger a flashlight. The system showed good results at high power levels but some problems occurred at lower levels and levels near zero. The tests were carried out at a diesel engine test bed of the Technische Universität Hamburg-Harburg. Further investigations will be undertaken after completion of this project.

In addition to this a measuring system based on torque measurement with strain gauges was developed. A commercial telemetry unit with magnetic transmission of data and power supply was modified. The transmission unit's coils were replaced by a flexible printed circuit board with two printed transmission coils, designed for better transmission and reliability. This board enables the user to very quickly and easily align two strain gauge half bridges for bending stress compensation opposite each other on either side of the shaft ensuring high accuracy. To avoid simple calibration a strain gauge bridge amplifier controlled by an interface for adjusting the zero offset and gain was developed. The adjustments are calculated by a PC and transmitted by an interface to the amplifier before starting the measurements. The preparation of the propeller shaft for mounting of the strain gauges should require 15 minutes or less. For this purpose a polished facet of 30 mm square on the propeller shaft protected against oxidation is needed. Alternatively strain gauges can be dot welded on. For this purpose a special equipment must be developed further on.

The project also aims to develop a simple engine power self recording unit for study and test purposes. This system used a microcontroller with analogue inputs which are interfaced to a strain gauge bridge via an amplifier and an acceleration sensor measuring the number of revolutions. Both the sensors and the battery for power supply are placed in a box mounted on the propeller shaft and cast with resin. The equipment will thus be tamper-proof except by physical damage. This system showed some software problems and needs further development before it can be used for monitoring engine power of fishing vessels.

Summary II

Recent EU Regulations have established zones of fishing closed to certain classes of fishing vessels. However, special licenses are granted for vessels with less than a specified engine power. Thus the enforcement of these regulations requires the ability of inspectors to routinely check the propulsion power of vessels fishing in the designated areas. This project was intended to develop the equipment for them to do so.

The „Torque Control" system to measure the speed, torque and propulsion power of fishing vessels was developed by the RWTH-Aachen during the project. The torque is measured by determination of the propeller shaft twist. The accuracy of the measurements obtained in the product testing department equals that of the results achieved in strain gauge measurements. However, notably less time and energy are needed to carry out a measurement. Assuming trained personnel and favourable circumstances, a measurement can be carried out within a very short time.

Two divisible gearwheels or shopper disk's are mounted on the propeller shaft at a distance of 100 to 300mm from each other. The torque is calculated by measured values of the displacement between every pair of facing teeth of both gearwheels. The values of displacement are averaged by software on a portable PC and the propulsion power is calculated according to values of displacement, number of revolutions, and mechanical constants and dimensions of the propeller shaft. Various types of sensors and transmitting devices have been developed for this measuring system, taking the requirements of the fishing vessels into consideration. Because of the enormous deviations when altering the distance, magnetic Hall sensors are inadequate for practical purposes. Light barriers display much better measuring characteristics as well as a higher measuring accuracy. Flexible chains and divisible chopper disk's were developed as transmitting devices for these light barriers. Two pairs of these chopper disks, suitable for shaft diameters of 80 to 120 mm and 120 to 200 mm, have been produced and tested.

Hardware and software were improved and adapted to the diverse transmitting devices and sensor elements during the course of this project.
A great deal of attention was given to the development of appropriate sensor supports during the project. A prototype portable sensor support which was held on the shaft by the contact pressure of roller and ball bearings was used in the laboratory as well as on the fishing boat *Poseidon*. Unfortunately, this concept could not be pursued further on account of the marginal conditions. Instead, a solution was found whereby the sensors are fastened to the ship by suitable clips and locked in place with hydraulic support systems. This solution can be significantly improved through holding devices which are fitted to the ship. The measuring system which was developed underwent extensive testing in both the laboratory and on the research vessel RV "*Clupea*". Various propeller curves for bollard pull and free running condition were recorded during different measuring campaigns on the RV "*Clupea*".

However, the limits of the measuring system became apparent during practical tests on commercial fishing boats. The shaft interval available for the measuring system was too short on one particular boat during tests. We do not believe that a further development of the measuring system on this particular boat, which is typical for a great part of the fleet, will allow the use of the system with a sufficiently accurate measurement. An axial and radial movement of the propeller shaft occurred on two other commercial vessels due to external forces, namely reactions to the propulsion and the effects of the sea motion and manoeuvring. This axial and radial movement of the shaft, caused by clearance in the gland, led to measuring reading errors which were equal to the end value to be measured. This means that without further developments to exclude these reading errors in general, the present measuring system cannot be used for vessels without roller bearings at both sides of the measured interval of the propeller shaft. Furthermore, a signal proved to be unstable on another vessel been tested, the cause of which we were unable to detect.

The modular design of the software means that various versions can be developed from the same tested program package, e.g. for special purposes such as supervision work. Until now the software is developed for application of the „Torque Control" system by trained experts.

The experience gathered on these fishing boats shows that the measuring system may only be used under favourable conditions and provides precise results within the scope of the project's requirements. Nevertheless, the measurements on the fishing boats disclosed basic problems which could not be solved with this system. A power measurement for engine power monitoring is not possible with the present system.

The BFAFi-IFH and the Technische Universität Hamburg – Harburg (TUHH) tested a simple second system for determination of torque by measuring propeller shaft twist ("IFH Displacement" system). Utilising a micrometer gauge it measures the displacement between two supports rigidly connected on the circumference of two planes of the propeller shaft at a distance of 100mm from each other. The supports are mounted on the propeller shaft with chains. Readout of the rotating gauge display is possible taking advantage of stroboscopic effect. For this purpose a mark on the propeller shaft is used to trigger a flashlight. The system showed good results at high power levels but some problems accord at lower levels and levels near zero. The tests were carried out at a diesel engine test bed of the Technische Universität Hamburg-Harburg (TUHH). Further investigations for improving the "IFH Displacement" system will be undertaken after completion of this project at the BFAFi-IFH and TUHH.

After tests of the "Torque Control" system in June 96 the Institut für Fischereitechnik started developing a measuring system based on torque measurement with strain gauges with can easily be used and installed („IFH Strain Gauge" system). The main problems with such a system are the preparation of the shaft for strain gauge application, transmission of the measured data from the rotating shaft to the vessel's hull, calibration of the strain gauge bridge amplifier and precise alignment of the gauges.

A commercial telemetry unit with magnetic transmission of data and power supply was modified. The coils for data and power transmission on the original system were built by winding a single wire around the shaft about 100 times. The coils were replaced by a flexible printed circuit board with two printed transmission coils or two flat coils applied between two self adhesive foils, designed for better transmission and higher precision. Additional reflectors for light sensors for determination of the number of revolutions are attached to the transmission coils. Both mounting systems of transmission coils enables the user to align very quickly and easily two strain gauge half bridges for bending stress compensation opposite each other on either side of the shaft ensuring high accuracy . The pickup coils for data and power transmission are aligned very simple by adjusting the power voltage of the electronic shaft unit at maximum value before starting calibration and measuring.

In the event that inexperienced personnel apply strain gauge a great zero offset may occur. To avoid this a strain gauge bridge amplifier controlled by an interface for adjusting the zero offset and gain for application at different vessels was developed. The adjustments are calculated by a PC and transmitted by an interface to the amplifier before starting the measurements. The preparation of the propeller shaft for mounting of the strain gauges should require 15 minutes or less. For this purpose a polished facet of 30 mm square on the surface of the propeller shaft protected against oxidation is needed. Alternatively strain gauges can be dot welded on. For this purpose an additional equipment for dot welding must be developed.

Software for calibration of the system for different engine power and propeller shaft dimensions, measurement of power via an interface, displaying and recording of the measurements is developed for application of the „IFH Strain Gauge“ system by fisheries inspectors.

The project also aims to develop a simple Engine-Power-Self - Recording unit for study and test purposes. This system used a microcontroller with analogue inputs which are interfaced to a strain gauge bridge via an amplifier and an acceleration sensor measuring the number of revolutions. The acceleration sensor produces a pulse signal with a frequency corresponding to the shaft rotating speed. The signal to noise ratio of an acceleration sensor could be improved for precise measurement. After calibration the amplifier settings are stored in the non erasable part of the microcontroller's memory and will be loaded to the amplifier before the start of each measurement. Both the sensors and the battery for power supply are placed in a box mounted on the propeller shaft and cast with resin. The equipment will thus be tamper-proof except by physical damage. This system showed some software problems and needs further development before it can be used for monitoring engine power of fishing vessels.

1.Introduction:

For young fish protection a closed area is established in the coastal waters from Belgium to the northern part of Denmark. A map of this Plaice Box is shown in Annex I figure 1. In this area fishing with beam trawls is forbidden except by vessels with special permit. The conditions for obtaining this permit include, among other stipulation, that the vessel must have a total engine power not exceeding 221 kw. At any time and additionally if the engine is de-rated, that it did not exceed 300 kw. before de-rating. In the past, de-rated vessels with permits have fraudulently increased their engine power by re-adjustments or by fitting new equipment. Therefore, in order to enforce the EU regulation effectively, it was proposed that a simple method of measuring engine output power at sea should be developed. During this research program different methods for measuring the engine power on fishing vessels at sea are investigated in order to implement the above mentioned measures laid down in the regulation 3094/86 article 9 or the future regulation 850/98 (in order from 01.01,2000) article 29 (see Annex I).

The engine power cannot be measured directly but calculated by following formula:

$$P = \omega M_t$$

M_t = Torsion moment

ω = Angular velocity

The methods for measurement of the angular frequency or number of revolution is well known and easy to handle by non specialist. Two different physical variables the twist angle and the stress on the surface were used for determination of the torque moment.

Four different systems were developed or investigated for different applications.

1. **Measuring the twist of the propeller shaft:**
   a) A portable "Torque Control" system which can be installed quickly and easily. This system is based on the measurement of the torque angle by displacement measurement of two gearwheels on the propeller shaft.
   b) A portable "IFH Displacement" system which can be installed very quickly and easily. This system is based on the measurement of the torque angle by displacement measurement of two supports clamped on the propeller shaft. A conditioning of the shaft is not required.

2. **Measuring the stress on the surface of the propeller shaft:**
   a) A portable "IFH Strain gauge" system which can quickly and easily be installed by pre mounted telemetry and strain gauges, calibration, measurement and recording is done by a PC.
   b) A "Self Recording" system for permanent installation on the propeller shaft, which will record engine power data for examination by fishery patrol officers.

With this portable devices two different applications should be possible:

1.1 Quick mounting and calibration (less than 15 minutes) for detecting engines with higher than permitted power (measurement accuracy +/- 10%)

1.2 More comprehensive mounting and calibration (60 minutes) for precisely measuring of engine power (measurement accuracy +/- 2%)

The "Self Recording" system should be mounted permanently on the propeller shaft. This system needs to be independently powered, tamper proof and yet readily accessible by fishery inspectors.

2. Materials and methods

On fishing vessels the engine power can be measured behind the gear box on the propeller shaft. It is therefore only possible to determine the engine power reduced by the loss of the gear box. The power follows the equation:

$$P = \varpi \cdot M_t = 2\pi \frac{n}{60} M_t \tag{2.1}$$

M_t = Torsion moment

ω = Angular velocity

n= Number of revolutions/minute

The revolutions are detected by a reflective optical sensor. The number of revolutions is determined by a frequency counter or frequency to voltage converter if a voltmeter or a PC interface is used.

Torque of the propeller shaft is determined in two different ways.

1. Measuring the twisting angle or displacement
2. Measuring the strain on the surface of the shaft

Both methods are described in detail as follows.

2.1 Torque measurement by determination of the twisting angle or displacement

Figure 1 shows in principle a shaft loaded with torque M_t. Because of the material's elastic property the shaft is twisted by the angle φ.The deflection angle γ caused by the torque follows the equation :

$$\gamma = \frac{\tau_{\max}}{G} \tag{2.1.1}$$

τ_{max}= shear stress on the outer diameter

G = shear modulus

From the geometry is:

$$\sin\gamma = \frac{\Delta s}{\sqrt{l^2 + \Delta s^2}} \qquad 2.1.2 \quad \text{and} \quad \sin\varphi = \frac{\Delta s}{\sqrt{r^2 + \Delta s^2}} \qquad 2.1.3$$

From the equations 2.1.2 and 2.1.3 results

$$\sqrt{l^2 + \Delta s^2} \cdot \sin\gamma = \sqrt{r^2 + \Delta s^2} \cdot \sin\varphi \qquad 2.1.4$$

With following approximations for small deflection angles γ and φ

$$\sin\gamma \approx \gamma \qquad 2.1.5 \quad \text{and} \quad \sin\varphi \approx \varphi \qquad 2.1.6$$

and for common propeller shafts of fishing vessels

$$\sqrt{r^2 + \Delta s^2} \approx r \qquad 2.1.7 \quad \text{and} \quad \sqrt{l^2 + \Delta s^2} \approx l \qquad 2.1.8$$

the equation 2.1.4 can be replaced by

$$l \cdot \gamma = r \cdot \varphi \qquad 2.1.9$$

The equation 2.1.1 can be replaced as follows and the shearing stress $\tau_{\max}$ on the surface is

$$\tau_{\max} = \gamma \cdot G = G \frac{r}{l} \cdot \varphi \qquad 2.1.10$$

The torsion moment is calculated using the equation:

$$M_t = \int_{d_i/2}^{d_a/2} \tau \cdot r \cdot dA = \frac{G \cdot \varphi}{l} \int_{d_i/2}^{d_a/2} r^2 \cdot dA = \frac{G \cdot I_p}{l} \varphi \qquad 2.1.11$$

With the polar resistance moment I_p of a

solid shaft $I_p = \frac{\pi \cdot d_a^4}{32}$ 2.1.12 or hollow shaft $I_p = \frac{\pi \cdot \left(d_a^4 - d_i^4\right)}{32}$ 2.1.13

From equation 2.1.9 and 2.1.11 results for the torsion moment M_t

$$M_t = \frac{G \cdot I_p}{l} \cdot \frac{\Delta s}{d} \cdot 2 = konst. \cdot \Delta s \qquad 2.1.14$$

2.1.1 Portable „Torque Control“ system measuring displacement by two marker devices on the shaft

Torque measurements using “Torque Control” system are carried out according to the physical principle of phase displacement. The twisting angle of the shaft proportional to the torque (see Figure 1), is hereby recorded using suitable markers mounted along a set measuring distance on the shaft. The basic design of the measuring system, consisting of the transmitting devices on the shaft, sync magnet, corresponding sensors and computer with the measuring software, is shown in Figure 2.

The markers on the shaft may be either magnetic belts with an alternating pole sequence, black/white-patterns, ladder chains or chopper disks. Sensors mounted on the ship detect the markers. Assuming thorough preparation, the entire measuring unit can be installed within a very short time.

The signals from the sensors are transmitted to a PC plug-in board which has been developed during the project. It calculates the number of revolutions of the shaft from the rotation of the markers and then directly determines the torsional angle from this at a hardware level. The prevailing torque is calculated from the torsional angle. The shaft power to be determined is the product of torque and known angular velocity.

The torsional interval Δs between two speed transmitters at a distance of l from each other follows the equation 2.1.14 and is recorded by measuring the difference between the times when two markers pass the stationary sensors assigned to each speed transmitter.

The basic displacement (Figure 3) of the individual pairs of speed transmitters is analysed in the no-load condition and taken into account separately during the measurement. A zero point marking allows the indexing of the pairs.

The sensors assigned to the speed transmitters initially deliver sinusoidal or rectangular signals the frequencies of which correspond to those of the passing markers. Time signals result from a digitalisation of the sensor signals, as shown in the diagram. The following applies for the upper representation (condition A - signal course for a no-load shaft): the markers rotate at a speed V_{ZO}. The time needed for a marker to pass a sensor is:

$$t_{zo} = \frac{Z_b}{v_{z0}} \qquad 2.1.1.1$$

whereby:

Z_b= length of a single marker

t_{ZO} = time needed for a marker to pass a sensor on an unloaded shaft

v_{ZO} = momentary speed of the marker on an low level loaded shaft

The relative torsional interval Δs_0 between the markers of the two speed transmitters results from the time interval Δt_0 measured between when the two markers start to pass their corresponding measuring pick-ups. Thus:

$$\begin{aligned} \Delta s_0 &= v_{zo} \cdot \Delta t_0 \qquad 2.1.1.2 \\ &= \frac{Z_b}{t_{zo}} \cdot \Delta t_0 \end{aligned}$$

If the shaft is stressed with torque, the relative torsional interval Δ_{so} changes by the amount δ on account of the elastic deformations. The time Δt_z (cf. condition B) then lies between the entry of both markers into their respective sensor fields. The influence of the torque can also alter the speed of the shaft, so that the time needed for a marker to pass the sensor is now t_z. The torque is then calculated from the time measurements on the basis of the following relations:

$$\delta = \frac{Z_b}{t_z} \cdot \Delta t_z - \frac{Z_b}{t_{zo}} \cdot \Delta t_0$$

$$= Z_b \cdot \left(\frac{\Delta t_z}{t_z} - \frac{\Delta t_0}{t_{zo}} \right) \qquad 2.1.1.3$$

Considering that the torsion of the shaft is not measured on its surface but on the speed transmitters, e.g. gear wheels, the torsional interval is

$$\Delta s = \delta \cdot \frac{d_W}{d_Z} \qquad 2.1.1.4$$

where d_Z is the diameter of the gear wheel. The torque is then

$$M_t = \frac{\pi \cdot d_w{}^4 \cdot G \cdot Z_b}{16 \cdot l \cdot d_z} \cdot \left(\frac{\Delta t_z}{t_z} - \frac{\Delta t_0}{t_{zo}} \right) \qquad 2.1.1.5$$

whereby

d_W = shaft diameter

d_Z = diameter of the impulse transmitters in the place of the markers

Δt_Z = duration of the phase difference between the two impulse transmitters

t_Z = passing time of a marker

However, the torsional interval may not exceed half the marker's length (with an identical length of marker and gap), i.e. the markers on the speed transmitters must not overtake each other.

The temporal measurement of the phase difference between the two speed transmitters and the passing time of a marker thus enables the direct determination of the torque. The problem of the torque measurement is elegantly reduced to the problem of a very precise time measurement; the resolutions of over 40 MHz achieved here allow precise measurements even at short measuring intervals.

2.1.1.1 Marker and sensor devices

A sensor which detects the markers on the shaft with a very high repeating accuracy is required for the measurement. Furthermore, the shaft has to be fitted with markers which are both easy to mount and remove, yet still guarantee a high accuracy of the measurement. Moreover, the markers should also facilitate a fast adjustment of the sensors.

Magnetic Hall sensors, optical reflex sensors or light barriers are examples of suitable sensors. Magnetic belts, black/white-patterns, quick-fitting chains or chopper disks are conceivable transmitting devices. In the course of the project, the following six combinations of sensors and transmitting devices were developed and tested for their aptitude for measurements on fishing boats:

- magnetic sensors and magnetic belt
- magnetic sensors on quick-fitting ladder chain
- magnetic sensors on divisible chopper disk
- optical reflex sensor to detect a b/w-pattern
- Light barrier with quick-fitting chain
- Light barrier with divisible chopper disk

A magnetic sensor records changing of the magnetic properties on the shaft surface. This may consist of a belt with alternating magnetic south and north poles or an alternating ferromagnetic sequence of teeth.

Because of the problems involved with the use of magnetic belts and subsequent adjustment a mechanical transmitting device was developed that can be easily mounted on the shaft, used without reading errors after the measurement and, in contrast to magnetic belts, allows a fast adjustment of the sensors with the aid of visible markers.

A milled chopper disk, such as is used in the laboratory, is ideal in terms of the transmitter geometry. A point of impact or blemish does not exist and the widths of teeth and gaps are identical. Thus, the time needed to fit the measuring system to this type of disk and to adjust the sensors is very short. However, a fixed chopper disk cannot be used on fishing boats since the propeller shaft has to be removed for installation. On the other hand, a retrofitting of the desired mechanical transmitting devices on the shaft and free adjustment to the given shaft diameter should be possible.

The first stage in the development is a 3/8" chain which is placed around the shaft and then closed. The chain is available in separate parts as a so-called repair chain. Steel cams are used as transmitting devices in place of bolts. The length of the chain can be varied so that the system can be adjusted to the shaft diameter. An adjustable lock which closes and tensions the chain ensures a safe installation on the shaft.

A further development was a chopper disk with an variable inner diameter that can be divided for installation. The calculations of a divisible chopper disk suggested an outside diameter of 250 mm for a desired range of shaft diameters from 80 to 120 mm. The geometry is essentially determined by the contour of the inner lever, which guarantees an almost constant contact force for all shaft diameters. The technical construction is shown in Figure 4.

Extensive market surveys were carried out during the entire project to get suitable commercial sensors. Samples of sensors that seemed to be appropriate were ordered and tested in a laboratory. It was discovered that sensors which are used in industry as proximity or limit switches are generally inappropriate for phase difference measurements. The reason for this is that in principle the amplitude depends on the sampling frequency, corresponding to the speed of the shaft.

However, this effect does not occur in the second type of magnetic sensors used in speed measurements, namely the Hall sensors. There is an almost invariable output amplitude at all speeds. Thus, the latter sensors are in principle suitable for torque measurement. However, even in this case we discovered that no sensors were commercially available which meet the demands of accuracy with respect to

the scanning ratio, i.e. the ratio between the high and low signal, and phase stability, i.e. the accuracy of detecting the rising flank of the transmitting device.
For these reasons, a sensor with the required accuracy has been developed and optimised on the basis of Hall sensor elements. The type of sensor which was developed and the magnetic belt used is shown in Figure 5. An example of an application with these components can be seen in Figure 6.

The Hall sensors optimised for the magnetic belt can be used on the above mentioned chopper disk and ladder chains after slight modifications. The alternating tooth/gap sequence of chain and disk is recorded instead of the alternating pole sequence of the magnetic belt. The design of a torque measuring system with chopper disk or ladder chain is shown in Figure 7 and Figure 8.

Optical sensors with an alternating black-and-white belt can be quickly bonded to a shaft and is thus extremely convenient for a quick measurement. Figure 9 shows the test set-up.

Light barriers have the advantage of being largely unaffected by radial and axial displacements. Only tangential displacements produce erroneous measurements, so that these sensors have to be just as firmly fixed as magnetic sensors if this interference factor is to be minimised.

Almost every light barrier on the market operates with pulsed light in the infrared range for reasons of secondary light compensation. Pulsed light barriers are, however, inadequate for speed and torque measurements since their pulse frequency interferes with the measuring frequency. Light barriers with continuous signal are required. These light barriers developed during the project time are presented in Figure 5, middle.

2.1.1.2 Sensor supports

The easiest and, as was revealed during measurements, most practical way of fixing the sensors is direct fastening to the hull. Several methods are possible. The sensors were initially aligned by a hydraulic support fixed to the hull by magnetic or vise – grip bases. A magnetic base can be attached to any even steel beam or plate of a ship. A two-piece, hydraulically locking arm is screwed to this base. A special holder housing the threaded sensor is attached to the end of this arm. The hydraulic support is commercial available and normally used for length measurement applications by e.g. micrometer gauges.

A second method of fixing the sensors uses a portable sensor holder attached to the shaft. The sensor holder is supported on the shaft by counter-braced deep groove ball bearings and self-aligning ball bearings. The sensor support is fastened to the vessel's hull by straps. This construction is based on the fact that every movement or shift of the shaft has a direct effect on the holder and attached sensor. Sensors are thus fastened relative to the shaft. On the one hand, this means that the fastening must prevent the portable holder from twisting and shifting on the shaft. On the other, it must be flexible enough to allow the holder to follow the motion of the shaft within certain limits. The fastening may take the form of strap retainers. Figure 10 and Figure 11 show the basic construction of the holder.

2.1.2 Portable "IFH Displacement" system measuring displacement using a micrometer gauge

The displacement is measured employing the system developed by RWTH-Aachen . The system's accuracy caused by the movement of the propeller shaft in the stern gland did not allow it to be used on most fishing vessels at sea. The BFAFI-IFH developed a model of an additional system measuring the displacement and tested it on an engine test bed. To measure of the displacement, two supports are attached to the shaft by high tension chains or belts. The sides of the supports facing away from each other are immovably held in place on the shaft, the sides facing each other contact the shaft with a roller or a ball bearing ensuring movability (see figure 12). The displacement Δs between the fixed outer sides is measured by a micrometer gauge which is mounted on the inward side of one of the supports. A direct readout of the micrometer gauge on the rotating shaft is not possible. An optical reflex mark which is taped to the shaft, triggers the sensor of a flash light every time it passes. Because of the stroboscopic effect the gauge display seems not to move and the value of the displacement can be read out.

On some fishing vessels displacement values of less than 100 µm were obtained. In these cases the resolution of the system is insufficient. For this reason a mechanical amplifier for the displacement Δs is added (figure 13). A flat spring is attached to both supports. The springs are welded together at the free end (see figure 13B). They are moved relative to the twisted shaft by the displacement Δs. The gained displacement Δy is measured by a micrometer gauge. For mounting, the two supports are connected by a mounting plate to guarantee a constant distance b at all times. Before starting the measuring process the plate must removed.

For rough calculation of the deflection Δy the springs are approximated by bearings at P_1, P_2 and P_3 and a stiff connection from P_1 to P_3 and P_2 to P_3 respectively (figure 13C). In the following calculations the equation for the mechanical gain factor V_{mech} is deduced.

The sinus of the angle α is calculated by the following two equations:

$$\sin\alpha = \frac{\Delta s}{\sqrt{b^2 + \Delta s^2}} \qquad 2.1.2.1 \qquad \sin\alpha = \frac{\Delta y}{\sqrt{l^2 - 1/4\left(b^2 + \Delta s^2\right)}} \qquad 2.1.2.2$$

From the equation 2.1.2.1 and 2.1.2.2 results for Δy:

$$\Delta y = \frac{\Delta s}{\sqrt{b^2 + \Delta s^2}} \cdot \sqrt{l^2 - 1/4\left(b^2 + \Delta s^2\right)} \qquad 2.1.2.3$$

Because Δs is very small compared with b the gain of the mechanic amplifier can be approximated by:

$$V = \frac{\Delta y}{\Delta s} \cong \frac{1}{b} \cdot \sqrt{l^2 - \frac{b^2}{4}} \qquad 2.1.2.4$$

l = free length of the flat springs

b = distance between both springs on the supports

2.1.2.1 Engine test bed at the TU Hamburg - Harburg

The test bed made it possible to check the systems at varying power ratings and numbers of revolutions under realistic dynamic conditions.
A schematic drawing of the test bed is shown in figure 14. The main characteristics are given in table 1 . An MAN four cylinder four stroke diesel engine type 4L 20/27 with a nominal power of 400 kW at 1000 rpm is linked to the gear box by an elastic coupling. The engine is commonly used on small fishing vessels.

The gear box has a reduction ratio of 3.56. The output drives an electric DC Generator with resistive load by a hollow shaft. The specifications of the shaft are shown in table 2.

For comparative measurements the engine power can be determined by the electric power of the DC-generator. In addition a battery powered strain gauge system with VHF data transmission is installed on the shaft.

