**Title:** 

# Lessons learnt

**30 years of experience for Wind Turbines and Wind Farms – lessons learnt**

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**Summary and Conclusion**

Wind turbines or components suffer from small and big problems, failures and unique as well as serial damages in a lot places around the world – onshore and offshore. Furthermore harmonised requirements are not kept always. Therefore it is important for manufacturers, banks and insurances of wind turbines and components to know the different problems as well as their root cause analyses and methods as well as processes to prevent them. This will serve for the benefit of the whole industry.

## Introduction

Certification, damage investigation and expert-evaluation of wind turbines has a history of almost thirty years. The experience from these activities provides a long list for lessons learnt. Such mistakes should not arise any more and could be prevented making use of the correct measures.

In cases of damage, questions are asked about remedial measures, action to prevent further damage and liability. The answers can only come from a conclusive failure evaluation and identification of the primary cause of the damage. Finding the primary cause of damage to a system or component calls for holistic investigative skills because the observable damage to a defective component or installation very seldom permits an unambiguous statement about the actual cause. In the case of material or component failure, the root cause is to be found in the complex interaction between relevant parameters relating to design, production and operation.

Because the wind energy industry saw quite some failures in the past, one should look at the lessons learnt and benefit as much as possible form those root cause analyses. This provides valuable information for all parties involved – manufacturers, banks and insurances, but also certification bodies, sub-suppliers, researchers and newcomers.

The paper provides a general overview and puts focus on defects for bearings and gearboxes. Foundations, towers and support structures as well as machinery components like cast and welded structures are covered in the corresponding presentation held at WindPower Asia 2008 in Beijing.

## The Challenge of Series Production

Technical problems occur again and again at wind turbines. Once the wind turbine has been set up, solving these problems is very often solely the task of the operator. For this reason, it is vital to be able to trust the product as purchased. It is becoming increasingly important for the manufacturer of a turbine to preserve the confidence built up over many years, even in the case of new developments – e.g. of offshore plants or new drive train technologies.

Nothing sticks in a customer's memory more than high operating and maintenance costs, even if the initial investments were very low. [9], [10]

**Typical Damages**

Germanischer Lloyd (GL) is doing several kinds of inspections at wind turbines. This includes periodic monitoring, operation and maintenance surveillance, inspection after commissioning of the wind turbine, condition inspection at the end of the warranty time, inspection for condition based maintenance, vibration measurements (e.g. for components of the drive train) and evaluation of damages. All the results hereof are combined within one data base of approximately 2.500 data sets. This inspection data base shows that about 26% of all defects and damages result from the gearbox (especially bearings and toothing), about 17% from the generator (especially bearings) and about 13% from the drive train (e.g. main bearing, coupling). These results are comparable to damage statistics of insurance companies or institutes.

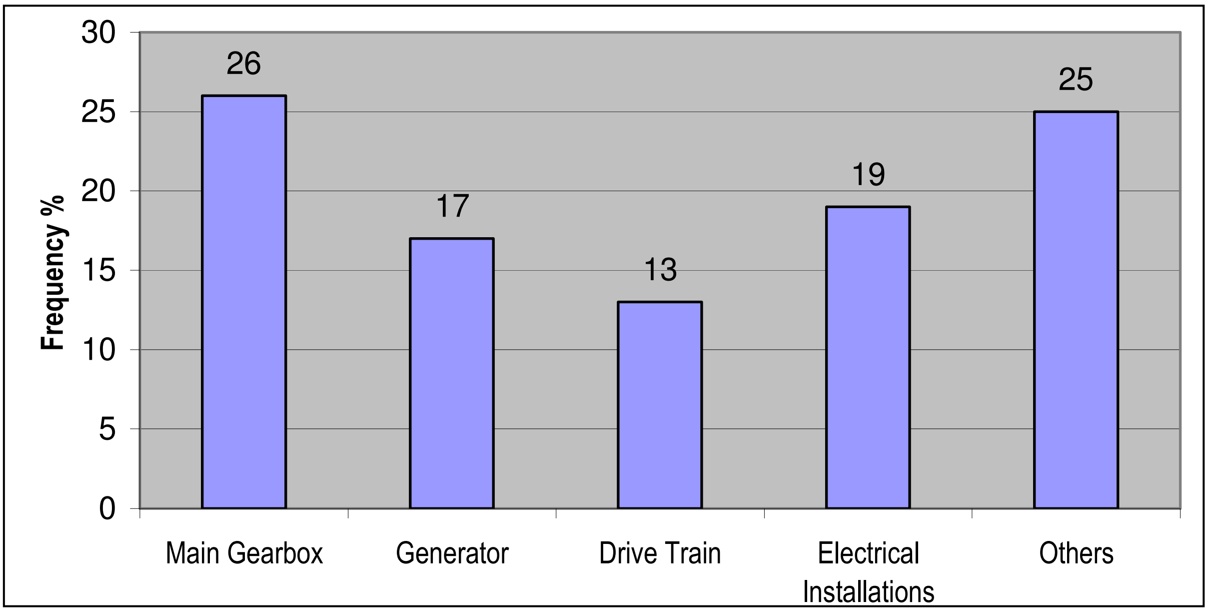


Fig. 1: Defects and damages of wind turbine components [Data base GL]

