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Performance of meta power rotor shaft torque meter

Schmidt Paulsen, Uwe

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Uwe Schmidt Paulsen
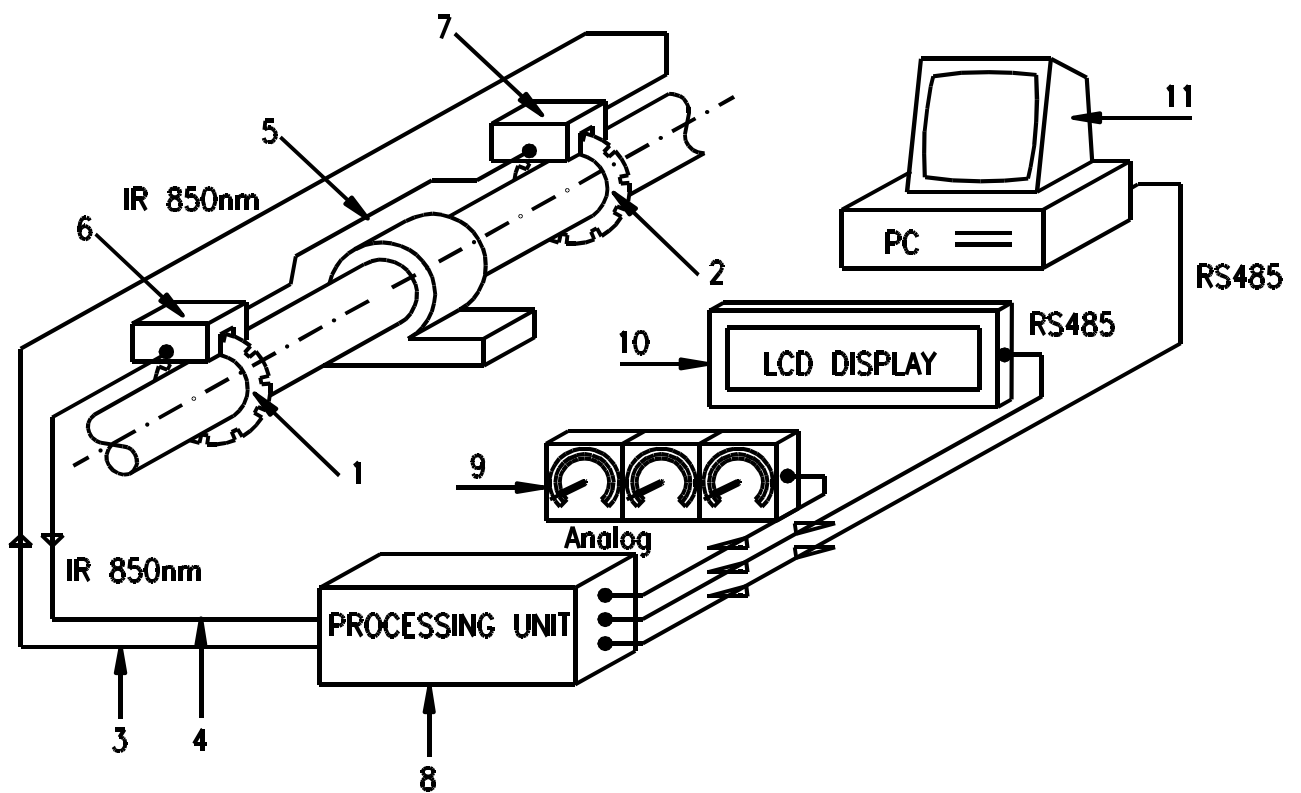
Abstract

The present report describes the novel experimental facility in detecting shaft torque in the transmission system (main rotor shaft, exit stage of gearbox) of a wind turbine, the results and the perspectives in using this concept. The measurements are compared with measurements, based on existing strain gauges and transducers mounted on the main rotor shaft and controller.

Contents

Preface

Wind turbines are increasing in capacity over the last years, in order to fit various political, technical and money wise needs from the wind energy/utility society/marked. The technical challenge is in long terms also to provide a reliable and safe power-generating tool. Within this perspective, advanced monitoring equipment for detecting loads applied on the wind turbine is interesting.

The report describes such a potential candidate enabling at the present an indication of azimuth-averaged rotor torque. The system is based on detecting the main shaft twist with a laser system, where the twist is the result of the torsion subjected to the rotor shaft via the wind loads acting over the wind turbine rotor.

The concept has been introduced successfully in the power-thrust control of ship propellers, and presently a study on the experimental wind turbine at RISØ has been performed to carry out a comparison of the performance of the system with traditional sensor/transducer systems detecting torsional stress.

1 Introduction

MetaPower™ is a new system for measurement of torque, RPM and power transferred through rotating shafts. The system is completely digital and based on LASER and optical fibres. MetaPower makes it possible to measure torque without any delicate electronics mounted on the shaft. The system is invented and developed by the company MetaSystems - F. K. Smith AS (www.fksmith.com). Patent is applied for in most significant industrial countries, consult Ref.1.

The MetaPower basic working principle is shown in the figure below:
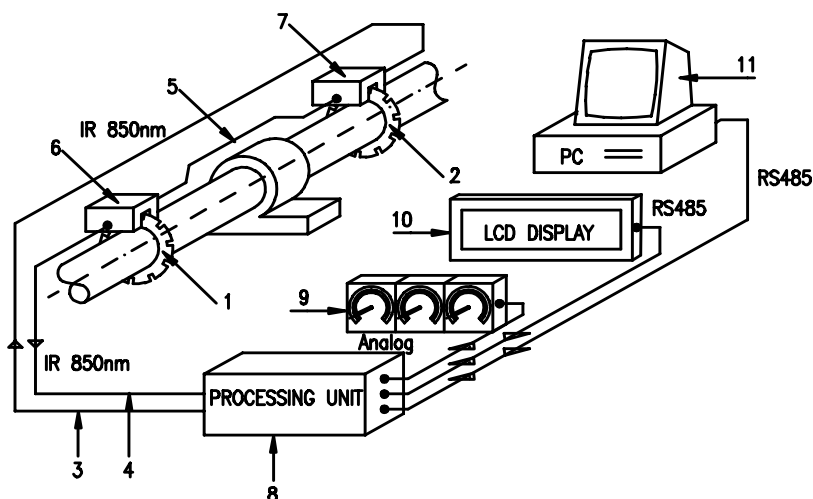
Figure 1.1 Basic working principle of the torque measurement system

An IR (infra red 850 nm) beam is transmitted through an optical fibre (3) from the LASER source mounted in the processing unit (8) to a specially designed optical fork (7). The IR beam in the air gaps is pulse modulated by the coding wheels (1) and (2) mounted on the rotating shaft at an adequate distance from each other. The generated pulse pattern will depend on the shaft torque and speed. The resulting IR light signal in the optical fiber (4) contains the information on the torsional angle between the two cuts (1) and (2) of the rotating shaft. In addition, the IR light signal contains the information on the shaft RPM. The IR signals are detected by one single light sensitive sensor in the processing unit (8). The light sensor converts the modulated IR pulses into electronic pulses for the calculation of twist and RPM.

When the elasticity modulus of the shaft and distance between coding wheel is known, the twist and the RPM figures makes it possible for MetaPower to calculate the torque - and consequently the power transferred.

Initially, MetaPower was intended for propeller shafts on ships, but as a general measurement system it may be applied on wind turbines as well. Risoe National Laboratory (www.risoe.dk), Wind Energy Department and MetaSystems - F. K. Smith AS agreed upon a project for testing of the system. The project is supported by The Danish Energy Agency (Miljø og Energistyrelsen) and The Research Council of Norway (Norges forskningsråd).

1.1 Objectives

The main objective of the project is to decide, how suitable MetaPower is for the use on wind turbines, and how the instrument could be achieved succesfully in order to be accepted in the market. This may be divided into the following steps:

- Decide modifications of the ship version for use on wind turbines.
- Resolve EMC-requirements and environmental demands to be met.
- Determine required / obtainable accuracy.
- Verify long-term stability of the system.
- Define user requirements covered by the system. Operation monitoring, gear condition indication, input-parameters for the control system etc.
- Estimate acceptable price levels.

1.2 Technology status

Before the introduction of MetaPower, the usual way of measuring torque in rotating shafts is by means of strain gauges glued to the shaft. This requires electronics on the shaft for the detection and amplifying of the strain gauge signals. A telemetry system is also required for the transmission of signals from the rotating shaft to the surroundings. The shaft electronics must be powered, either by a battery or by means of an inductive transmission. Due to centrifugal forces on all the equipment required on the shaft, the RPM will be limited. Long-term stability of strain gauge systems is often relatively poor.