2.1.2.2 Test bench for mechanical amplifier tests

To optimise the mechanical amplification of the „IFH Micrometer Gauge", a test bench was constructed for the amplifying flat springs. Figure 15 shows the test bench with one mechanical amplifier just being tested. The test bench consists of a carriage system for the amplifier mounted on a ground plate. A support for a micrometer gauge is also mounted on the plate for measuring the simulated displacement of the shaft. A defined displacement Δs of the shaft is lead into the spring by a micrometer screw connected with the movable spring of the mechanical amplifier. The other spring is fixed to the support. The system, especially the movable spring, is free of clearances. The displacement is very accurately measured by a micrometer calliper with a resolution of 0.5 μm. The amplified displacement Δy is measured and displayed by a digital micrometer gauge with a resolution of 1 μm.

The force of the spring is measured by a strain gauge sensor between the micrometer screw and the spring with a measurement range of 200N. The force value is displayed on a high resolution micro-volt digital voltmeter.

2.2 Torque measurement by determination of the stress on the propeller shaft surface

Loading a shaft with torque will cause it to twist by a very small angle. As a result, a shearing stress τ is generated between the radial planes. This shearing stress can not be measured directly but must be deduced from the measured strain on the surface. The shearing stress τ is:

$$\tau = \frac{\sigma_1 - \sigma_2}{2} \qquad 2.2.1$$

σ_1, σ_2 =stress in main directions

Figure 16 A shows an unloaded shaft. A square facet on the surface generates lines parallel to the shaft axis. Under a torque load the shaft is twisted by a small angle and the square surface element is deformed to a diamond. The deformation results in a strain on the surface with main directions of +/- 45° angle to the direction of the axis. The strain σ_1 and σ_2 are according to equation 2.2.2 and 2.2.3 (extended to two axis Hook's law):

$$\sigma_1 = \frac{E}{1-\nu^2}\left(\varepsilon_1 + \nu \cdot \varepsilon_2\right) \qquad 2.2.2$$

$$\sigma_2 = \frac{E}{1-\nu^2}(\varepsilon_2 + \nu \cdot \varepsilon_1) \qquad 2.2.3$$

E = elastic modulus

ν = transversal contraction

ε = strain

For a torque shaft the strain of the two main directions is:

$$\varepsilon_2 = -\varepsilon_1 \qquad 2.2.4$$

The absolute value of the strain in the both main directions is equal.

$$|\varepsilon_1| = |\varepsilon_2| = \varepsilon \qquad 2.2.5$$

From equations 2.2.2 to 2.2.5 follows:

$$\sigma_{1,2} = \pm\frac{E}{1-\nu^2}(1-\nu)\cdot\varepsilon = \pm\frac{E\cdot\varepsilon}{1+\nu} \qquad 2.2.6$$

Therefore, equation 2.2.1 can be replaced as follows:

$$\tau_{\max} = 2\cdot\varepsilon\cdot\frac{E}{2\cdot(1+\upsilon)} = 2\cdot\varepsilon\cdot G \qquad 2.2.7$$

The following equation applies for the torque (2.2.8):

$$M_t = \int_{d_i/2}^{d_a/2} \tau\cdot r\cdot dA = \frac{\tau_{\max}}{d_a/2}\int_{d_i/2}^{d_a/2} r^2\cdot dA = 2\cdot\varepsilon\cdot G\cdot W_p \qquad 2.2.8$$

With the polar resisting momentum W_p for a full shaft [2.2.9] and a hollow shaft [2.2.10] :

$$W_p = \frac{\pi\cdot d^3}{16} \qquad 2.3.9\,; \qquad W_p = \frac{\pi(d_a^4 - d_i^4)}{16\cdot d_a} \qquad 2.3.10$$

2.2.1 Portable "IFH Strain Gauge" systems measuring stress using strain gauges

The most common method of measuring stress is to use strain gauges connected to a Wheatstone Bridge. The figure 19 shows the principle drawing of a full bridge consisting of four resistor elements (R_1 to R_4) . The bridge can consist of four strain gauges for a full bridge, two strain gauges and two fixed resistors for a half bridge and one strain gauge and three fixed resistors for a quarter bridge. The output signal U_A follows the equation:

$$U_A = U_B \cdot \left(\frac{R_1}{R_1 + R_2} - \frac{R_4}{R_3 + R_4} \right) \qquad 2.2.1.1$$

If the relations R_1 / R_2 and R_4 / R_3 are equal, the Output Signal is Zero. In this case for small changes of the strain gauge resistors the equation can be extended to:

$$U_A = U_B \cdot \left(\frac{R_1 + \Delta R_1}{R_1 + \Delta R_1 + R_2 + \Delta R_2} - \frac{R_4 + \Delta R_4}{R_3 + \Delta R_3 + R_4 + \Delta R_4} \right) \qquad 2.2.1.2$$

Because of very small ΔR_n of strain gauge resistors the output signal U_A can be approximated by following equation:

$$U_A \cong \frac{U_B}{4} \cdot \left(\frac{\Delta R_1}{R_1} - \frac{\Delta R_2}{R_2} + \frac{\Delta R_3}{R_3} - \frac{\Delta R_4}{R_4} \right) \qquad 2.2.1.3$$

Figure 9 shows the principle circuit diagram of a Wheatstone Bridge with zero offset balance used in the developed torque measurement telemetry system. The zero offset is balanced by digitally controlled voltage divider in 2^9 steps for coarse and 2^8 steps for fine offset compensation. To compensate for the bending stress two half bridges are mounted opposite each other on the shaft. For the zero offset balance the sensitivity of the strain gauges is reduced by the voltage divider R_{ZTR4} / R_4 and R_{ZTR3} / R_3 respectively. The same number of divisions is needed for resistor R_1 and R_2. Therefore a resistor with a value of R_{ZTR} / 2 is added to R_1 and R_2 in series. In the worst case, the influence of the bending stress to the torque measurement is less than 2.5% of bending stress value ($R_{1\text{-}4}$ = 1000Ω , R_{ZTR}=220Ω).

The output voltage is:

$$U_A \cong \frac{U_B}{4} \cdot \left(\frac{\Delta R_1}{R_1} \cdot \frac{R_1}{R_1 + R_{ZTR}/2} - \frac{\Delta R_2}{R_2} \cdot \frac{R_2}{R_2 + R_{ZTR}/2} + \frac{\Delta R_3}{R_3} \cdot \frac{R_3}{R_3 + R_{RZTR3}} - \frac{\Delta R_4}{R_4} \cdot \frac{R_4}{R_4 + R_{ZTR4}} \right) \quad 2.2.1.4$$

with

$$R_{ZTR3} = \frac{R_{ZTR} \cdot N_{ZERO}}{2^8} \quad 2.2.1.5 \text{ and } \quad R_{ZTR4} = R_{ZTR} - R_{ZTR3} \quad 2.2.1.6$$

N_{ZERO} = steps of coarse balance

R_{ZTR} = zero trim resistor

When stress is applied to a strain gauge, the change of the resistance follows the equation:

$$\frac{dR}{Ro} = \varepsilon \cdot (1 + 2v) + \frac{d\rho}{\rho} = k \cdot \varepsilon + \frac{d\rho}{\rho} \quad 2.2.1.7$$

For strain gauges the changes in the structural conditions $d\rho / \rho = 0$ and for the bridge resistor R_n equation 2.2.1.7 is approximated by :

$$\frac{\Delta R_n}{R_n} = k_n \cdot \varepsilon \quad 2.2.1.8$$

For a torsion shaft is :

$$\varepsilon_2 = -\varepsilon_1 = \varepsilon_3 = -\varepsilon_4 \quad 2.2.1.9$$

The absolute value of all main direction strains is equal

$$|\varepsilon_1| = |\varepsilon_2| = |\varepsilon_3| = |\varepsilon_4| = \varepsilon \quad 2.2.1.10$$

For the output voltage of the bridge then follows:

$$U_A = \frac{U_B}{4} \frac{M_t}{2 \cdot G \cdot W_p} \left(k_1 \frac{R_1}{R_1 + R_{ZTR}/2} + k_2 \frac{R_2}{R_2 + R_{ZTR}/2} + k_3 \cdot \frac{R_3}{R_3 + R_{ZTR3}} + k_4 \cdot \frac{R_4}{R_4 + R_{ZTR4}} \right) 2.2.1.11$$

The output voltage of the telemetry receiver at full scale is 1000 mV. The gain of the amplifier and telemetry system should therefore be:

$$g = \frac{1000}{1000 \cdot U_{Af}} \quad 2.2.1.12$$

U_{Af} = Output Voltage at full scale of torsion moment

A commercial telemetry system for torque measurement with magnetic transmission of data and power supply was modified. The unit mounted on the propeller shaft was completely redesigned. The transmission coils were made from a flexible printed circuit wrapped around the shaft only three times and fixed on the shaft with scotch tape at both ends of the board. This board incorporates the optical reflectors for measurement of the rotation speed and aligns the strain gauges opposite each other on either side of the shaft for precise measurements with bending stress compensation. This can be set up in less than 10 minutes and will provide highly accurate results.

Before the first use of the system the shaft must be conditioned for mounting the strain gauge. The time required for this preparation depends on the state of the shaft surface. It will typically be the most time consuming step in installing the system. The coils for power and data transmission are attached to the shaft by tape while the strain gauges are aligned. The pre-mounted strain gauges are bonded with quick-curing cement. Two minutes later the electronic box is fastened on the shaft with straps and the pickup coils for data transmission need to be adjusted. The quality of the alignment of the coils can be checked by measuring the power supply voltage of the telemetry shaft unit. The power supply voltage gets a maximum at best alignment of the transmission coils.

For calibration and zero offset compensation purposes the electronic box on the shaft is connected with an interface of the PC. During the shaft is not rotating the zero offset resistors are changed by the PC until the output voltage of the telemetry is set close to zero. Following the Amplifier gain depending from the gauge sensitivity and the shaft dimensions and properties is calculated by software and the digital controlled Amplifier is set to the required value. Small final deviations are taken in account during the measurements.

2.2.2 "Permanent Self-Recording Strain Gauge System"

Torque measurements are performed by means of the commonly used strain gauge technology. The strain gauge signals are amplified and directly converted to a digital signal by a micro controller. The number of revolutions is measured by an acceleration sensor. This sensor type needs no external contact and measures the frequency of an sinuous signal resulting from the acceleration by gravity during rotation. The frequency is linearly proportional to the number of revolutions. Both values are processed by a micro controller and the resulting engine power values are saved to a memory every ten minutes. For the time between measurements the controller is switched into sleep mode with very low power consumption. The access to the memory by external interface is only readout. Both the sensors and a battery for power supply are placed in a box mounted on the propeller shaft and cast with resin to protect it. The equipment will thus be tamper-proof except by physical damage.

2.3 Comparative measurement for calibration

To obtain improving and calibration of measurements done by the new developed systems a resistance strain gauge measurement system was chosen. After a precise abrading of the shaft a half or full bridge of strain gauges are bonded by fast curing cement. The measured torque was transmitted by a VHF telemetry system. This method has been well tried and tested on a number of applications in strain measurement techniques.

3.Results

3.1 „Torque Control“ system

3.1.1 Magnetic sensors on magnetic belt

The results of the laboratory tests with this type of sensor and the magnetic belt revealed that a measurement is possible under favourable conditions provided the blemish, which is always found at the belt's joint, is of a tolerable size. Under adverse conditions, however, a pole variation or loss may occur at the joint so that both measuring belts have a different number of poles. If this error occurs, the desired torque cannot in principle be measured and the only remedy is to remove both magnetic belts and bond them anew.

The Hall sensor system with magnetic belt could not be improved in laboratory tests so that these errors became acceptable and a measurement possible despite the existing joint. After the development and optimisation of the magnetic Hall sensor, lengthy tests revealed that the difficulty of bonding a magnetic belt around a shaft so that the alternating pole sequence is continued at the joint is comparable to the problems that arise when bonding a strain gauge. To make matters worse, we were only able to discover whether the bonded magnetic belts are suitable for measuring purposes during the actual measurement. If this proves unsuitable, the entire measuring construction and belt fitting has to be repeated, thus doubling the time needed for the measurement. This is why the idea of measurements using Hall sensors and magnetic belts on fishing boats was abandoned.

3.1.2 Mechanical transmitting devices

Because of the fixed cam distance of the 3/8" chain, a gap which differs from the norm can be found at the connecting point of the lock. However, the problems posed by this gap are considerably smaller than those encountered with a magnetic belt, which also has a joint. The gaps in both chains are essentially identical in size and are directly detected with a corresponding adjustment of the sensors. Furthermore, the TorqControl software to measure the power has an option to correct teeth that takes errors of this kind into consideration. The third sync sensor shown in Figure 2 is used for this purpose. The chains cannot have different numbers of teeth, an error that may easily occur with magnetic belts and prevent measurement. The chain was used in measurements on the RV "*Clupea* " and proved its practical aptitude.

The calculations of a divisible chopper disk suggested an outside diameter of 250 mm for a desired range of diameters from 80 to 120 mm. The geometry is essentially determined by the contour of the inner lever, which guarantees an almost constant contact force for all shaft diameters. The technical construction is shown in Figure 4; Figure 18 and Figure 19 show the ready-to-use disk; Figure 20 and Figure21 the adjustment of the disk to various diameters. A great advantage here is that both measuring disks can be used on different shaft diameters, i.e. the system can even be used on ships which have a varying diameter. A second pair of disks was designed and constructed for measurements on ships with a larger shaft diameter. It covers a range of 120 - 200 mm. Although the measuring accuracy increases with an increasing outside diameter, the new disk pair was optimised to obtain the smallest possible outside diameter. Whereas the outside diameter of the small disk is 250 mm with a maximal inside diameter of 120 mm, an outside diameter of only 306 mm could be achieved for the new disk with a maximum shaft diameter of 200 mm. The weight too only rose disproportionately, so that the new pair of disks was notably easier to handle.

3.1.3 Magnetic sensors on quick-fitting chains or divisible chopper disk

The measurements with this sensor type shown in Figure 22 reveal that a basic gap between sensor and chopper disk of 1 mm produces ideal results. The maximum reading error in this case is only 10 μm. Unfortunately, the behaviour is not symmetrical so that the reading error cannot be balanced to the mean value zero with vibrating sensors. Thus, a torsion-related twist of the propeller shaft under full load of approximately 100 μm results in a max. measuring inaccuracy of 5 - 10 %, provided that the sensors are adjusted perfectly.

A basic gap of 1.5 mm doubles the errors, though this then becomes symmetrical. As of a gap of 2 mm, the reading error becomes so large that it is no longer negligible. However, a gap between sensor and chopper disk of less than 0.5 mm is impractical.

These tests thus reveal that the ideal gap between sensor and chopper disk or chain is between 1 and 1.5 mm. This distance can be determined exactly with feeler gauges. Practical measurements on fishing boats have confirmed these results.

The measurements were carried out with every available sensor. It was discovered that commercial sensors display significantly more reading errors (up ten times more). Thus, from the aspect of measuring accuracy and gap tolerance, the sensors developed at the Institute of Mining and Metallurgical Machinery (RWTH-Aachen) have proven superior to customary sensors. However, the Hall sensors developed at the Institute of Mining and Metallurgical Machinery are considerably worse than optical sensors, which operate independent of distance.

3.1.4 Optical reflex sensor to detect a b/w-pattern

Both the commercial sensors and those developed at the Institute of Mining and Metallurgical Machinery show a high susceptibility to pollution and secondary light. Therefore, the reflex sensors were neither used nor developed further.

3.1.5 Light barriers with quick-fitting chains or divisible chopper disks

The RWTH-Aachen has thus developed forked light barriers wich house a signal Filter , a signal amplifier and a signal converter for digital PC-input within their case. These light barriers are presented in Figure 5,middle.

On the basis of the measuring results obtained with our sensors, a customary non-clocked forked light barrier was later discovered with the same basic accuracy as the light barrier developed at the RWTH-Aachen. The signals from the purchased light barriers were amplified, filtered, and digitised with appropriate electronic devices so that they could be used directly for the Torqe-Control-PC-board. Figure 29 and 34 illustrate the use of this forked light barriers. The lower half of figure 29 shows the divisible chopper disks (small version, outside diameter of 250 mm) described above. The quick-fitting chain which is detected by the light barriers can be seen directly above this. Figure 34 presents the light barriers together with the large version (outside diameter of 306 mm) of the divisible chopper disk.

The calculated measuring accuracy of the system obtained with the light barrier and divisible chopper disk is shown in Figure 23, Figure 24 and Figure 25. The error at zero is not included.

3.1.6 Overview of the sensor types used

Transmitting device	Advantages	Sensor type	Disadvantages	test result
• Magnetic belt, bonded	• easy and quick installation • unaffected by pollution	Magnetic sensor	• serious problems at the joint, possibly irreversible gap needs reinstallation	Unsuitable for practical use on account of the serious disadvantages with the magnetic belt.
• Quick-fitting chain • Divisible chopper disk	• fitted as quickly as magnetic belt • gap problems are tolerable in the chain • no gap problems with the divisible chopper disk	Magnetic sensor	• chopper disk more expensive than chain • rather susceptible to displacement and change of sensor gap	The gap between sensor and disk must be strictly maintained, since a axial and radial movement causes a shift of the sensor working point, leading to a considerable increase in reading errors. Therefore, little aptitude for practical use.
• b/w-pattern, bonded	• optical method with a high precision • relatively unaffected by axial and radial movement of the sensor	Reflex sensor	• very susceptible to pollution	No advantages over light barriers, however considerable disadvantages. Therefore not to be used in practice.
• Quick-fitting chain • Divisible chopper disk	• optical method with higher accuracy and easier and quicker installation • relatively unaffected by axial and radial movement of the sensor • under ideal conditions very high precision, comparable to strain gauges	Light barrier	• reading error occurs in principle only with tangential shift of position	According to test results, the only measuring system that is fit for use. Tangential movements, however, have to be avoided by all means.

3.1.7 Sensor installation on the ship with clamps

The welding accessories trade offers self-clamping pliers that are normally used to hold plates before welding. These pliers, available in various sizes and versions, were modified so that one or two hydraulic holding arms could be fastened to their heads. These holders can be attached to the ship within a few minutes, so that the measuring system, complete with measuring disk, can be installed ready for work within a quarter of an hour.

3.1.8 Installation of sensors on the shaft with portable sensor holders

The holder can only be used in a few ships on account of the outer dimensions of the portable sensor holder (300 mm x 250 mm) and the overall length as defined by the beam length. Furthermore, the shaft must be freely accessible to mount the holder, i.e. no cross struts near the shaft. This is why only one ship was found during the project where the holder could be fitted, and this only with its shortest beam length of 300 mm. Since the engine and gear box of most modern ships are mounted close to the propeller to save space, the portable sensor holder can rarely be used. Another difficulty connected with the holder is the large space required by the clamping devices in direction of the shaft, leading to a loss of valuable measuring distance. A free shaft length of at least 400 mm is necessary for a beam length of 300 mm, through the max. measuring interval available is only 200 mm. This reduction of the measuring interval leads to a very high inaccuracy of the measurement, which requires an extremely quiet operation of the holder on the rotating shaft.

The difficulties experienced in the laboratory with the quiet running of the portable holder were also encountered during working measurements on the *Poseidon* in Carolinensiel. (see Figure 16) In general, the propeller shaft of fishing boats is at best turned on a precision lathe, so that apart from strong vibrations, oscillating movements also occur. Great pains were taken to vary the pre stressing forces during practical measurements in order to minimise these kinds of movements.

Since the disadvantages of this construction are of a fundamental nature, the prototype was not developed any further. Moreover, discussions about the system's safety were another reason to abandon the idea of a sensor holder that moves along the shaft. In the event of an erroneous fastening, damage to the bearing or fracture of the holder, the system could be caught by the shaft and set in motion. This would completely destroy the device, with the consequence that flying parts could constitute a risk to the life and limb of persons commissioned with the measurement.

3.1.9 Summary of the sensor tests

The sensor is the most important component of the measuring system to be developed. In principle, various laws of physics may apply. However, tests have shown that against the background of the problem, magnetic sensors are unfit for practical use. If a magnetic plastic belt is used as a transmitting device, there is always the problem that a void exists at the joint, where identical or different poles may come into contact which then delete or amplify the magnetic field. Since the two belts may be affected differently under adverse conditions, the magnetic belts may have to be re-installed. Unfortunately, this can only be detected during the measurement, which spoils the chance of installing the entire measuring system within 15 minutes. These problems do not arise with mechanical transmitting devices. A quick-fitting chain or a divisible chopper disk is easy to mount on the shaft and the chopper disk with variable inside diameter can even be installed on ships with shafts of varying diameters. The light barrier with a divisible chopper disk provides the highest measuring accuracy as well as the quickest construction of the measuring system.

3.1.10 Result of tests with possible sensor holder

Although a firm, screwed connection of the sensors with the ship is the safest, and in terms of measuring accuracy, best method to fasten the sensor, it is only suitable for permanent measuring points and not for temporary measurements, such as checks of the shaft power by fishing supervisors. If, however, every fishing boat in question to have a support to hold sensors with a quick-action coupling, this would facilitate the application and simultaneously increases the measuring accuracy. Such a locating device may be simple as well as cost-effective.

Another practical possibility is the use of vise-grip wrenches with hydraulic sensor holders. Not only can they be locked in place quickly, they also facilitate sensor adjustment. However, they do have the disadvantage that the clamping point must be determined for each ship and before each measurement by the person who carries out the measurement. Moreover, this version is rather susceptible to sensor vibrations, so that one has to reckon with a slightly less accurate measurement.

The most obvious solution, namely to fasten the sensors directly on the rotating shaft with a clamping device and to secure the required holder against axial and radial movement and twisting using only tightening straps, has considerable disadvantages compared to other solutions presented here. The measuring interval is shortened on account of the geometry of the holder; the sensor is subjected to significantly higher vibrations due to the surface structure. The accuracy achieved in these practical measurements was considerably lower than in those cases where sensors were attached by vise-grip wrenches or hydraulic arms. Moreover, the system cannot be used for the majority of fishing boats, where in general the shaft is either too short or not easily accessible.

3.1.11 Measurements executed at sea

3.1.11.1 Measurement on the *Clupea*

The measurements on the research vessel RV "*Clupea*" in Rügen and Warnemünde were intended to test various sensor and transmitting device developments. The magnetic belt, the quick-fitting ladder chain , the divisible chopper disks, magnetic Hall sensors and light barrier sensors were used.

The torque measurements were carried out on the shaft section between gear box and a roller bearing. The geometrical dimensions of the measuring points were a measuring interval of 300 mm with a shaft diameter of 96.3 mm. The shaft was of a solid material: steel with a shear modulus of 81500 N/mm².

A nominal power of 160 h.p. and a speed of 375 rpm produced a resolution of 76.5 Nm, depending on the geometry of the measuring interval and with a maximum reading error of the measuring equipment of 2 µm. This corresponds to a measuring accuracy of approximately 2.5 %.

The measuring system was calibrated and the speed corrected at idling speed immediately before the start of the measurement. For this purpose, the shaft is driven at a constant speed. This reference measurement on the one hand determines the zero-point of the measurement and on the other, it generates a correction file containing the geometric position of each toothed pair relative to the sensory device. The correction file was consulted during the measurement and thus enabled the physical measurement resolution of about 2 µm.

Flexible ladder chains, which were scanned magnetically with Hall-sensors, served as transmitting devices on the shaft. The construction of the measuring system is shown in Figure 8.

The vessel was driven at a total of five power levels for a few minutes during each measurement. On the bridge, these power levels were termed "1/4-power", "1/2-power", "3/4-power", "full power" and "110%-power". The measuring diagram in Figure 28 shows that power values of 12 kW, 40 kW, 65 kW, 100 kW and 120 kW were achieved during the measurement. The latter value corresponds to the nominal output of the diesel engine of 160 h.p..

A propeller curve was plotted from the measured values for both rotational speed and shaft propulsion power. This is shown in Figure 26 and Figure 27.
The results of measurement with divisible chopper disks were compared with the results obtained during measurements with flexible ladder chains. The light barrier shown on the right in Figure 28 is mounted on a hydraulic magnetic holder and encloses the ladder chain.

The different relations between a turbulent current on the propeller at bollard pull and the free running condition are shown as time signals in Figure 29 and Figure 30 and propeller curve in Figure 31 and Figure 32.

3.1.11.2 Measurement on the commercial vessels *Gudrun Albrecht*, *Poseidon* and *Christine*

Measurements were to be carried out on board three ships in the harbour Carolinensiel: the *Gudrun Albrecht*, the *Christine* and the *Poseidon*.
It was discovered that the *Gudrun Albrecht* only had a free space of approximately 70 mm between the gear box and gland. A divisible chopper disk could not be used since two disk's could not be attached to an area as small as this. Flexible ladder chains could have been used, but the threaded joints of the gland which protruded into the measuring point would have had to have been removed beforehand. On the basis of our experience in the laboratory, we decided against the use of magnetic belts. A subsequent estimation resulted in a theoretical measuring inaccuracy of at least 10 % for such a short measuring interval. Consequently, it was agreed that a measurement on vessels with short free length of the propeller shaft was impossible with the measuring equipment available at the time.

The measuring interval on the *Christine* was in principle long enough. The construction of the components on the shaft is illustrated in Figure 33. This shows the two installed chopper disks which are detected by the light barriers. The third magnetic sensor which records the sync pulse for the tooth correction is shown in the left of the picture. The torque measuring point with strain-gauges for reference measurements is still visible between the two chopper disks.

Subsequent measurements at all the different power levels on the whole suggested a good compliance between the torque measured with TorqControl and the torque measured with strain gauges. The deviation at full load was less than 5 %; with a partial load and no-load it was in principle higher. However, increasing deviations occurred between the two systems after longer running periods. Figure

35 and Figure 36 show the course of these deviations and the corresponding measuring errors. Because of the extent of the deviation and its dimension, which is a multiple of the maximum torque of the propeller shaft, the reference measurement with strain gauges can be excluded as cause of the failure. The offset accumulation could not be localised with the measuring devices available until now.

The next measurement was carried out on the vessel *Poseidon*. This vessel has a free shaft length of almost 500 mm and a shaft diameter of 81.5 mm. We used the same measuring equipment as for the *Christine*. However, in this case the smaller version of the chopper disk was used. Since the shaft was easily accessible, the measuring system only took about 15 minutes to install.

The engine of the *Poseidon* has an output of approximately 250 h.p.. At a maximum speed of n=2100 rpm and a gear ratio of i=3.913, the maximum torque is 3.33 kNm. At a measuring interval of l = 450 mm for a shaft with a diameter of d = 81.5 and a chopper disk of D = 250 mm, this torque causes a torsion of Δs = 530 μm . An accuracy of 0.5% was expected.

The results of the measurements carried out on the *Poseidon* are revealed in Figure 37 and figure 38. At idle speed, i.e. the speed at which the calibration of the measuring system TorqControl is executed, the portable system shows the value zero on principle. Hence, a measuring error of 100 % results, since the torque at no-load speed, 500 Nm in this case, is not recorded. When driving normally, a failure of less than 20 % results for all speeds, which almost equals zero for the second highest speed. At the highest speed, however, a deviation occurs that amounts to 50 % of the measuring value. To narrow down this failure, the measuring point was observed under full load. Extremely strong vibrations were measured at this speed, which, however, did not bring about an interruption of the measuring signal. Other types of failures were not detected.

To determine the effect of the vibrations, various ways of fixing the sensors were tested thereafter, that should facilitate a stronger or weaker vibration tendency.

Different tests of vibration reduction as well as the use of spare sensors produced the same measuring deviation for all the sensor constructions. To exclude the interference of a erroneous software, once more various software versions were tested, among them the version used in the measurements on the *Clupea* with no reduction of errors.

