UpWind

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Concept report
simulation platform and
reference gearbox measurements

SAMTECH
BOSCH-REXROTH

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2 INTRODUCTION

2.1 Necessity of a global approach

The work package WP1B2 is dedicated to the reliability of the entire drive train, which is today the most critical component of modern wind turbines. Field experiences throughout the entire wind industry show that the present construction approach (based on compactness) results in many types of failures (especially gearbox failures) of drive train components, although the components are well designed according to contemporary design methods and all known loads.

It is assumed that the basic problem of all these unexpected failures is based on a principal misunderstanding of the dynamic behaviour of the complete system “wind turbine”. This misunderstanding seems to be due to the lack of an integral approach ready to use, which at the same time integrates the structural nonlinear elastic behaviour with the coupled dynamic behaviour of multi body systems together with the properties of electrical components.

To overcome the actual limitations in design and reliability, it is necessary to develop and verify new and enhanced simulation tools. Within this work package a simulation tool will be used, adapted and verified for detailed analyses of drive train behaviour. The following different system parts need to be addressed within one coupled “integral” model that would take into account:

- Wind field simulation;
- Aero-elastic interaction at blades;
- Nonlinear flexibilities of fibre blades;
- Linear flexibilities of metal components of e.g. drive train;
- Nonlinear behaviour of drive train components e.g. gears, bearings, bushings;
- Electro-mechanic behaviour of generator;
- Electrical behaviour of power electronic converter and grid.

This tool has obviously to be validated by some comparison with experimental results. These measurements have to be carried out in a close relationship with the computation, in order to ensure an effective equivalence between the model and the reality.

This report will in this first version describe this duality computation / measurements. The first part presents the computational aspects and the model that will be used for the WT; the second part details all the measurements that will be done.

2.2 Analysed Wind Turbine

The selected test turbine is a **GE 1.5xle** located at Hoya-Gonzales (Spain), with these characteristics:

- Rotor diameter: 82.5 m
- Gearbox type: GPV 455 S with adjustments on the design for the measurements.

3 PART 1: SIMULATION

3.1 SAMCEF for Wind Turbine (S4WT)

SAMCEF for Wind Turbine is a new tools developed by SAMTECH, for which a demonstrator is built in the scope of the UPWIND project. This tool is based on SAMTECH general tools, i.e. mainly **CAESAM**, **SAMCEF Field** and **SAMCEF Mecano**.

- **CAESAM** is a general framework able to integrate models and computation tools in a user friendly environment. This framework will be customized in order to be able to handle WT components and computation tools. Components on one side will be defined in a modular way, so that they could be changed by other compatible models. Each component will be possibly parameterised so that the end-used can modified the exposed parameters. Analyses on the other side will cover most of the needs concerning the WT dynamics, including fatigue analyses etc.
- **SAMCEF Field** is the standard graphical pre-processor program of SAMCEF. It will be used to build the various components of the WT. This modelling tool will not be used in the first version of the demonstrator.
- **SAMCEF Mecano** is the general purpose non linear solver of SAMCEF, which will be the kernel of all dynamic analyses on WT.

The aim of this part is to describe the way the wind turbine will be modelled for a dynamic computation in the **MECANO** solver. These models are today available as parameterized **BACON**[1] data files and will be integrated under this shape in the first version of S4WT. Later on, they will be translated into **SAMCEF Field** in order to provide the end user with an easy way to edit them, or to build some new ones.

3.2 Computation Tool

3.2.1 SAMCEF Mecano

3.2.1.1 *Mathematical background of SAMCEF-Mecano: non-linear Finite Element approach for flexible Multi-Body Dynamics*

The applied mathematical approach is based on a non-linear Finite Element formalism, which accounts for flexible Multi-Body-System functionalities, control devices and aerodynamics in terms of the Blade Element Momentum Theory simultaneously.

In the context of the "one-step time integration method of Newmark", the incremental form of the equations of motions in the presence of constraints is stated as follows:

$$\begin{bmatrix} [\mathbf{M}] & [0] \\ [0] & [0] \end{bmatrix} \begin{bmatrix} \Delta\ddot{\vec{q}} \\ \Delta\ddot{\vec{\lambda}} \end{bmatrix} + \begin{bmatrix} [C] & [0] \\ [0] & [0] \end{bmatrix} \begin{bmatrix} \Delta\dot{\vec{q}} \\ \Delta\dot{\vec{\lambda}} \end{bmatrix} + \begin{bmatrix} [K] & [B^T] \\ [B] & [0] \end{bmatrix} \begin{bmatrix} \Delta\vec{q} \\ \Delta\vec{\lambda} \end{bmatrix} = \begin{bmatrix} \vec{R}(\vec{q},\dot{\vec{q}},t) \\ -\vec{\phi}(\vec{q},t) \end{bmatrix} + 0(\Delta^2) \qquad (1)$$

[1] BACON is the SAMCEF preprocessing program based on command language files.

Note that stiffness matrix $\mathbf{K}(q)$, damping matrix $\mathbf{C}(\dot{q})$, mass-inertia matrix $\mathbf{M}$, residual vector $\mathbf{R}(q,\dot{q},t)=\mathbf{g}(q,\dot{q},t)-\mathbf{M}\ddot{q}-\mathbf{B}^T\lambda$ and constraint Jacobian matrix $\mathbf{B}=\partial\phi/\partial q$ show non-linear dependency on the generalized solution vector:

$$\begin{pmatrix} q \\ \lambda \end{pmatrix}_{iter+1}^{t_{N+1}} = \begin{pmatrix} q \\ \lambda \end{pmatrix}_{iter}^{t_N} + \begin{pmatrix} \Delta q \\ \Delta\lambda \end{pmatrix}_{iter+1}$$

Vector $\mathbf{g}(q,\dot{q},t)$ presents the sum of internal, external and complementary inertia forces where centrifugal and gyroscopic effects are included.

Vector ϕ introduces additional equations of solution λ, which is used to include general Multi-Body-System functionalities, aerodynamics and controller constraints.

3.2.1.2 Originality of MECANO concepts

The originality of the solution proposed by MECANO consists in the fact that the adopted formulation allows to handle in the same set of equations terms coming from (non linear) finite element formalism and other coming from other types of modelling, in which we can find the macroscopic kinematic joints and the control, which are widely developed in the software.

3.2.2 Using MECANO for WT computation

The advantage of using SAMCEF Mecano in the WT computation is its ability to mix in a single model the various aspects of the WT:

- MECANO-Structure is able to take into account a sharp representation of all structural components: the tower, the blades, the shafts, etc. This representation includes the possibility of using composite materials, linear or non linear properties, with the necessary damping definitions. Super elements can be used to spare calculation time as long as this linearization of the model remains a valid assumption, but keeping the full 3D representation is a standard way of using the software.
- MECANO-Motion offers in addition a wide range of kinematic joints, which provide us with a macroscopic representation of various links between all components involved in a WT. Despite this macroscopic representation, these joints can represent a complex behaviour, including non linear stiffness and damping features. This is a key point in particular in the gear box definition, which can be finely represented.
- The global *large displacements* / *large rotation* dynamic modelling is thus able to represent exactly the phenomena appearing during the functioning of a WT.
- Finally, some specific elements have been included in MECANO for coupling its natural mechanical modelling with other sets of equations. In the case of the WT analyses, a special attention has been paid to the aerodynamic aspects for the wind load definition, and to the control integration, which is fundamental to get a valuable behaviour representation.

3.3 Adaptation to Wind Turbines

3.3.1 “Aerodynamic Blade Section Elements” for wind loads

Bearing in mind that blades are represented by Super Elements or non-linear beam elements respectively, the Blade Element Momentum theory can be applied very efficiently in order to introduce the wind loads by “Aerodynamic Blade Section Elements”.

As depicted in figure 1, the discretisation of aerodynamic loads corresponds to the structural discretisation in terms of retained Super Element nodes or, respectively, beam nodes.

Aerodynamic loads are introduced by “Finite Blade Section Elements” which contribute in terms of elemental aerodynamic forces to the global equilibrium equation (1). The actual blade geometry is discretized by surface contributions A_i, which correspond to the airfoil span times the chord length of section *i*. The three-dimensional shape of wind turbine blades is accounted for by local blade section twist ψ^i and coning angles θ^i. Twist and coning angles are introduced in terms of local “*blade section coordinate systems*”, which are attached to each blade node. According to twist and coning angles, blade section coordinate axes are aligned with the tangential and normal directions of the respective blade section and follow any deformation or rotation of the blades naturally.

Actual wind loads are computed with respect to a “*wind coordinate system*” the orientation of which is a priori an unknown, because it is rotated with respect to the associated local blade section coordinate systems by the unknown angles of attack α^i. The angles of attack α^i depend implicitly on the unknown induced velocities at each blade section, and thus on the solution of the global constraint field problem (1).

Aerodynamic force components can be stated in the a-priori unknown “wind coordinate system” by the classical expression:

$$
\begin{aligned}
F^i_{\mathrm{LIFT}} &= \tfrac{1}{2} C^i_{\mathrm{LIFT}}(\alpha_i)\rho V^2_{\mathrm{rel}\,i} A_i \\
F^i_{\mathrm{DRAG}} &= \tfrac{1}{2} C^i_{\mathrm{DRAG}}(\alpha_i)\rho V^2_{\mathrm{rel}\,i} A_i \\
M^i_{\mathrm{PITCH}} &= \tfrac{1}{2} C^i_{\mathrm{M}}(\alpha_i)\rho V^2_{\mathrm{rel}\,i} A_i
\end{aligned}
\qquad (2)
$$

where:

- F^i_{LIFT} is the lift force, which acts normally to the relative wind velocity vector;
- F^i_{DRAG} is the drag force, which acts perpendicularly in the direction of the relative wind velocity;
- M^i_{PITCH} is the torque generated with respect to the blade pitch axis.

Lift, drag and moment coefficients, denoted C^i_{LIFT}, C^i_{DRAG} and C^i_{M} are functions of the angle of attack. Note that the relative velocities V_{rel} account for the induction corrections due to the global flow interaction with the blades and have to satisfy the constraints which are stated in the following equations (3a to 3c).:

- tip speed ratio: $a'(1+a')x^2 = a(1-a)\cos^2\theta$ (3a)
- thrust coefficient:

- $a \leq a_c$: $C_t = 4aF(1-a)$ (3b)
- $a > a_c$: $C_t = 4F\left[a_c^2 + (1-2a)a\right]$ (3c)

with:

- $x = \dfrac{\Omega r}{W}$ (3d)
- $a_c = 0.2$ (empirical constant) (3e)
- $F = \dfrac{2}{\pi}\arccos\left(\exp\left[-\dfrac{B(R-r)}{2r\sin\phi}\right]\right)$ (Prandtl tip loss factor) (3f)

In order to couple equations (2) and (3) to the global field problem (1), the induction factor for speed normal to the rotor plane, denoted "*a*", and the induction factor for speed tangent to the rotor plane, denoted "*a*' ", are defined in equations (3a to 3c). In that context, $\Omega.r$ represents the unperturbed tangential rotor plane speed at blade section *i* of radius *r*, ϕ presents the angle between relative wind vector and plane of rotation and *W* represents the unperturbed wind speed normal to the rotor plane:

According to the "Wilson and Walker" approximation for the thrust of an annular rotor segment, one can write the equality of the thrust coefficient C_t^i and the projection of the aerodynamic lift and drag loads on the rotor plane:

$$C_t^I = \mathrm{Proj}_{\mathrm{RotorPlane}}\left[F_{\mathrm{LIFT}}^i, F_{\mathrm{DRAG}}^i\right]$$

thus coupling equations (1), (2) and (3*).

Taking into account that the aerodynamic loads $\left[F_{\mathrm{LIFT}}^i, F_{\mathrm{DRAG}}^i, M_{\mathrm{PITCH}}^i\right]$ presented in equation (2) are included in the internal forces of vector $\mathbf{g}(q, \dot{q}, t)$ of equation (1), once the iterative solution of coupled equations (1), (2) and (3*) is found, the induced velocities, angles of attack, Prandtl's tip loss coefficients and local aerodynamic forces are consistent.

It is emphasized that the methodology applied permits a "strong coupling", i.e. all equations associated either with aerodynamics, structures, mechanisms, or control loops are solved simultaneously. A major advantage of a "strong coupling" is that blade vibrations induced by aerodynamic forces implicitly affect the latter.