An emerging system is based on laser speckle interference, and Steen G. Hanson at Risoe National Laboratory upholds patents for this system. The laser speckle interferometer system is based on cameras monitoring laser light reflected from two cuts of the shaft. The camera images are processed for pattern recognition of the shaft's surface to extract the twist. Image processing and pattern recognition is to be performed by a

powerful computer. Apart from the twist determination, a lot of the practical issues for this system is the same as is for the MetaPower system. The strength of the speckle interferometer system is that measurements may be done on very thin shafts, and on shafts at very high speed. The system is not yet implemented for commercial use, for details consult Ref.4,5,6.

2 Experimental Setup

In this project MetaPower was installed and tested on the 550 kW Nordtank wind turbine at Risoe. The wind turbine is situated at a field some hundred meters away from the office buildings for The Test Station for Wind Turbines. The description of the turbine can be found in Ref. 3. Various equipment for data acquisition and recording is located in a little hut on the ground beside the wind turbine. A dedicated computer in the same hut distributes the recorded data into Risoe's LAN (local area network).

The MetaPower Processing Unit (MPU) was installed in the hut, together with a PC and a mobile phone for the purpose of transmitting data to MetaSystems - F. K. Smith AS in Bergen - Norway.

The optical forks and the rings on the shafts were installed in the motor cabin (nacelle) at the top of the wind turbine. Fibre-optical cables were drawn from the optical forks in the nacelle, down through the tower of the turbine, and into the MPU in the hut.

An outline of the installation is shown in the figure below:
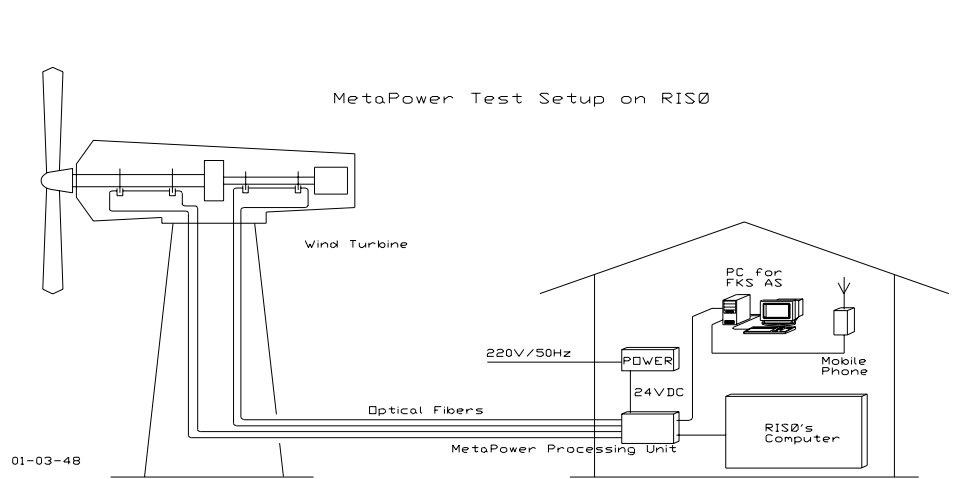
Figure 2.1 Principal outline of the measurement system

2.1 Implementation adaptations

In the nacelle there are two shafts.   A low speed shaft (nominal speed 26 RPM) transfers the movement of the blades (wings) to the gear.   The gear is connected to a generator by a high-speed universal shaft (nominal speed 1500 RPM).
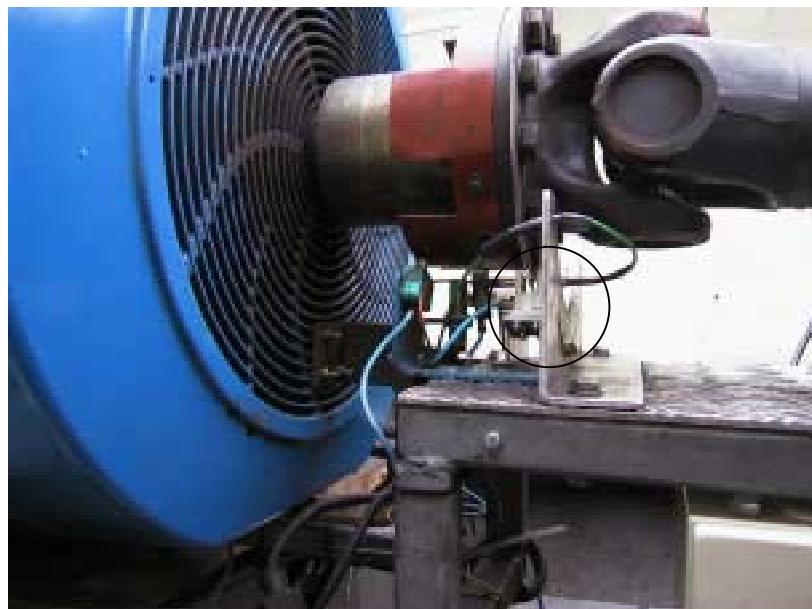
Figure 2.1.1 Light fork and rpm sensor at the high speed shaft

The low speed shaft rotates in a steel cast cover and is exposed only a short length at each end.   The diameter of the low speed shaft becomes wider the closer the blades.   This conical form of the shaft is chosen to

withstand tilt forces from the rotor blades.   The measuring rings (coding wheels) have accordingly two different diameters, 280 and 300 mm.   As the number of teeth/slots on each ring is equal, this imposes no problem for the measurement.   But the narrow space for the optical forks made it necessary to manufacture special forks.   Those forks use prisms to bend the light 2 times 90 degrees.   Thus, the in- and out-going optical fibres need no space length-wise parallel to the shaft.

The high-speed universal shaft neutralises the eccentricity of the gear and the generator.   This type of shaft has four joints and one telescopic spline to accept minor movements in all directions.   MetaPower is originally not intended for this type of shafts.   But as the MPU has the capacity of measuring two shafts simultaneously, the occasion to test on this type of shaft was grasped.   Like for the low speed shaft, narrow space made the use of 2x90 degrees optical forks required.   By measuring power on both sides of the gear, some degree of gear condition monitoring might be possible.

3 Measurement Reference Setup

The equipment for performing comparative measurements consists of a calibrated torque sensor and transmitter measurement system, a rotor shaft speed-recording device, an electrical power transducer and a data recording system. These reference signals are recorded simultaneously with the signals provided by the optical system and with signals providing overall wind turbine operating conditions. The signals are described in Table 3.1.1.

3.1   Measured parameters

The measured parameters are shown in Table 3.1.1 together with the channel number and their sampling frequency. Status signals of the Metapower system are excluded. Measuring meteorological parameter signals comprises the general wind turbine test conditions, and the focal point is drawn on measured signals from the nacelle, the hut and the controller system for comparison of the Meta system with known principles.

Position	Parameter	Channel number	Sampling frequency Hz
Met. Mast	Wind speed at hub height	10	35
	Wind speed at hub height -3m [1]	11	35
	Wind direction sin at hub height -3m [2]	5	35
	Wind direction cos at hub height -3m [2]	6	35
	Wind direction	8	35
	Air temperature at hub height -3m	8	35
	Air pressure	9	35
	Rain	1	35
Nacelle	Rotor rotational speed(LSS)	41	35
	Rotor shaft torque(LSS)	17	35
Hut	Rotor rotational speed Metapower (LSS)	20	35
	Rotor shaft torque Metapower(LSS)	21	35
	Rotor power Metapower(LSS)	22	35
	Rotor energy Metapower(LSS)	23	35
	Rotor rotational speed Metapower (HSS)	25	35
	Rotor shaft torque Metapower (HSS)	26	35
	Rotor power Metapower(HSS)	27	35
	Rotor energy Metapower(HSS)	28	35
Control system	Electrical power	2	35

Table 3.1.1 Measured parameter list

1) The wind speed measured 3m below the top-mounted cup-anemometer was used to verify proper operation of the top-mounted cup-anemometer

2) The wind direction is calculated from the sin and cos signals

LSS low speed shaft,i.e. 27 RPM output at shaft between hub and gearbox

HSS high speed shaft, i.e. 1500 RPM output on shaft between gearbox and generator

The instrumentation of the wind turbine with sensors and transmitter boxes necessary for the evaluation of the torque system is described in Table 3.1.2.