An axial and radial movement of the shaft was suggested as cause of the deviation. For test purposes both sensors were mounted on one shopper disk at an angle of 180° to each other to exclude the shaft displacement by torsion twisting. This method is used to asses the residual error which occurs with a normal measurement. Both sensors are hereby aligned to the same chopper disk. After the calibration run, the basic displacement between the two sensors is defined as zero torque. Since no displacement can occur between both the scanned teeth during a measurement on one chopper disk, an error-free measurement should produce a torque of o Nm during the entire test run. Any deviation from 0 Nm is thus a measuring error. Possible causes of deviation can be thermal drift, sensor oscillation, shaft displacement or slipping of the measuring disk. Since the extent of thermal drift is negligible, sensor oscillation leads to an increase in the signal's noise and not a signal displacement, and disk slippage can be easily checked as a mechanical problem, this method reveals a measuring error caused by displacement to one chopper disk. Because of diametric position of both sensors on a single chopper disk doubles the measuring error, since every displacement is recorded as a positive occurrence by one sensor and as a negative occurrence by the other.

The errors which occurred were measured with this single-disk method. The table below lists the reading errors caused by the driving manoeuvres:

Manoeuvre	**Reading error**	**Apparent twisting**	**Remarks**
maximum power	approx. 3300 Nm	530 µm	reference value for error-free measurement
run up to maximum power	approx. 3000 Nm	480 µm	Proportional to power
rudder manoeuvres	approx. 1500 Nm	240 µm	left rudder stronger than right rudder
influence of sea motions	approx. ±750-1000 Nm	120-160 µm	

Unfortunately , this method does not exactly determine the reading error that occurs during a real measurement with two chopper disks. During a real operational measurement , however one sensor , e.g. near the gear box , could record the chopper disks without displacement, whereas the other sensor which records the chopper disk near the gland is subject to the shaft displacement in the gland.

Measurements on the *Christine* generally revealed the same shifts due to sea motions and manoeuvres as on the *Poseidon*. For instance, a displacement of approximately ±2000 Nm was caused by sea motion at a maximum torque of 8000 Nm (corresponding to a shift of approximately 100 μm). However, the extent of this reading error was smaller than on the *Poseidon*, one possible reason being that there is less bearing clearance on the *Christine*.

It was striking that the reading errors detected on the *Christine*, namely signal drift and offset accumulation, did not occur on the *Poseidon*. Here, the signal was stable and returned to its neutral position after the engine power was switched off.

3.2 „IFH Micrometer Gauge"

The resolution of a simple system without mechanical amplifier was calculated for different fishing vessels. The expected resolution of 30 kW in the worst case was insufficient however. To improve resolution an amplification device built from two flat springs with a gain of 10 was added.

From this torque measurement system a model was tested in July 1997 . The results measured at a test bed of the TU Hamburg-Harburg showed linear interrelationship in the range from 70 to 220 kW. Problems at measurements of power less than 70 kW occurred. It was not possible to detect the reasons until end of project. The results of this measurements are shown in table 2 and plotted in figure 38.

Because of vibration, rotational oscillation of the torque etc. the readout of the micrometer gauge must be averaged by eye. The accuracy was about 10µm (The resolution and accuracy of the gauge was 1µm). With this results a resolution of less than 5 kW is possible for measurements at inshore fishing vessels operating in the area of the plaice box.

The supports were attached to the shaft with chains and tightened with a chain adjuster. Chains of different lengths are required for different shaft diameters. Therefore the installation is rather complicated and can only be done in less than 15 minutes if conditions are favourable. The system can be mounted in less than 10 minutes if the supports are fastened with straps in the same way the electronic box of the „IFH Strain Gauge" is fastened (see chapter 3.3.2 and Figure 43 and 44).

The TUHH will start in close co-operation with BFAFI-IFH detailed investigation to clear the problems at zero values and will redesign the system including a shield mounted on the shaft for safety protection.

3.2.1 Test bench for mechanical amplifier

A test bench was constructed to investigate the flat spring mechanical amplifier. Flat springs constructed from spring steel of different thickness were tested. The gain and necessary force were measured and subsequently compared with the calculated values obtained using the equation 2.1.1.4. These forces do not influence the measurements of deflection but they have to be considered for construction of the supports.

The diagram figure 39 shows the plotted values of force and deflection Δy in dependence on the displacement Δx. The plotted dots are adequately approximated by a linear regression curve. The difference between the calculated and the measured values of gain were less than 5 %.

3.3 „IFH Strain Gauge"

Preparing for a measurement using this system, a rectangular facet of 4 x 12 cm on the shaft along its axis needs to be degreased and cleaned for fasten the transmission coils by scotch tape. Then a 2 x 2 cm square must be (wet) grind and polished with a battery operated angle grinder. Different grinding wheels and abrasive discs with increasing grade of grain need to be used. The preparation of the shaft is finished by polishing the treated area using abrasive paper and by cleaning it. This is the most time consuming step of the installation process. The actual duration depends on the condition of the shaft surface and the experience of the personnel. This work only can be done by trained technical members of the crew of patrol boats.

After assembling the engine in the shipyard a power measurement using strain gauges is necessary, during which the engine is de-rated to 221 kW. The area polished for this strain gauges measurement should be protected with grease or a removable coating for further applications. If this is done only cleaning of the area for strain gauge bonding is needed, the time required for subsequent installations of the complete system is reduced to less than 15 minutes.

An accuracy of +/- 10 % of power measurement should be possible and depends mainly on the accuracy of bonding of the strain gauges. If the measurements show results of more than the allowed power limit, a more precise measurement done by specialists is required and the bonding of the strain gauges and installation of the measurement equipment should be done In port. In this case the accuracy of the system is +/- 2% like the commercial telemetry system used first.

3.3.1 Telemetry unit for power and data transmission

The commercial telemetry system consists of an electronic box mounted on the shaft and two transmitting coils for data and power transmitting. The electronic unit supplies the strain gauges with power, amplifies the signal and converts the output voltage to frequency. The power supply and the frequency signal are transmitted by two coils from the shaft to two pickup coils of the receiver unit. If a minimum of power is transmitted the signal transmission runs correct. A simple measurement of the power voltage is used for aligning of the pickup coils. The power voltage gets a maximum at the best alignment.

The system needs two pairs of buck wound transmission coils consisting of 2*15 and 2*30 windings. They are wound of a single wire around the shaft. The mounting time was reduced by using an auxiliary device developed for precise alignment of the coils although more than 30 minutes was still required before the first transmission tests of telemetry could be carried out. This technique needs a lot of experience and the transmission was not always sufficient. Therefore additional development was done:

3.3.1.1 Flat cable for transmission

First the transmission coils are replaced with a flat cable wound around the shaft three times. At the ends of the flat cable 5 or 10 pairs of cores are connected with each other. Thus the transmission coils consist of 2*5 or 2*10 buck wound coils with 3 windings connected in series. The cores between the coils are not needed for transmission and therefore are not connected. They are necessary, however, to guarantee the correct distance between the coils. This makes it very easy to align quickly and precisely the energy and data transmission coils. The pickup coils are mounted at a distance equivalent to that between the transmitting coils.

3.3.1.2 Flexible printed circuit board for transmission

A flexible printed circuit board with two printed transmission coils was designed for increased reliability and mounting accuracy (see figure 40 and 41). The printed board is thinner than the flat cable and the interferric space consequently reduced improving the magnetic coupling of the coils. The number of windings per layer is limited by the minimum distance and width of the strip conductors. As the electrical resistance of the 35 µm thick strip conductors is high, the electrical power dissipation is also high.

Figure 48 shows the measured transmitted supply voltage and equivalent power measured at different load resistors. From these values the current and transmission power are calculated. Over a wide range the transmitted power remains nearly constant at 250 mW. The telemetry unit and the sensors of the newly designed torque measurement system need a constant current of appr. 25 mA and a minimum supply voltage of 6 Volts.

The shaft is part of the transformer core for magnetic transmission. Three windings of Mumetal foil are only required for measurements on shafts with non sufficient magnetic properties, e. g. hollow shafts. In those cases the Mumetal must be attached to the shaft first.

3.3.1.3 Flat coils for transmission

In addition to this a transmitter coils device was developed built from flat coils of enamelled copper wire. The two flat coils are sandwiched between two layers of self adhesive foil. This device is very similar to the printed circuit board but more wires can be fitted into the same space of the magnetic field of the pickup coils. This results higher power voltage and less electrical power dissipation.

3.3.1.4 Mounting and calibrating of telemetry

A small flexible board with a pre-mounted strain gauge half bridge is attached to the transmission board with scotch tape and protected from impurities with a cover(figure 40 and 41). The scotch tape is hinged and the bridge mounting board is folded away from the shaft surface. The strain gauges are bonded with a quick-curing cement. The pressure during curing can either be applied by a thumb pressure for appr. one minute or permanently by a silicone pad developed for this purpose which is forced by the tightening strap of the electronic box (see figure 43).

After connecting the transmission coils and the strain gauges the electronic box is fixed with a strap rolled up on a reel. The reel is blocked in one direction by a ratchet and tightened with another ratchet on the opposite side. Equal tension at both ends of the strap is guaranteed by leading it around two rolls mounted in a frame. Fig. 44 shows a principal drawing of the course of the strap. Fixing of the box takes only a very short time.

The pickup coils are mounted together with the revolution sensor on a hydraulically fixable support. The support can be attached using different vise-grip wrenches to the hull next to the telemetry coils (to pipes, frames, bottom plates etc.). The support and the wrenches are shown in figure 45. The pickup coils are adjusted for maximum supply voltage of the shaft unit measured at the interface connector. A constant distance between the coils is simple using an adjusting plate between the transmission and the pickup coils. After adjusting the pickup coils the support is fixed by a central hydraulic clamping device and the adjusting plate has to be removed.

The strain gauge bridge amplifier of the commercial telemetry system was improved for more simple adjusting of the gain by using register controlled resistors. Switching the feedback resistor of a non inverting amplifier in linear steps the gain is changed non linearly. During tests the zero offset of the bonded strain gauges exceeded the telemetry unit's range in some cases. For this reason an additional zero offset device was added. With this device the gain is in coarsely steps $10/10^2/10^3$ and 256 fine steps adjustable. The zero offset is adjustable ranging from +/- 200 mV in 512 coarse and 256 fine linear steps.

The strain gauge bridge amplifier is controlled by an interface for adjusting the zero offset and the gain during calibration. The calibration is commonly done very quickly by PC software via an interface before the start of the measurement. The results are stored in the amplifier's memory during the measuring process.

3.3.2 Measurement of the number of revolutions

A reflector at the end of the printed circuit board is detected by an optical reflex sensor once every revolution. The number of revolutions is determined subsequently by a frequency counter.

Black/white reflectors are printed on the flexible transmission device at a distance of 10 mm. The number of revolutions is measured by converting the frequency of the reflex sensor output signal to voltage. The output voltage of the converter is 1 mV/Hz. Only the reflectors on the outer layer can be detected by the sensor. Therefore the number of the reflectors N must be found at the end of the transmission device (see figure 48) and entered into the PC. The number of revolutions n is calculated according to the number of reflectors N and the output voltage U_a of the converter by following the equation

$$n = \frac{U_a}{N} \cdot 1000$$

3.3.3 PC interface and program

Two different interfaces were developed. A simple interface for setting the register controlled resistors for gain and zero offset adjustment is shown in figure 46. The addresses of the four resistors and their values are programmed using switches and then transmitted by an SDI interface to the control registers. This simple system does not record the measured data. The measured data has to be readout by a voltmeter. A block diagram of the power measurement system is shown in figure 47.

After the 31st of August an additional interface with digital serial output for controlling the amplifier and two channel analogue input for torque and rotation speed measurement was developed. An additional box for a notebook computer contains the telemetry receiver for torque measurement, the frequency to voltage converter for measurement of the number of revolutions, the interface for the PC and a battery pack for power supply. An additional connector for the power supply of a battery operated angle grinder is integrated. Figure 48 shows the block diagram of the system and figure 49 all the assembled hardware.

The software developed PC-program starts with input windows for vessel and inspection data and for engine ,shaft and sensor properties. After all necessary input data entered, the program asks for the name of the record file. The software will automatically suggest the vessel's name. If the data input is sufficient for the calculations, the calibration window is opened and a header file including the manually entered data is saved. After the calibration is completed the data display window shows the current values and plots the measured data. Appending of measurements to the record file is started and stopped by push buttons. The data of the plot display is included in the record file.

3.4 Self Recording System

The measurement of torque is done by the commonly used strain gauges technology. A microprocessor with very low power consumption controls the self recording system. A strain gauge bridge is bonded on the shaft. The strain gauge signals are gained by low noise and low temperature drift amplifier and are directly converted to a digital signal by a microcontroller with analogue input. Zero offset and gain of the bridge amplifier are adjusted by resistors. Because the bonding of strain gauges for long term applications can be done by experts only this adjusting by resistors is no problem. The final amplifier gain, strain gauge bridge sensitivity, shaft diameter and material properties of the propeller shaft are stored in the one time programmable part of a micro controller memory and are used to calculate the engine power when measuring.

The number of revolutions are measured by an acceleration sensor. This sensor type needs no external contact and generates a sinuous signal produced by the acceleration by gravity during rotation. The frequency is proportional to the number of revolutions. The acceleration sensor for the measurement of the number of revolution is designed for a range of +/- 50 g. The origin sinus signal output signal caused by the gravity is +/- 20 mV interfered by the rotation acceleration signal of maximum one Volt. An AC coupled amplifier gains the wanted signal to +/- 1.5 volt. The signal is averaged by software and then the rotating speed is determined.

The electronic box with the controller for measurement and data storage and the acceleration sensor for measuring the number of revolutions is fixed with a chain on top of the gauges. After calibration and final programming the electronic box including all sensors and battery must be encapsulated with resin.

Every 10 minutes a measurement is started. The results are stored together with time and date. Between the measurements the system switches to power down mode for reduced power consumption. A battery lifetime of more than 5 years is expected.
So far the program of the microcontroller did not run error-free. Bugs have to be removed from the microprocessor program.

4. Discussion

The "Torque Control" system which was developed has proven its value in the laboratory and on the research vessel *Clupea*. However, measuring deviations did occur during practical tests on three commercial fishing boats which were due to the special characteristics of the boats. For instance, a measurement with strain gauges is possible even when the shaft is too short, albeit with great difficulty, whereas a measurement with "Torque Control" system is impossible in this case. The problem of shaft displacement due to the clearance in the gland cannot be solved with sensors that are attached to the ship and hence cannot follow its movements. Therefore the system operates well only on the propeller shafts with a roller bearing at both ends of the measured part thereof its accuracy is in this case comparable with that of a system using strain gauges for torque measurement. Precise measurements can only be obtained on very few fishing vessels. On most of the vessels the "Torque Control" system is influenced by sea motion or manoeuvring and is consequently not suitable for engine power measurements . A practicable solution which enables fishing supervisors to carry out power measurements on fishing boats could not be achieved with the current measuring system.

The following theoretical approaches to a further improvement of the measuring system with regard to the physical properties of engines, gear box, shaft and propeller on fishing boats are worth considering:

- A solution such as the portable sensor supports could provide a means for better sensor installation. However, the corresponding support would have to be completely redesigned to fit into the very small spaces available, for example on the *Christine*. Similarly, it is doubtful whether such a miniature holder would meet the accuracy demands of the project.
- Another option is to measure the shaft displacement with position sensors which may then allow a compensation by means of their dimension.
- Furthermore, one could consider establishing several measuring points with a number of sensors that are mounted at an angle of 90° or 120° to each other. The errors at the measuring points could be evaluated with a logic in order to arrive at the exact measured values.

Unfortunately, these ideas would greatly complicate the measuring system within the scope of the research objectives. The last two solutions would require double the number of sensors for the measurement, thus making the installation more complicated. An exact adjustment of six or more sensors is inconceivable within the framework of fishing supervision. Solutions such as these, which are possible in theory, are inappropriate for a quick measurement within 15 minutes, since they are far too complex.

The „IFH Strain Gauge“ system relies on the well known strain gauge technique. A commercial telemetry system for strain gauge measurement was modified for this purpose. Less than 10 minutes are needed for installation and calibration of the telemetry system and bonding of the strain gauges. The time necessary for conditioning the shaft for gauge bonding depends on several factors and therefore can not be calculated. If a polished area of 20 x 30mm protected against corrosion exists and only cleaning of this area is needed the measurement can be done within 15 minutes.

For derating engine power to 221 kW a power measurement must be done. The polished area used for this purpose should be protected for subsequent measurements. Failure to do so the fishermen is losing more time for fishing during of engine power inspection.

Using dot welded strain gauges can reduce the set up time because conditioning is less difficult. Only a cleaned and not polished area is needed for welding the gauges on the shaft. It does, however, require additional equipment for dot welding.

The additional developed „IFH Displacement“ system worked well during tests at a test bed with engine power exceeding 70 kW. Problems in the range from zero to 70 kW need to be solved before testing at sea. This system is less accurate than the others investigated but +/- 10% is possible. The torque sensor is mounted directly onto the shaft. Hence the movement of the shaft or sensor fixing points can not influence the values obtained. Installation is very simple and requires no conditioning of the shaft. The measurements can be carried out in less than 15 minutes by crew members with no experience in torque measurement.

The micrometer of conventional technique used during the tests has a limited lifetime under centrifugal forces. But a new type of micrometer measuring the distance by a magnetic differential transformer is insensitive to centrifugal forces because of ball bearing of the shaft measuring the distance. The electronic measurement together with a signal processing allows to present the results for readout by an inspector without problems.

At this state of development the „IFH Displacement“ system can not be tested on fishing vessels. The development of this system by the BFAFi-IFH in co-operation with the TUHH is ongoing.

According to EC regulations only the engine power is limited. The development of measuring equipment for inspection of engine power at sea is not practical for enforcing this rule. For example, the fisherman is aware of the adjustment of the fuel rack for limiting the power to 221 kW. Before inspection he reduces the fuel injection. Less than 221 kW are measured. After the inspectors leave the vessel the fuel injection is readjusted for more engine power.

Alter the EU-regulations to prohibit licensing of ships with installed power greater than 221 kw. needs an assembling of a new engine in the most of the fishing vessels. Additional the assembling of non de-rated engines with 221kw. limits the lifetime of the engines because they have to run at full power during fishing. This measure increases the costs and therefore is an expensive option.

In Germany, fishing vessels can only obtain their license for fishing in the plaice box if their engine power is de-rated by a classification company. The adjustments are fixed by welding and the measurement record and a picture of the welded adjustments then form part of the licence. For inspection the welded seal is compared with the picture including in the license and several typical maximum numbers of revolution are measured. During the last tests on commercial vessels some of these de-rated engines where investigated. An example of the adjustments to the fuel rack of one vessel is shown in figure 50 and in more detail in figure 51. The author knows several ways of manipulating the fuel rack of this vessel within a few minutes without any visible deviations from the shown picture. For one particular engine type an additional equipment is available since about one year which increase engine power after derating and sealing. The equipment can be removed in less than 5 minutes. Diesel engines with electronically controlled injection are state-of-art in the automobile industry and will also become so on next generation of fishing vessels. This technology allows derating the engine power by software parameters. These parameters can be changed using an PC-interface and a PC. However, the same equipment can be used for manipulating the power.

It seems it is almost impossible to develop an entirely tamper proof method of limiting engine power to 221 kW for all different types of engines.

For supervision of engine power, a tamper proof self recording power measurement system mounted on the propeller shaft is required. The sensor developed for measuring the rotation speed is tamper proof because gravity can not be influenced. All physical damages on the strain gauge sensor for torque measurement will be detected and recorded by the micro controller. During the course of this project only a simple system for study purposes of these problems was developed. For supervision purposes a new highly reliable system must be developed and tested.

5. Finalization of tasks

The power measurement system measuring the twist of the propeller shaft was developed. A software for easy use was not developed. Because of great errors of the system a monitoring of the engine power at sea is not possible.

A torque and revolution measurement system measuring torque with strain gauges was developed for easy and quick installation. The measurements are recorded and calibrated by software with easily handling. Monitoring of engine power at sea is possible with this system.

A self recording system for study purposes was developed. Further work on software is required.

Additionally a system measuring torque with a micrometer gauge was tested. Monitoring of engine power at sea with this system is not yet possible.

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7. List of figures

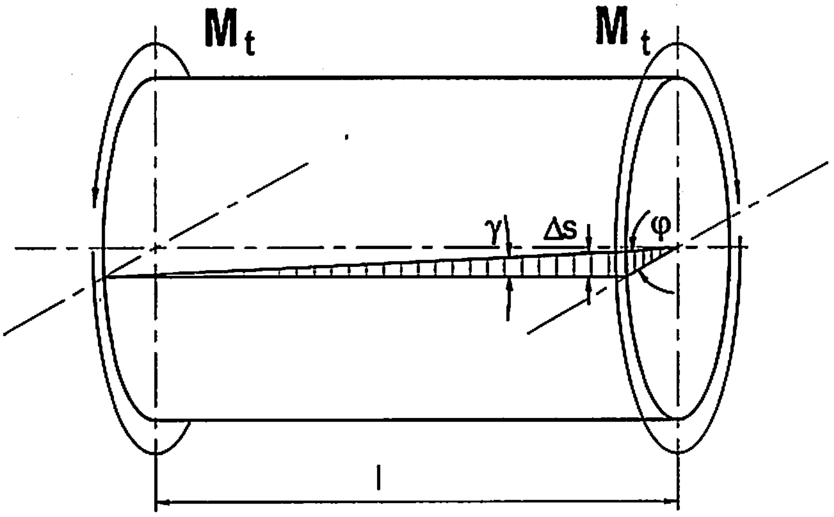


Fig. 1 : Physical principle of displacement measurement

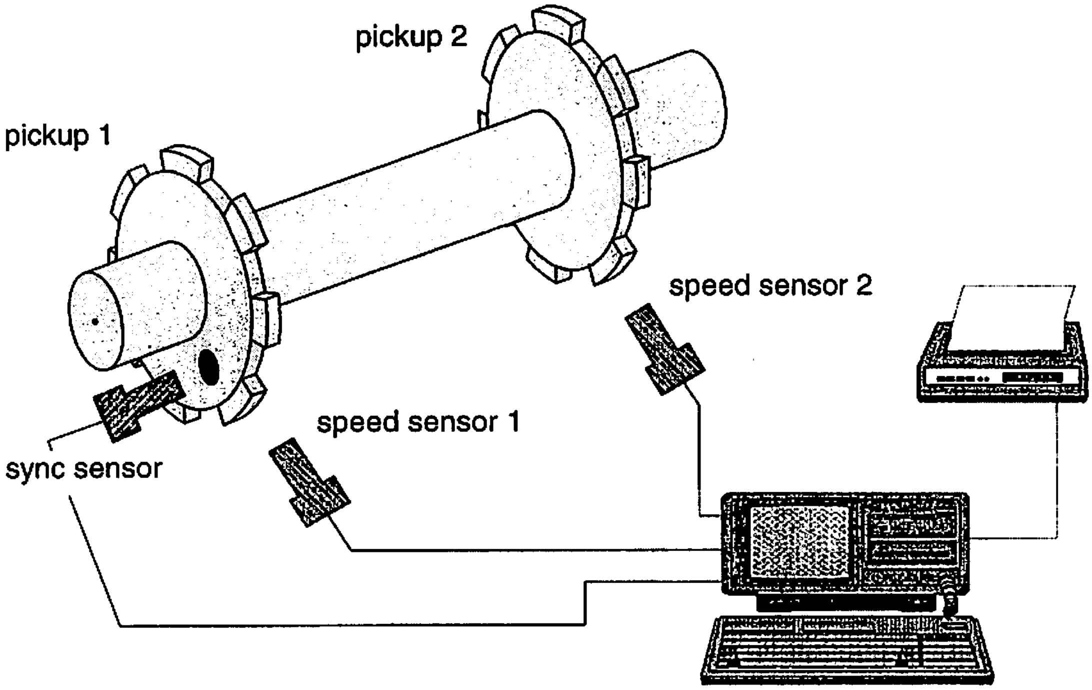


Fig. 2: Basic design of the measuring system TorqControl

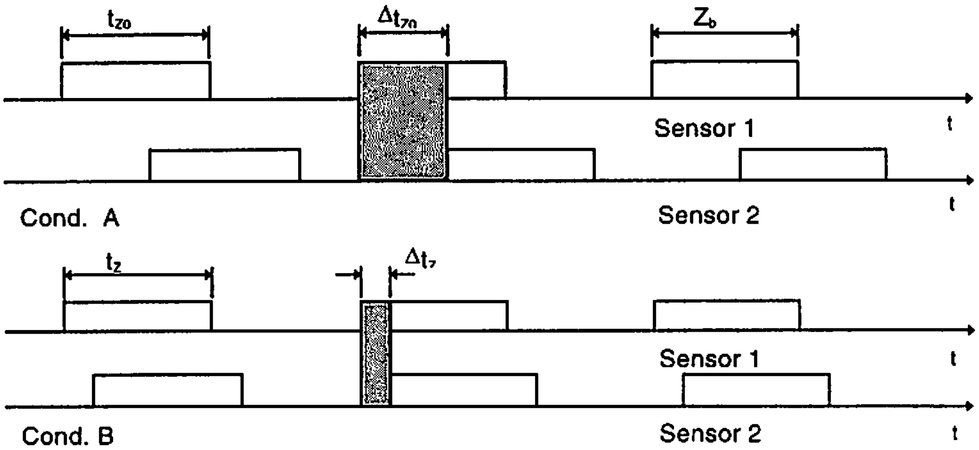
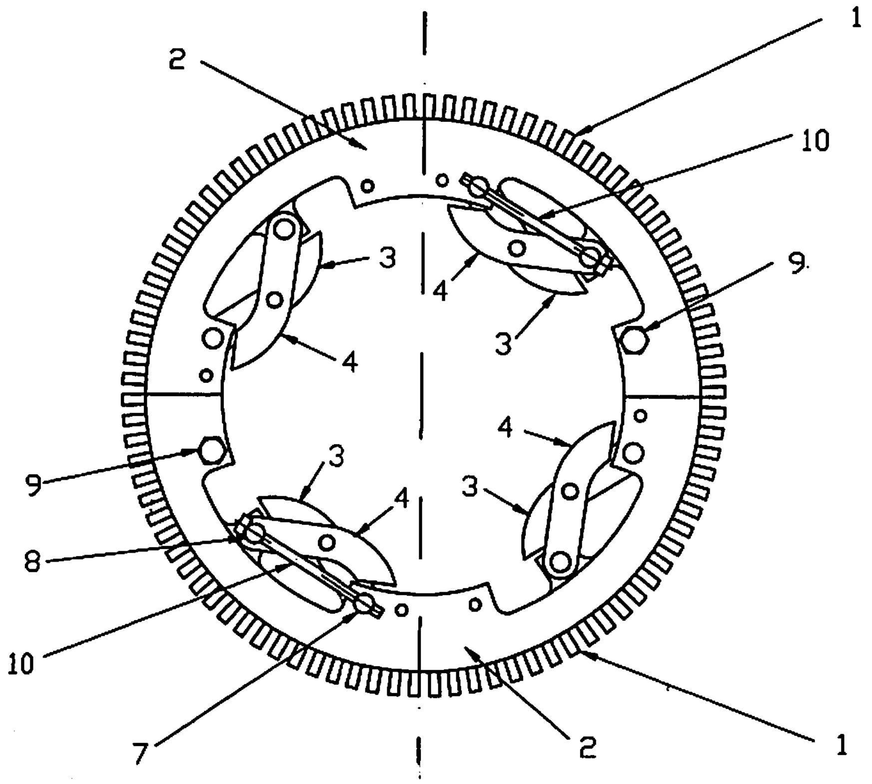