3.3.2 Tower shadow and wind shear

Before computing the proper induced velocities at the different blade sections, some adjustments are performed beforehand on the unperturbed wind field. First, the unperturbed speeds of the three-dimensional turbulent wind field are adjusted in order to take into account the velocity gradient induced by ground effects and then, secondly, to account for the impact of the tower shadow.

In order to account for the wind shear close to the ground, the wind speed is written as an exponential function of the relative height h of a "blade section node" with respect to the rotor hub height h_{HUB}. The incoming, unperturbed wind speed V_∞ is taken as reference at the rotor hub and is corrected by an exponential law yielding the wind speed without induction, $V(h)$ as a function of ground distance:

$$V(h) = V_\infty (h / h_{HUB})^{Shear\_coef} .$$

The impact of the tower on the unperturbed wind field is modelled by classical “non-lifting flow theory over a circular cylinder”. An analytical solution for the radial flow V_r and tangential flow V_θ is obtained from the stream function ψ as function of azimuth angle θ and tower distance r:

$$V_r = \frac{1}{r}\frac{\partial \psi}{\partial \theta}$$

$$V_\theta = -\frac{\partial \psi}{\partial r}$$

with

$$\psi = V_\infty r \sin\theta (1 - \frac{R^2_{\mathrm{TOWER}}}{r^2})$$

The proper computation of the induced velocities at the blade sections is performed after the cited corrections on the unperturbed wind field.

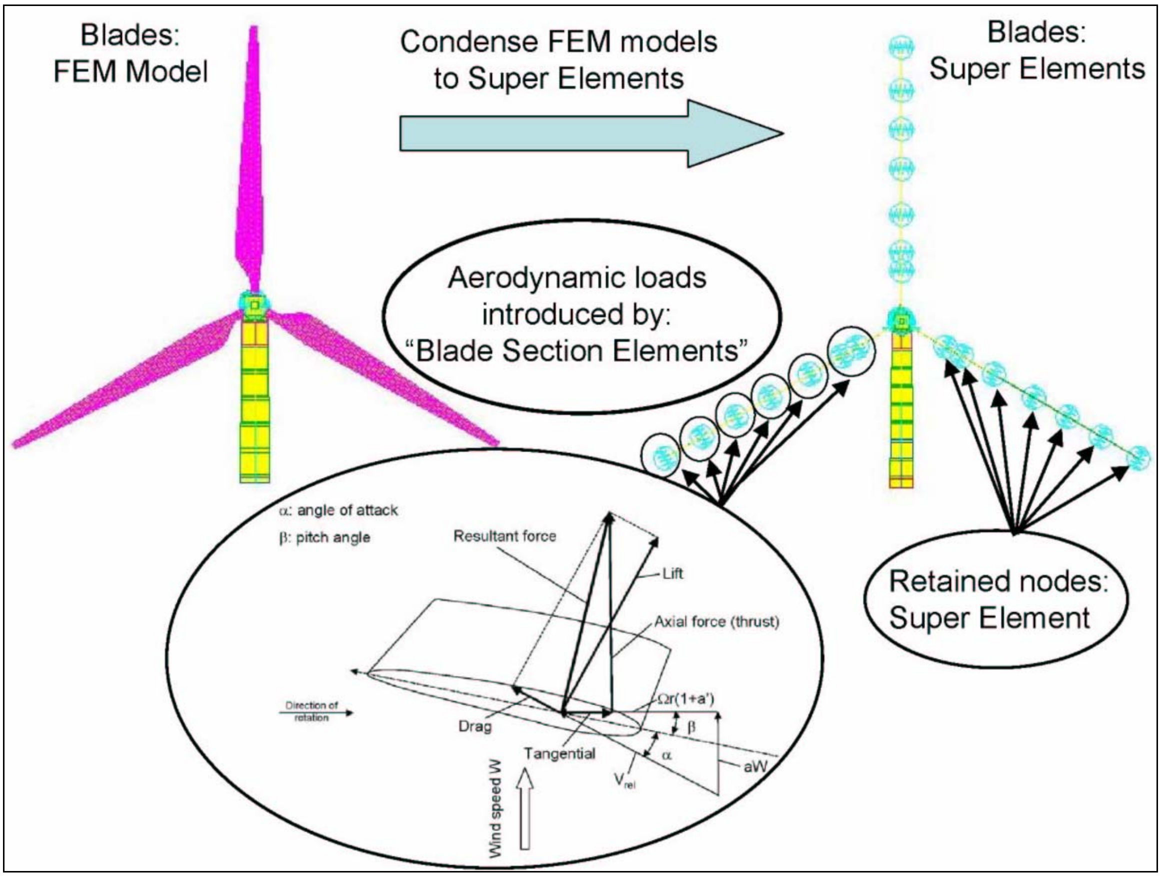


Figure 1: Modelling of blades by Super Elements and aerodynamic blade section elements

3.4 Structural and Multi-Body-System Modelling of a Wind Turbine

Structural components, which are subject to elastic deformations and which have impact on the dynamic properties, are included in the complete wind turbine model in terms of FEM models. Taking into account that long time intervals – longer than 1000 [s] - have to be analysed, the total number of degrees of freedom (DOF) of the complete analysis model should stay below 20.000 DOF's. As a consequence, the FEM-structures, which are subject only to small deformations, are condensed by the Super-Element Method. The rotor shaft, all gearbox shafts, the generator rotor and the tower are modelled by non-linear "beam elements".

Further flexible "mechanism type components" like gears, bearings, drive train couplings and generator mechatronics are introduced through a Multi-Body-System (MBS) approach in terms of additional degrees of freedom of the global equilibrium equation (1).

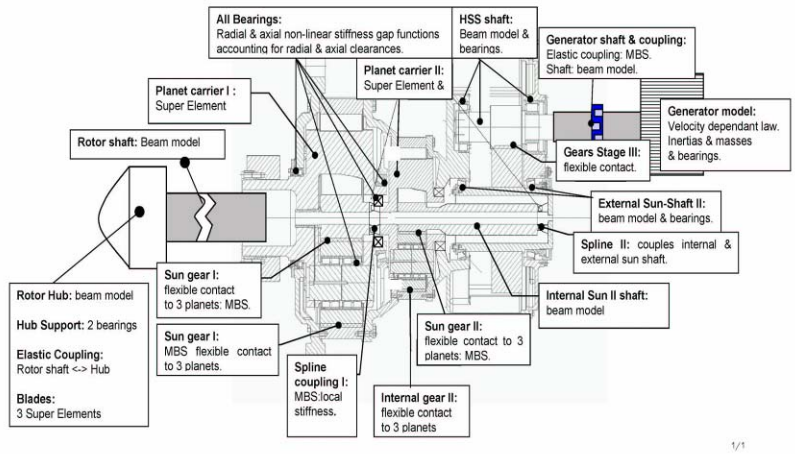


Figure 2a: Schematic description of the gearbox model and modeling

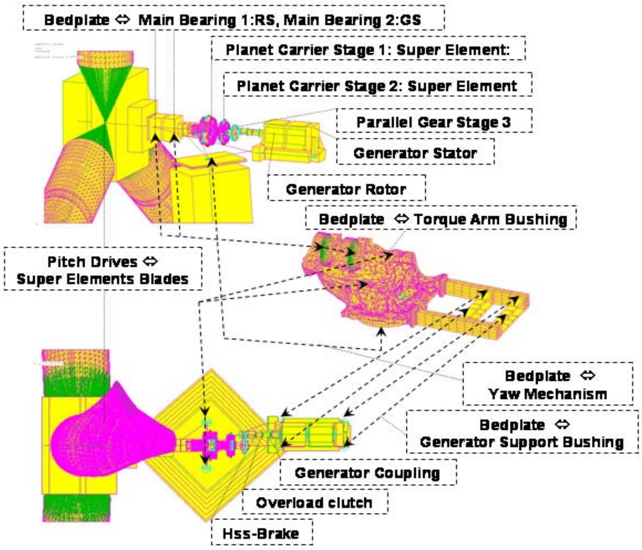


Figure 2b: General example for connection of retained nodes of bedplate Super Element and further modelling details

3.4.1 Damping modelling

Stiffness proportional damping is applied to all structural components, which are presented either by beam elements or by Super elements. The amount of damping is set for all components to 2% critical damping, except for the composite material blades where 4% of critical damping is applied. Viscous damping, or respectively Coulomb friction, is applied to every bearing and gear contact. In the case of torque arm coupling elements, a non-linear deformation speed dependant viscous law is applied.

Note that the aerodynamic loads can also be considered as damping forces, because aerodynamic laws of type of equation (2) are essentially related to speeds.

3.4.2 Gearbox modelling: coupled MBS & FEM approach

The gearbox is included in the global analysis model combining FEM and MBS approaches. All gearbox shafts, including the rotor shaft, are represented by non-linear beam elements. The gearbox housing and the planet carriers are modelled by a solid FEM model, which is condensed to a Super Element in order to reduce the number of degrees of freedom.

Frictional contact problems between flexible gears are reduced to geometrically variable and point wise flexible contacts. Gear geometry is defined by helix, cone and pressure angles, normal modulus, respective teeth number and, if needed, further correction factors for the gear teeth.

In context of noise prediction, geometric imperfections (typically due to manufacturing tolerances) can be included in the analysis model in terms of “geometrical transmission error”.

Gear teeth flexibility is defined by non-linear gap-functions, which account for stiffness variation, when passing along one tooth engagement. It is emphasized that the proper modelling of gear and bearing clearances is of crucial importance when evaluating gearbox loads during backlashes. The so-called “parameter-excitation” (non-linear “gear teeth contact stiffness functions”) can be defined in terms of Fourier series containing as many harmonics as necessary to describe the stiffness variation when passing along one tooth engagement. That extension of the gear tooth flexibility is necessary in order to reproduce the higher frequency content generated by the teeth engaging properly.

Every bearing of the wind turbine, including those of the rotor main shaft, the entire gearbox and the generator, is modelled by non-linear stiffness functions, which account for the coupling of radial and axial bearing properties. All bearing clearances in radial and axial directions are accounted for.

3.5 FE modelling of Wind Turbine Dynamics as a flexible mechanism

The presented GE-1.5 wind turbine model will be further adapted to the specific configuration of the reference configuration in order to reproduce experimental data obtained during measurement campaign conducted by GE in early 2007.

The wind turbine is equipped with:

1. GPV455 gearbox.

The present 1.5GE-XLE configuration incorporates following global characteristics:

1. Rotor: **m
2. Tower: **m
3. HSS brake: higher torque (14800 Nm). Note: brake value was changed when going to SLE which is a 60 Hz machine.
4. Generator: 50 Hz generator
5. Main bearing: FAG 240/600B.MB

All cited mechanical properties and results use the following unit system:

Units: Forces: [N], Moments: [Nm], Length: [m], Time: [s], Density: [Kg/m3], Stress: [GPa=N/m2], Frequencies: [Hz].

3.5.1 Modeling of structural components: bedplate, planet carrier, gearbox housing

Blades, Bed Plate, Planet Carrier, and Gearbox Housing are implemented as Super Elements in this complete model of wind turbine. Corresponding FE-meshes are presented in the following figures.