Ch. No	Sensor	Transmitter	Placement
2	Watt transducer	Camille Bauer. PFV 2113	Controller
41	Rpm/Rotorposition	P2858a DAU	LSS/HSS
10	Cup anemometer P2546b. Ser.nr. 0875 PFV 1109	P2858a DAU	Hub height/metmast
11	Cup anemometer P2546b. Ser.nr. 0878 PFV 1109	P2858a DAU	3 m below hub height
17	Strain gauges CEA-06187UV-350, bridge Hottinger no 14	P2858a DAU	placement 65mm from hub flange
20	Rotor rotational speed Metapower (LSS)	Metapower, RS485	Rotary encoder on LSS
21	Rotor shaft torque Metapower(LSS)	Metapower, RS485	Rotary encoder on
22	Rotor power Metapower(LSS)	Metapower, RS485	LSS
23	Rotor energy Metapower(LSS)	Metapower, RS485	Rotary encoder on
25	Rotor rotational speed Metapower (HSS)	Metapower, RS485	Rotary encoder on HSS
26	Rotor shaft torque Metapower (HSS)	Metapower, RS485	Rotary encoder on HSS
27	Rotor power Metapower(HSS)	Metapower, RS485	Rotary encoder on HSS
28	Rotor energy Metapower(HSS)	Metapower, RS485	Rotary encoder on HSS

Table 3.1.2 Description of sensors and transmitters.

3.2 Measurement system

The signals are transmitted serially from a data acquisition unit (DAU) by means of optic fiber/ serial cable to a computer communication port.

The DAU system presents a 16-bit processor system capable in converting frequency, count and analogue signal inputs into RS485 serial outputs. Signals from the met mast are processed via a DAU, so are the signals provided in the nacelle and in the hut/controller box. The signals provided by the Metapower processor unit (MPU) are recorded via a serial RS485 connection to the measurement computer as indicated in Figure 2.1.

The following software is used for the data acquisition and data analysis:

Data acquisition: DAQ (Risø)

Data analysis: GNU Plot, DADISP, MS Excel, DaqTime

3.3 Calibration

The DAU unit is a self-calibrating device, providing high accuracy and resolution voltage outputs in the range –5V to +5V. It facilitates both analogue and digital data conversion.

The rotor shaft sensor and the transmission line were calibrated by applying a known force at the blade tip providing an external torque on the rotor shaft at low wind speeds assuring low loading on the wind turbine rotor. The load-cell HBM No 1360948 99 is calibrated at FORCE under EN 10002-3 and traceable to PTB Braunschweig, Germany. The uncertainty of this instrument is found to 0.075%.

The load-cell and strain gauge signals from the calibration run are shown in Figure 3.3.1. The respective wind speed record is shown in Figure 3.3.2.
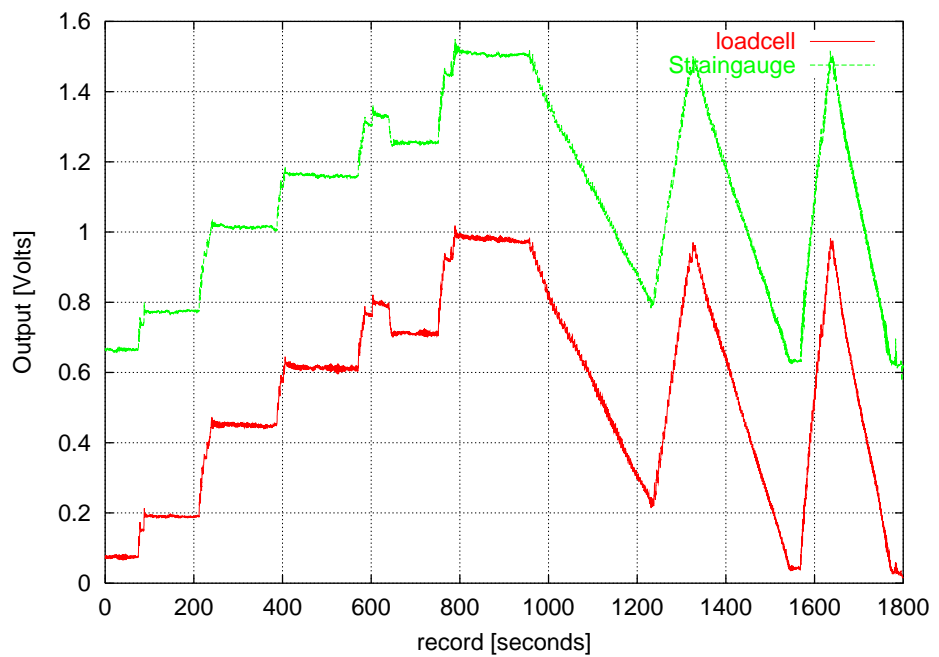

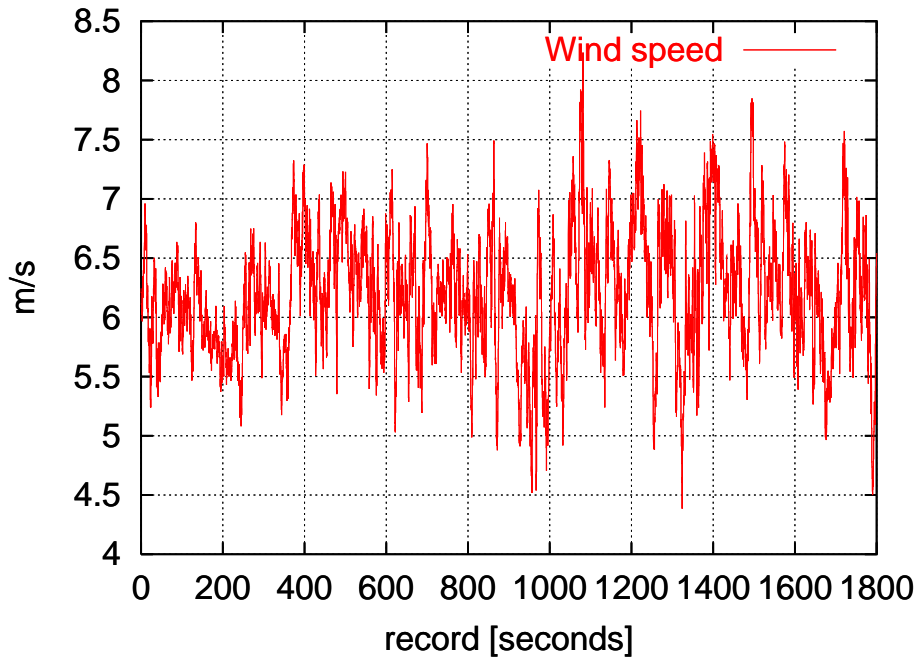*Figure 3.3.1 Calibration trace of load-cell and strain gauge signals*

Figure 3.3.1 wind speed during calibration

The standard error from the regression of strain gauge signal upon load cell input is σ_e=1 kNm. The additional uncertainty of applying the external torque, with force F with and the torque lever L is found to 2.25-2.5%, taking the amplification of strain gauge signal into consideration. The calibrations are performed at 63% nominal load, which is 200 kNm. The standard uncertainty of the torque signal at low wind (Offset) is less than 1‰. The uncertainty on RPM signals is 100-200 ppm.

The results are of the calibration session is presented in table 3.3.1. For MPU results, the angular twist per kNm is provided.

Channel	Signal/Parameter	Gain	Offset
2	Electrical Power	200 kW/V	0 kW
8	Air temperature	6 °C/V	5 °C
9	Air Pressure	92 hPa/V	600 hPa
10	Wind speed	0.62 m/s/Hz	0.2 m/s
10	Wind speed	0.62 m/s/Hz	0.2 m/s
17	Shaft torque	-124.574 kNm/V	+78.53 kNm
20	Torsion LSS	2.887E-08 /Nm	a.c.
41	Rotor shaft rpm	17.2 RPM/Hz	0 RPM