Fig. 3 : Sensor signals for shaft torsion



1	inner ring
2	outer ring
3	inner lever
4	outer lever
5	transition piece
6	bolt
7	dowel
8	hexagon socket screw
9	alignment pin
10	hexagon head cap screw

Fig. 4 : Divisible chopper disk

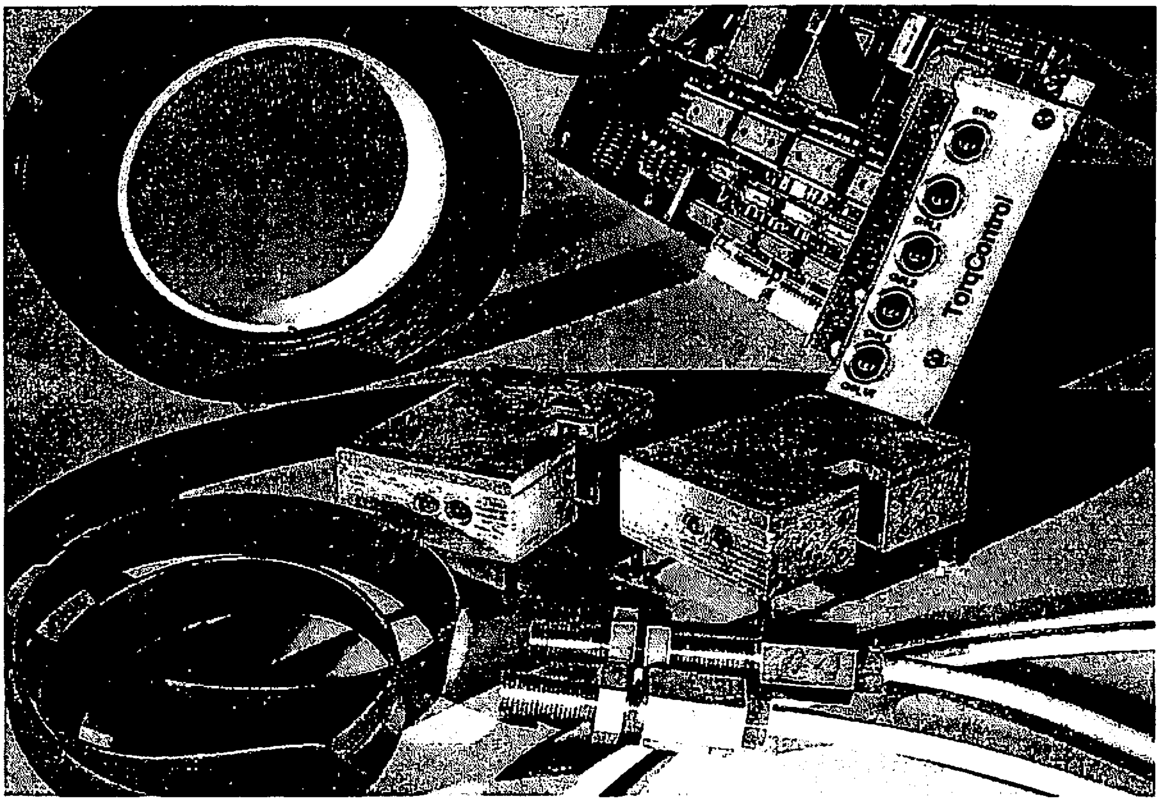


Fig. 5 : Measuring board, magnetic belt, Hall-sensors, optical sensors

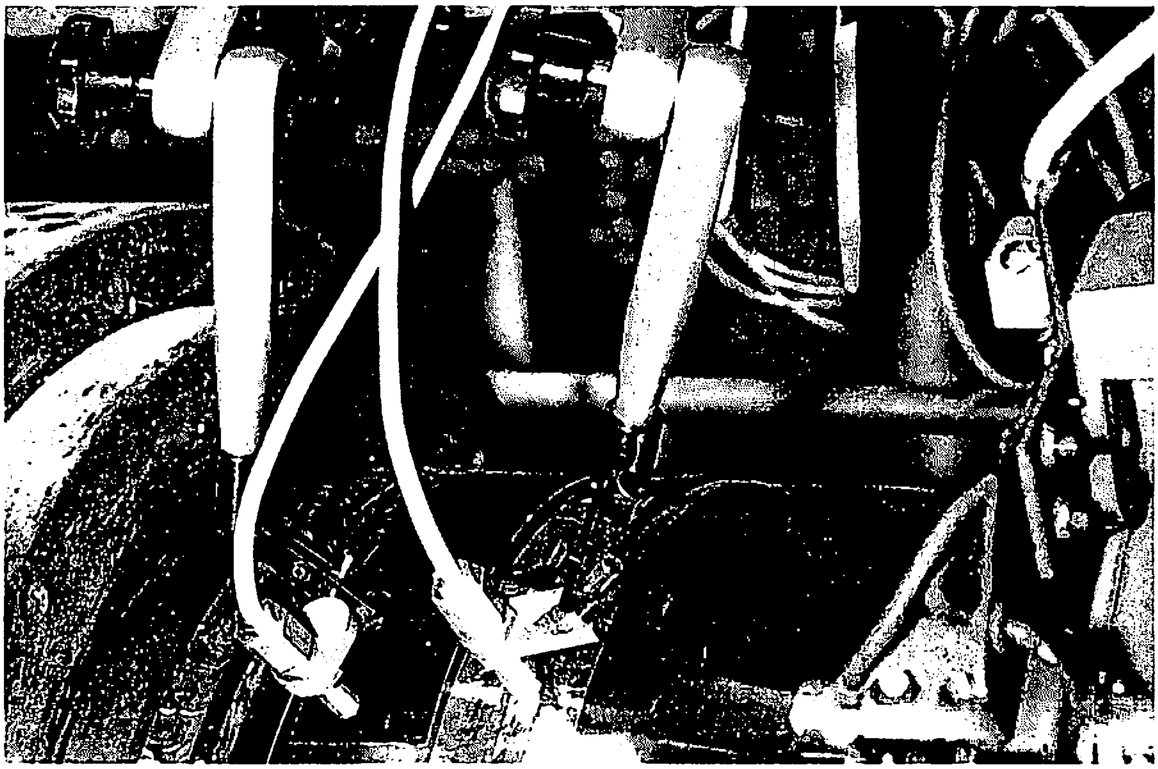


Fig. 6 : Measurement Hall-sensors with magnetic belt

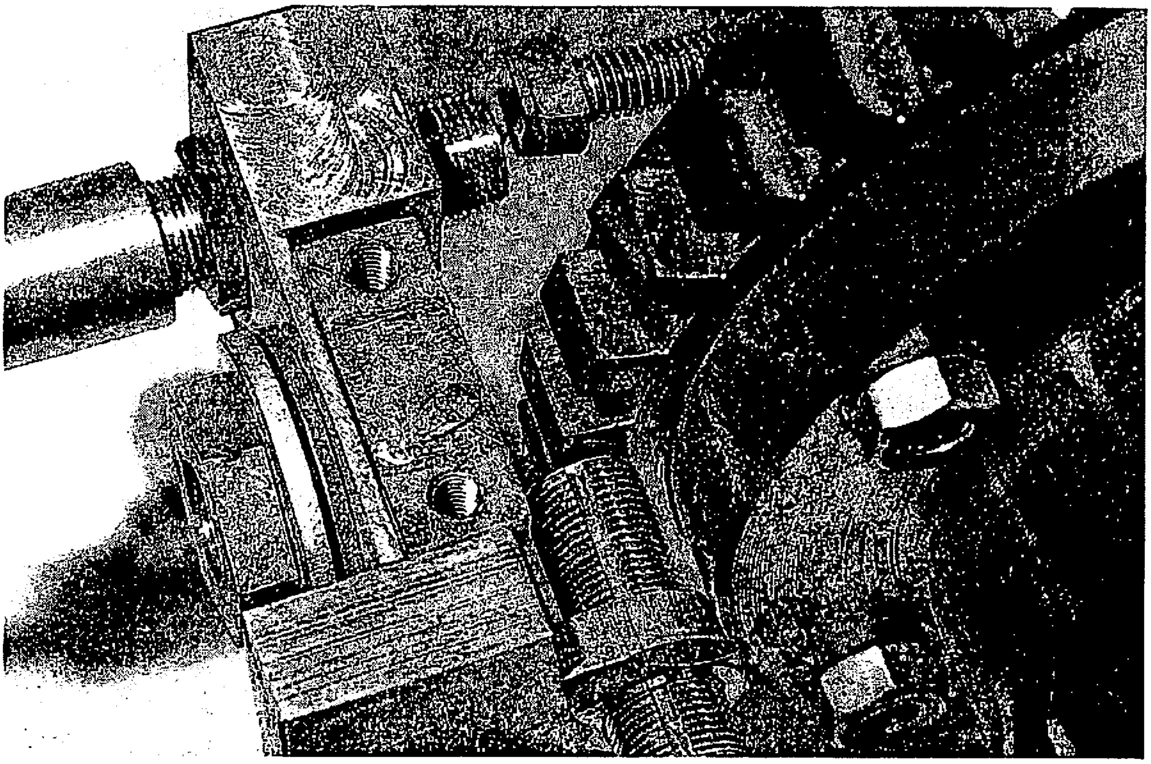


Fig. 7 : Measuring set-up Hall-sensor and chopper disk, axial arrangement

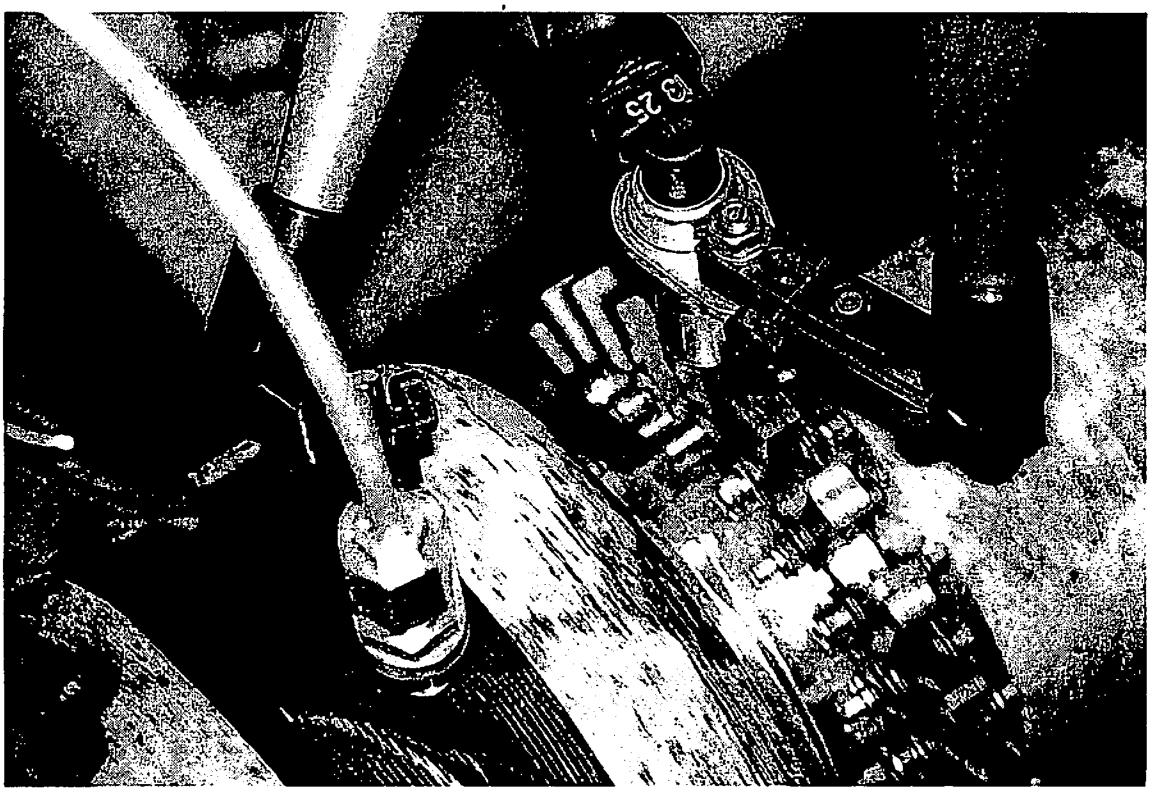


Fig. 8 : Measurement on *Clupea*, June 1995, ladder chain with Hall-sensor

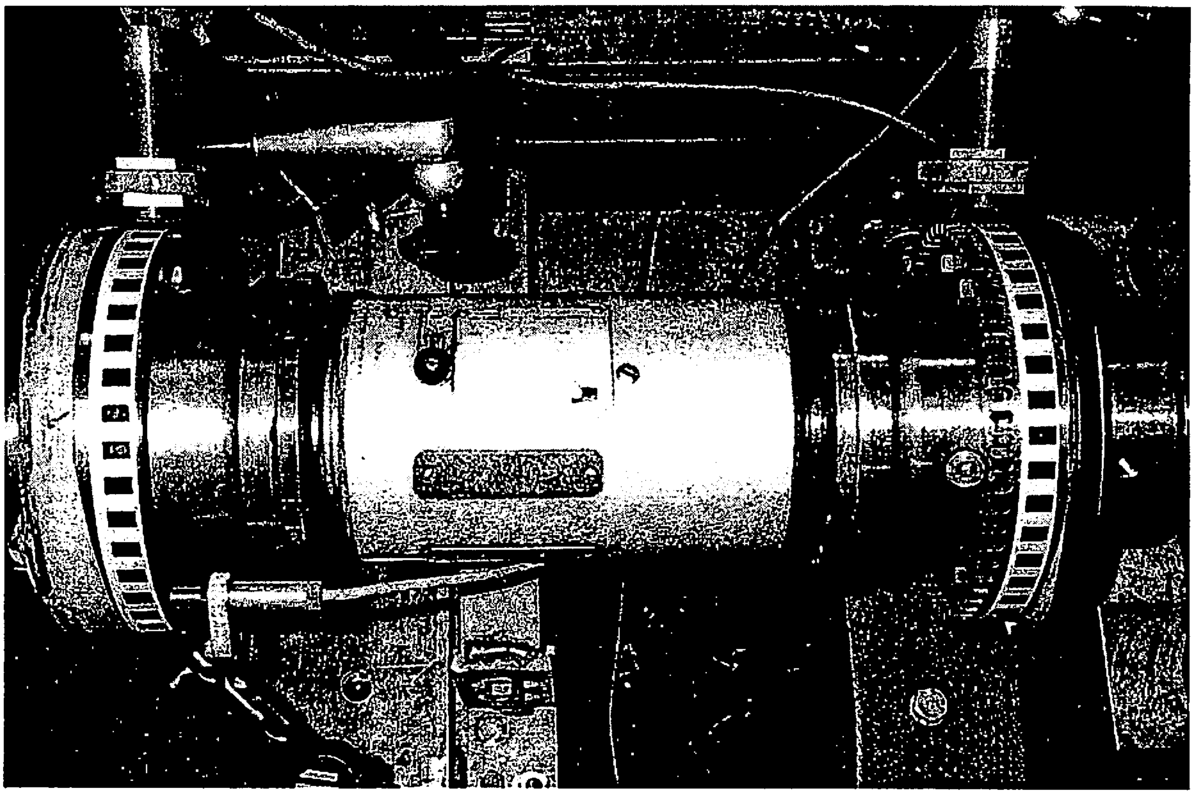


Fig. 9 : Test set-up reflection sensor on b/w-belt

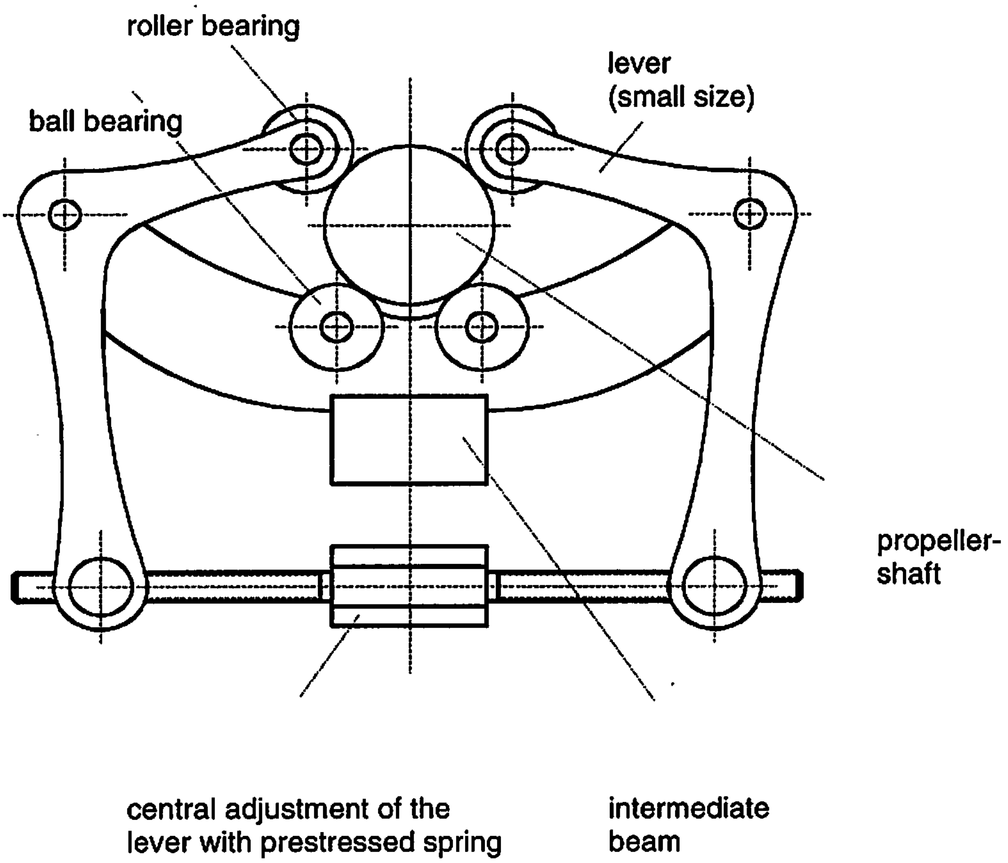


Fig. 10 : Portable sensor holder with double-6-fold bearing, front view

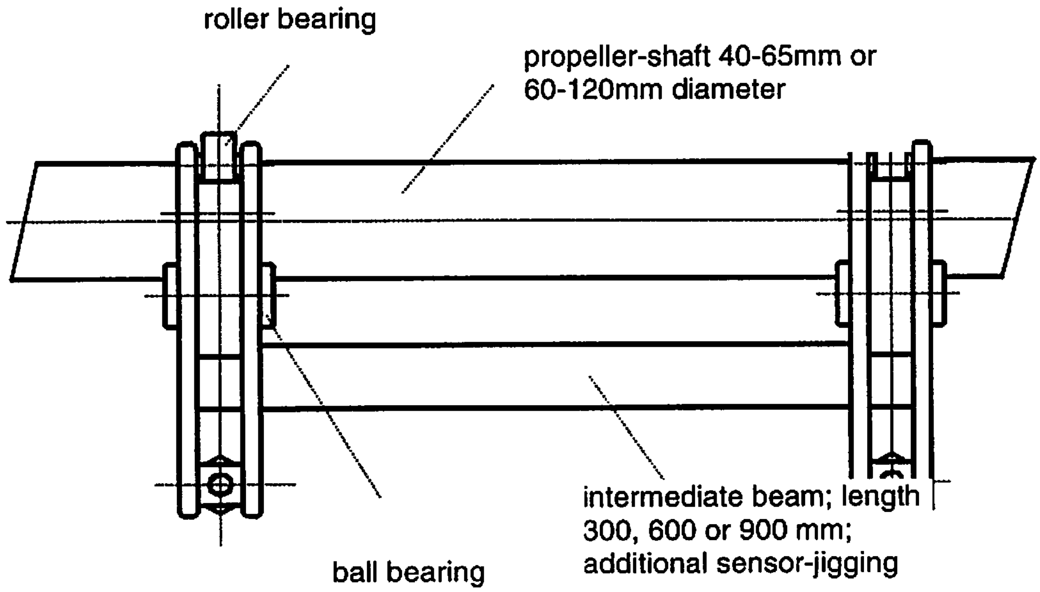


Fig. 11 : Portable sensor holder with double-6-fold bearing, side view

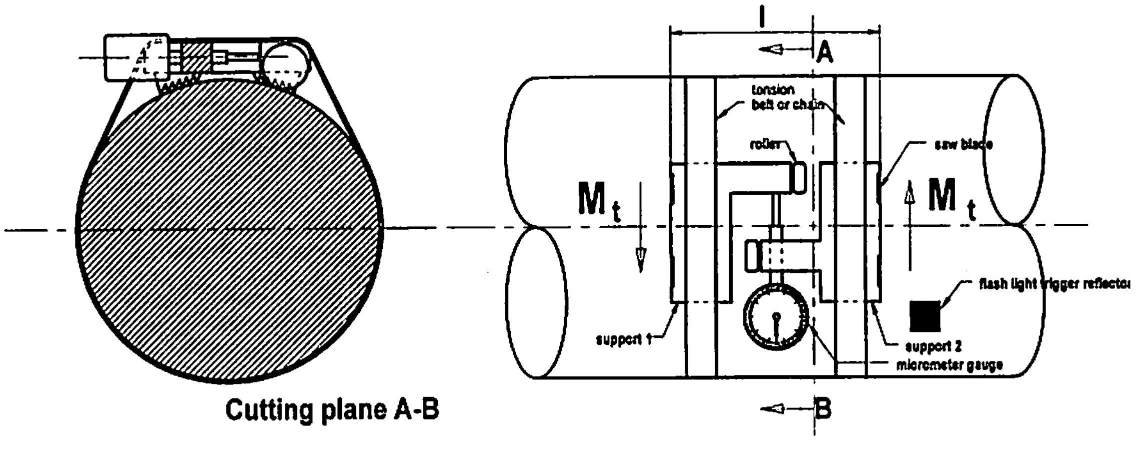


Fig. 12 : Torque measurement by micrometer gauge
Measurement of displacement between support1 and support 2

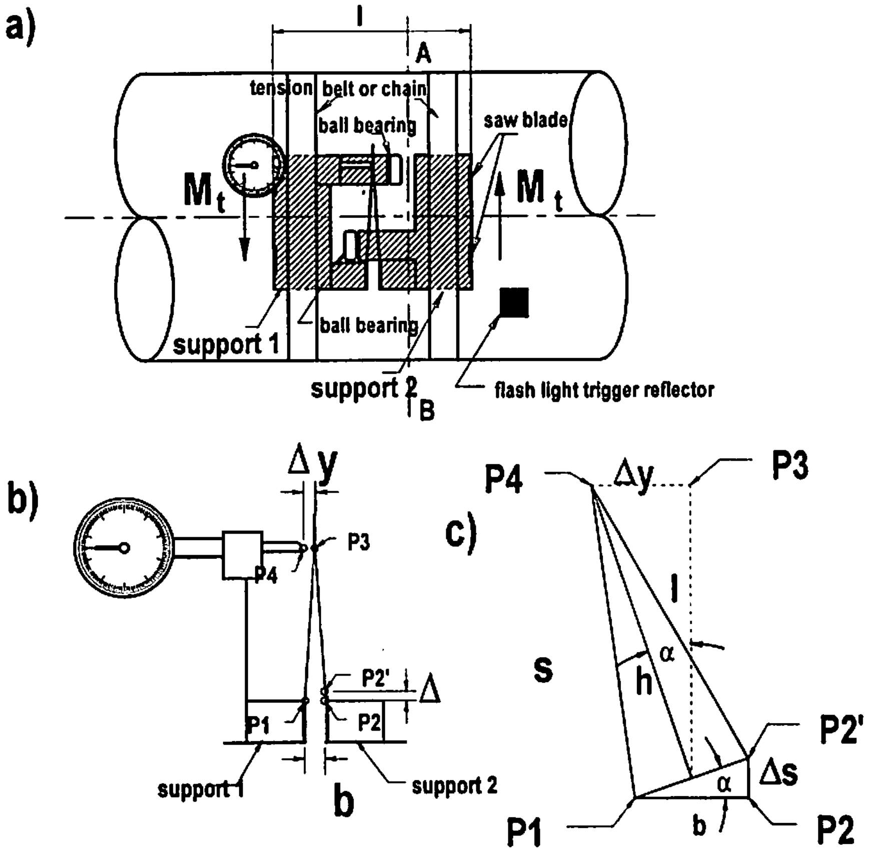
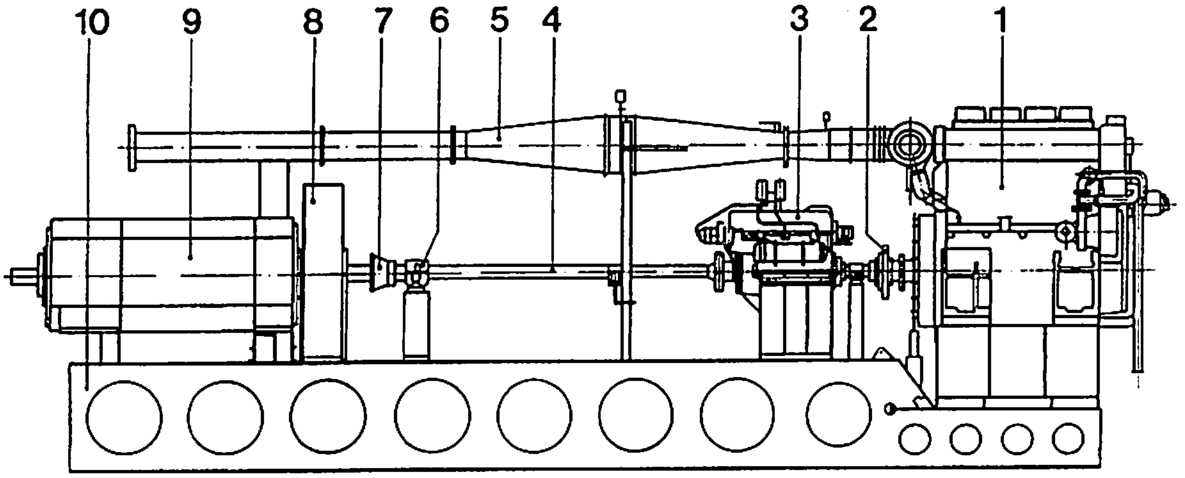


Fig 13 : Drawing of displacement measuring system with mechanical amplifier
a) Top view of the system mounted at a shaft
b) Detailed drawing of mechanical amplifier
c) Principle function of mechanical amplifier



1	**Four stroke diesel engine**	6	**Plummer block**
2	**Torsion elastic coupling**	7	**Membrane coupling**
3	**Reverse-reduction gear**	8	**Flywheel**
4	**Torque tube**	9	**DC-engine**
5	**Air suction pipe**	10	**Bed-plate**