**Example: Gearboxes and Bearings [8]**

The industry experiences a lot of problems with gearboxes and bearings. To safeguard the operational reliability of gearboxes for wind turbines, a number of national and international standards and guidelines have been formulated in recent years. They provide fixed rules (e.g. for determining the load distribution of spur and helical gears) and requirements (e.g. minimum safety factors) when applying these standards, with a view to adapting them to the operating conditions of wind turbine gearboxes. For the verification of load capacity in respect of components for which there are no standardized rules (e.g. structural components), the method (e.g. FEM) as well as the boundary conditions (loads, stress concentration, material properties, equivalent stress hypotheses, partial safety factors etc.) are specified in detail.

The demands on wind turbine gearboxes are characterized by their special constraints. These can be subdivided into internal and external boundary conditions.

The external boundary conditions are:

- Varying climatic conditions (temperature, humidity, ...)
- Lack of stable foundation

- Fluctuating wind speeds and directions, wind turbulence
- Frequent start-up and shut-down (braking), standstill
- High availability, cost-effective, light structure, …

The internal boundary conditions are:

- High speed-increasing gear ratio
- High loading of the individual components
- Stringent demands on the design, materials and quality
- Low noise emissions

In addition to the computational verification of the load capacities and lifetimes of the individual components of a gearbox, the newer standards also prescribe a functional verification in the form of practical demonstrations and tests. Here a distinction is made between prototype trials, field tests and series tests. The aim of the prototype trial is to examine whether the assumptions and boundary conditions that were set in the design phase are indeed correct. In the field test of the wind turbine, the load assumptions are checked and the system response is studied. Finally, the series tests are intended to demonstrate that the series-manufactured gearboxes comply with the performance standard set by the successfully tested prototype. Further component tests and function tests (leakage, cooling and lubricating system etc.) may also be stipulated in the test specification.

The prototype trial may be performed on a gearbox test bench. The objective of the prototype trial is to verify the assumptions and boundary conditions that were applied in the design phase. In this test, the torque is increased in at least four steps up to the rated value. The gearbox is then operated at rated torque until steady-state temperatures have been attained in the oil sump and at the bearing points. In addition, an overload test is recommended. The parameters to be investigated include:

- Measurement of the load distribution using strain gauges
- Measurement of the load distribution at the planetary stage using strain gauges at each load level
- Temperatures, vibration and noise at each load level

Following the prototype trial, the gearbox must be dismantled and the condition of the various components evaluated.

The field test is performed with the gearbox mounted in the wind turbine. This test should include the following operational conditions:

- Entire speed and torque spectrum to check the system response
- Starting at cut-in and cut-out wind speed
- Shutting down at cut-in and cut-out wind speed
- Braking procedure (reversing load)
- Emergency shut-down

All gearboxes of a series should be subjected to an acceptance test. This acceptance test is best done at a series test bench. Only the original oil system may be used for this test, and the stipulated oil quality must be assured. Besides the usual measurements, the noise and vibration measurements play a special role in this test, because these results make it possible to identify any shortcomings.

The drive train of a wind turbine must be viewed as a complex topic. Because its operational reliability can no longer be assessed solely by verifying the strengths of the individual components, dynamic simulation of the drive train is becoming necessary to an increasing degree. In future, these simulations will come to represent an important factor in the further development of the standards and guidelines in the field of wind turbines.

In the simulations, the complex drive train is reduced to a spring-mass system to simplify the drive train for the global load simulation. It is necessary to prepare a detailed simulation model, for example with the aid of multibody or hybrid systems, to derive local loads from the simulations. Parameters such as the moments of inertia and stiffnesses of the individual components are determined with the aid of FE models or formulae derived from the field of mechanics. The drive train is represented by rigid elements and spring-mass elements. This model is then used to study the resonance behaviour of the drive train. This can be done in the frequency domain (modal analysis) or through simulation in the time domain. Analysis in the time domain has proved to be most demonstrative. Operational scenarios, such as a start-up procedure from standstill up to activation speed, are simulated here. Excessive load increases at the individual components can be identified by scanning the logs, and it is possible to draw conclusions about potential resonance points. A comparison with the analysis in the frequency domain is likewise possible. These simulations therefore constitute a further approximation of the model towards reality.

In future, the gearbox will not be considered as an isolated entity, but rather as an integral part of the overall drive train whose operational reliability can no longer be described solely through the separate verification of load capacity for the individual components. Operational reliability is therefore increasingly being considered on the basis of the results obtained from dynamic simulations of the entire drive train. The approach used for such simulations is therefore an important factor in the ongoing development of the standards and guidelines in the field of wind turbines. For a detailed overview on the situation and development of standards for gearboxes see [8].

## Certification

Certification acts as a connecting link that not only offers a seal of quality for the buyer but also helps build up a process-oriented quality system for the manufacturer.