Figure 3a: FEM Model blades: anisotropic multiplayer shell composite elements. Condensed to Super Element

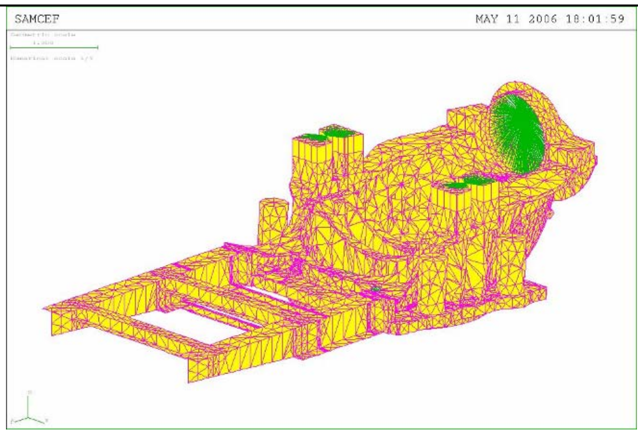


Figure 3b: FEM Model “Bedplate”: Condensed to Super Element

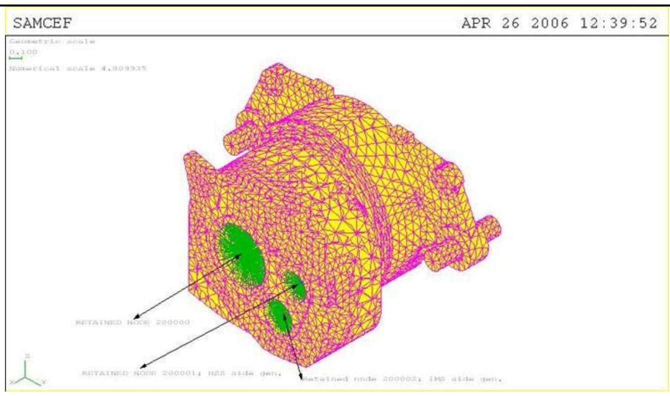


Figure 3c: FEM Model “Gearbox housing”

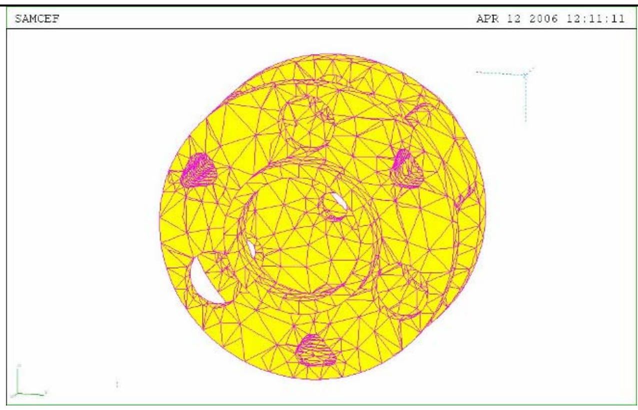


Figure 3d: FEM Model “Planet carrier”:

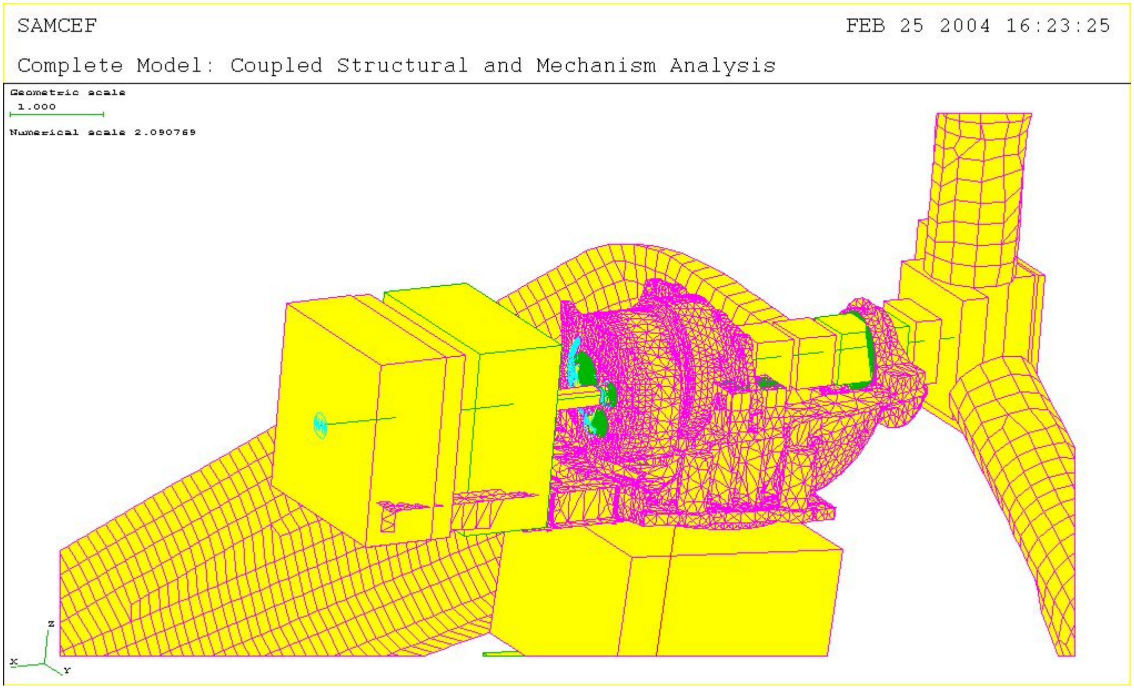


Figure 4: Model GE-1.5: coupled structural and mechanism elements: displayed FEM meshes are condensed to Super Elements

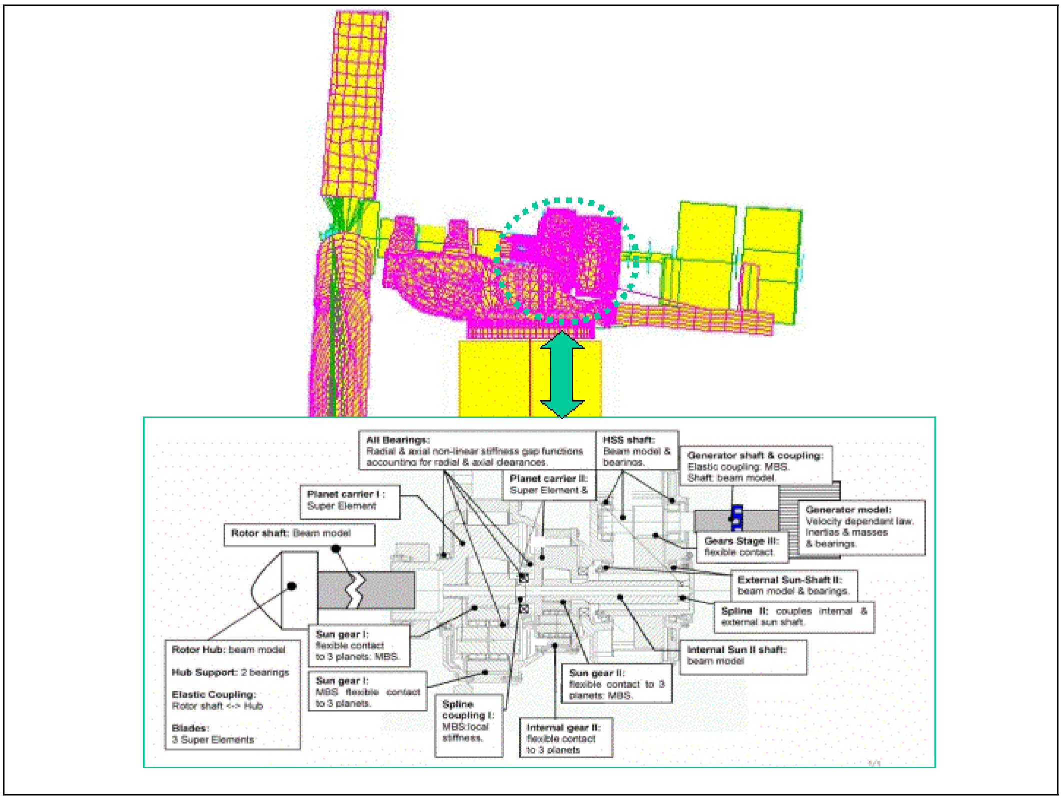
3.5.2 Gearbox model

All gearbox shafts are represented by non-linear beam elements according to the geometry exposed in technical drawings.

Gearbox housing is modelled by a solid FEM model, which is condensed to a Super Element in order to reduce the number of degrees of freedom.

The frictional contact problems between flexible gears are reduced to geometrically variable, and point wise flexible contacts. Gear geometry is defined by helix-, cone- and pressure angles, normal modulus, respective teeth number and, if needed, further correction factors for the gear teeth. Gear teeth flexibility is defined either according to ISO 6336, or by non-linear gap-functions. It is emphasized that the proper modelling of gear and bearing clearances is of crucial importance when evaluating gearbox loads during backlashes.

Every bearing of the wind turbine, including the rotor main shaft, the entire gearbox and the generator, is modelled by non-linear stiffness functions. All bearing clearances in radial and axial directions are accounted for.



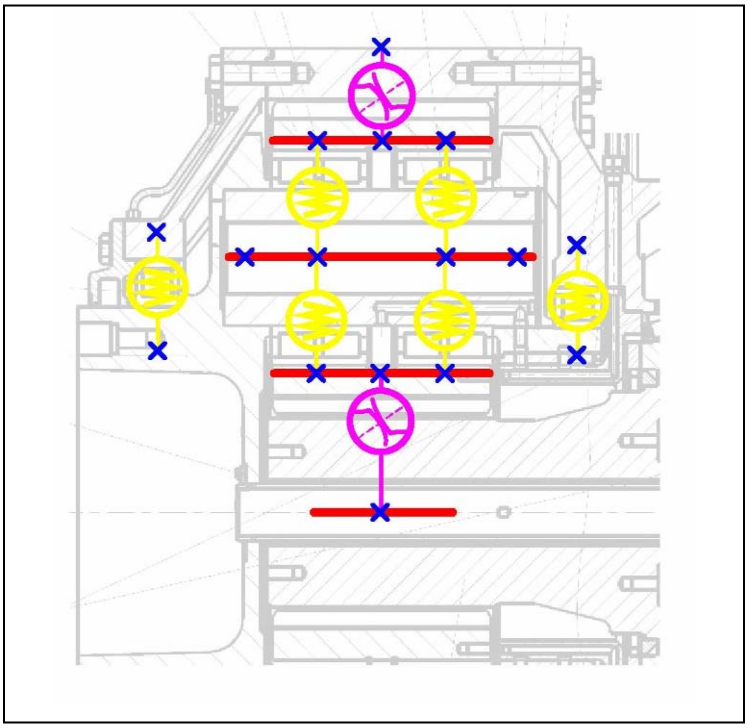


Figure 5: Schematic presentation of modeling of planet bearings and gear contacts. Planet pins are modeled by non-linear beam elements