Fig. 14 : Diesel engine test bed TUHH

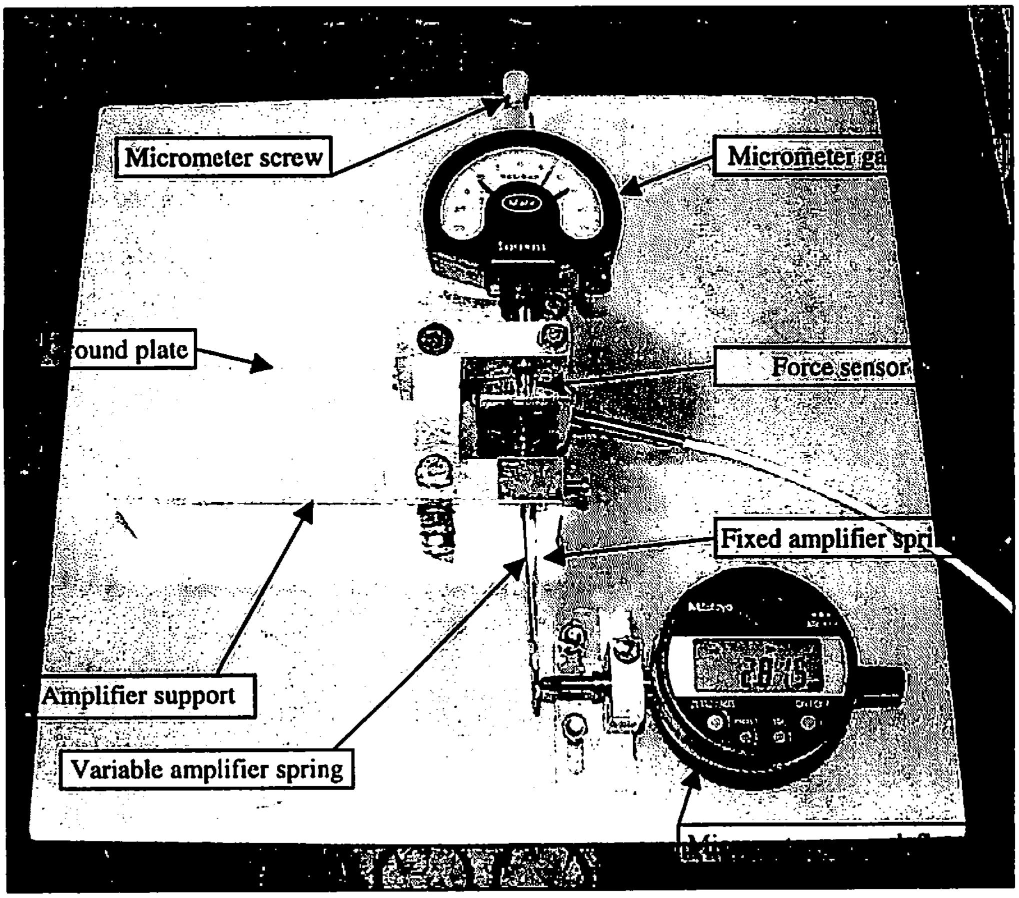


Fig. 15 : Bench for mechanical amplifier tests

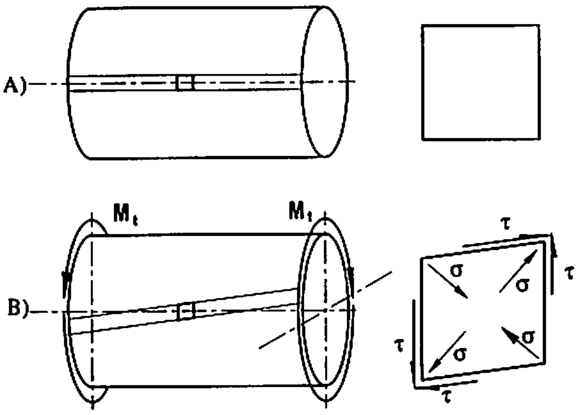


Fig. 16 : A) Unloaded shaft. Generating lines parallel of the axis. Surface element square
B) Shaft loaded with torque. Generating lines oblique of axis. Surface element diamond

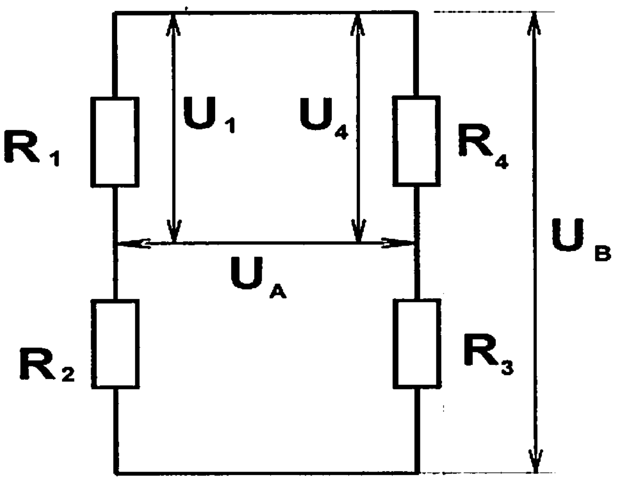


Fig. 17 : Principle circuit diagram of a Wheatstone Bridge

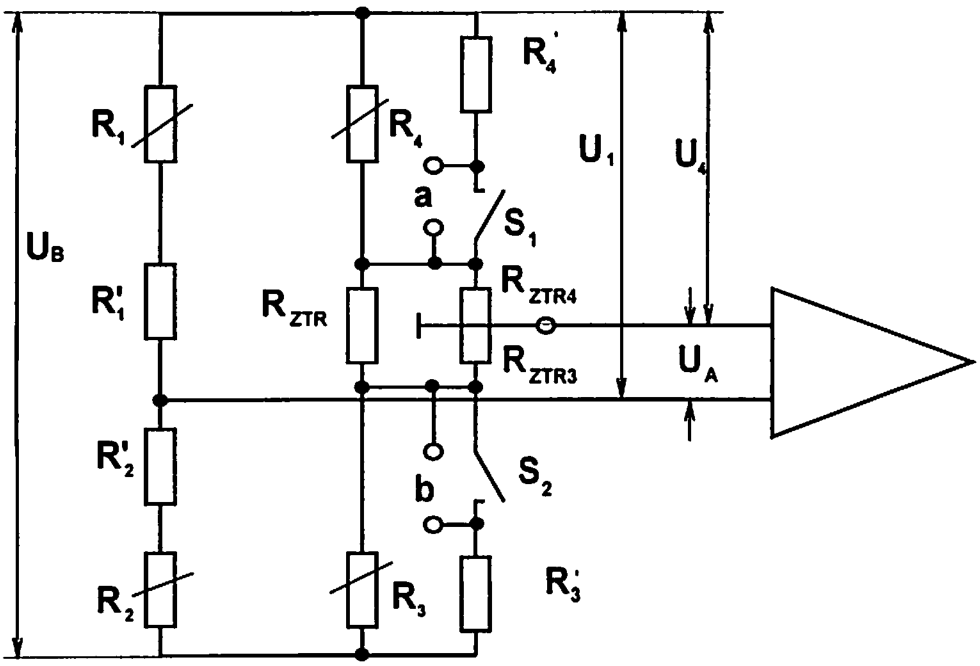


Fig. 18 : Principle circuit diagram of a strain gauge bridge with offset balance for half and full bridge application

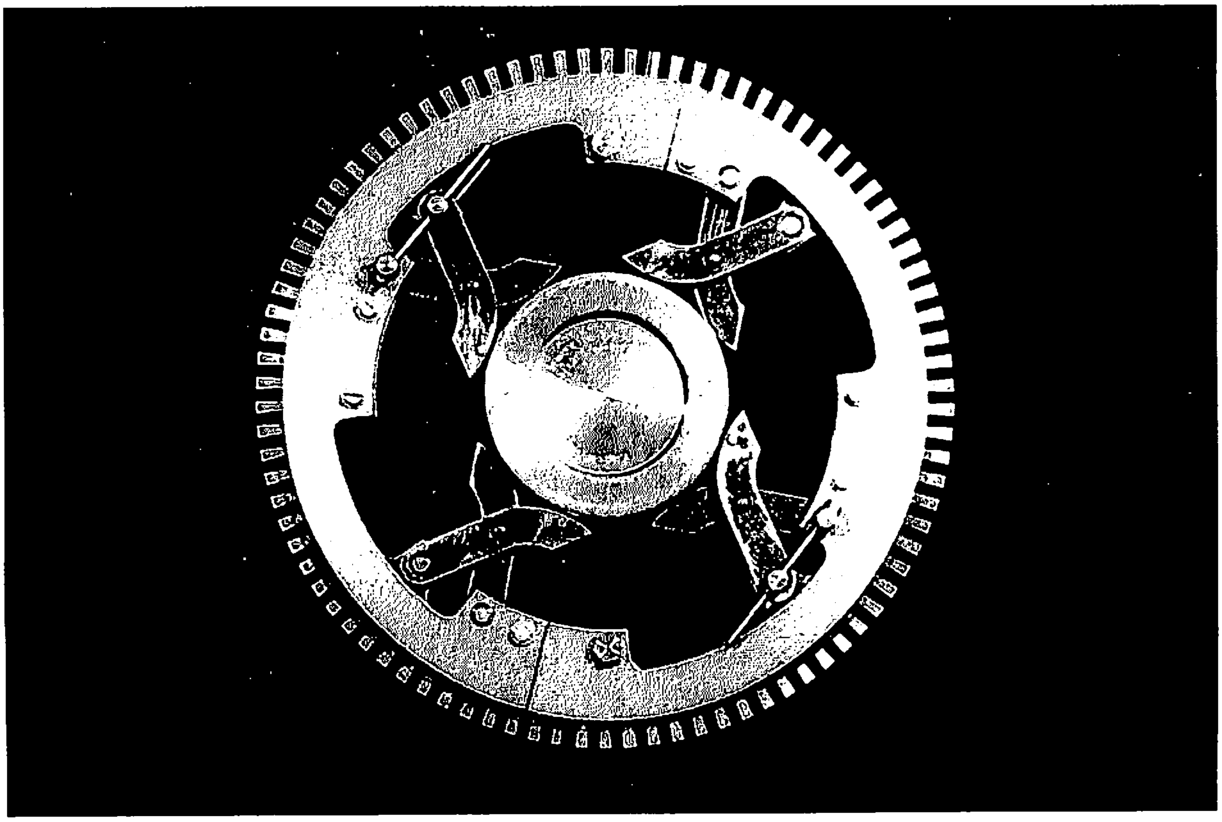


Fig. 18 : Divisible chopper disk, shaft diameter 80-120 mm, fully assembled

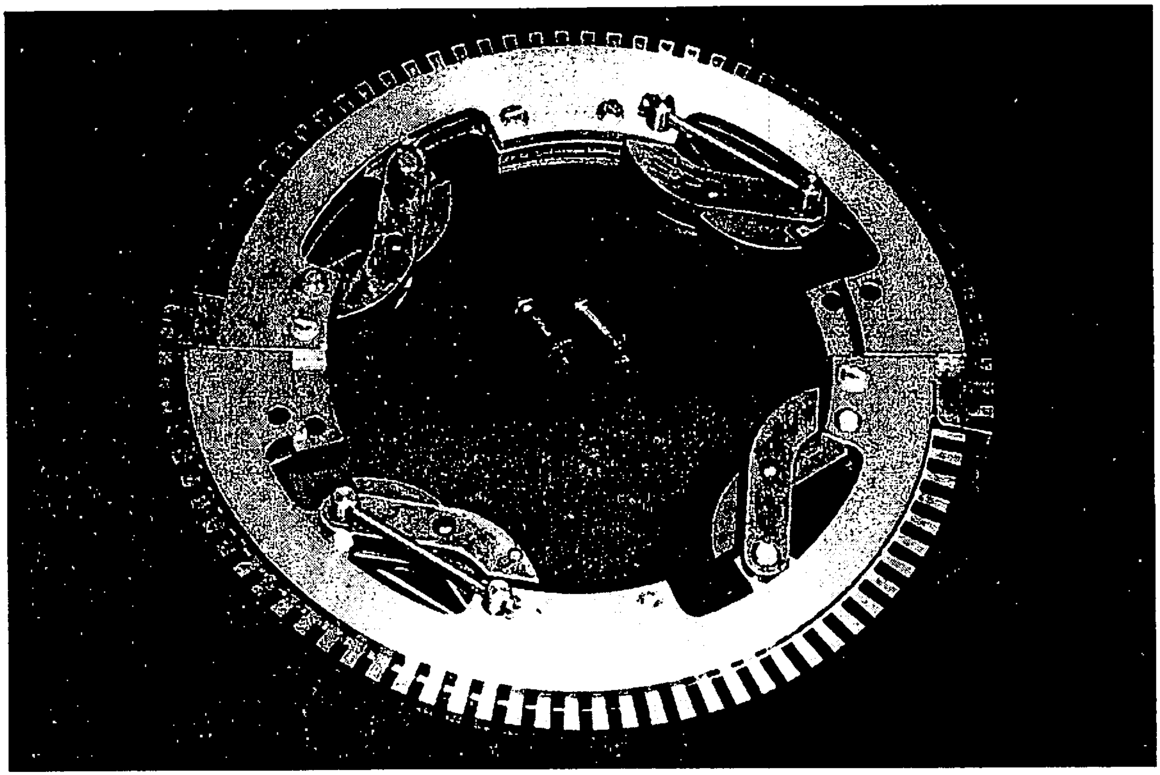


Fig. 19 : Divisible chopper disk, half closed

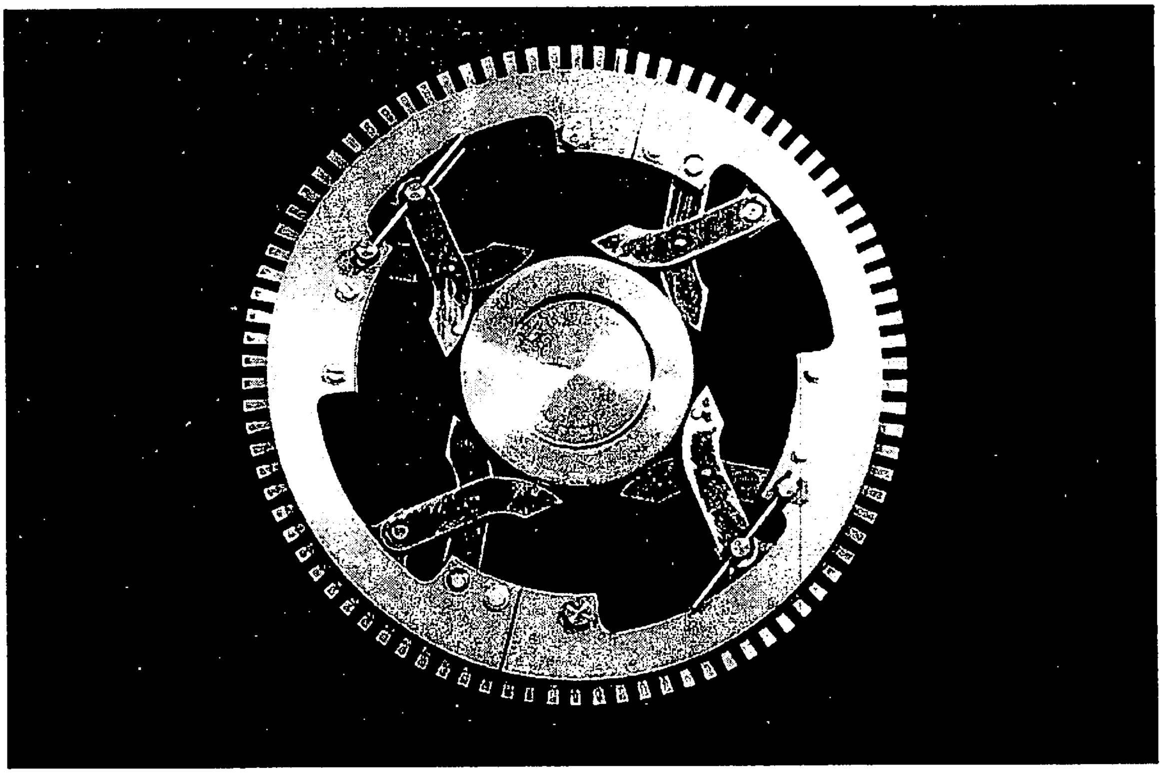


Fig. 20 : Divisible chopper disk, shaft diameter 80-120 mm, fully assembled

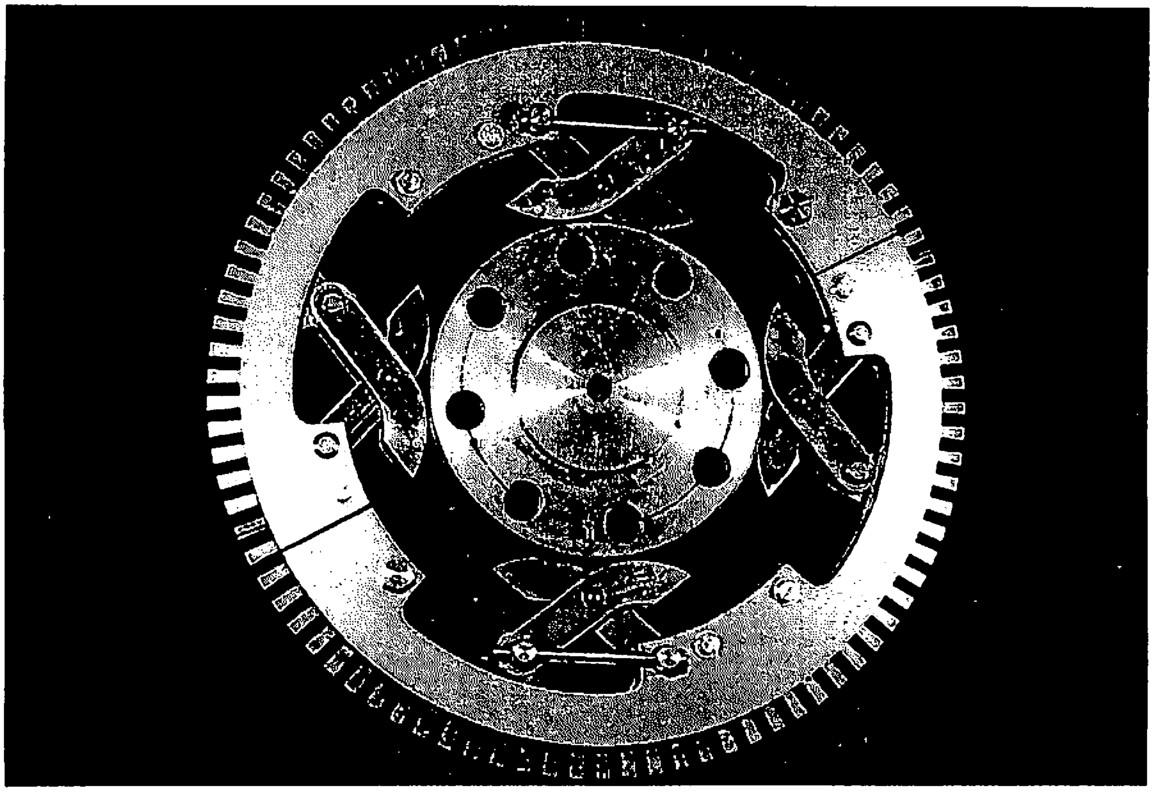


Fig. 21: Divisible chopper disk, fitted on shaft Ø 110 mm

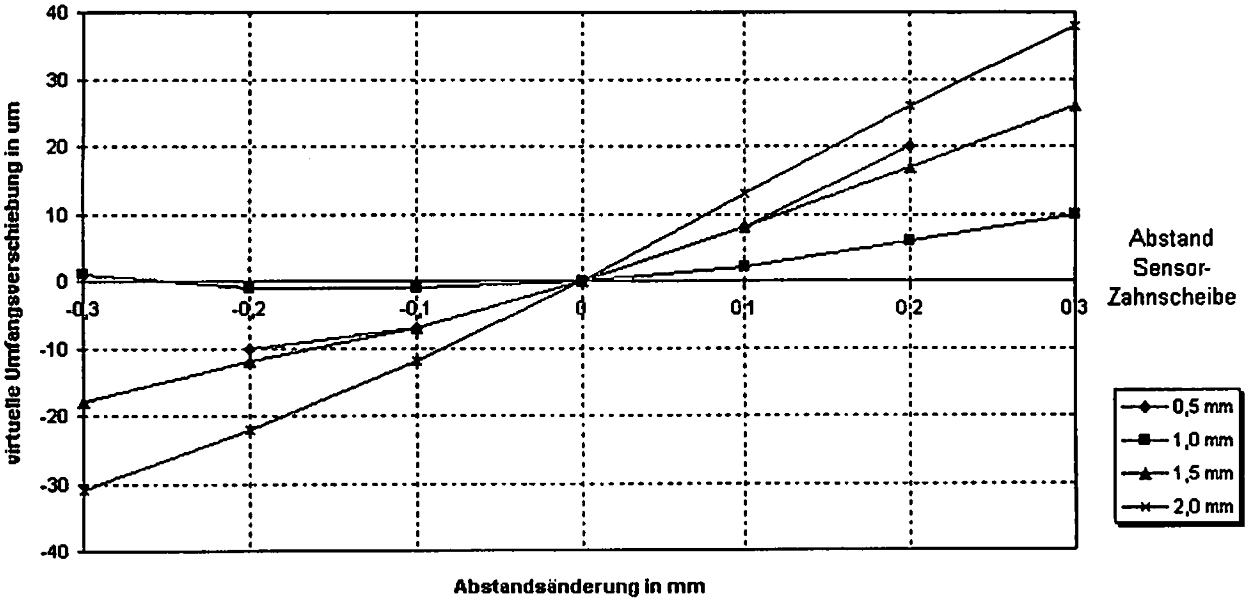


Fig. 22 : Susceptibility to sensor dislocation, magnetic Hall-sensors with chopper disk (virtual shift of circumference versus alteration of distance)