Table 3.3.1 Calibration coefficients

4 Results from low speed shaft tests

4.1 Stability and Performance

During the test period, various experiences with the equipment were made. The usual coding wheel design known from ship propellers and now intended for use at the hub was re-engineered in order to accomplish with space limitation and firm installation of the coding wheel assembly and taken into operation autumn 1999. The solution of this mechanical problem was a device with a clamp, which could be disassembled into two parts, by using a traditional bolt-assembly. The rotor axially moves some space combined with a bending of the shaft in tilt wise movements. Temperature will interact as well as relative differences in the light beam path. Unfortunately, the bolt head was not suitable for all wind turbine operations, since there we detected collisions with the light fork. Even though counter-measures were taken to prevent the collisions, results indicated in Figure 4.1.1 stipulate stability problems and performance loss on the low speed side (LSS). Offsets are shown very distinct in the graph, indicating that the MPU offset was changed in the periods. The 2001 data indicates a branching of the MPU output with high electrical power. Indeed this is not variability due to the system, but is explained by and to the stalling of the rotor, since the same is observed for the rotor shaft torque.
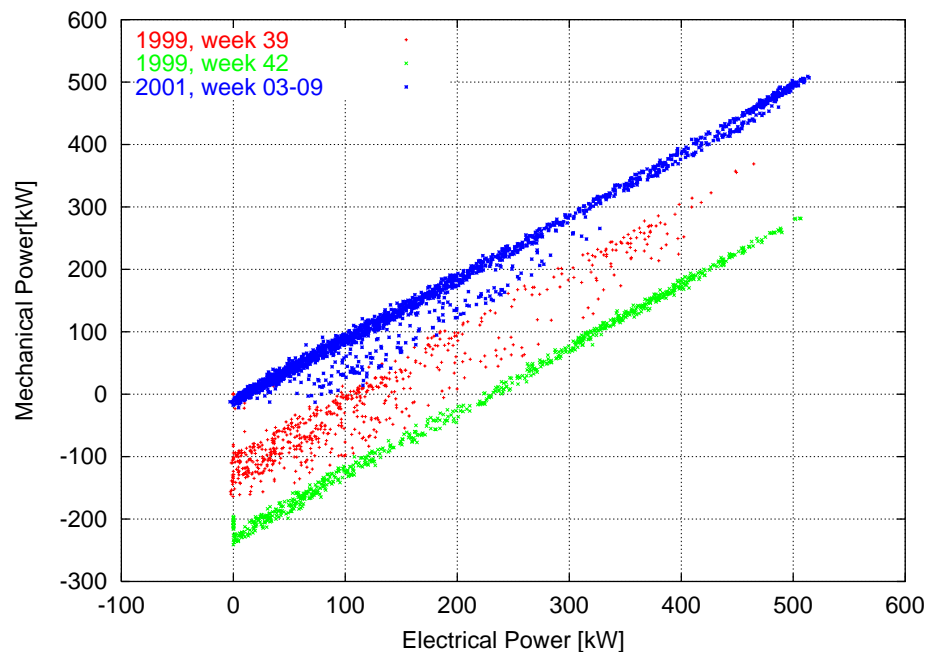

Figure 4.1.1 Comparison of signal from MPU (LSS mech. Power) with measurement reference (electrical Power)

The stray points are occurring in the measurement period randomly over time and likely associated with low to medium loadings of the wind turbine. Compared with past experience the picture with the strays provides comparative effects. There is indication that the instrument for this period, with the strain gauge torsion meter in operation, has been under influence of events, which are not explained by the reference measurements on the wind turbine. However week 42 provides 'good' data with no strays. Even with more or less presence of data around 0 power, different ranges of operation the almost paralleled regressed lines are within 0.3%-1.2% for weeks 42-45. Weeks following show changes. On the basis from the long duration measurements, we conclude that the instrument is not 'technically' stable. The damping of the light beam is above the normal 'standard'. In our case the beam is bent 2 times 90 degrees per fork. This optical arrangement of the light fork does not provide a technical 'good' signal/noise ratio. It is recommended to do additional refinements on the coding wheel and the light beam arrangement.

The difference between the mechanical and electrical power facilitates filtering out these stray points from the year 2001 data. If the figure exceeds 10-30 kW, data are filtered out. In this way we can provide a graph with data grouped around the average as indicated in Figure 4.1.2, with the ability of a -+7kNm strip around the regressed line fit(y). The distribution of |fit(y)-y| is shown in Figure 4.1.3, where y stands for the torsion provided by the MPU and f(y) is the linear regression of the torsion vs. shaft torsion measured with reference equipment.
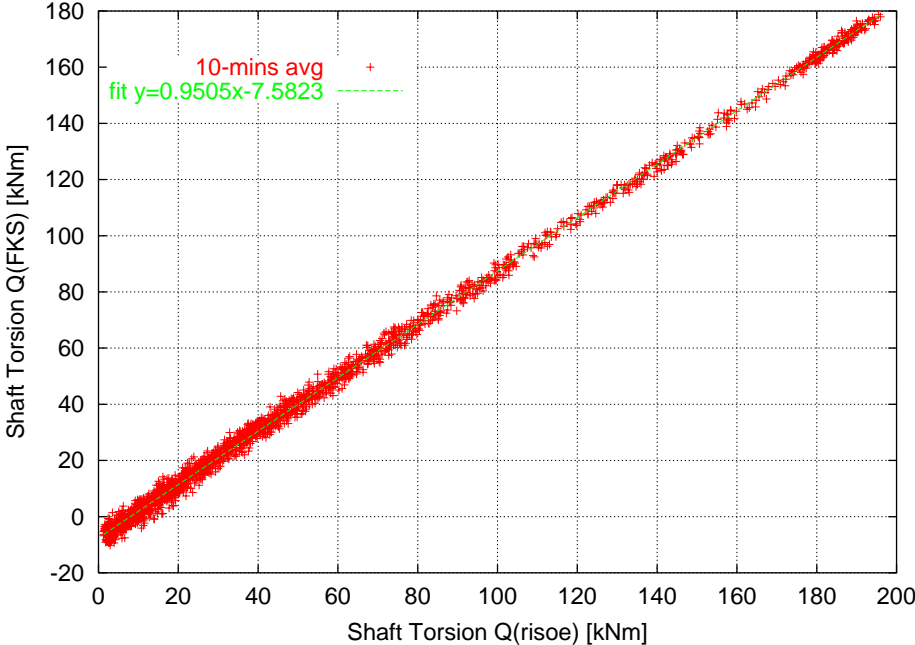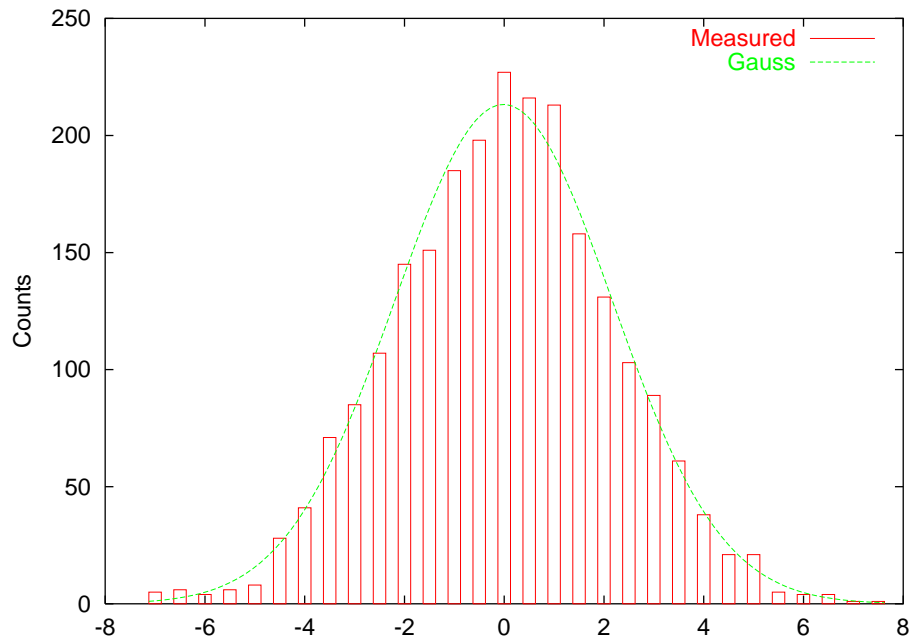

Figure 4.1.2 Evaluation of the MetaPower MPU data

Figure 4.1.3 Frequency distribution compared with N(0,4.34kNm)

The distribution shows a 0 average, the standard deviation of the data is found to σ=4.34 kNm and comparable to the uncertainty of 5-6 kNm from the strain gauge calibrations.

4.2 Response and accuracy

The mechanical power, derived as torque times rotor angular speed is in terms of uncertainty dependent on the accuracy on angular speed measurement. Figure 4.2.1 illustrates the difference between the rpm provided by the MPU and the reference measurements with very good agreement.

For small rotor speed the accuracy is less than at high rpm, which is due to a biased offset quantity: when the rpm is high the importance of the constant is little, and significant when the rpm is low. The deviations are within +- 0.02 RPM at low angular speed and roughly 1/5 of the figure at high rpm. It is obvious that a gaussian frequency distribution describes the distribution of these data.