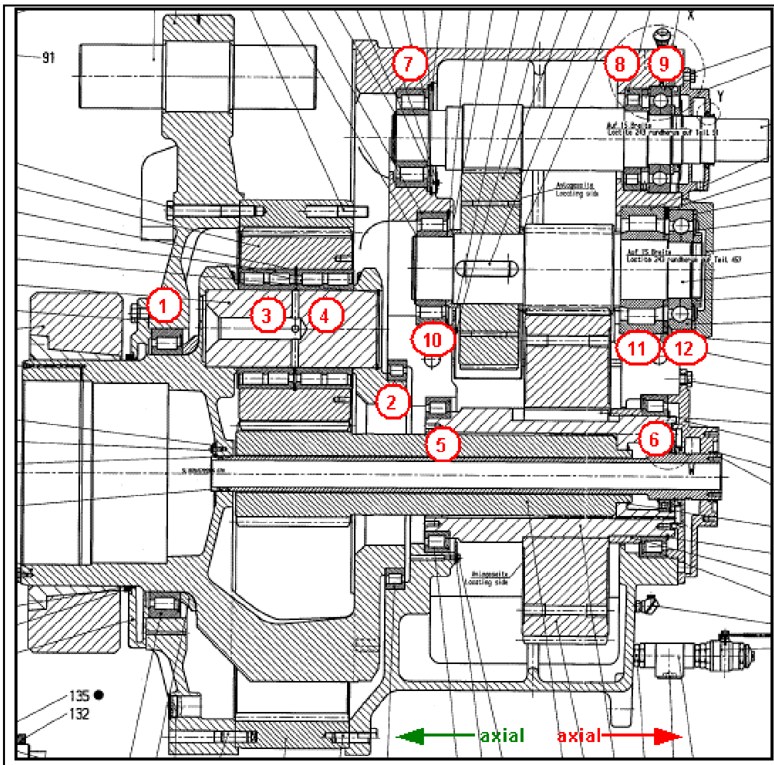


Figure 6b: Bearing location PEAB 4410 Gearbox

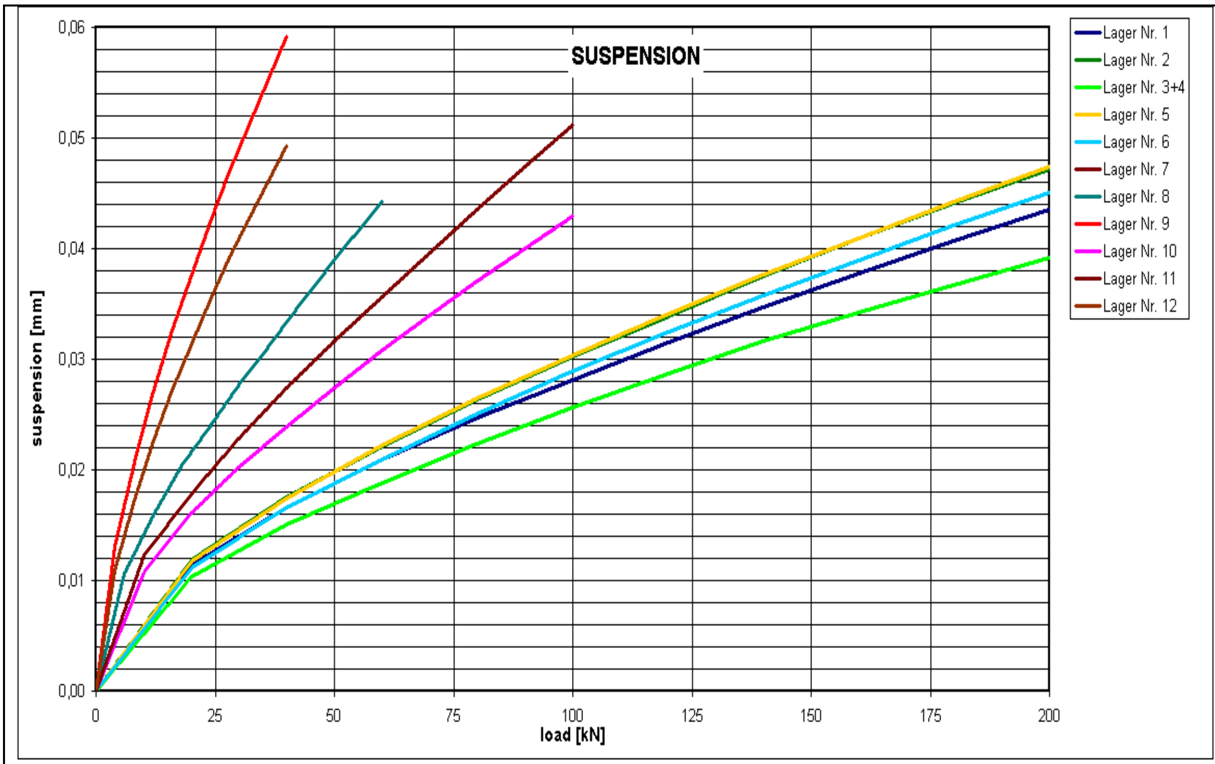


Figure 6c: Radial Bearing stiffness

Gap and Stiffness are modeled as non-linear load vs. displacement functions for each bearing in axial and in radial directions.

Component	number of teeth	module [mm]	base circle radius [mm]	pitch circle radius [mm]	rolling circle radius [mm]	pressure angle [deg]	helix angle [deg]	axial distance [mm]	tooth width [mm]	impact stiffness [N/um/mm]	impact stiffness [N/mm]
internal gear											
planet											
planet											
sun gear											
LSS gear											
IMS pinion											
IMS gear											
HSS pinion											

shaft	location	bearing type INA / SKF	loading capacity radial	 axial ->	 <- axial	clearance [mm] radial	 axial	number on drawing	stiffness available
IMS	left								
IMS	right (left)								
IMS	right (right)								
HSS	left								
HSS	right (left)								
HSS	right (right)								
LSS	left								
LSS	right								
planet	left								
planet	right								
planet carrier	left								
planet carrier	right								

Summary of bearing characteristics of gearbox

3.5.3 Blade Model: Super elements & aerodynamic loads

Blades are modeled by anisotropic FEM models which are condensed by the Super Element Method.

The initial FEM model accounts for the multiple composite layers and orientations in terms of anisotropic multi-layer SAMCEF shell elements.

Rigid body spiders (RBE2 or RBE3 type) are used to condense blade section to single node for sub-sequent Super Element reduction procedure. In the following figures the rigid spiders of each blade section are presented in terms of black sketches.

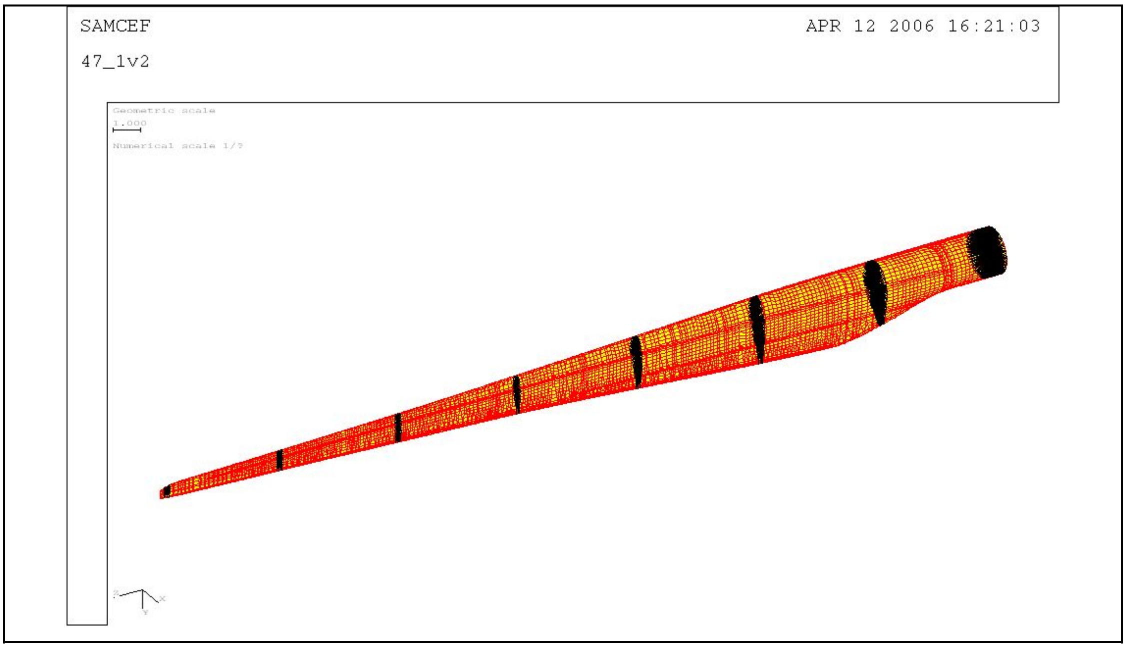


Figure 7: Blade Model including anisotropic multi-layer SAMCEF shell elements. Rigid body spiders (RBE2 or RBE3 type) are used to condense blade section to single node for Super Element reduction. Accordingly, each master node of rigid spiders present retained node for Super Element generation.

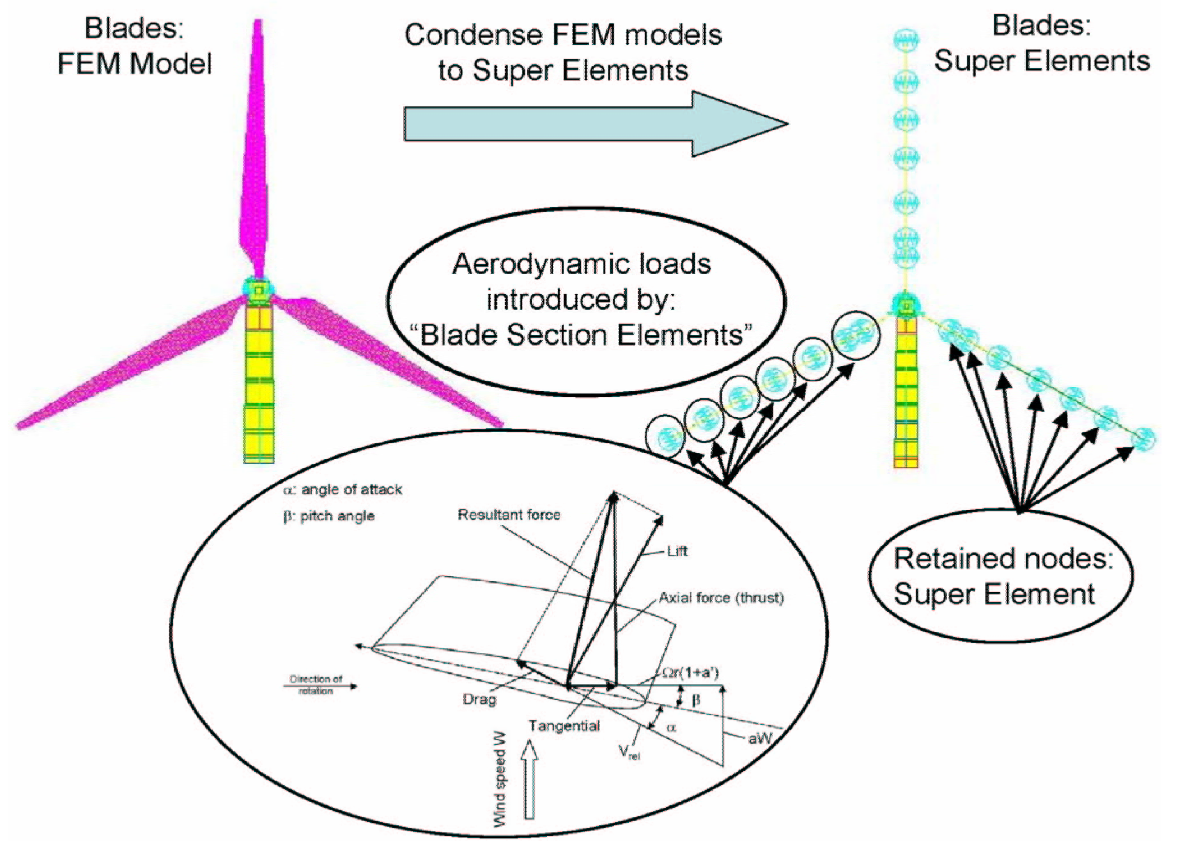
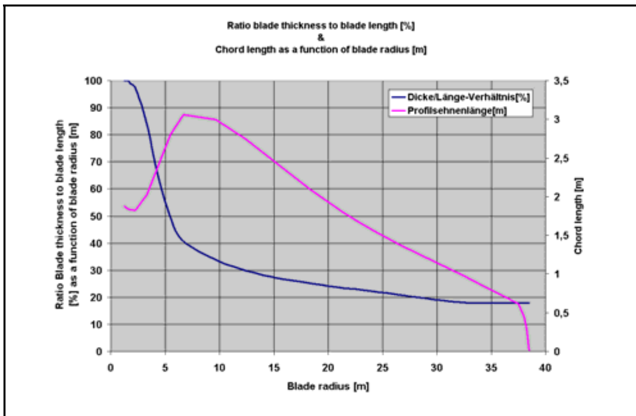
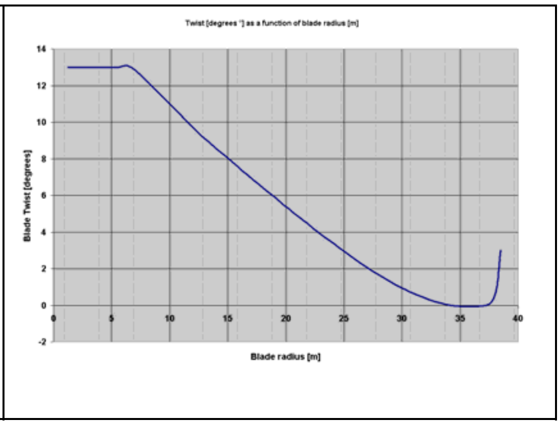