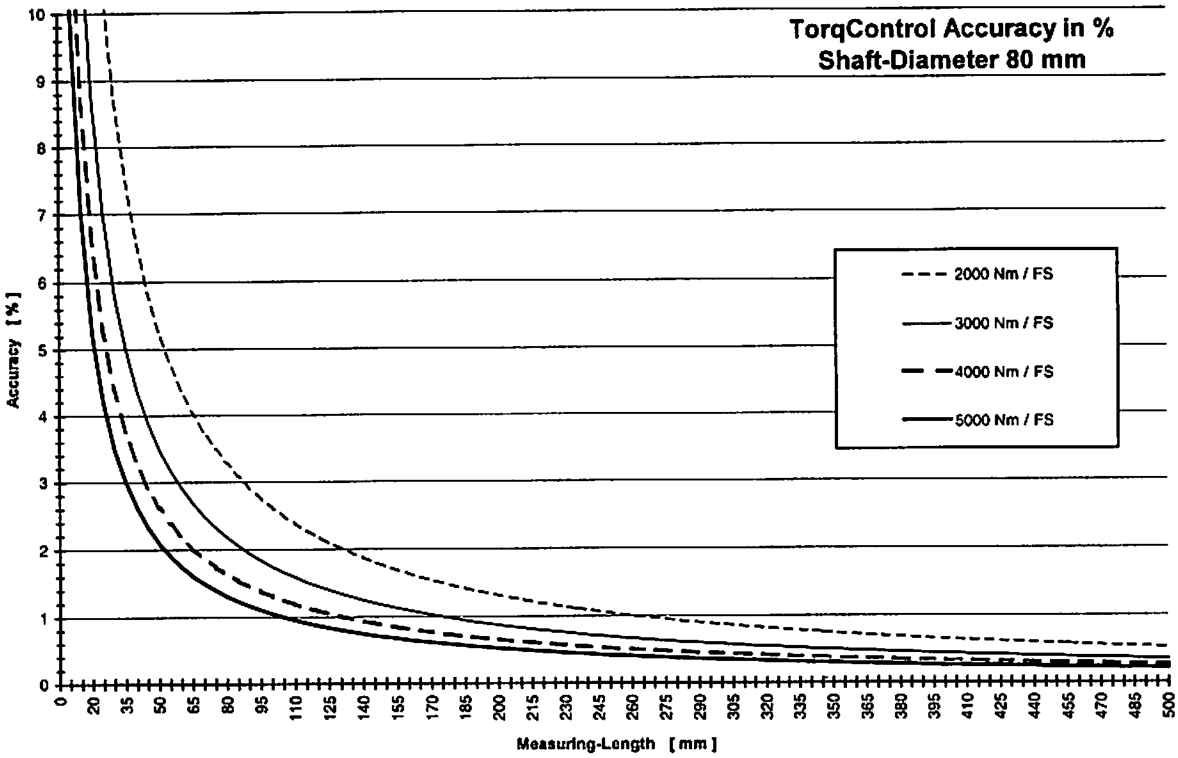


Fig. 23 : Accuracy of the portable system. Propeller shaft diameter 80 mm

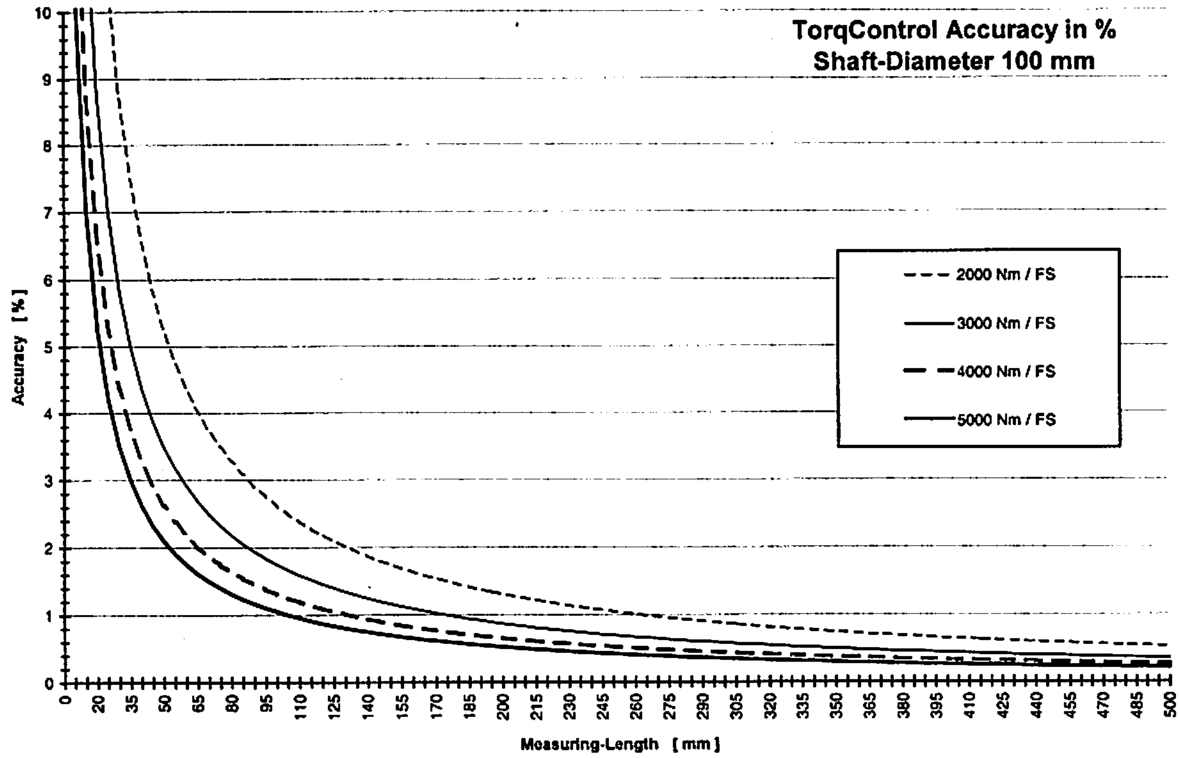


Fig. 24 : Accuracy of the portable system. Propeller shaft diameter 100 mm

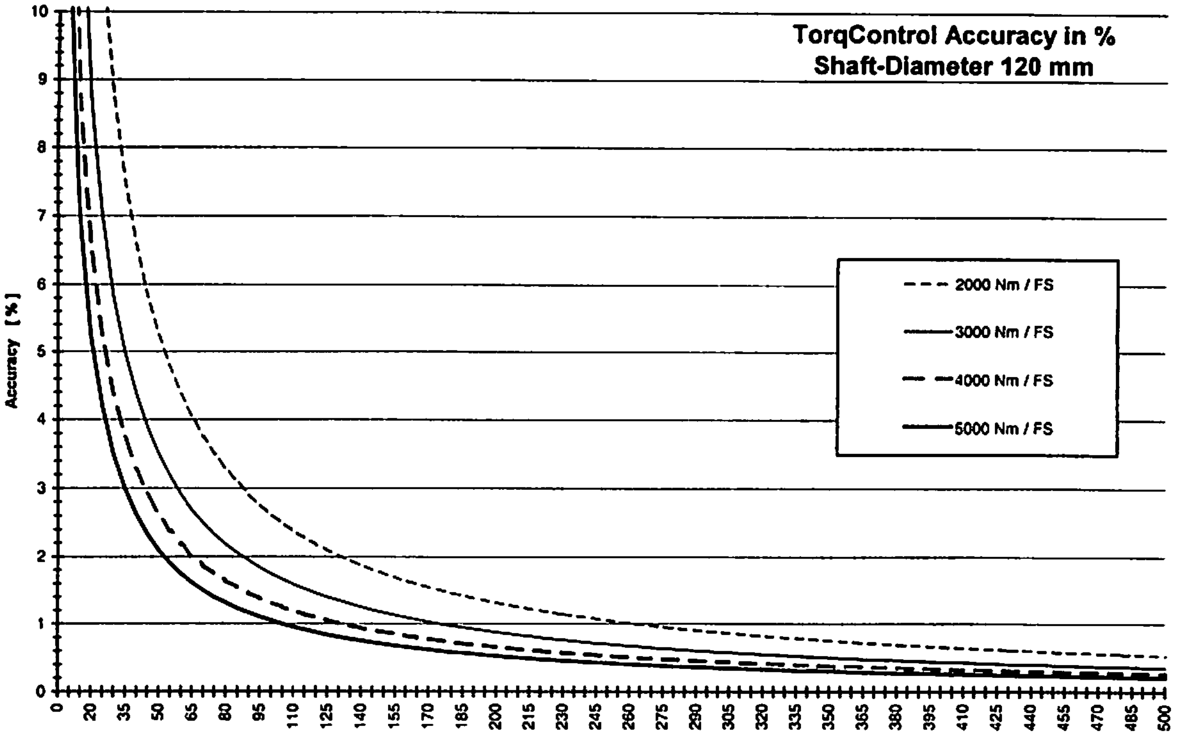


Fig. 25 : Accuracy of the portable system. Propeller shaft diameter 120 mm

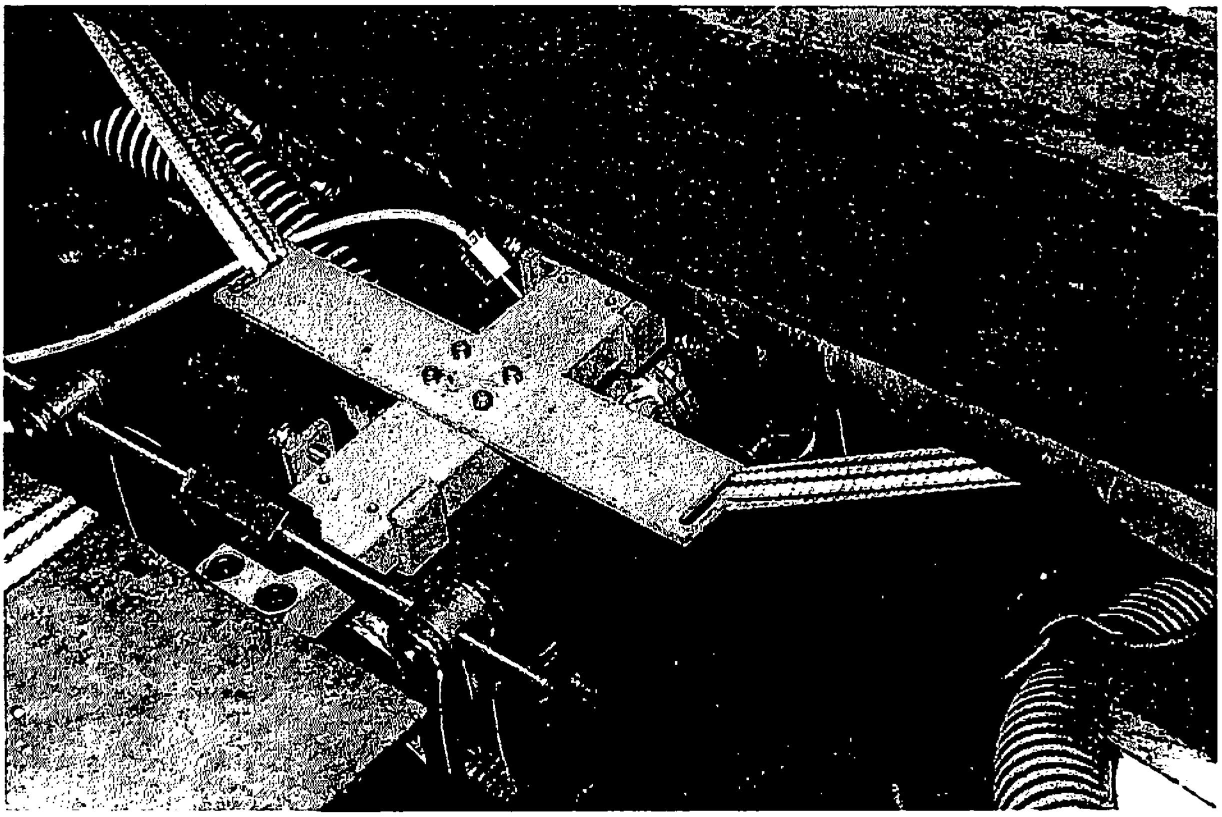


Fig. 26 : Mobile sensor support, mounted on the shaft of the fishing vessel *Poseidon*

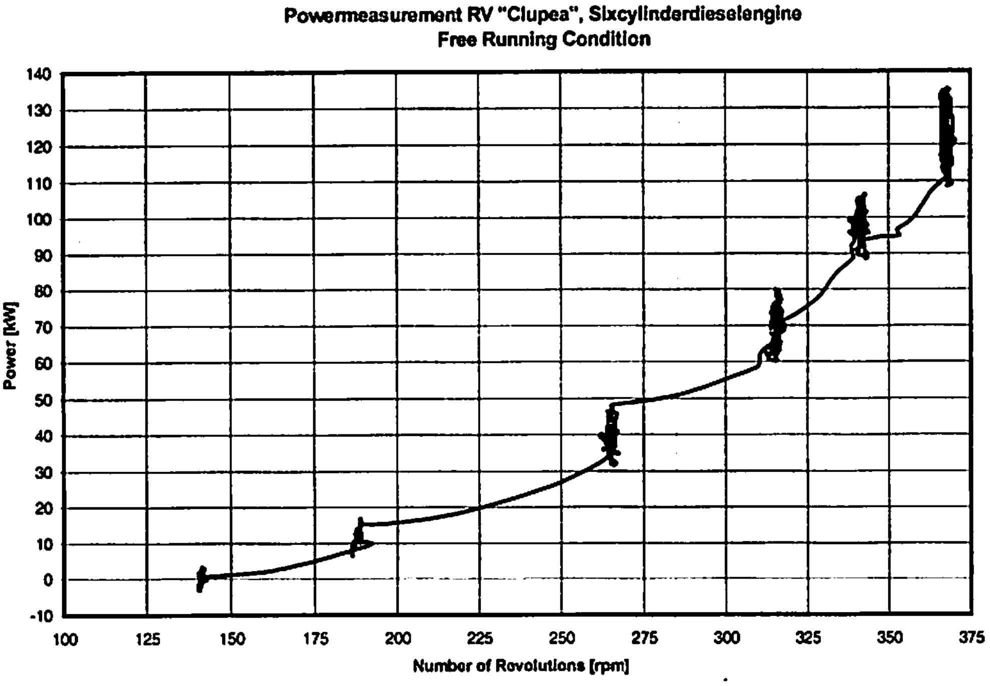


Fig. 27 : Calculation of propulsion power of FRV *Clupea*. Torque and speed measured by ladder chain gear during free running, June 1995

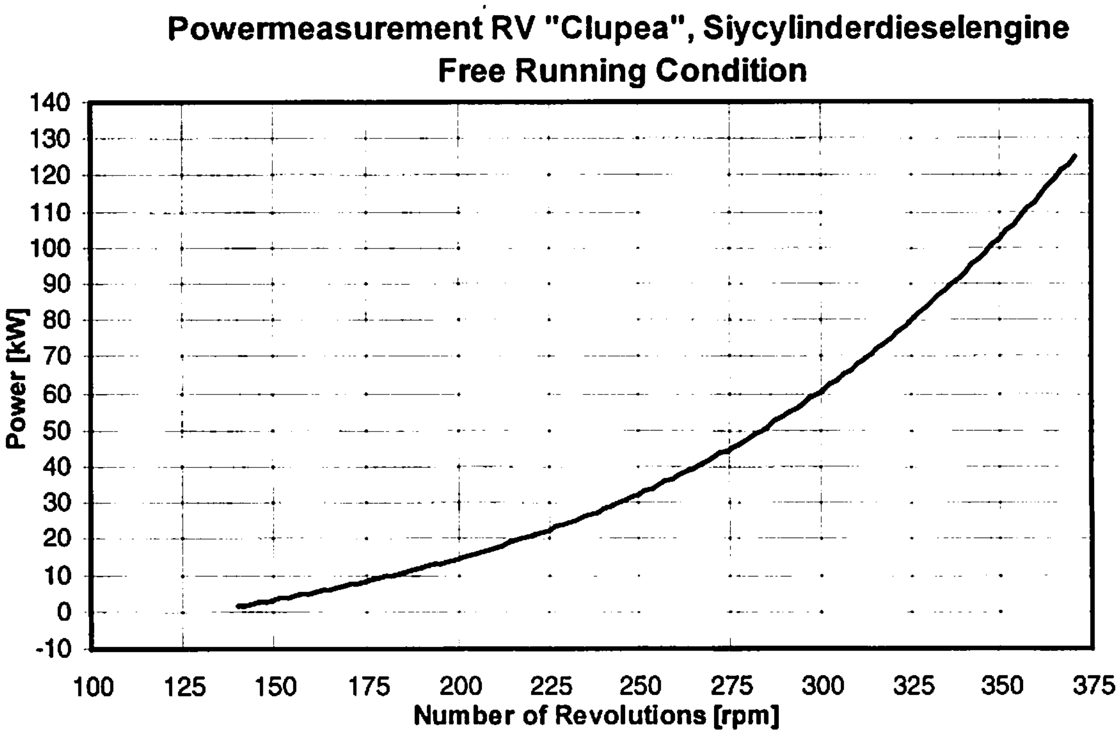


Fig. 28 : Propeller Curve of FRV *Clupea*. Mean value of propulsion power.

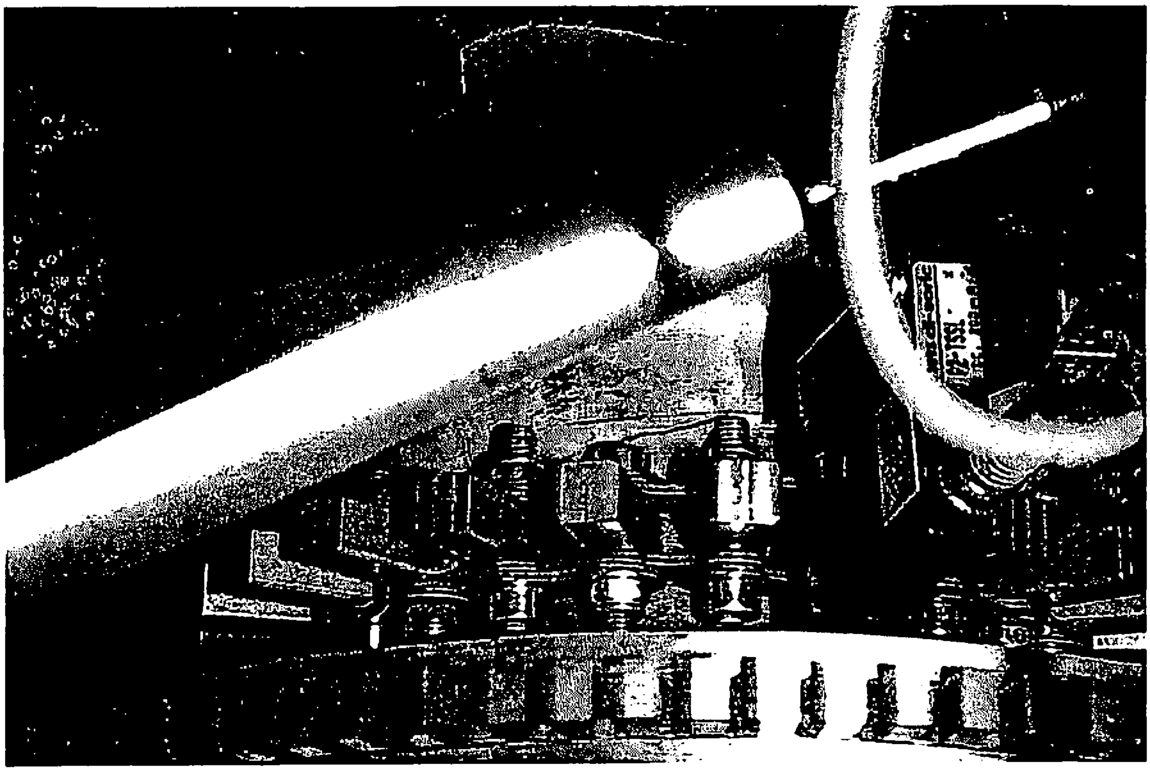


Fig. 29 : Measurement on *Clupea*, February 1996, light barrier on ladder chain

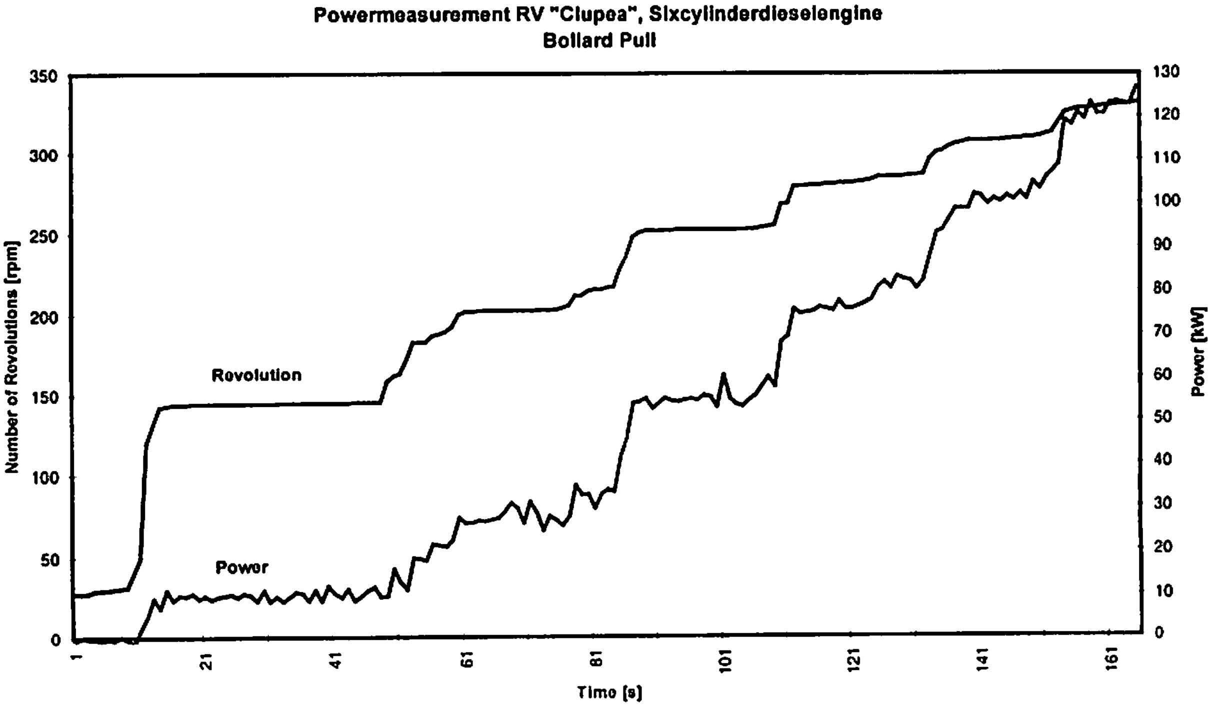


Fig. 30 : Measuring signal for speed and power. Measured on board of FRV *Clupea*. Divisible chopper disk with light barrier. Bollard pull condition", February 1996

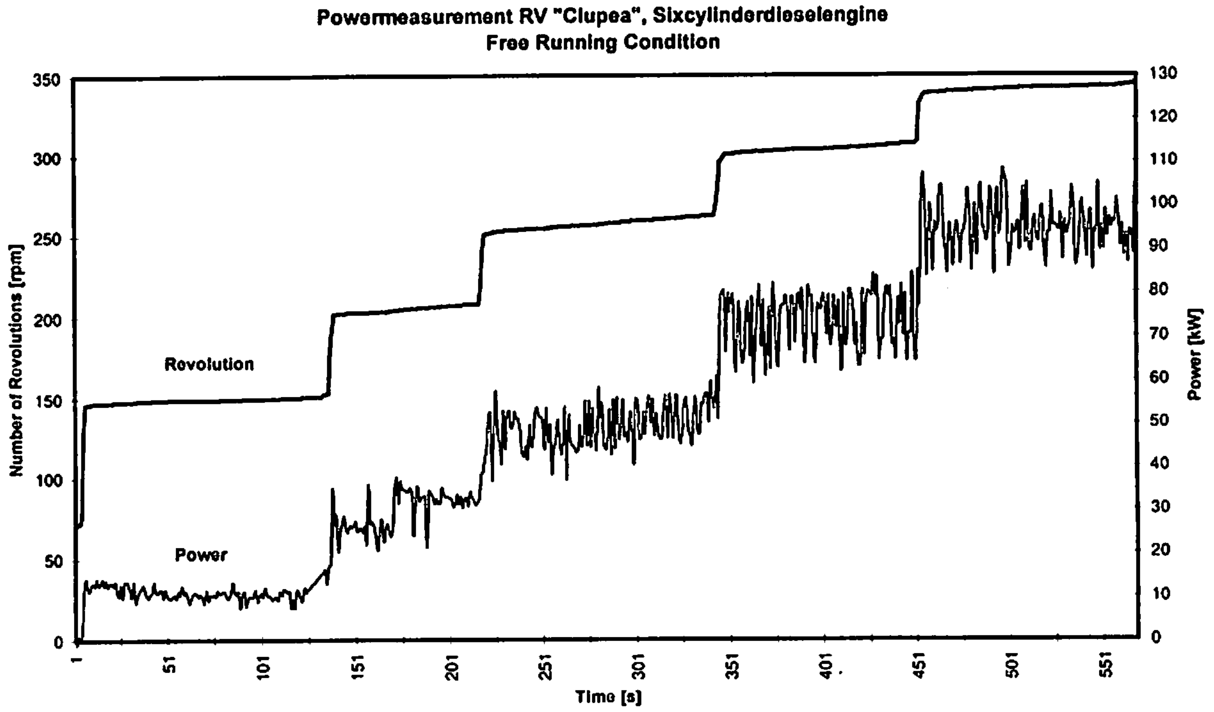


Fig. 31 : Measuring signal for speed and power. Measured on board of FRV *Clupea*. Divisible chopper disk with light barrier. Free running condition, February 1996

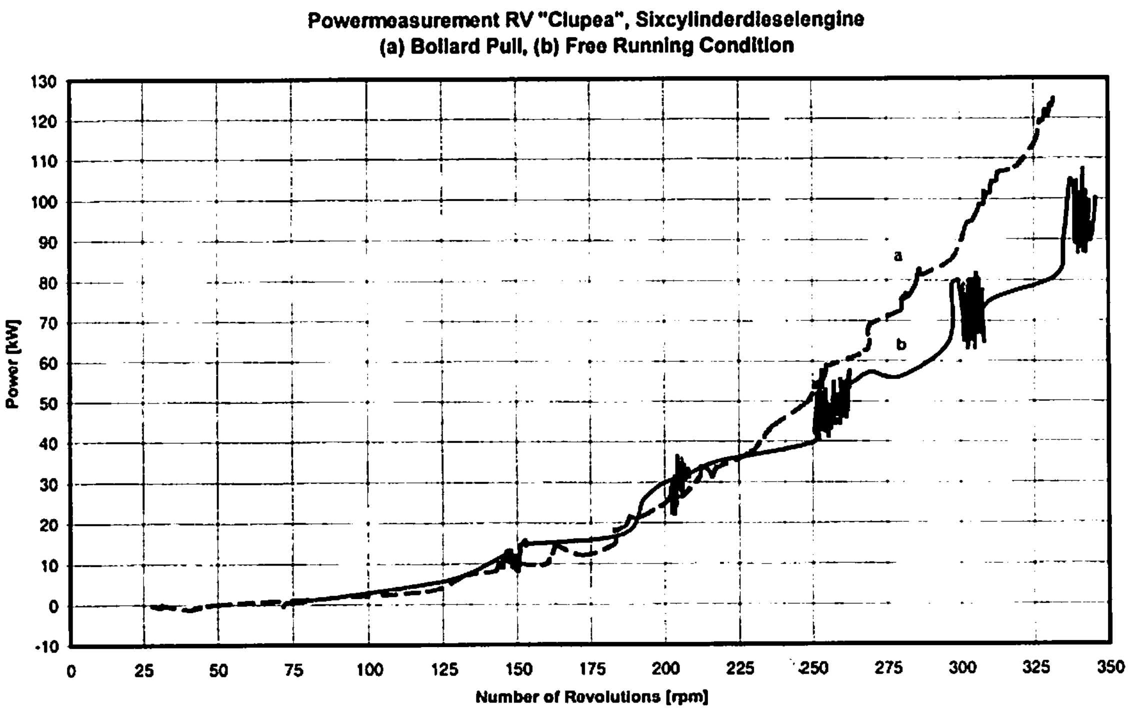


Fig. 32 : Calculation of propulsion power of FRV *Clupea*. Torque and speed measured by divisible chopper disk at bollard pull and during free running condition

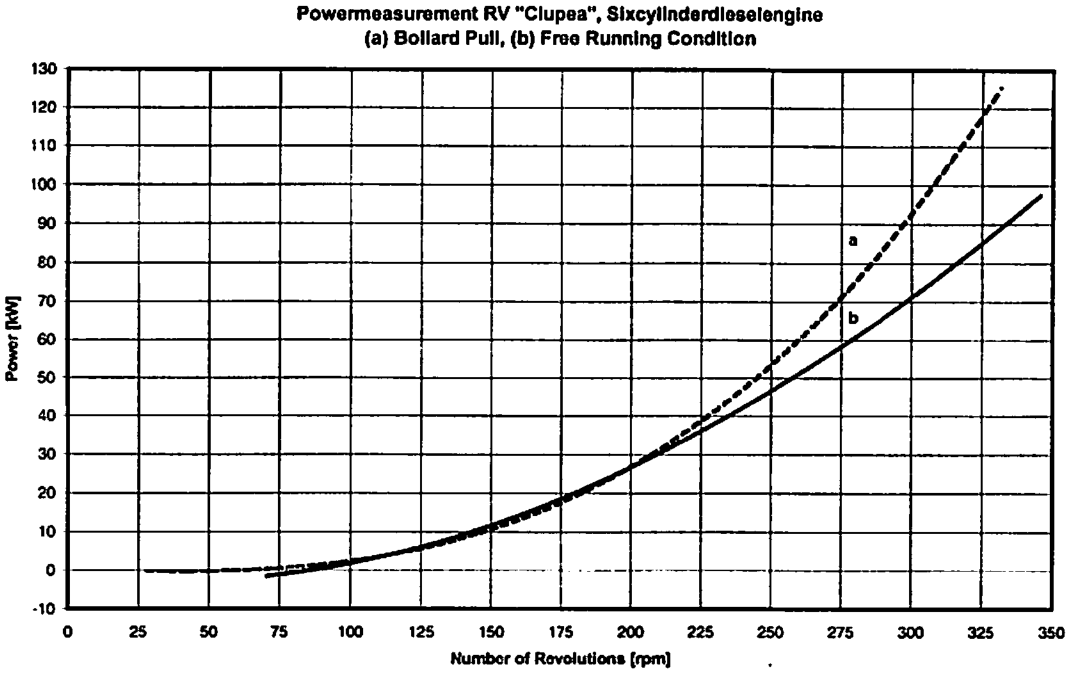


Fig. 33 : Propeller curves of FRV *Clupea*. Average calculation of propulsion power. Torque and speed measured by divisible chopper disk and with light barrier at bollard pull