A different way of looking response is to look o the variance of the 10-minute values: theoretically the variance σ^2 of a stochastic, linear time varying process $Y(t)=a\cdot X(t)$ is equal to the square of the constant a times the variance of the variable $X(T)$, $\sigma^2(X(t))$. The relation between the MPU and the reference is found in Figure 4.2.2.
The graph shows additionally the standard deviation relationship of the transfer function of the electrical Power, converted into torque under the assumption of constant angular speed. The stall influence from the rotor

provides the branch at the low values, indicating that the system is able to measure un-linear aerodynamic conditions. In general, there is a good linearity of the system. Still, under the present conditions there is more spread around the 'mean line' as there will be compared with the strain gauge sensor.
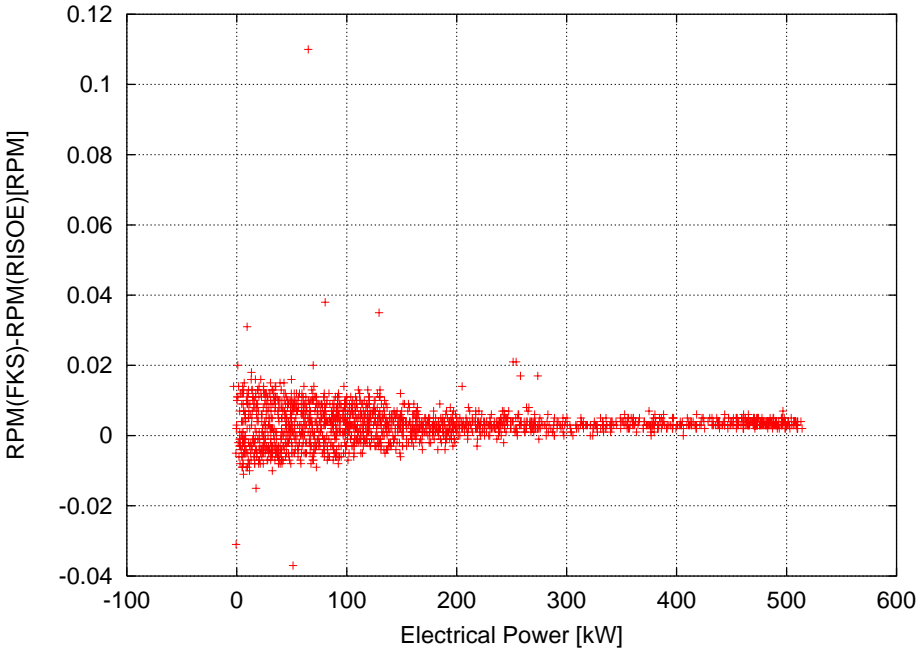

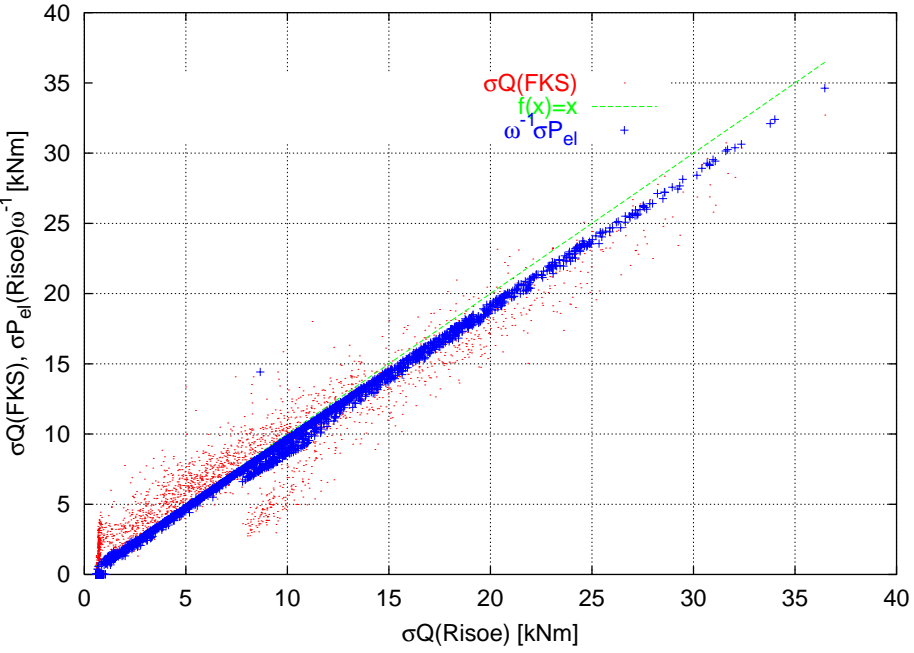*Figure 4.2.1 Comparison between MPU RPM and measurement reference*

Figure 4.2.2 Comparison of standard deviation σQ(FKS) with σQ(Risoe)

Finally a scatter plot of mean, standard deviation, maximum and minimum is provided in Figure 4.2.3.
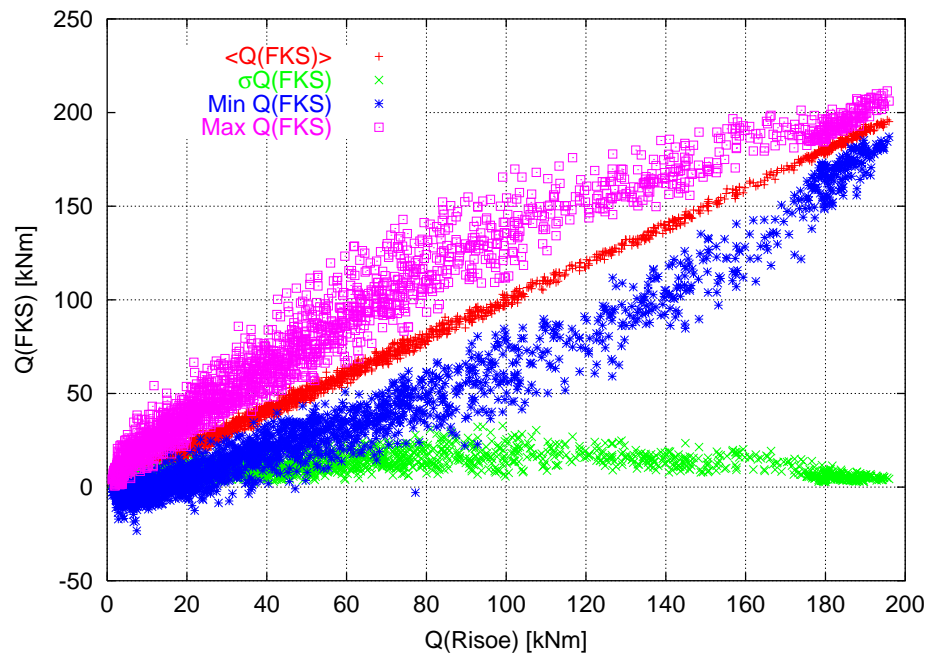

Figure 4.2.3 Scatter plot of mean, standard deviation, maximum and minimum.

In general the strain gauge signal naturally performs with the better resolution than the MPU does at low loads. This is due to that the coding wheels do have a limited number of slots, and consequently, at low angular speed the MPU would need more number of turns (revolutions) to account for.

On the time trace basis, the picture is generally that the signal varies with the load more or less as expected. The following plot illustrates the problem of a dataset being not typical for the expected input-output relationship. The trace has been recorded 08-02 2001 at 12:10 with statistics given in Table 4.2.1:

Table 4.2.1 Statistics of run not typical for regression line

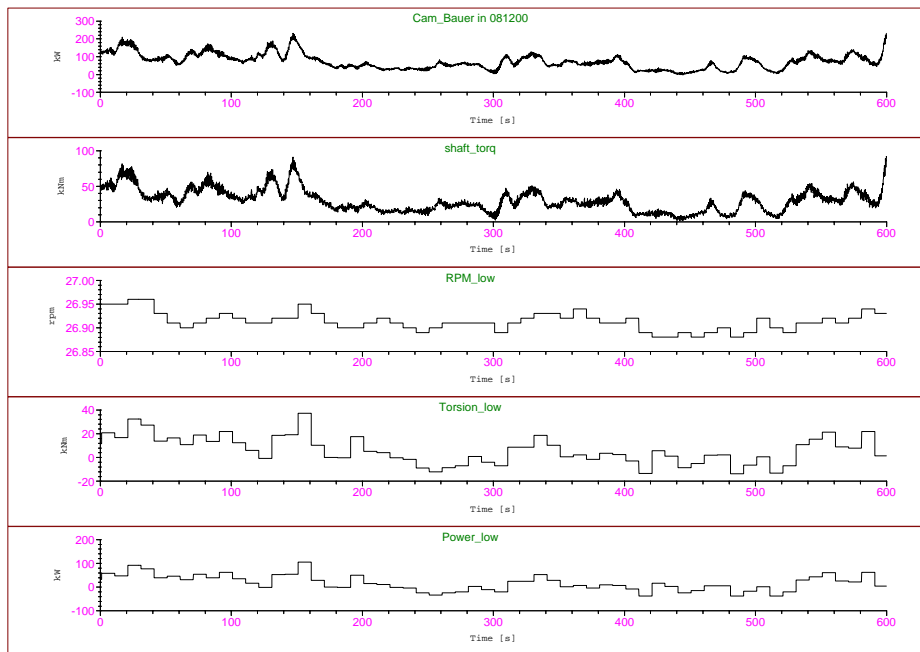| Parameter	Avg	stdev	min	max
El. Power [kW]	7.231E+01	4.238E+01	-2.350E+00	2.310E+02
Shaft_torq [kNm]	3.001E+01	1.556E+01	1.657E+00	9.153E+01
Rpm_low [RPM]	2.691E+01	1.906E-02	2.688E+01	2.696E+01
Torsion_low [kNm]	5.891E+00	1.154E+01	-1.365E+01	3.75E+01
Power_low [kW]	1.663E+01	3.255E+01	-3.850E+01	1.048E+02