Figure 8: Aerodynamic loads by BEM-Theory - discrete blade section elements





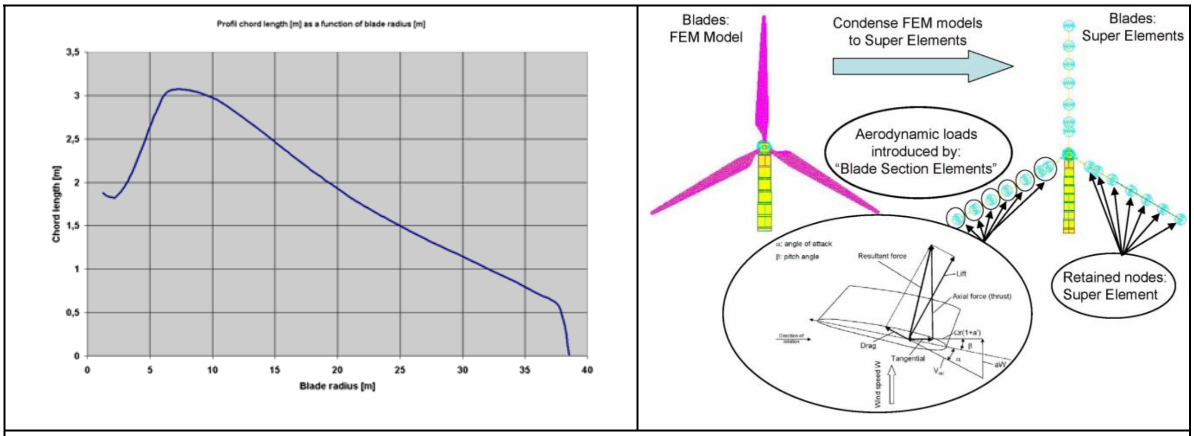


Figure 9: Blade geometry used for aerodynamic BEM-elements

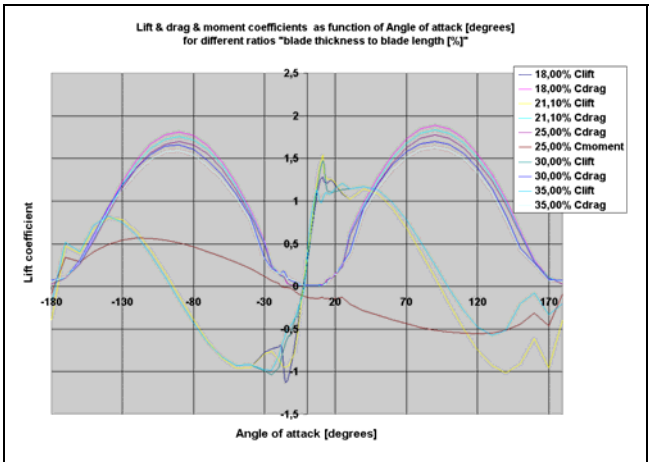


Figure 10a: Lift, Drag and Moment coefficients as a function of angle of attack for several blade sections

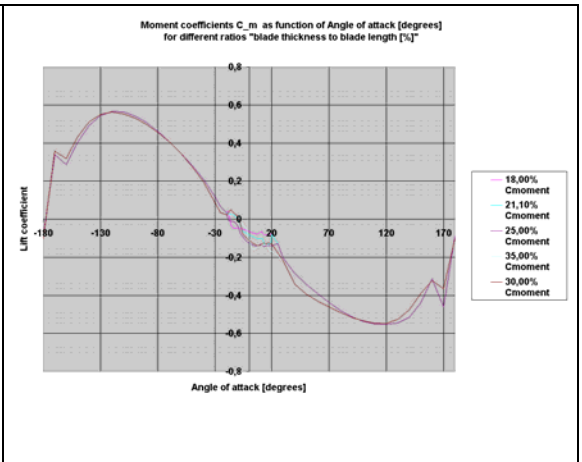


Figure 10b: Moment coefficients as a function of angle of attack for several blade sections

3.6 Loads and Boundary Conditions

3.6.1 Boundary Conditions: Turbulent wind & aerodynamics

Aerodynamic loads are introduced by *“Finite Blade Section Elements”* which contribute in terms of elemental aerodynamic forces to the global equilibrium.

Example for input for the three dimensional wind field:

Input Wind File (received from GE/Salzbergen):	**Turbulence intensity:**	**Direction:**
W6614U0.080	0.1843	Incoming wind

W6614V0.080	0.14744	Lateral
W6614W0.080	0.0921	Vertical

The three-dimensional character of the rotor plane wind file is defined as function of:

1. Time
2. Azimuth angle of the respective blade section
3. Radius of the respective blade section.

The following figure presents for a given blade radius of approx. 35m, the wind speeds as a function of the azimuth angle.

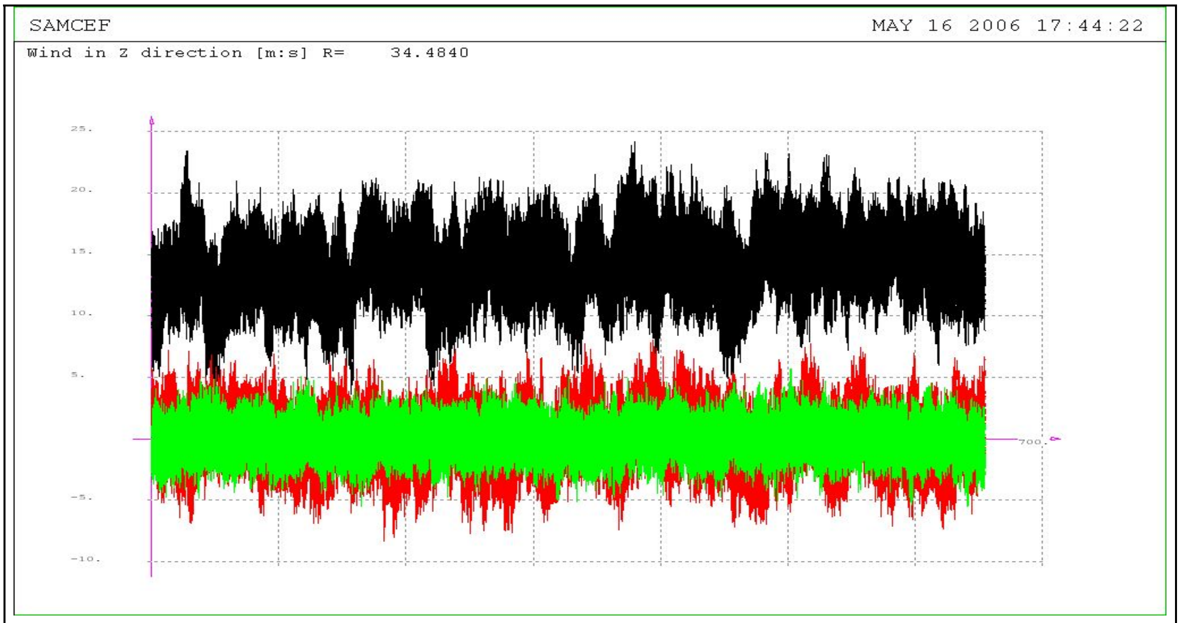


Figure 1: Example for turbulent wind speed distribution at specific blade radius (34.5 m) and azimuth position as a function of time (abscissa). Black plot: incoming wind direction (XGL). Red plot: lateral (YGL). Green plot: vertical wind speeds.

3.6.2 Pitch and generator control

Pitch and generator control is accounted in terms of a DLL delivered by GE/Salzbergen. The blade pitch angle and generator torques are thus obtained by an implicit coupling of the DLL:

1. “discon_pitch_V205.dll”

The DLL "discon_pitch_V205.dll" is coupled consistently to SAMCEF-Mecano. The start Up of the turbine is simulated with controllers of SAMCEF Mecano.

The input data for the pitch control DLL delivered by GE is defined in file:

1. 15sle_GE37c_60_fat

3.6.3 Boundary Conditions:

- Constraints:
    - Node of Tower (beam model) foundation: Fixed (TX, TY, TZ, RX, RY, RZ) (see figure 1 for structural model).
- Loads on blade nodes of Super Elements.
    - Aerodynamic loading on seven blade sections using BEM using three-dimensional wind field with turbulence.
    - Gravity load: -9,81 [m/s2] on complete structure in –Z
    - Control:
    - Generator and pitch control according to DLL "discon_pitch_V205.dll" and according to parameter file: 15sle_GE37c_60_fat

3.7 References

[1] Flex5 – Theory Manual.Version: 1.0. Published: 09/22/2003. Author: Anand Natarajan. Amarnath S. GE-internal document -classified confidential.

[2] Description of DLLController (discon_pitch_V205.dll). Author: Martin.staedler. Saved 2005-11-23. GE-internal document-classified confidential.

[3] GH Bladed. Version 3.65. User Manual. July 2004. Appendix A. Communication in between Bladed and external controller.

[4] Fatigue Load Computation of Wind Turbine Gearboxes by Coupled Structural, Mechanism and Aerodynamic Analysis. A. Heege, Y. Radovcic & J. Betran. Dewi Magazin No. 28 February 2006.

[5] Samcef/Mecano ®. User Manual version 11.0.5. Samtech SA, http://www.samcef.com.