The objective is to ensure that the quality management measures are so implemented in the production and erection of a wind turbine that the structures and components can adequately fulfil their intended purposes during later operation within the scope of their design objective. The right course for the quality management measures is already set in the concept phase, i.e. before series production of the turbine. In the design phase of the prototypes, the modifications can again exert a strong influence on the quality management measures. Assistance with regard to the necessary scope of the quality management measures can be obtained from international guidelines ([1] to [3]).

Owing to the large number of influencing factors (such as design, material, production, assembly and erection), it is clear that a higher-ranking control of all these disciplines is needed. Here certification is an eminently suitable tool. The above-mentioned measures can only be realized in the entirety of (type or project) certification.

In general, certification is subdivided into:

- (A-, B-, C-) Design Assessment
- Site-specific Design Assessment
- Type Certification
- Project Certification

Whereas in the past the certification body primarily issued type certificates for which a complete assessment of the design analyses with all the necessary material and component tests, a quality management system, prototype tests and the witnessing of commissioning for one of the first turbines were necessary, the required quality in production and assembly is now ensured by an IPE (Implementation of design-related requirements in Production and Erection) as part of a Type Certificate and Surveillance services for production, transport, erection and commissioning during Project Certification. For this reason, the Type and Project Certificates are becoming more and more important, through the evaluation of all the participating disciplines. [9], [10]

## Type Certification

The most important part of the Type Certification is the assessment of the design documentation, a thorough design review with respect to the requirements defined in the relevant codes and standards as presented above.

The testing of the prototype wind turbine represents the practical aspects of the Type Certification. In order to validate the design calculations, to optimise control, performance and noise behaviour and to verify the performance of the safety and control systems the (Proto-)Type Testing is an integral part of the design and certification process. For the incorporation of measurements in the certification process the measurements shall be performed by accredited institutions, alternatively witnessing of the calibration and plausibility checks of the measurements by the certification body or by an accredited institute are required. Furthermore the prototype of the gearbox is to be tested on an adequate test bench and on the wind turbine as described above. All measurement results are to be evaluated and documented. The test reports will be checked for plausibility of the measurement results and compared to the assumptions in the design documentation.

The evaluation of the manufacturer's QM covers the whole range of activities necessary to confirm the quality of the product. The certification of the manufacturer's QM system according to ISO 9001 covers a large portion of these requirements. In general the QM system is certified by an accredited certification body. However, the link between quality management and product quality needs to be specially addressed. It shall be ensured that the requirements stipulated in the technical documentation with respect to the components are observed and implemented in production and erection. This is shown to the certification body by the manufacturers of the components and the wind turbine within the Manufacturing Evaluation or IPE. Therefore the requirements for conformity assessments of designs, work shops and special fabrication techniques remain a necessary part of the (type) certification procedure. [1] to [7]

## IPE as a Practical Implementation of the Quality Management

The first and, at the same time, central step in implementing the IPE is the definition of the important processes in manufacturing of the turbine. The important processes are defined as a result of the structural demands expressed in the Design Assessment, such as e.g. the quality grade of the materials and the production quality, and also the quality management measures agreed upon between the suppliers and the turbine manufacturers. For instance, the turbine manufacturer may have chosen a special quality grade for the calculation of the tower welding seams. This requirement must be expressed in the purchasing specifications of the turbine manufacturer as well as in the (goods) incoming and outgoing checks of both partners (turbine manufacturer and supplier). According to past experience, this results in more findings for the manufacturer arising solely from the definition of the critical (from the quality assurance standpoint) parts and production processes. [9], [10]

## Project Certification

The surveillance of installation at the site of erection shall be restricted to the important steps during support structure and erection work. An identification and inspection of component manufacturing, transportation, on site work and installation shall be carried out before start-up of the wind turbine. Commissioning witnessing forms an integral part of the certification process between the building phase and the operation phase. During commissioning, which is performed according to the previously approved procedures all components related to operation and safety are being inspected and / or tested.

The condition of the systems with respect to safety, maintenance and operation should be inspected by third party at regular intervals within the scope of the Operation and Maintenance Surveillance or Periodic Monitoring. [1] to [7]

Fig. 2: Wind farm

### The Certification Body

Germanischer Lloyd Industrial Services GmbH, Business Segment Wind Energy (GL) is an internationally operating certification body for wind turbines and leads the world in this field. GL carries out examinations, certifications and expertises and is actively involved in the development of national and international standards (e.g. TC 88). GL offers the complete range of services for certifying wind energy products and projects. Certification of wind turbines is carried out on the basis of the GL Guideline for the Certification of Wind Turbines (Edition 2003 with Supplement 2004) [2] and the GL Guideline for the Certification of Offshore Wind Turbines (Edition 2005) [3]. Furthermore, GL is accredited to carry out certification in accordance with all relevant standards in the field of wind energy.

### Conclusion

The rapid growth of the wind energy industry and the growing size of wind turbines itself leads to smaller and bigger defects and damages. Experience with these problems has been gained and root cause analyses have been made in combination with inspections. Taking into account the existing standards and tools for the design (verification), the ongoing developments of these and the opportunities in type and project certification including their modules for inspections and surveillance, the wind energy industry will manage to improve the turbines and components and to make use of the “lessons learnt”.

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