Figure 4.2.4. Time trace of record forming a stray data point

Taking for example the saddle points of electrical Power at time 130-200 seconds, the corresponding proportionality at the two tops is not representative for the signal Torsion low. Additionally there is a misfit at 200 seconds, where the power/torque is halved with respect to the first top. On the time trace for torsion low (MPU), it is equal to the value at the first top. At the present moment there is no explanation for this. Towards the end of the run, the MPU is capable to respond on the variation in the signal, which is manifested by counting the tops and valleys. The rise at the very end is not registered because of the signal delay involved. It has been verified when subtracting the average the remaining signal provides the principle of a random walk: summing up differences of the individual steps from the random sample, the result will be zero.

Because of the dynamical equilibrium principle involved it makes no sense to view data with angular speed=0. The MPU basically needs minimum 1 turn to compile the information into an angular deflection. The strain gauge works also at no speed because torsion in the rotor shaft will create an elongation of the outmost metal fibres of the shaft, which is measured by the sensor down to 0.1 kNm (run 120922, 12 January 2001).

4.3 Comparison with FEM results

The shaft has been subjected to finite element as well as a simple structural modelling. While the FEM model is based on an axial-symmetrical model of the shaft and subjected to a realistic bearing towards the gearbox-end, the simple, ideal model uses two discrete shafts neglecting any details of the bearings. The FEM model (ANSYS) assumes in particular supports at the main bearing in radial and axial direction, a inter median

bearing in the radial direction and towards the gearbox a support in radial and torsion direction. The dynamics of the roller elements, inside the bearings will likely contribute to additional deflections by rigid motion. In the present model no such analysis is made.

The sensor positions are described in global Cartesian coordinates $U_x(=r)$, $U_y(=z)$ and $U_z(=r\cdot\theta)$, and details are found in the appendix. The FEM model takes into consideration deflections at the places coinciding with the coding wheels, so that deflections are analysed for axial thrust, bending tilt moments and rotor shaft torsion at the low speed side. It is found that only twist will affect the rotor shaft and the measurement equipment; the axial and bending influence will not affect the operation of the coding wheels. The material specifications are such, that Young's modulus of elasticity is set to E=210 GPa, and that Poisons ratio is set to v=0.3. The material data are uncertain, since there exists no material analysis of the test turbine rotor shaft(E varies between 200 and 210 GPa).

The resultant sensitivity from the analysis is found to 3.159E-08 rad/Nm at the front code wheel, and 1.011E-08 rad/Nm at the code wheel towards the gearbox. For 1 Nm a change of angular displacement is correspondingly 2.148E-08 rad. The torsional rigidity at the gearbox end has shown to be adjusted, because a misprint of the shaft length influences the calculus of the twist. Adjusting the rigidity of the torsional influence at the gearbox encoder wheel for the particular distance, the resultant twist is calculated as 2.300E-08 rad/Nm. A simple calculation of the shaft with two different diameters renders for 1 Nm torque a twist of 2.9563E-08 rad at the front code wheel, 6.3195E-09 rad at the gearbox code wheel and 2.324E-08 rad as the resultant twist, which is in agreement with the FEM result of 2.300E-08 rad.

Compared with the MPU figure of 2.887E-08 rad/Nm, this gain has to be adjusted about 5% to account for what has been regressed upon in comparison with the reference equipment. The gain-wise regression of Q(FKS) with Q(RISØ) rendered 0.9507, so that the stiffness is adjusted to 2.887E-08·0.9507, which is 2.745E-08 rad/Nm.

The emphasis has been to establish a calculation tool for providing a way to calibrate the MPU. The shaft with its well-described and regular geometry represents no engineering difficulty in providing reasonable calculated results. Since the method involves a calibration dynamically at constant angular speeds, we must consider the significant difference of approximately 18% between calculations and reality as a serious draw back.

Since the material property (E) linearly influences the calculated twist, we can allow a variation of E with respect to the literature value for E within say 5%. An analysis of the rotor shaft would result in a remaining difference of about 12%. Presently this number would represent the gross deviation between the methods applied.

5 Results from high speed shaft tests

5.1 Stability and Performance

The results from the high-speed shaft measurement are shown in Figure 5.1.1. The equipment has been subjected to various impacts during operation, which are related to the deflections of the HSS arrangement as such. The objective of the arrangement is to dampen unbalance by 'filtering' out elevation differences as well as tangential motion differences of the rotating system.

The sensor is as shown from the layout part of the more 'fixed ' nacelle system and sensing the light shuttering from the coding wheels moving or more likely preceding in a complex orbit.
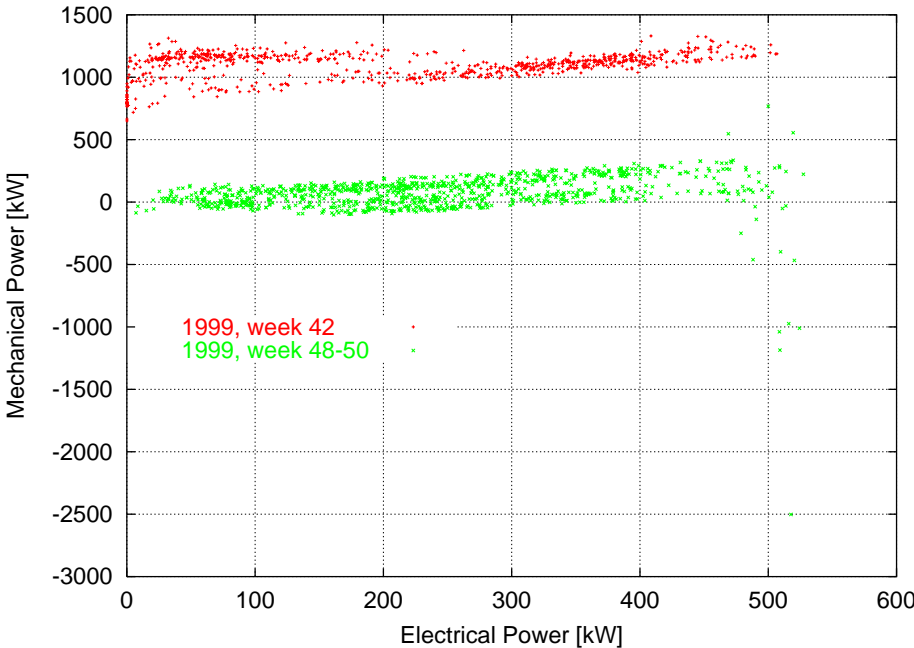

Figure 5.1.1 Comparison of HSS mech. Power signal with measurement reference

The plot is not corrected for any trend, and it demonstrates that the sensor system is not suitable in the present layout to predict the power for 'flexible' joints.
It is further seen that the low load portion of the curve seems to have some un-linear trend.

6 Discussion

6.1 Geometrical bindings and worn impacts

The laser-based sensing of the light beam from a rotating disc with appropriate open, radial cut slots is only influenced by relative motion of either the coding wheel and the reference coding wheel, or by rigid motion of the lens fixed on the non-rotating part of the hub-shaft-nacelle. The sensor arrangement is schematically shown in Figure 6.1.1, indicating motion in different directions. Also a slot is indicated to show the passing of the light beam through the fork.