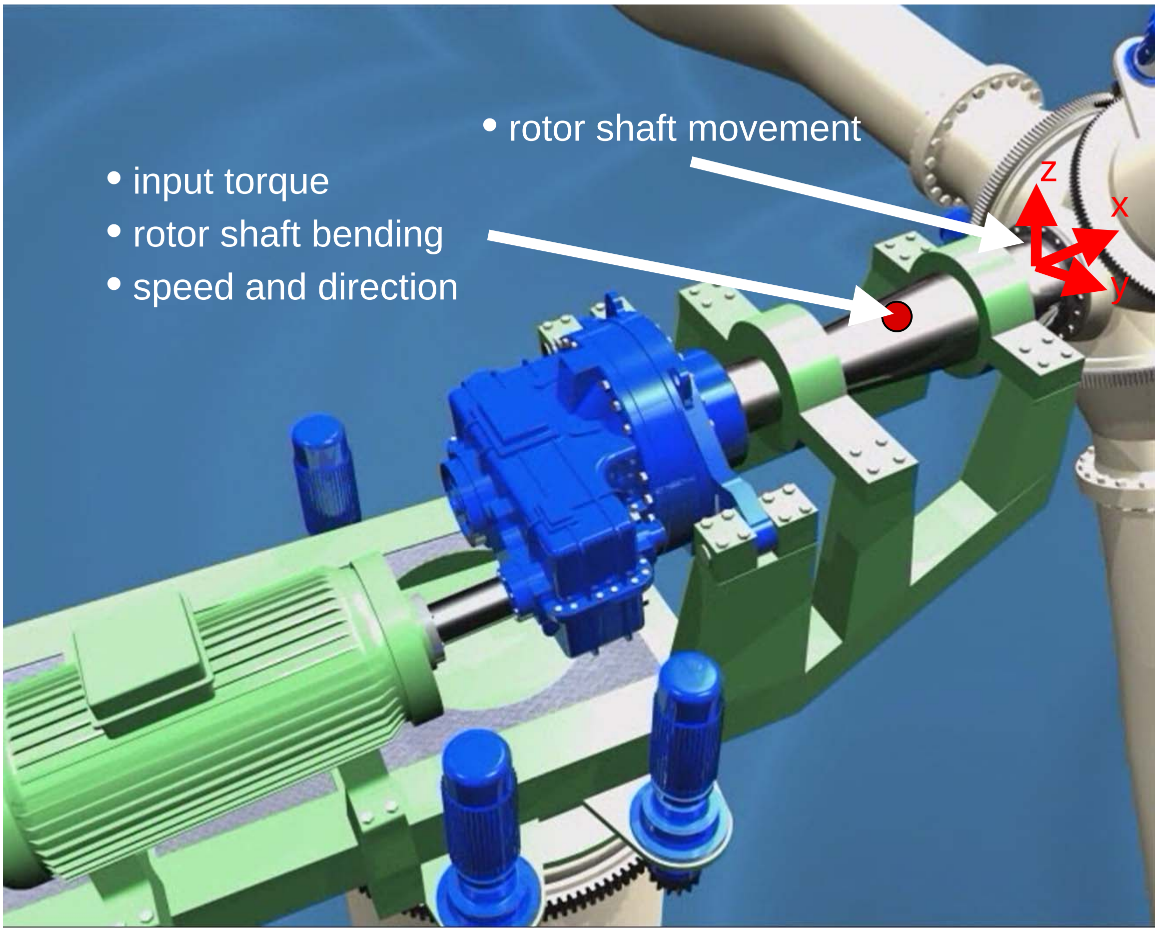
4 PART 2: MEASUREMENTS

4.1 Type and locations of measurement

The measurements

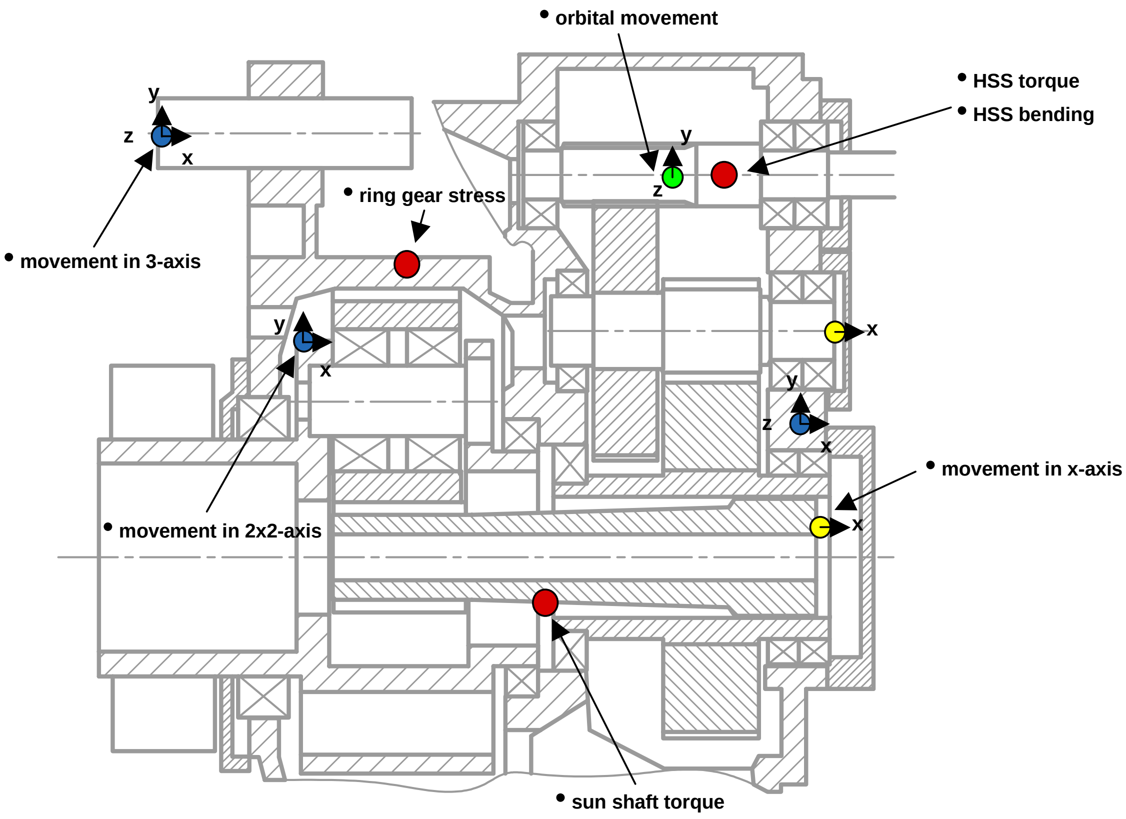
4.1.1 Rotor shaft

- Input torque
- Bending torque (two axis)
- Input speed
- Rotation direction
- Shaft movement (near main bearing x, y, z direction)



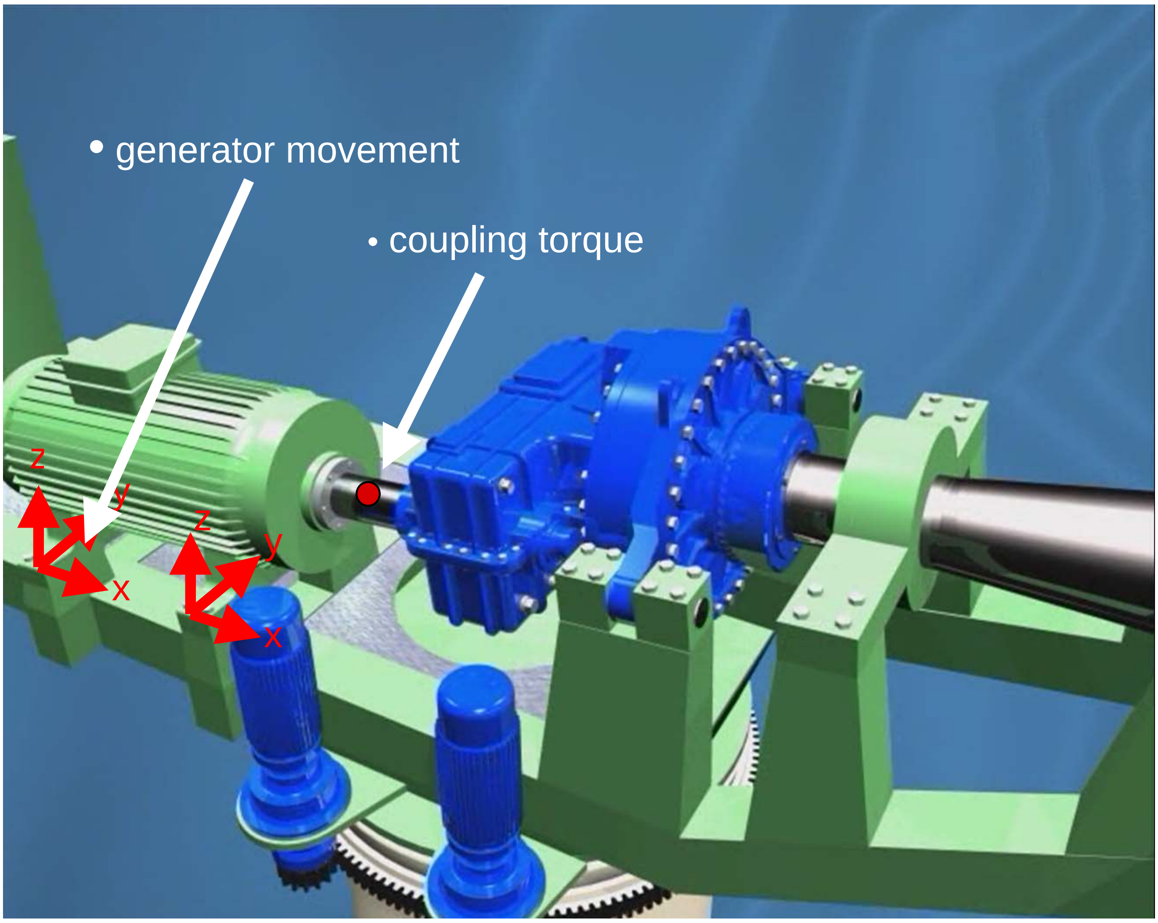
4.1.2 Gearbox

- Torque sun shaft
- Torque high speed shaft (HSS)
- HSS bending
- Movement of planet carrier (2 x, 2 y direction)
- Movement of gearbox in 3 points and 3 directions
- Sun shaft movement in x direction
- Intermediate shaft movement in x direction
- HSS movement in 3 directions
- Ring gear stress on 3 points
- Oil sump temperature
- Ambient temperature
- Output speed and direction



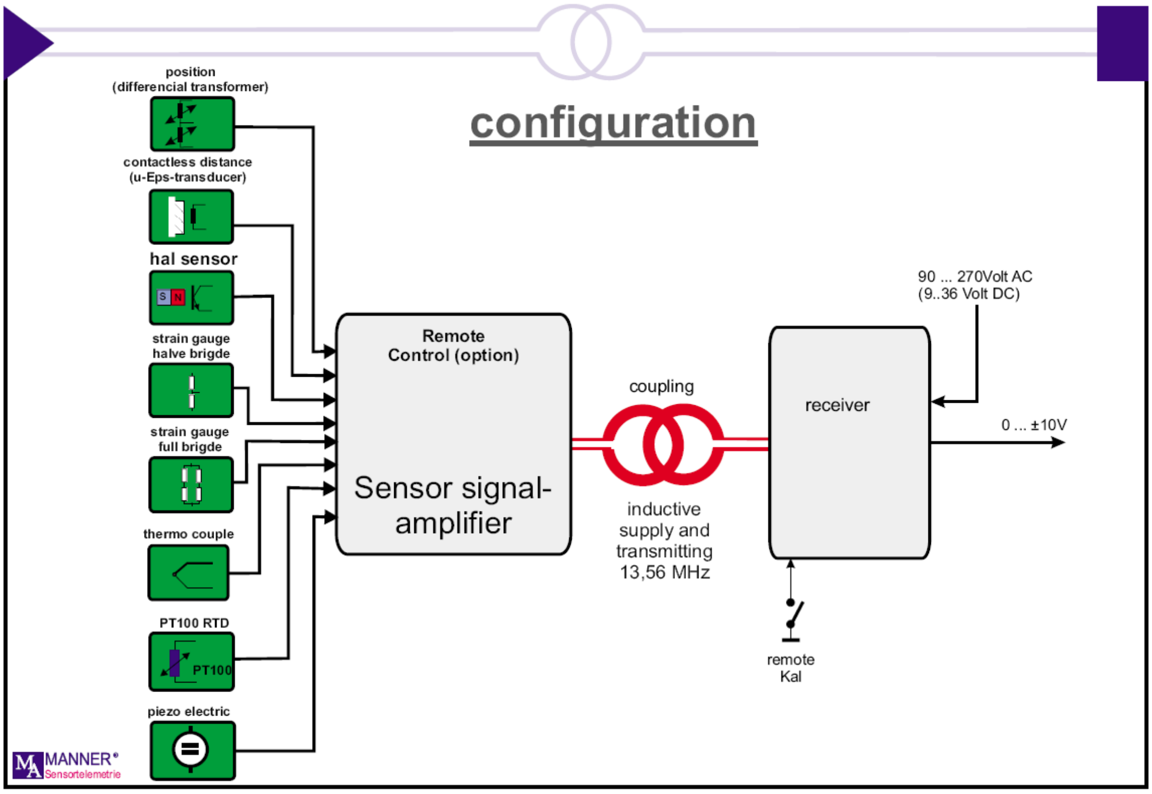
4.1.3 Generator

- Movement on 3 points in 3 direction
- Coupling torque

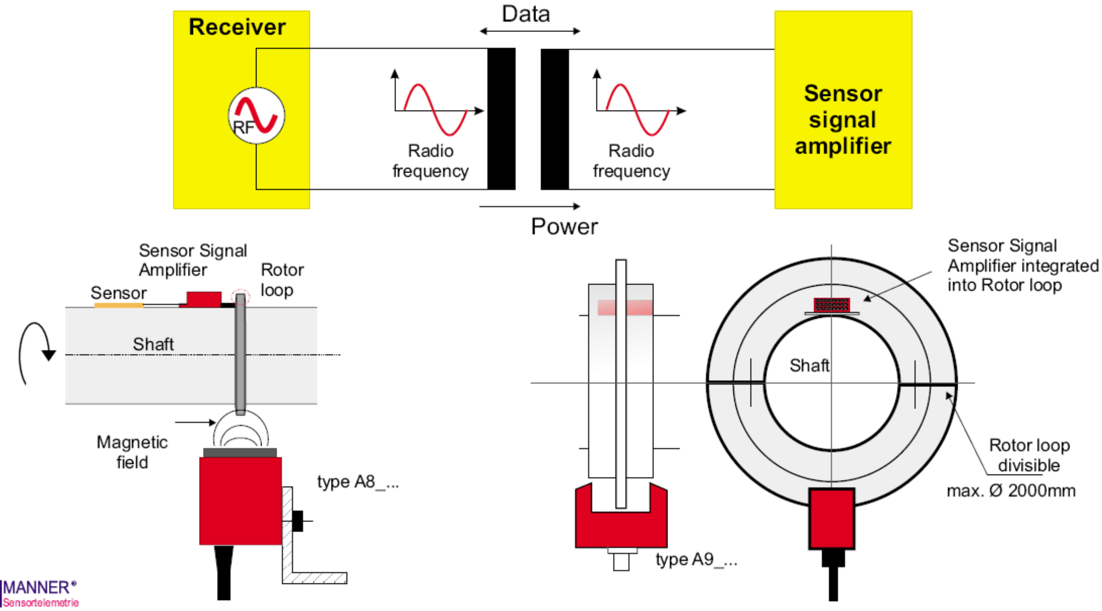


4.2 *Measuring equipment and configuration*

4.2.1 Principal configuration of rotor shaft and sun shaft system



Principle of Transformer (Rotor and Stator Loop)