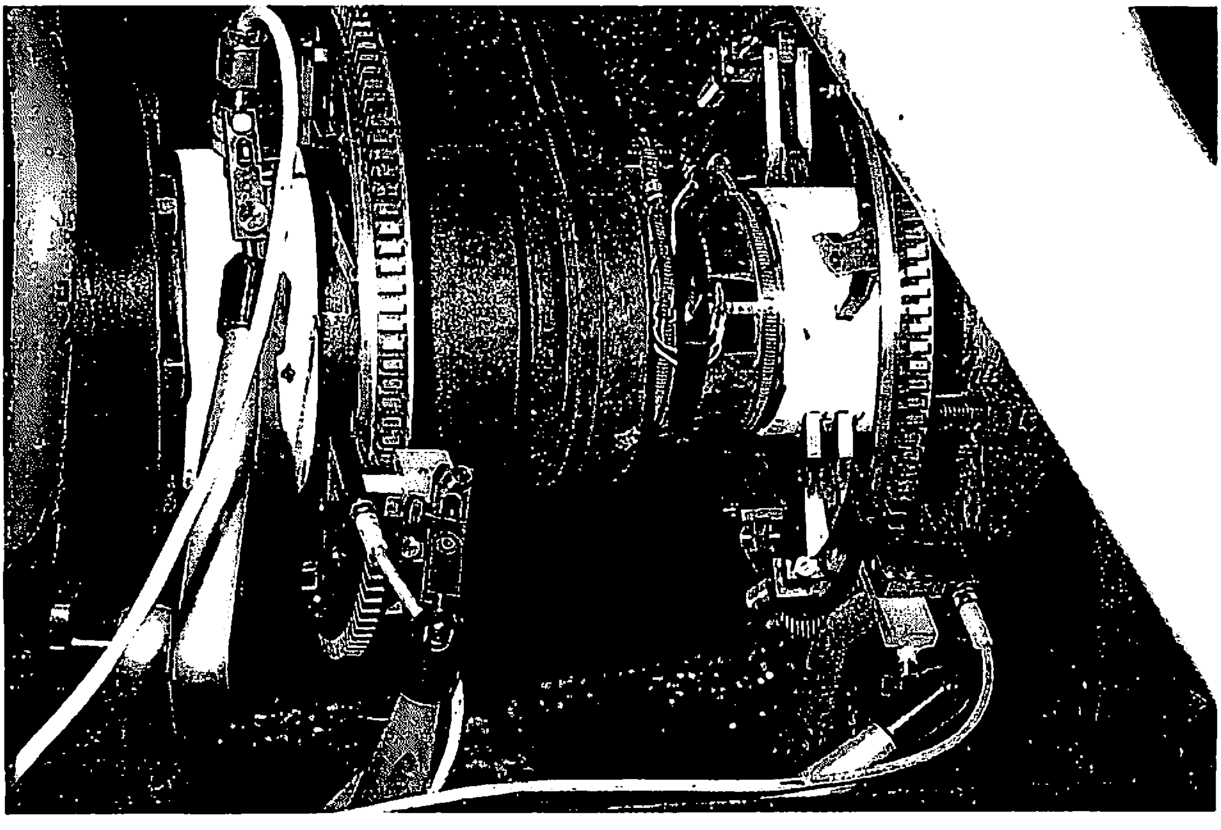


Fig. 34 : Measurement on *Christine*, June 1996, light barrier on divisible chopper

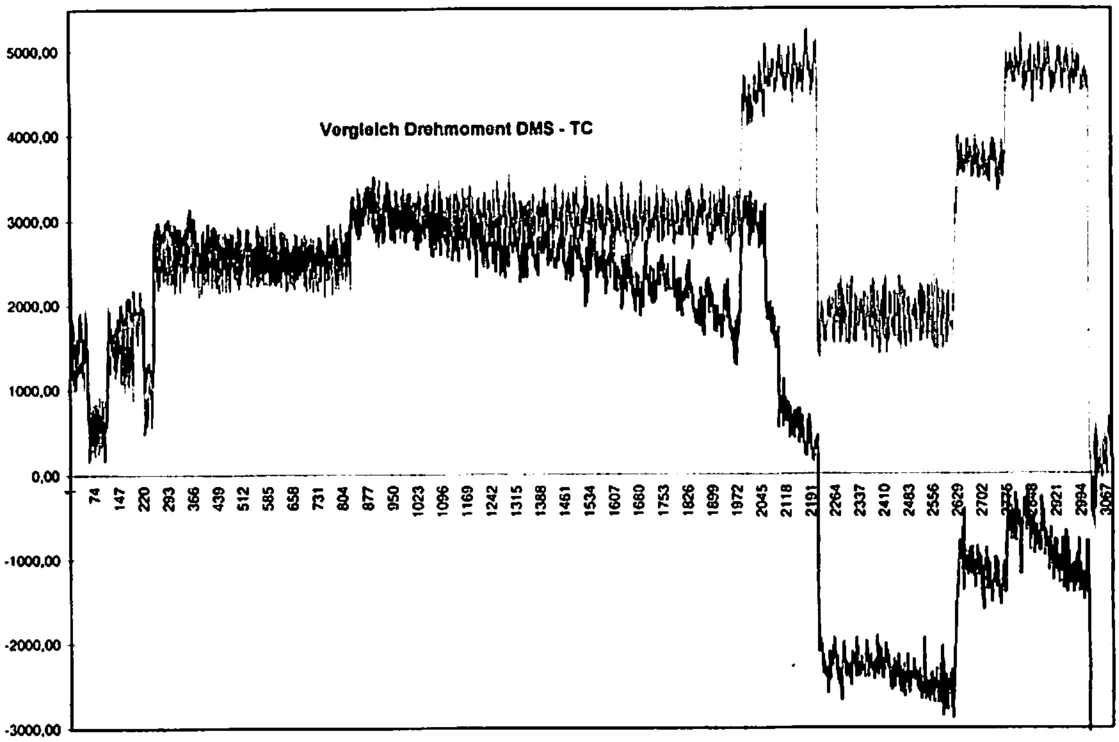


Fig. 35 : Measurement on the vessel *Christine*, June 1996, drift of the portable system's signal

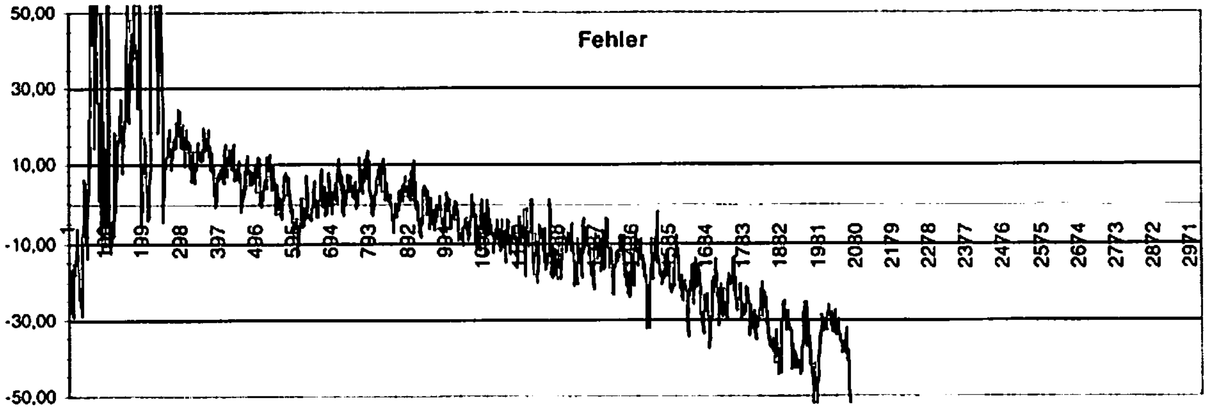


Fig. 36 : Measurement on the vessel *Christine*, June 1996, relative error during drift

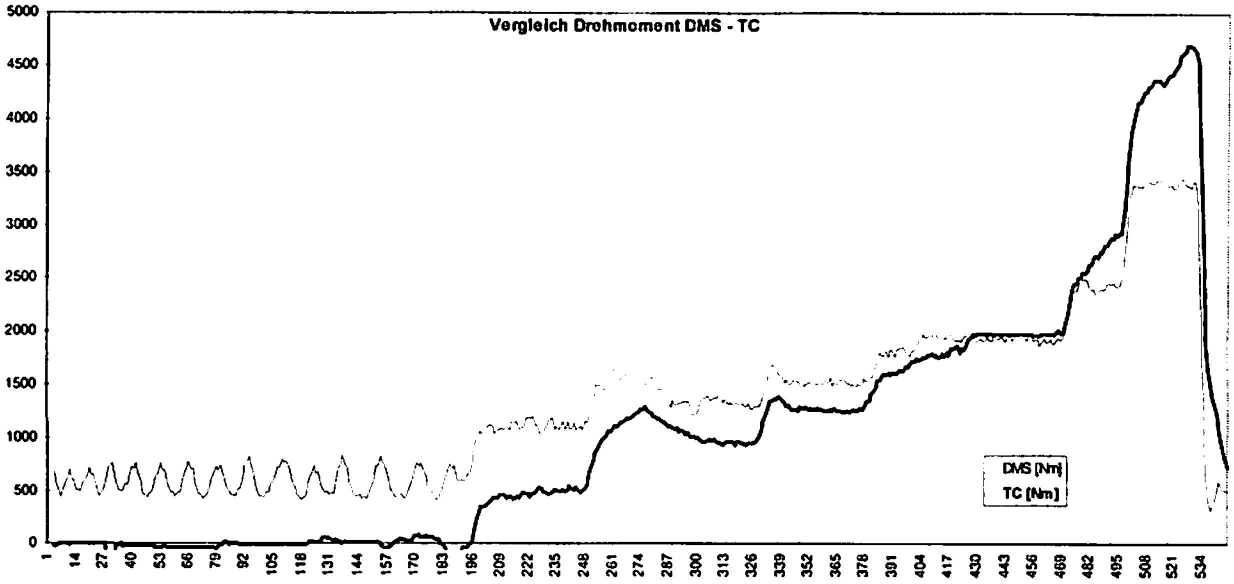


Fig. 37 : Measurement on the vessel *Poseidon*, November 1996, measuring deviation under full load

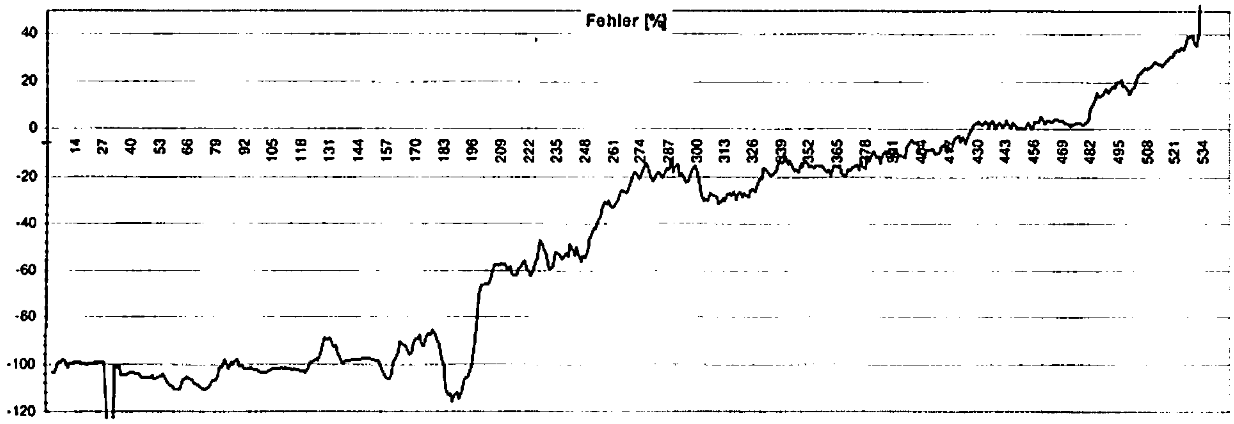


Fig. 38 : Measurement on the vessel *Poseidon*, June 1996, relative error of measuring deviation

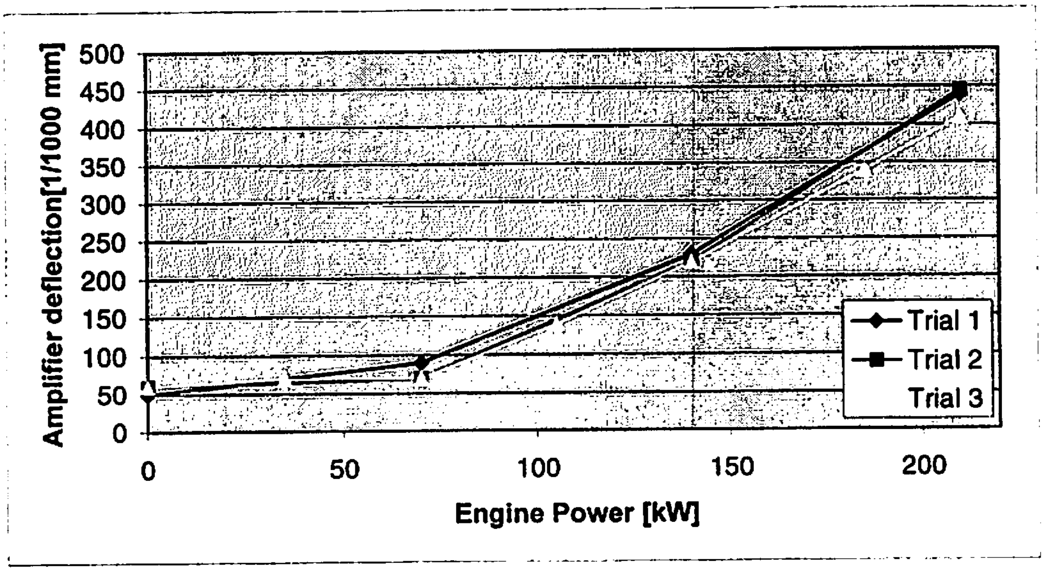


Fig. 39 : Results of "IFH Displacement" system tests

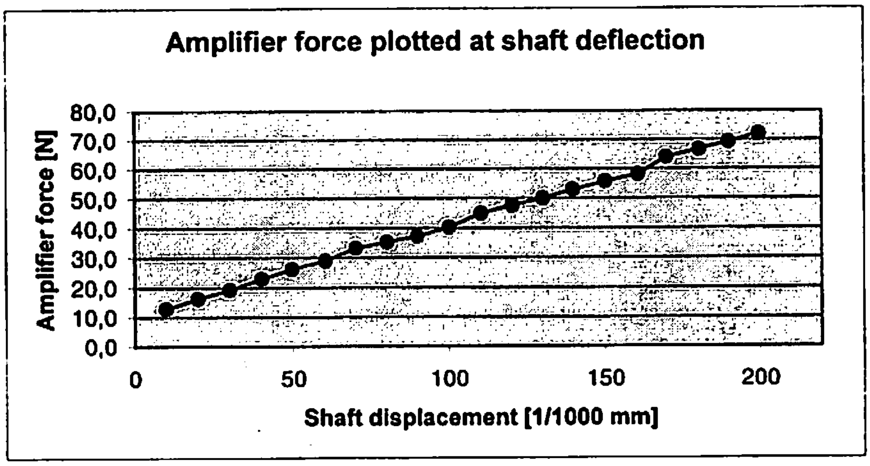


Fig. 40 : Diagrams of a typical amplifier test

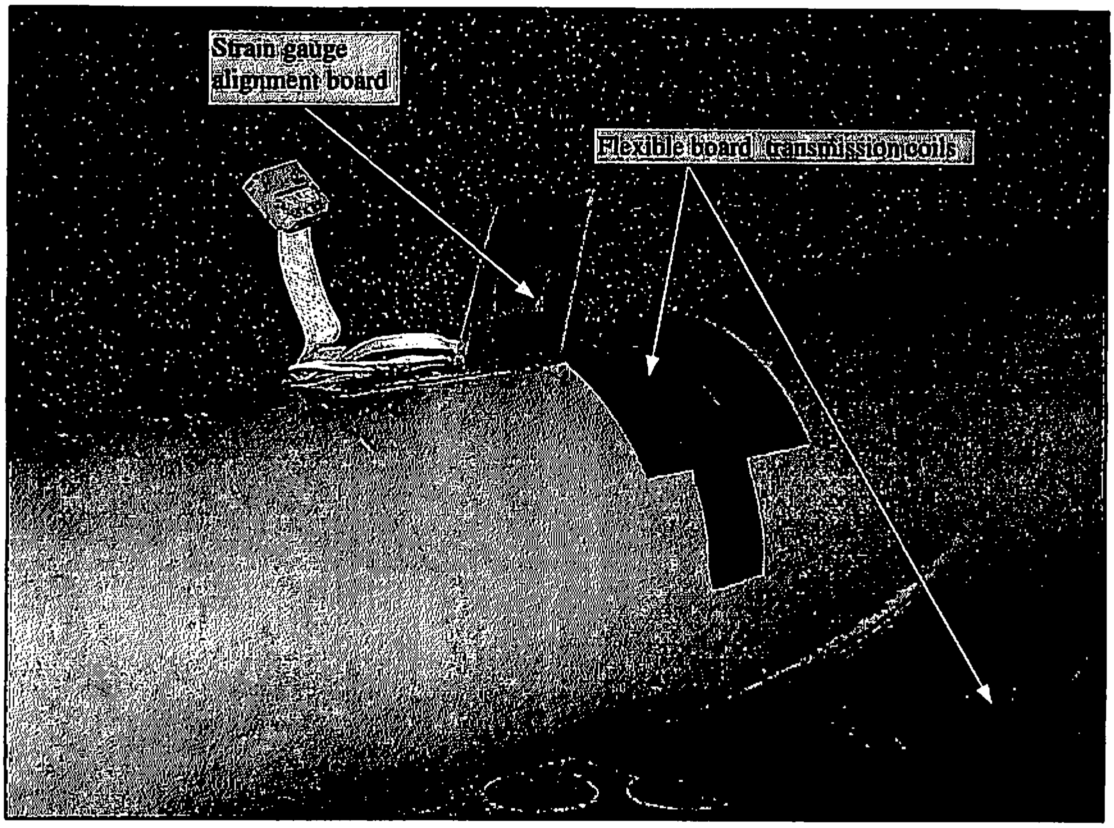


Fig. 41 : Fixing of the flexible board transmission coils at the shaft

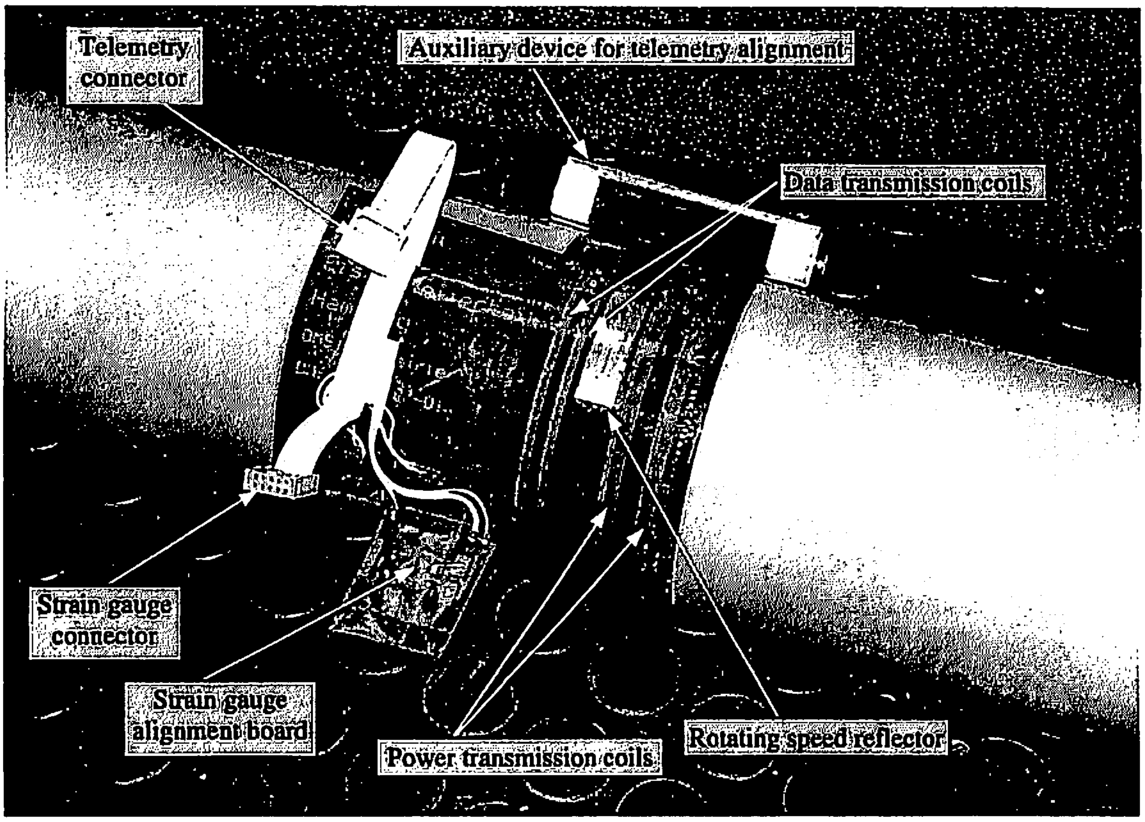


Fig. 42 : Flexible board transmission coils completely mounted at the propeller shaft

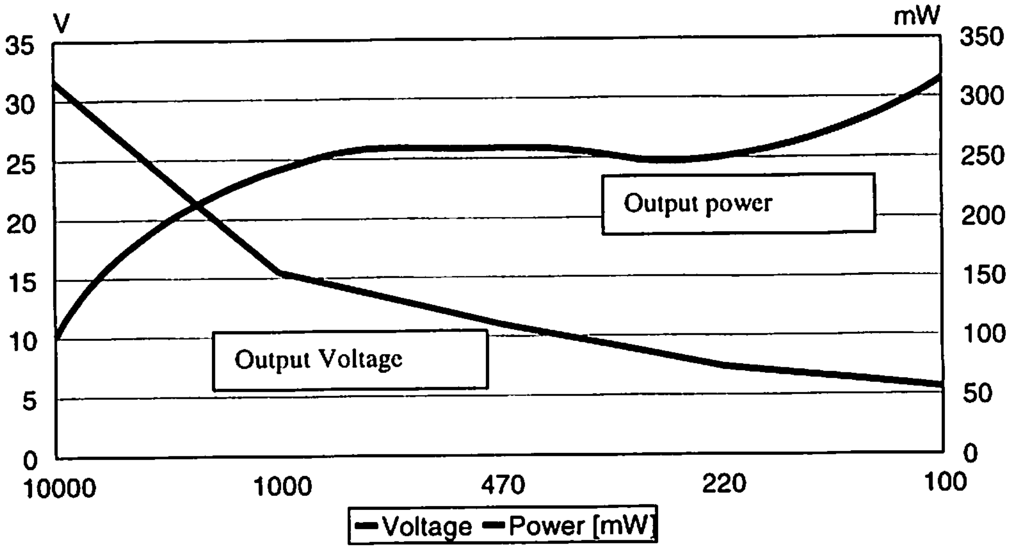


Fig. 43 : Output voltage and power supply of flexible board power transmission

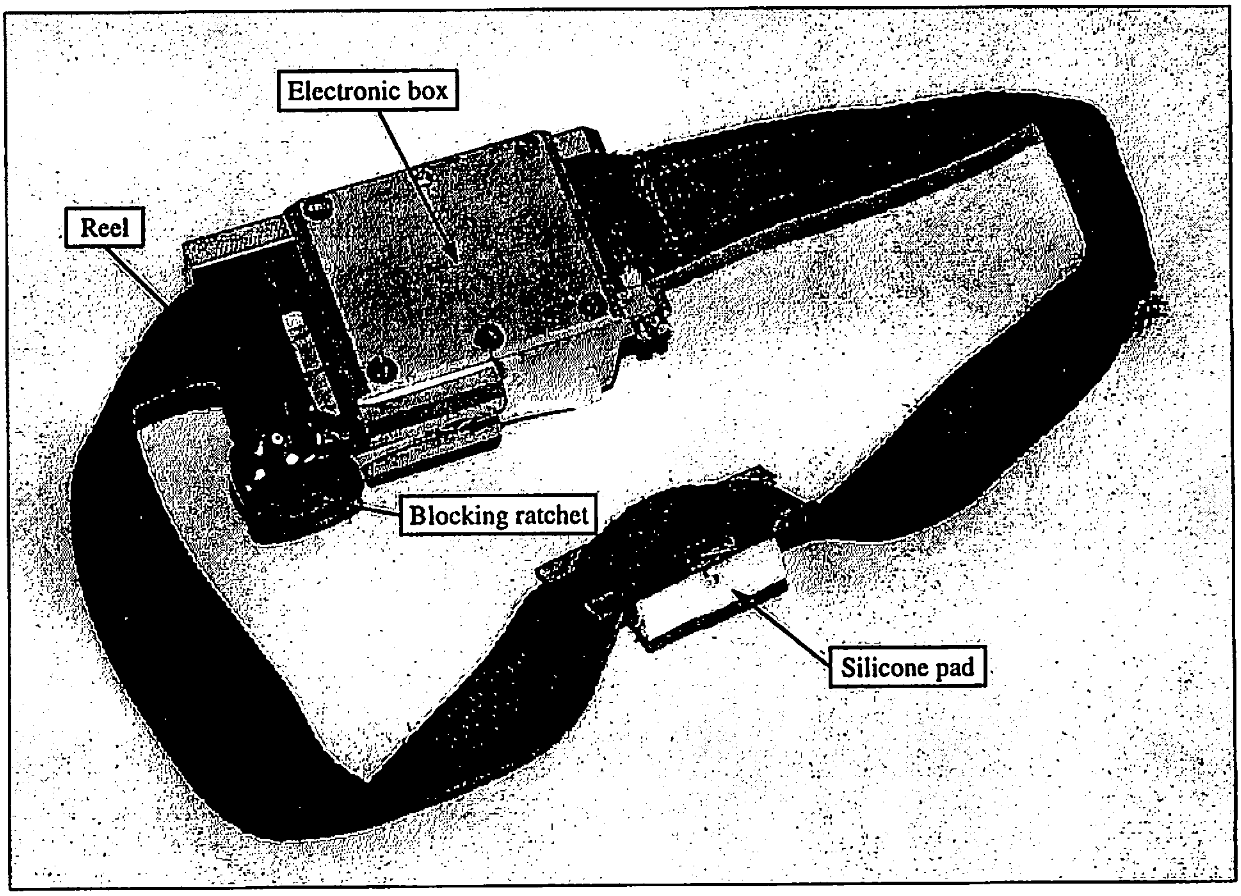


Fig. 44 : Silicone pad for curing pressure of the strain gauge bond

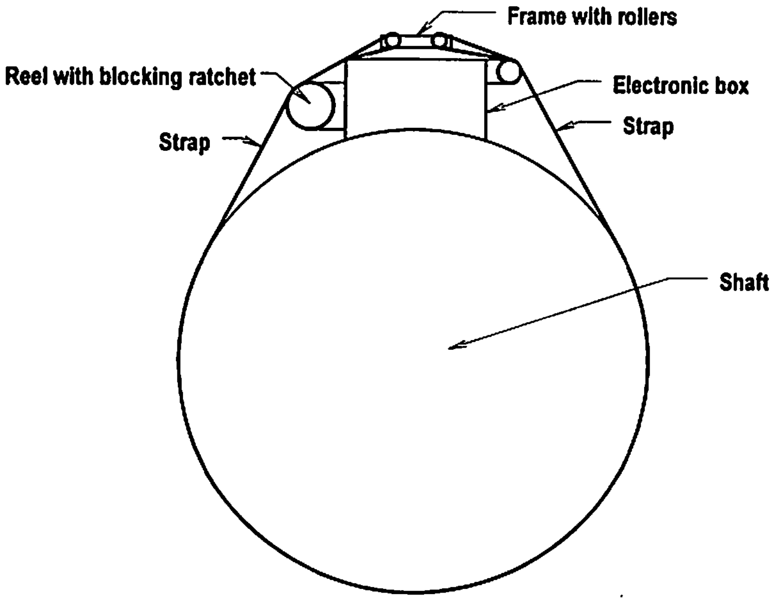


Fig. 45 : Principal drawing of the course of the strap for tightening of the electronic box at the shaft