If the fork carrier is stiff and not subject to any rigid motion, the system will determine the motion of the rotating part. This could cover gyroscopic motion/ rotor unbalance. In this case the sensor system is detecting impacts caused by wear out of machinery parts.
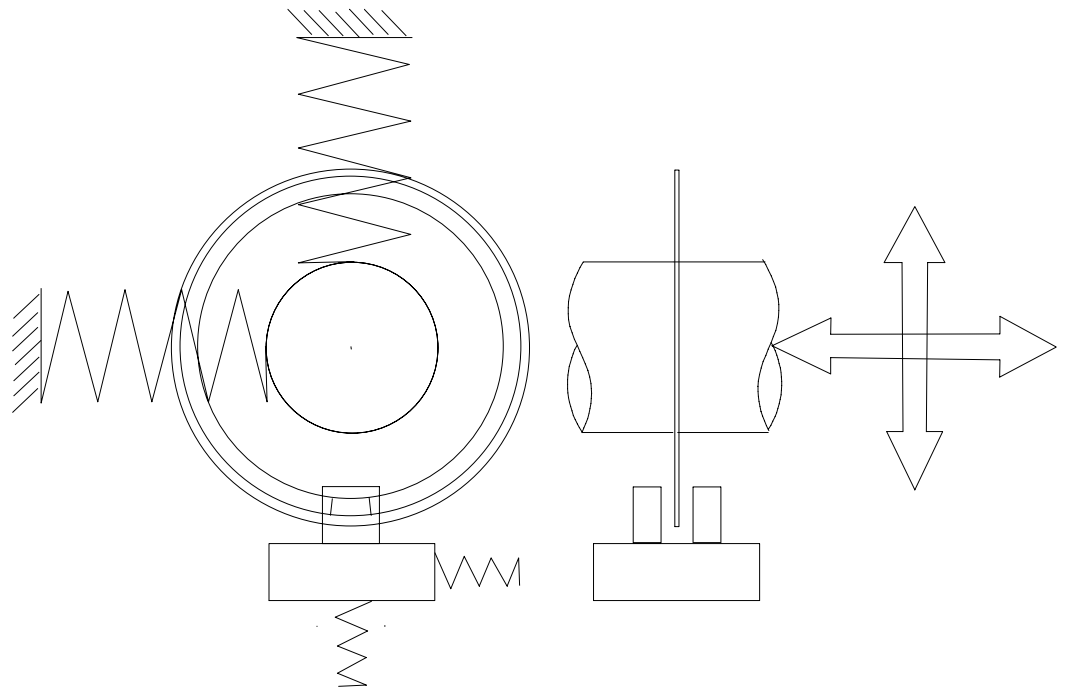
Figure 6.1.1 Sketch of sensor system and indication of degrees of freedom motion wise

Possible sources for errors on the sensor system could be:

- Relative rigid motion can be mechanically caused by deflections or something caused by temperature changes.
- If the sensor part independently vibrates, the shutter function of the slot is changed. Additional, probably subtle oscillations of the disc, where wavelength coincides with the slot length can induce a fraction of an mm difference between the flanks.
- Rigid motion of the fork carrier relative to the reference fork.
- Collision of the rotating parts with the stationary parts

The high-speed shaft and the joints proofs a flexibility with respect to rigid motion, demonstrating that the wear and tear on this part is difficult to monitor with the system as built. Also space has turned up to be a limitation for applying the parts in a confined place.

6.2 Calibration procedure

The power conversion of the wind turbine is taking place in the rotor plane, the gearbox and the generator. The wind power is converted into mechanical power in the rotor (disc) plane; the gearbox converts the high torque and low angular speed into low torque and high angular speed. The generator finally converts the mechanical power at the high-speed shaft into electrical power.

The calibration of the system can be achieved by dynamically to equalize the output and the mechanical power at two load-points, taken at the high-speed side of the gearbox and to utilize that the system is linear.

The mechanical power at the gearbox is assumed to have friction losses of 3% of current load. This procedure is similar to one of the ways strain gauges are calibrated 'electrically' without applying an external force. This method is feasible for large wind turbines and provides acceptable results if the power converter is reasonable responsive (low time constant).

The conditions of zero inertial forces are met at constant angular speed with the turbine idling in the wind (no grid connection).

6.3 Perspectives

The long-term measurements proved, although with some limitations on the redundancy of the system, that the equipment with minor improvements on the measurement stability is a potential candidate for the control of a wind turbine.

A simple correlation with a transducer providing electrical Power from the wind turbine provides information with respect to judging the 'quality' of the information, i.e. stray points can be filtered out.

The calibration of the equipment can be made, either by [1]correlating the electrical Power, properly adjusted for transmission losses for the turbine drive system, at constant angular rotor shaft speed and at two levels with the corresponding outputs from the MPU or [2]calculating the angular deflection of the drive shaft between the code wheels for a unit

torque(provided that the shaft can be modelled by analytical or by FEM approaches).

The equipment, in its present layout is suitable for measuring torque, averaged over one revolution. This figure provides the azimuth-averaged torque with the perspective of predicting the maximum shaft torque during operation of the wind turbine.

Large wind turbines, probably operating at isolated sites- would benefit in operations and maintenance with controller specific hard- and software as demonstrated by the FKS-system, in order to check the mechanical power of the turbine or even to feed back the information in the wind turbine controller.

It is quite easy to change the MPU with respect to access the shaft torsion variations over one revolution, by replacing the code wheels and a MPU chip. Angular resolved information is interesting because of the variations of the loads transferred via the blades to the rotor shaft. Detection of wind shear, tower shadow and fluctuations of the inward wind(affected by possible wakes of up-stream wind turbines) are possible to detect and account for in the loads of the wind turbine.

7 References

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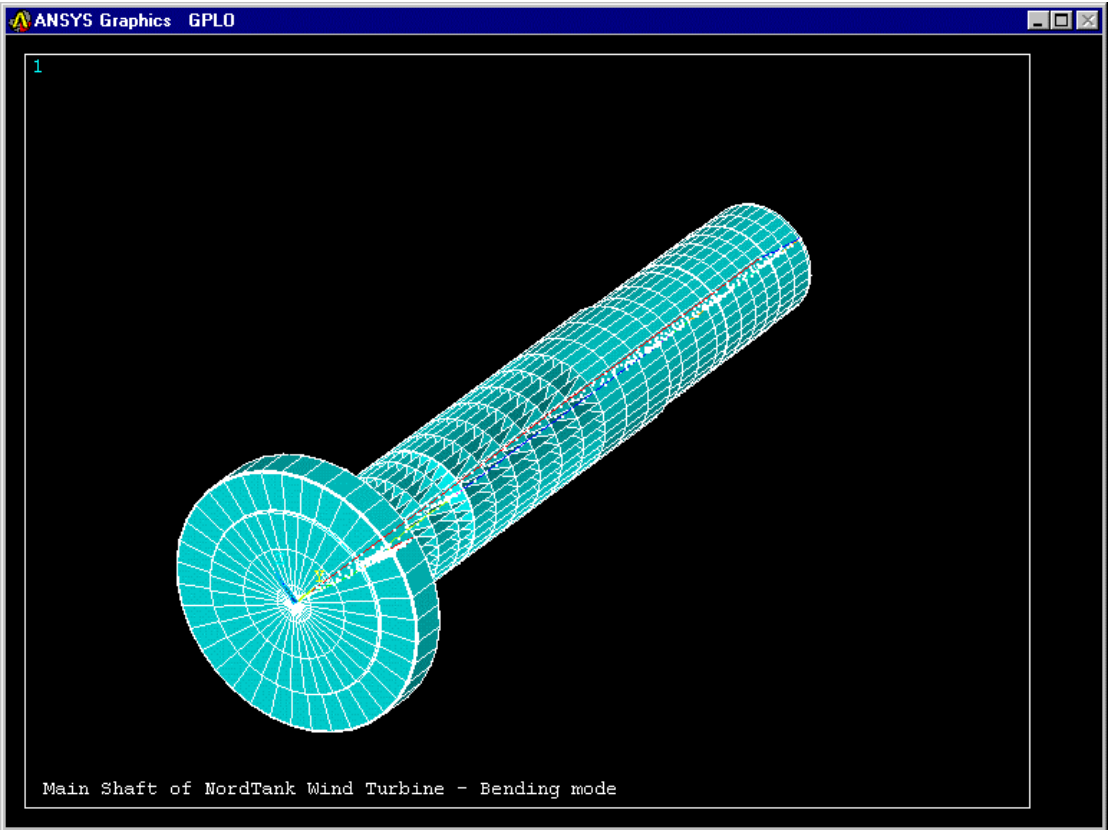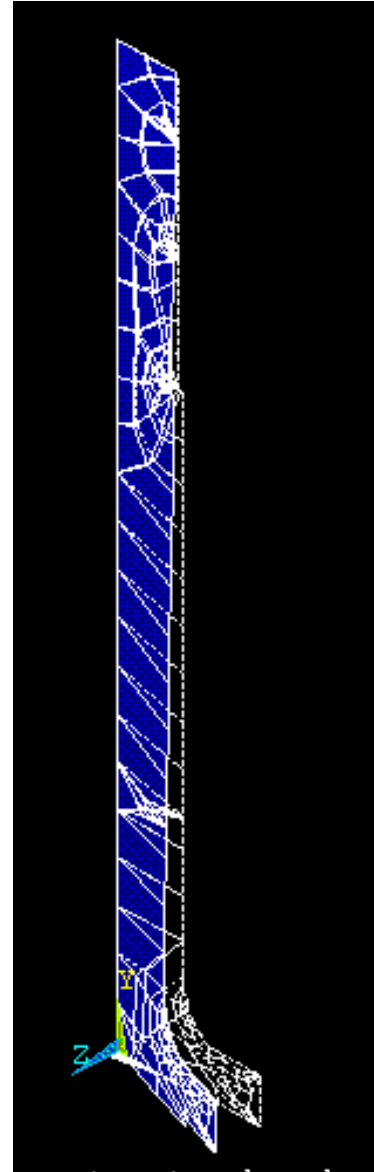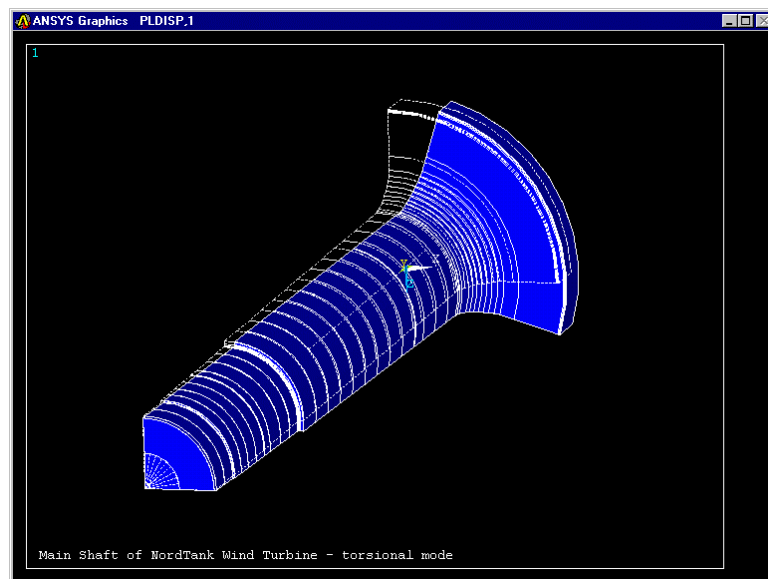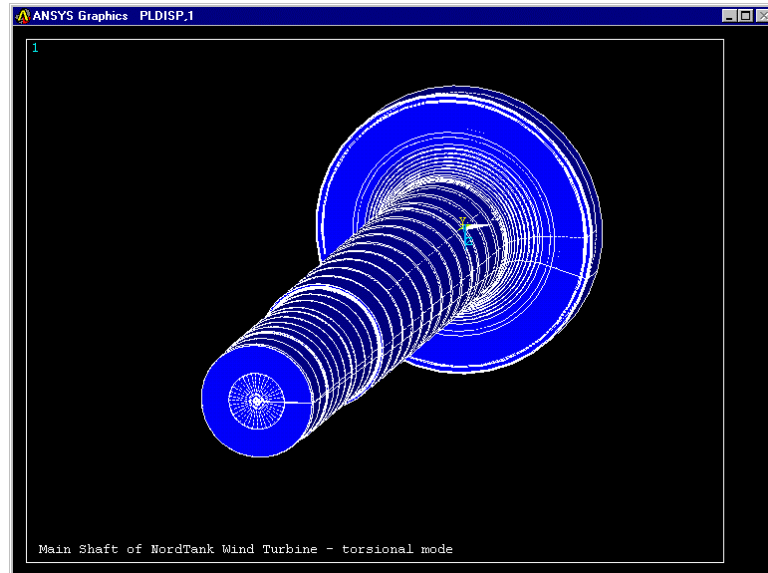
8 APPENDIX