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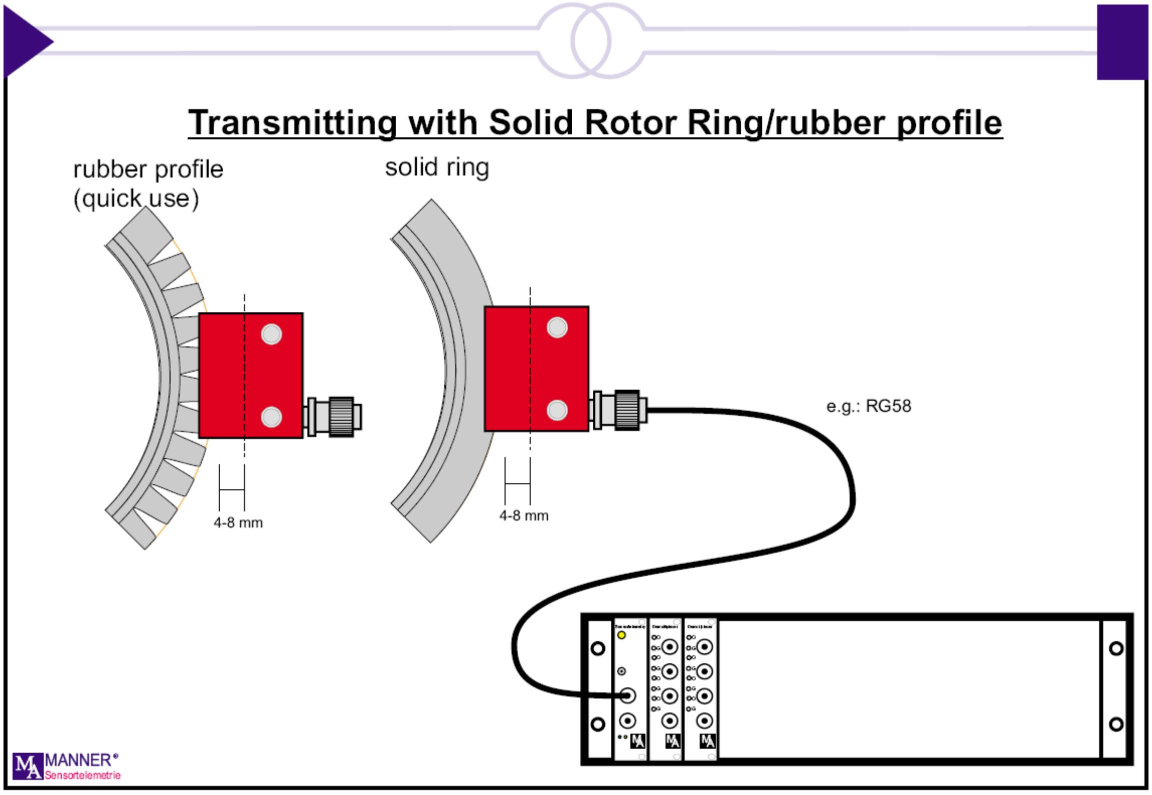
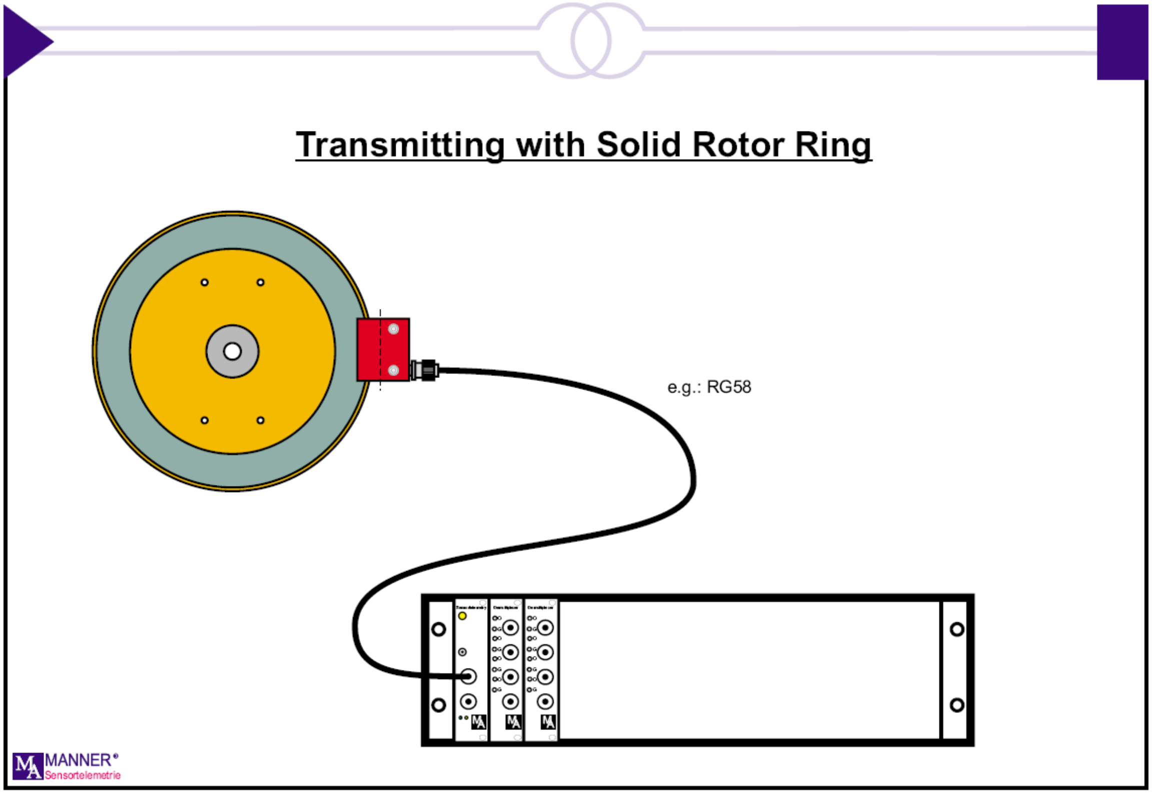
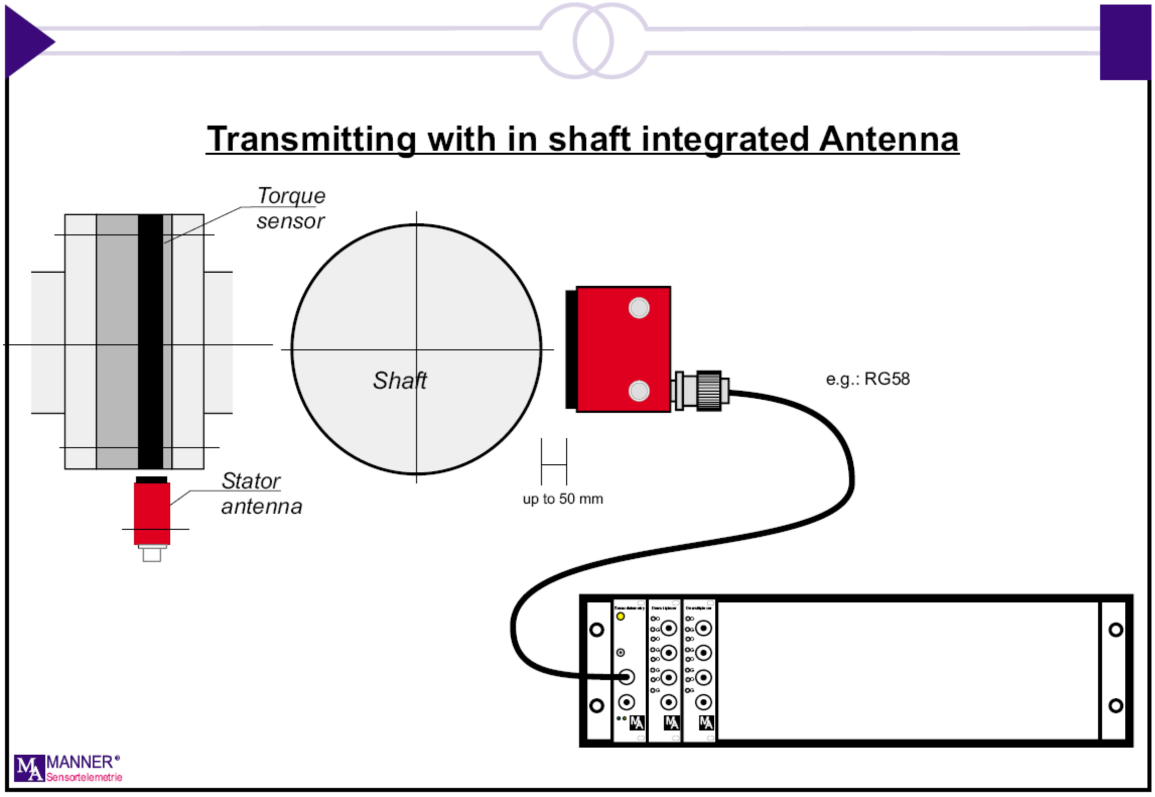
4.2.2 Transmitter system of rotor shaft signals



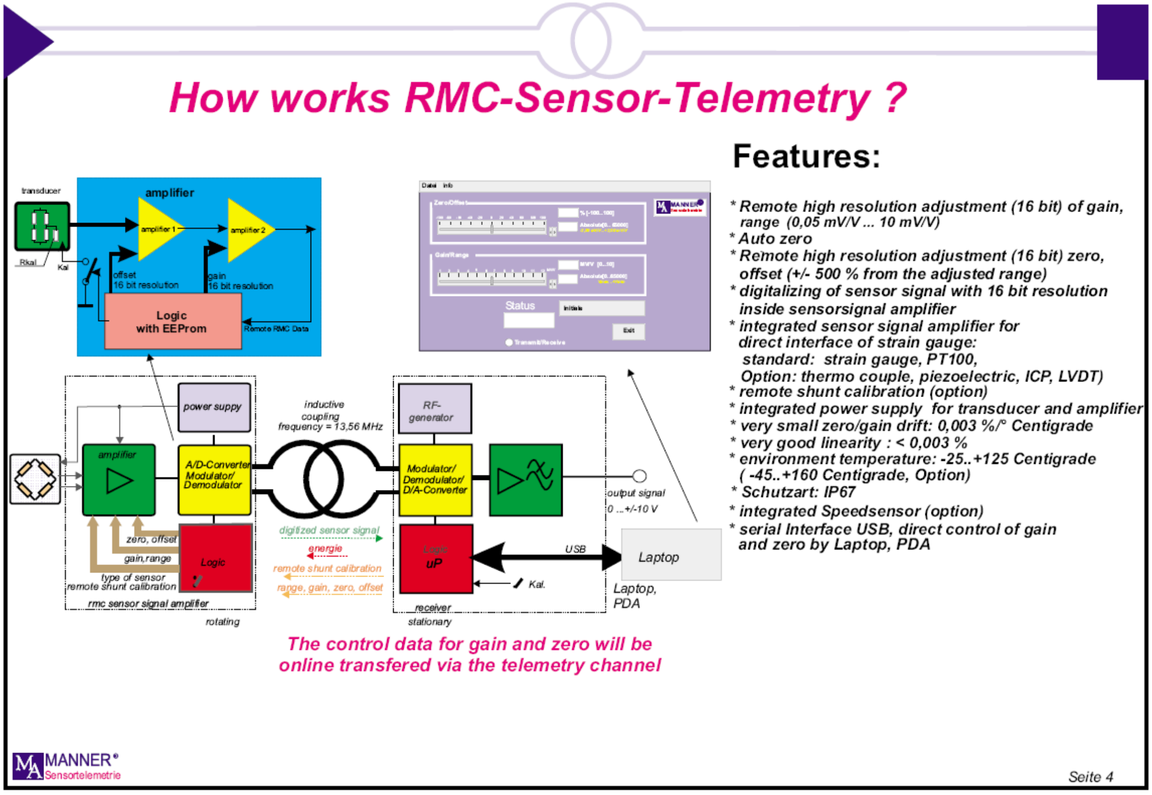
4.2.3 Transmitter system of sun shaft signals