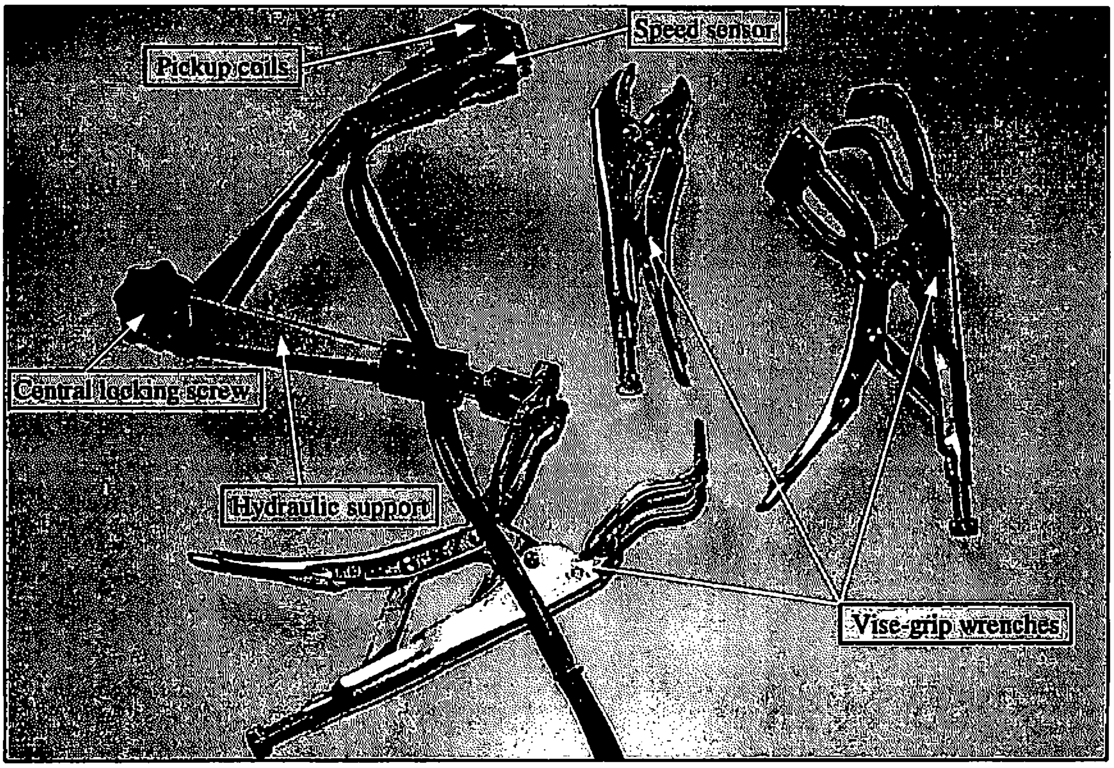


Fig. 46 : Mounting plate with pickup coils, optical reflex-sensor for revolution measurement and hydraulic support with different vise-grip wrench

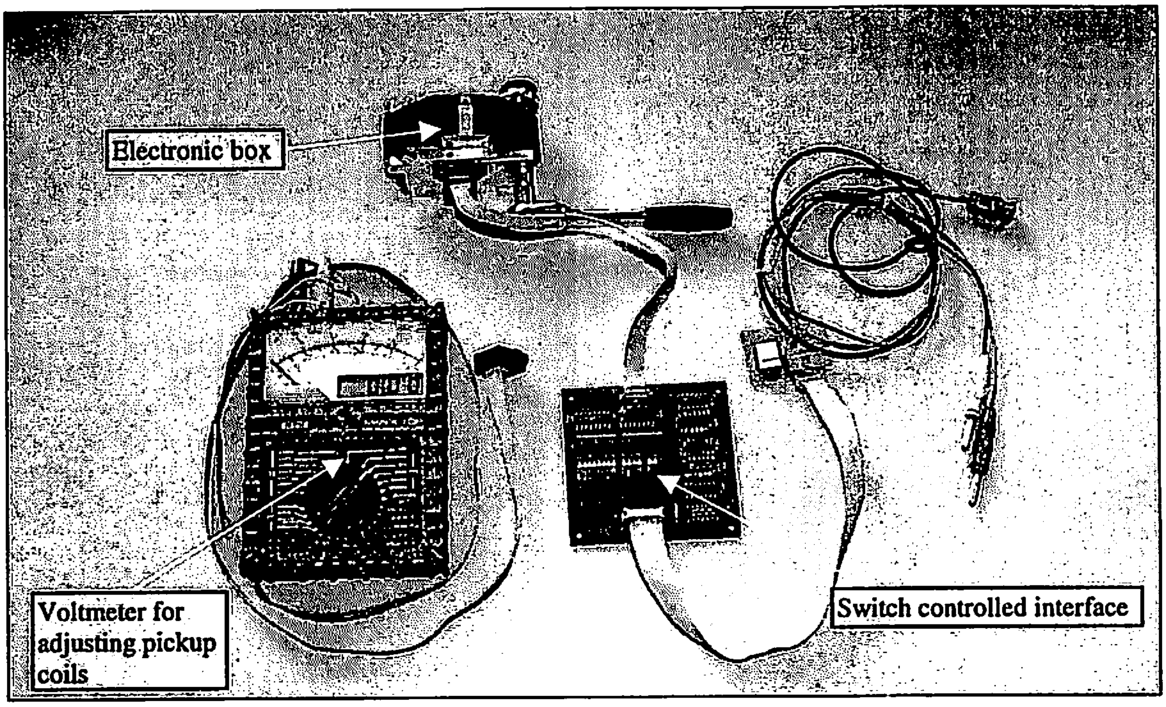


Fig. 47 : Hardware for calibration of portable "IFH Strain Gauge" system by switch controlled interface

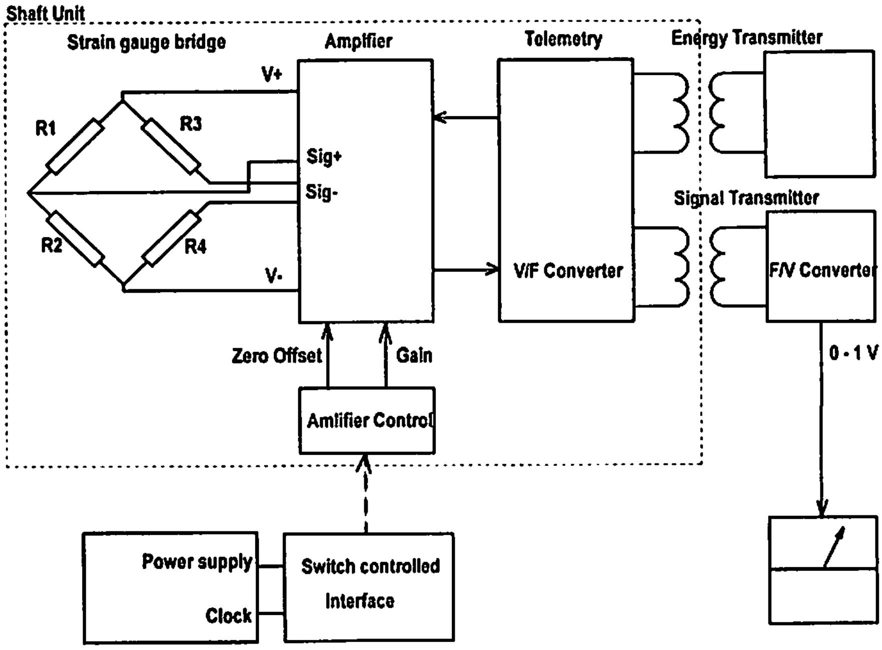


Fig. 48 : Block diagram of portable torque measurement system with switch controlled interface for calibration and readout by galvanometer

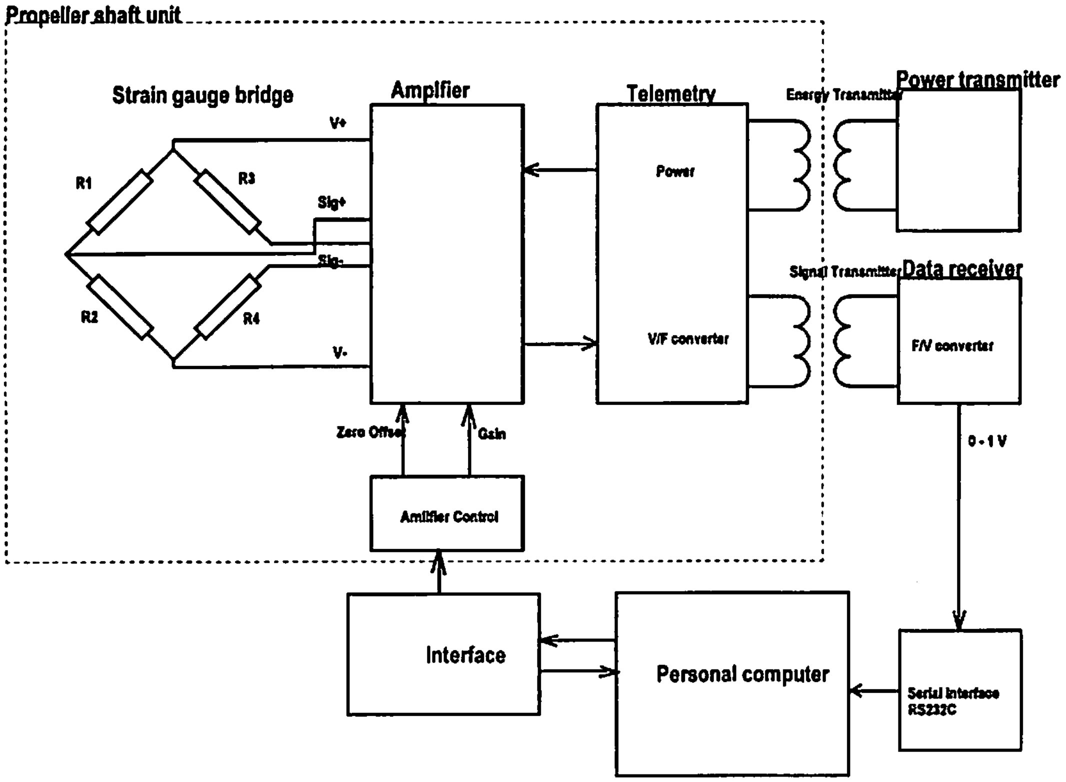


Fig. 49 : Block diagram of portable torque measurement system with interface for calibration and readout

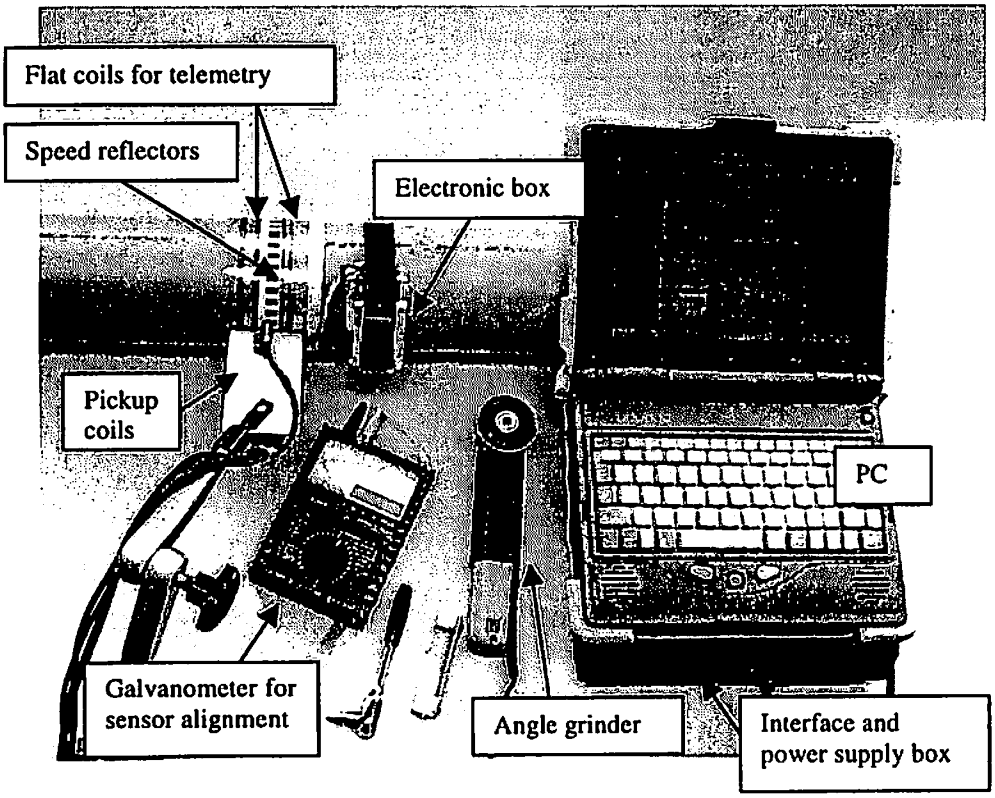


Fig. 50 : Hardware of portable torque measurement system with interface for calibration and readout by galvanometer

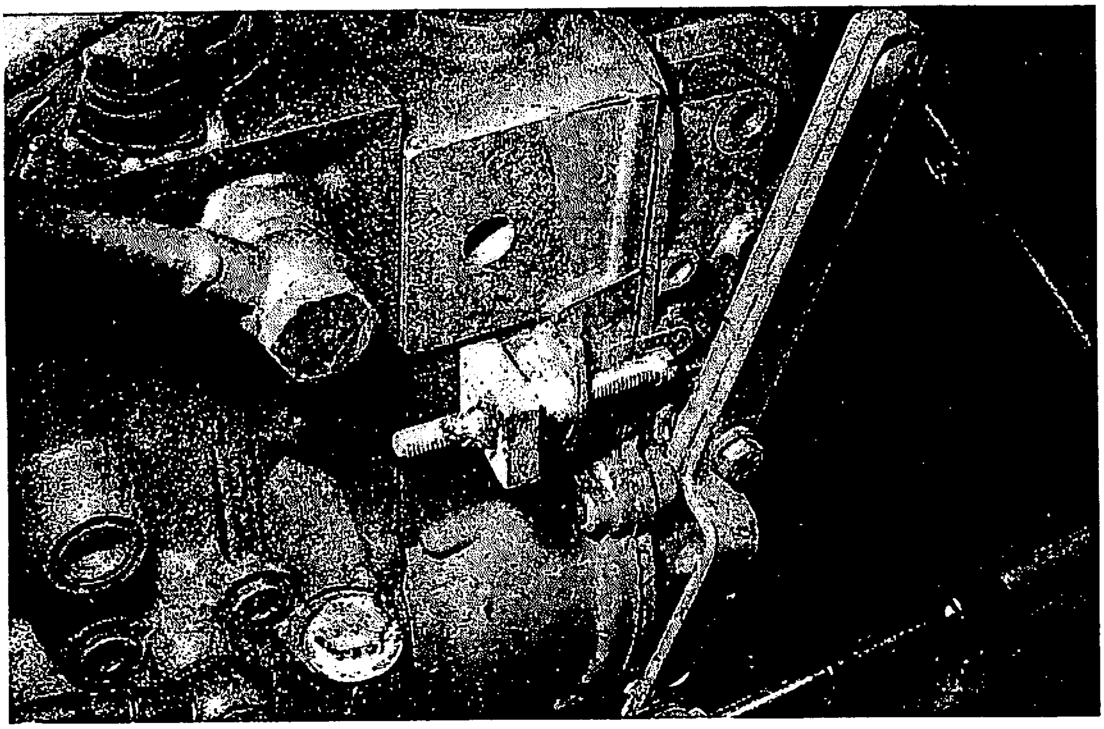


Fig. 51: Sealed fuel rack of derated diesel engine

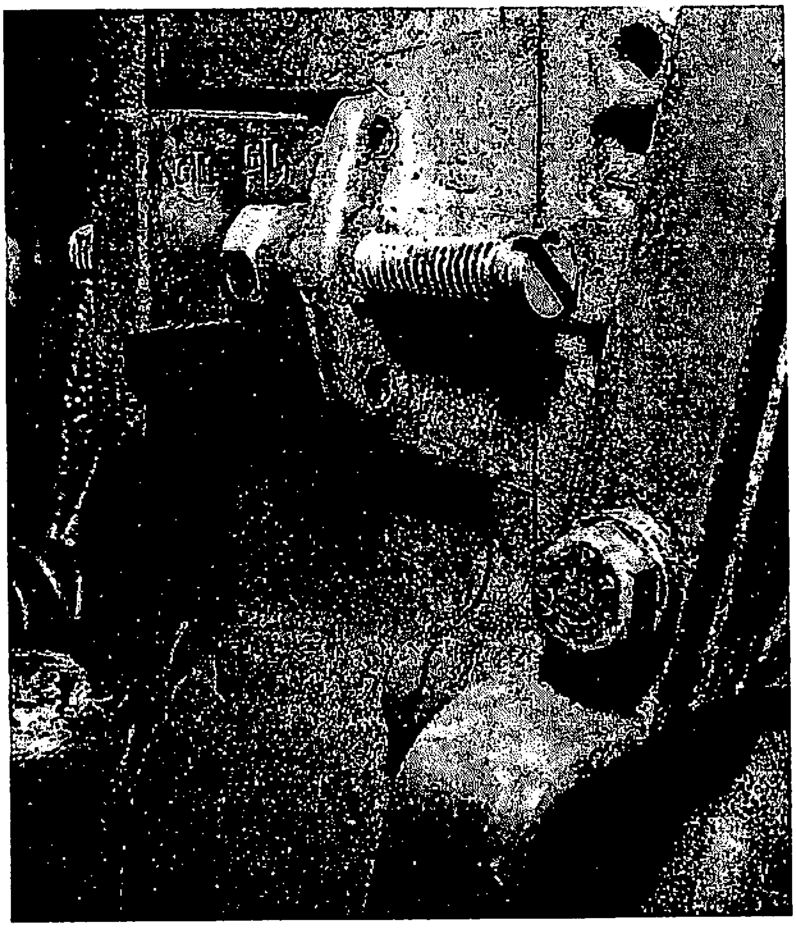


Fig. 52 : Detailed view of sealing

Annex I

Regulation 850/98, article 29

Article 29

Restrictions on fishing for plaice

1. Vessels exceeding eight metres length overall shall be prohibited from using any demersal trawl, Danish seine or similar towed gear inside the following geographical areas:

(a) the area within 12 miles of the coasts of France, north of latitude 51° 00' N, Belgium, and the Netherlands up to latitude 53° 00' N, measured from the baselines;

(b) the area bounded by a line joining the following coordinates:

- a point on the west coast of Denmark at latitude 57° 00' N,
- latitude 57° 00' N, longitude 7° 15' E,
- latitude 55° 00' N, longitude 7° 15' E,
- latitude 55° 00' N, longitude 7° 00' E,
- latitude 54° 30' N, longitude 7° 00' E,
- latitude 54° 30' N, longitude 7° 30' E,
- latitude 54° 00' N, longitude 7° 30' E,
- latitude 54° 00' N, longitude 6° 00' E,
- latitude 53° 50' N, longitude 6° 00' E,
- latitude 53° 50' N, longitude 5° 00' E,
- latitude 53° 30' N, longitude 5° 00' E,
- latitude 53° 30' N, longitude 4° 15' E,
- latitude 53° 00' N, longitude 4° 15' E,
- a point on the coast of the Netherlands at latitude 53° 00' N;

(c) the area within 12 miles of the west coast of Denmark from latitude 57° 00' N as far north as the Hirtshals Lighthouse, measured from the baselines.

2. (a) However, vessels to which a special fishing permit has been issued in accordance with Article 7(3) of Regulation (EC) No 1627/94 shall be authorised to fish in the areas referred to in paragraph 1 using beam trawls. The use of any beam trawl of which the beam length, or of any beam trawls of which the aggregate beam length, measured as the sum of the length of each beam, is greater than nine metres, or can be extended to a length greater than nine metres, shall be prohibited, except when operating with gear having a mesh size between 16 and 31 millimetres. The length of a beam shall be measured between its extremities including all attachments thereto.

(b) Notwithstanding Article 1(2) of Regulation (EC) No 1627/94, special fishing permits for the purposes indicated in (a) may be issued for vessels exceeding eight metres length overall.

(c) Vessels to which a special fishing permit as referred to in (a) and (b) has been issued shall comply with the following criteria:

- they must be included in a list to be provided to the Commission by each Member State

  such that the total engine power of the vessels within each list does not exceed the total engine power in evidence for each Member State at 1 January 1998,

- their engine power does not exceed 221 kilowatts (kW) at any time and, in the case of derated engines did not exceed 300 kW before derating.

(d) Any individual vessel on the list may be replaced by another vessel or vessels, provided that:

- no replacement will lead to an increase for each Member State in its total engine power indicated in the first indent of (c),
- the engine power of any replacement vessel does not exceed 221 kW at any time,
- the engine of any replacement vessel is not derated, and
- the length overall of any replacement vessel does not exceed 24 metres.

(e) An engine of any individual vessel included in the list for any Member State may be replaced, provided that:

- the replacement of an engine does not lead to the vessel's engine power exceeding 221 kW at any time,
- the replacement engine is not derated, and
- the power of the replacement engine is not such that replacement will lead to an increase in the total engine power as indicated in the first indent of (c) for that Member State.

(f) Fishing vessels which do not comply with the criteria specified in this paragraph shall have their special fishing permit withdrawn.

3. Notwithstanding paragraph 2(a), vessels holding a special fishing permit and whose primary activity is fishing for common shrimp, shall be permitted to use beam trawls of which the aggregate beam length, measured as the sum of the length of each beam, is greater than nine metres when operating with gear having a mesh size between 80 and 99 millimetres, provided that an additional special fishing permit to this effect has been issued to these vessels. This additional special fishing permit shall be annually reviewed.

Any vessel or vessels to which such an additional special fishing permit has been issued may be replaced by another vessel, provided that:

— the replacement vessel does not exceed 70 GRT and does not exceed an overall length of 20 metres, or

— the capacity of the replacement vessel does not exceed 180 kW and that the replacement vessel does not exceed an overall length of 20 metres.

Fishing vessels which cease to comply with the criteria specified in this paragraph shall have their additional special fishing permit permanently withdrawn.

4. (a) By way of derogation from paragraph 1:

— vessels whose engine power does not exceed 221 kW at any time and, in the case of derated engines did not exceed 300 kW before derating, shall be authorised to fish in the areas referred to in that paragraph using demersal otter trawls,

— paired vessels whose combined engine power does not exceed 221 kW at any time and, in the case of derated engines did not exceed 300 kW before derating, shall be authorised to fish in said areas using demersal pair trawls.

(b) However, vessels whose engine power exceeds 221 kW shall be permitted to use demersal otter trawls, or paired vessels whose combined engine power exceeds 221 kW shall be permitted to use demersal pair trawls, provided that:

(i) — the catch of sand eel and/or sprat retained on board and caught in the said areas constitutes at least 90 % of the total live weight of the marine organisms on board and caught in the said areas, and

— the quantities of plaice and/or sole retained on board and caught in the said areas do not exceed 2 % of the total live weight of the marine organisms on board and caught in the said areas;

or

(ii) — the mesh size used is at least 100 millimetres, and

— the quantities of plaice and/or sole retained on board and caught in the said areas do not exceed 5 % of the total weight of the marine organisms on board and caught in the said areas;

or

(iii) — the mesh size used is at least 80 millimetres, and

— the use of such mesh sizes is restricted to an area within 12 miles of the coast of France north of latitude 51° 00′ N, and

— the quantities of plaice and sole retained on board and caught in the said areas, do not exceed 5 % of the total live weight of the marine organisms on board and caught in the said areas.

5. Within areas where beam trawls, otter trawls or bottom pair trawls may not be used, the carrying on board of such nets shall be prohibited, unless they are lashed and stowed in accordance with the provisions laid down in Article 20(1) of Regulation (EEC) No 2847/93.

6. Detailed rules for the implementation of this Article shall be drawn up in accordance with the procedure laid down in Article 48.

Schutzgebiete in der Nordsee

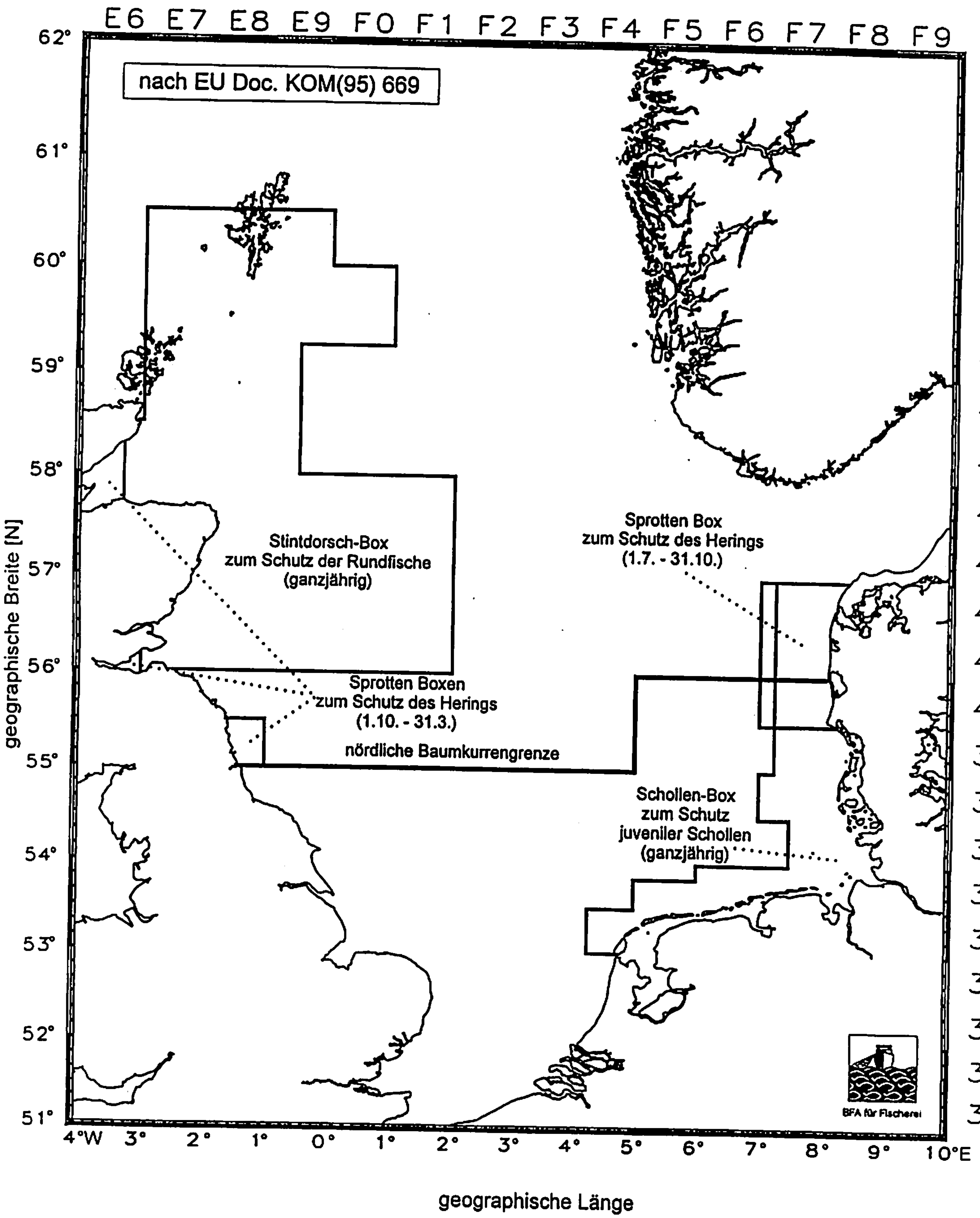


Fig. 1: Map of protected areas in the North Sea