NordTank deflection analysis

Sensor positions:

	Node	U_X	U_Y	U_Z
Drive End:	16	0.150001000000	0.290049067653	0.00000000000
Non Drive End	160	0.140001009076	1.59098388697	0.00000000000

Main Shaft of NordTank Wind Turbine - Bending mode

Torsional unit load:

Main Shaft of NordTank Wind Turbine – torsional mode

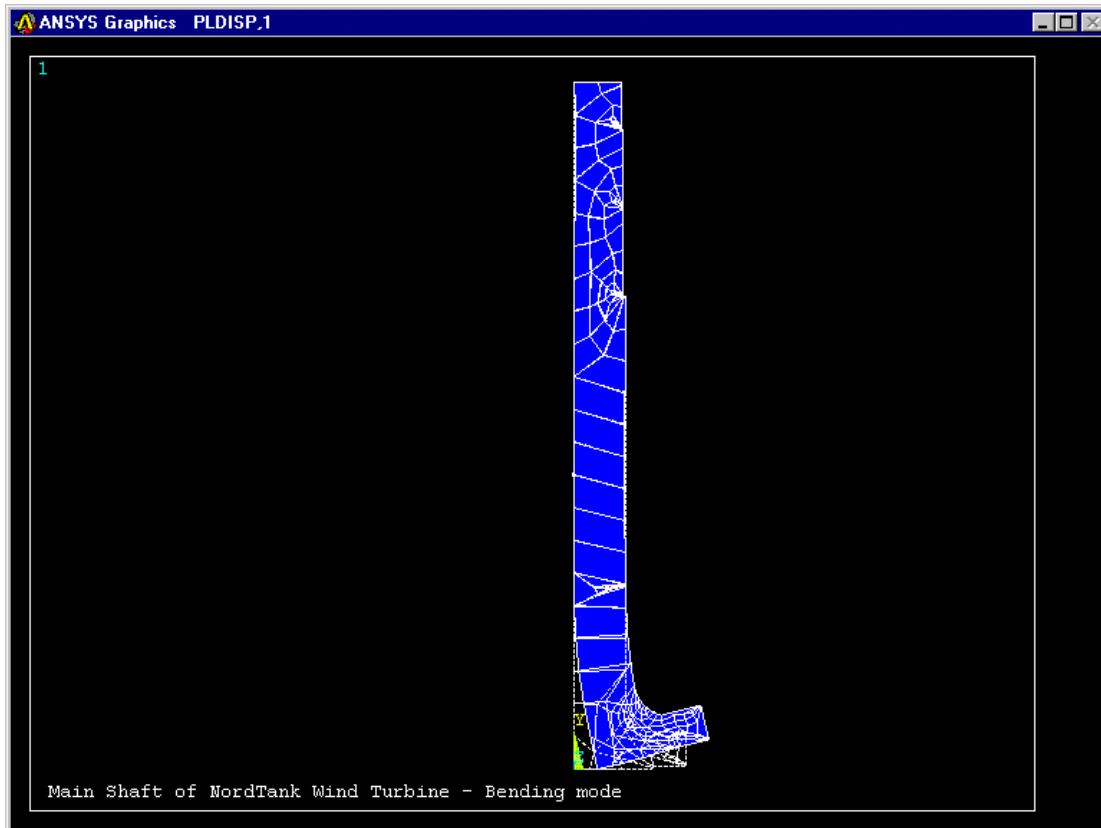Main Shaft of NordTank Wind Turbine – torsional mode

Supports:

1. Supported at Main bearing in radial and axial direction.
2. Inter median bearing in the radial direction
3. At the connection to the gearbox in radial direction and torsion direction

Results at sensors:

	Node	U_X	U_Y	U_Z
Drive End:	16	0.0000	0.0000	0.47392E-08
Non Drive End	160	0.0000	0.0000	0.14164E-08

Moment unit load:

Supports:
1. Supported at Main bearing in radial and axial direction.
2. Inter median bearing in the radial direction
3. At the connection to the gearbox in radial direction and torsional direction

Results at sensors:

	Node	U_X	U_Y	U_Z
Drive End:	16	0.14826E-09	0.20062E-09	0.0000
Non Drive End	160	0.13542E-11	-0.44993E-11	0.0000

Unit load:

Main Shaft of NordTank Wind Turbine - Unit Load

Supports:
1. Supported at Main bearing in radial and axial direction.
2. Inter median bearing in the radial direction
3. At the connection to the gearbox in radial direction and torsional direction

Results at sensors:

	Node	U_X	U_Y	U_Z
Drive End:	16	0.29034E-09	0.17318E-09	0.0000
Non Drive End	160	0.52461E-12	-0.18728E-11	0.0000

9 Comment:

For evaluation of the sensor point movements during operation it shall also be considered that the rotor move in a rigid mode inside the clearances of the roller bearings. This may distribute with further dynamics to the sensor wheels.

Abstract (max. 2000 characters)

The present report describes the novel experimental facility in detecting shaft
torque in the transmission system (main rotor shaft, exit stage of gearbox) of a
wind turbine, the results and the perspectives in using this concept. The meas-
urements are compared with measurements, based on existing strain gauges and
transducers mounted on the main rotor shaft and controller.