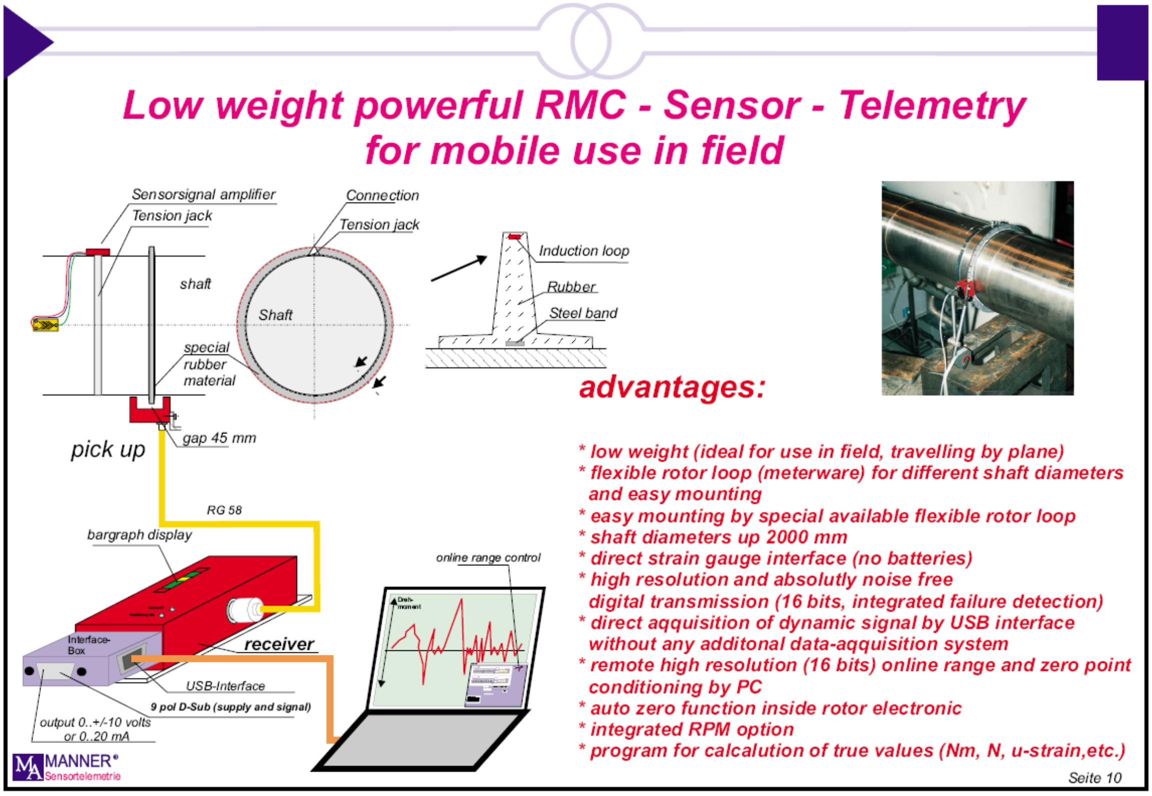


4.2.4 Transmitter system of coupling signals

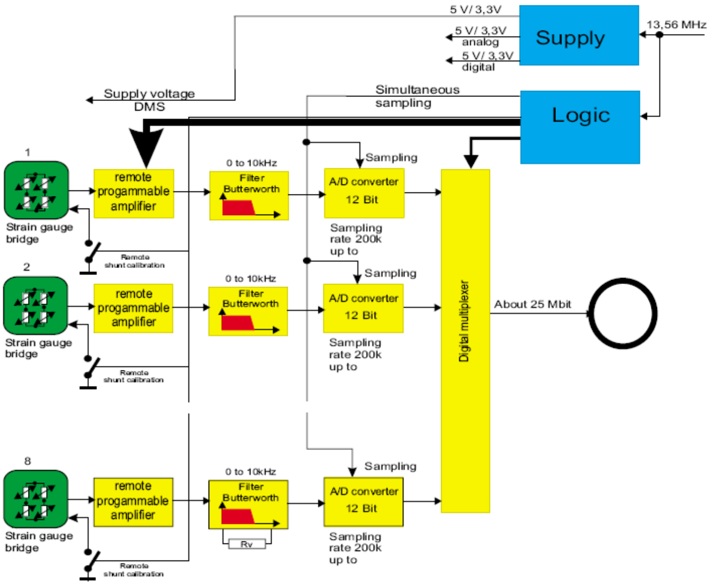


4.3 Description of telemetric system





Overview
Multi channel sensortelemetry



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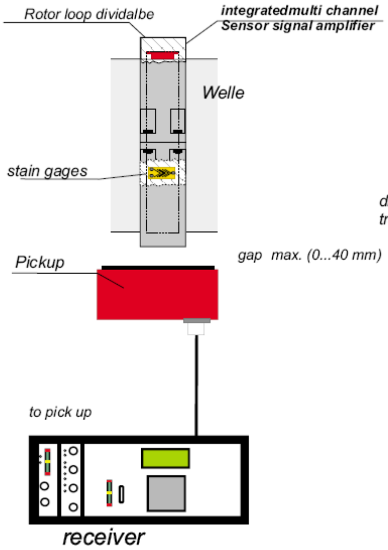
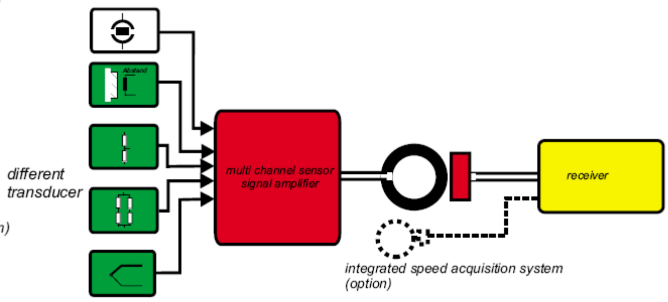
RMC-Sensor-Telemetry for universal use
Multi channel sensor telemetry on drive shaft

(Without batteries)





Features:

channel count: max. 64 (time multiplex
sample rate per channel: 40000 sample/sec (max. 200 000)
Integrated sensor signal amplifier channel
(remote controlled): 0,064 mV/V ....10 mV/V
Auto zero per channel (remote controlled)
sensor: DMS, NiCr.-Ni, distance sensor (u-Epsilon)
zero drift: 0,01 %/° Celsius
Environmental temperature: -25° .... 125° Celsius (150° Celsius)

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4.4 List of Signals

Rexroth Bosch Group		List of Signals UpWind Project 1B.2		Gearbox : GPV 451 Project : UpWind Departm. : ENT
pos	signal name	signalgroups, function	sensor, switch, amplifier	range, resolution
1	InputTorque	torque input shaft	strain gauges with pcm telemetrie	0 .. ±4832 kNm, 75 Nm @ 3.25kHz
2	OutputTorque	torque output shaft	strain gauges with pcm telemetrie	0 .. ±45 kNm, 11 Nm @ 3.25kHz
3	SunTorque	torque sun shaft	strain gauges with pcm telemetrie	0 .. 763 kNm, 12 Nm @ 3.25kHz
4	HSSDeflection	HS shaft deflection	strain gauges with pcm telemetrie	0 .. 2000 µm/m, µm/m @ 3.25kHz
5	RotBending 0°	rotor shaft bending	strain gauges with pcm telemetrie	0 .. 2000 µm/m, µm/m @ 1kHz
6	OutputSpeed	speed output shaft	impulse transmitter digital	0 .. 2500 rpm, @ 1kHz
7	InputSpeed	speed input shaft	impulse transmitter digital	0 .. 25 rpm, @ 1kHz
8	AmbiTemp	ambient temperature	temperature transmitter NiCrNi K-Typ	-25 .. 125 °C, 1°C @ 1Hz
9	OilTemp	oil sump temperature	temperature transmitter NiCrNi K-Typ	-25 .. 125 °C, 1°C @ 1Hz
10	RotMovXA	rotor shaft movement X	displacement transmitter	0 .. ±2 mm, 10 µm @ 1kHz
11	RotMovXB	rotor shaft movement X	displacement transmitter	0 .. ±2 mm, 10 µm @ 1kHz
12	RotMovXC	rotor shaft movement X	displacement transmitter	0 .. ±2 mm, 10 µm @ 1kHz
13	RotMovXD	rotor shaft movement X	displacement transmitter	0 .. ±2 mm, 10 µm @ 1kHz
14	GeaMovLX	gearbox movement left X	displacement transmitter	0 .. ±2 mm, 10 µm @ 1kHz
15	GeaMovLY	gearbox movement left Y	displacement transmitter	0 .. ±2 mm, 10 µm @ 1kHz
16	GeaMovLZ	gearbox movement left Z	displacement transmitter	0 .. ±2 mm, 10 µm @ 1kHz
17	GeaMovRX	gearbox movement right X	displacement transmitter	0 .. ±2 mm, 10 µm @ 1kHz
18	GeaMovRY	gearbox movement right Y	displacement transmitter	0 .. ±2 mm, 10 µm @ 1kHz
19	GeaMovRZ	gearbox movement right Z	displacement transmitter	0 .. ±2 mm, 10 µm @ 1kHz
20	GeaMovBX	gearbox movement rear X	displacement transmitter	0 .. ±4 mm, 10 µm @ 1kHz
21	GeaMovBY	gearbox movement rear Y	displacement transmitter	0 .. ±4 mm, 10 µm @ 1kHz
22	GeaMovBZ	gearbox movement rear Z	displacement transmitter	0 .. ±4 mm, 10 µm @ 1kHz
23	GeaMovPAA	planet carrier axial A	displacement transmitter	0 .. ±2 mm, 10 µm @ 1kHz
24	GeaMovPRA	planet carrier radial A	displacement transmitter	0 .. ±2 mm, 10 µm @ 1kHz
25	GeaMovPBA	planet carrier axial B	displacement transmitter	0 .. ±2 mm, 10 µm @ 1kHz
26	GeaMovPRB	planet carrier radial B	displacement transmitter	0 .. ±2 mm, 10 µm @ 1kHz
27	GeaMovIX	ims shaft movement axial X	displacement transmitter	0 .. ±2 mm, 10 µm @ 1kHz
28	GeaMovHX	hss shaft movement X	displacement transmitter	0 .. ±1 mm, 5 µm @ 1kHz
29	GeaMovHY	hss shaft movement Y	displacement transmitter	0 .. ±1 mm, 5 µm @ 1kHz
30	GeaMovHZ	hss shaft movement Z	displacement transmitter	0 .. ±1 mm, 5 µm @ 1kHz
31	GenMovLX	generator movement left X	displacement transmitter	0 .. ±4 mm, 10 µm @ 1kHz
32	GenMovLY	generator movement left Y	displacement transmitter	0 .. ±4 mm, 10 µm @ 1kHz
33	GenMovLZ	generator movement left Z	displacement transmitter	0 .. ±4 mm, 10 µm @ 1kHz
34	GenMovRX	generator mov. right X	displacement transmitter	0 .. ±4 mm, 10 µm @ 1kHz
35	GenMovRY	generator mov. right Y	displacement transmitter	0 .. ±4 mm, 10 µm @ 1kHz
36	GenMovRZ	generator movement right Z	displacement transmitter	0 .. ±4 mm, 10 µm @ 1kHz
37	GenMovBX	generator movement rear X	displacement transmitter	0 .. ±4 mm, 10 µm @ 1kHz
38	GenMovBY	generator movement rear Y	displacement transmitter	0 .. ±4 mm, 10 µm @ 1kHz
39	GenMovBZ	generator movement rear Z	displacement transmitter	0 .. ±4 mm, 10 µm @ 1kHz
40	RotMovRA	generator shaft mov. RA	displacement transmitter	0 .. ±2 mm, 10 µm @ 1kHz

Rexroth Bosch Group	List of Signals UpWind Project 1B.2			Gearbox : GPV 451 Project : UpWind Departm. : ENT
pos	signal name	signalgroups, function	sensor, switch, amplifier	range, resolution
41	RotMovRB	generator shaft mov. RB	displacement transmitter	0 .. ±2 mm, 10 µm @ 1kHz
42	GeaStrAL	stress ring gear left AR	strain gauges with amplifier	0 .. ±2000 µm/m, 2 µm/m @ 1kHz
43	GeaStrAR	stress ring gear right AG	strain gauges with amplifier	0 .. ±2000 µm/m, 2 µm/m @ 1kHz
44	GeaStrBL	stress ring gear left BR	strain gauges with amplifier	0 .. ±2000 µm/m, 2 µm/m @ 1kHz
45	GeaStrBR	stress ring gear right BG	strain gauges with amplifier	0 .. ±2000 µm/m, 2 µm/m @ 1kHz
46	GeaStrCL	stress ring gear left CR	strain gauges with amplifier	0 .. ±2000 µm/m, 2 µm/m @ 1kHz
47	GeaStrCR	stress ring gear right CG	strain gauges with amplifier	0 .. ±2000 µm/m, 2 µm/m @ 1kHz
48	ElePow	electrical power	potential free from control system	0 .. ±2 MW, 10 kW @ 1kHz
49	Pitch	pitch blade I	potential free from control system	0 .. 360°, 1° @ 1kHz
50	WindSpeed	wind speed	potential free from control system	0 .. 40 m/s, 0.5 m/s
51	WindDir	wind direction	potential free from control system	0 .. 360°, 10° @ 1kHz
52	BreakPre	brake pressure	potential free from control system	0 .. ± Pa, Pa @ 1kHz
53	GearMovLSX	LSS shaft movement axial	displacement transmitter	0 .. ±2 mm, 10 µm/m @ 1kHz
54	TorqueCoupl	coupling torque	strain gauges with pcm telemetrie	0 .. ± kNm, @ 1kHz
55	RotBending 90°	rotor shaft bending	strain gauges with pcm telemetrie	0 .. ± µm/m, µm/m @ 1kHz