It is difficult to put your finger on precise lines of development in gear transmission technologies: No other component seems to stay as consistently out of the limelight as the drive train. But one thing can be said: We will be seeing more and more integrated drive solutions in the future, but at the same time also more directly driven wind turbines.

The trend to ever higher nominal outputs for wind turbines is unbroken, even though the pace has admittedly slowed somewhat since the original “boom years” of the wind industry. An output of 6.5 MW is today state of the art – and we can reasonably chance the prediction that Siemens Wind Power will raise the bar another notch with its announced new development. The second trend: Offshore applications are growing fast in numbers. In the meantime, there are serious plans for offshore farms in both of the two key markets USA and China.

**In search of alternatives**

Such developments have not been without influence on the drive train of the wind turbines. The gearless variant which Enercon has been offering for some years is gaining ground – the pilot installation of two gearless Siemens turbines in 2008 can be taken as a tangible indication. It is not merely out of curiosity that the world market leader in offshore turbines has decided to develop and build directly driven machines. Frank Zimmermann, head of the Siemens offshore division, was full of praise at an offshore wind energy conference in Bremerhaven in June: “If we remove the gearbox, then we have a lot less rotating parts. That is why direct drives are very promising.” Zimmermann even went as far as to say that the planned 5+ MW Siemens turbine will “probably” be gearless.
With Vensys, Goldwind and Leitwind, further suppliers are also ready to enter the arena with directly driven multi-megawatt turbines. “In five years, there will be more gearless turbines on the market than today”, says Reinhard Grever, Head of Design at German wind power developer Wind-To-Energy (W2E). But it remains to be seen, he adds, with reference to the high tower-top masses, whether direct drives in their current form will also be able to establish themselves for turbines with outputs beyond the 6 MW mark.

Direct drives are certain to win market shares, but they are not set to oust drive trains with gearboxes. And no one genuinely doubts that alternatives to the standard transmission solutions will come to the fore. As pointed out by Swiss engineer Urs Giger, well known through his work with Jahnel-Kestermann Getriebewerke and now the owner-director of consultants GDC, alternative solutions are not just products of a wish for optimisation, but are in fact unavoidable: “There are no more reserves for sensible technical enlargement of existing power gears. New concepts are imperative.”

Load distribution

How could such a concept look? The classic drive train of a wind turbine comprises a hub, a rotor shaft and a flanged gearbox to step the slow blade rotation up to a speed compatible with the generator. This arrangement, however, displays a fundamental problem: The flanks of the gear teeth are subjected to disproportionately high radial and axial forces.

In this context, Urs Giger has calculated the so-called “k-factor” for such drives – a pressure load value which can be derived through simple geometry. The power, tooth width, rolling circle diameter and the centre-to-centre distance are the determining parameters. Giger calculated a comparative value of k = 13 N/mm² for a modern 1.5 MW system. Too high, he says: “A good transmission solution for the wind industry should operate with a k-factor between 5 and 8. Values above 13 are to be avoided.” Giger draws attention to the Allianz Centre for Technology (AZT) in Ismaning, Germany: “They share a similar philosophy.”

In place of a classic drive train dissolved into individual elements, Giger proposes an “Integrated Tubular Gear System” (ITGS), which he understands as a drive train for a multi-megawatt wind turbine incorporating load division and distribution. “It also uses an overdimensioned bearing with a statistical safety factor of more than five for the main rotor shaft”, Giger continues.

The major advantage of this design: “The consistent load division and distribution concept permits small, light planets. As the same load is transferred to a multitude of small components, the individual toothed elements – in other words the planets – are subjected to much less stress than in a conventional
power gear.” Increasing the number of planets from three to eight or ten results in significant enhancements. Compared to a three-planet solution, the transmitted torque can be increased by 166 or 233 %, respectively, thanks to the reduced axis loads.

**Flex-pin for compensation**

Giger comments that a compensation mechanism must be found to guarantee the load distribution between the greater number of small planets: “It is of fundamental importance to determine a means of compensation permitting parallel and geometrically exact displacement of the planets.” For the time being, Giger uses the flex-pin solution certified for wind power use by Germanischer Lloyd.

The planets are carried on sleeves which are only connected with the planet pin at one end. The opposing bending forces acting on pin and shaft due to the load effectively cancel each other out, enabling the planet wheels to maintain the parallelism of their axes in the rotary direction.

“The problem with the loads across the width of the teeth”, says Giger, “is shifted to a statically loaded pin, which is able to flex to a greater or lesser extent. With appropriate specification of the flex-pin, excellent tooth contact patterns can be achieved over the whole output variation of the turbine.”

The pins are nevertheless a matter of controversy in the branch. Some experts refer to the “extremely challenging” calculation of the flex-pin bearing. “It is not easy to achieve a long-term positive result”, says W2E technical manager Kai Lubenow, for example. “It is not the avenue we favour.”

**Coupled gear with high number of planets**

The increased number of planets also brings certain disadvantages: The sun is larger and the range of possible gear ratios becomes smaller. Giger accepts this reservation – and proposes a coupled gear system: “The apparent disadvantage can be overcome ideally with a coupled planetary gear. Through the nesting of the rotating stages, single-wall planet carriers are used for the individual stages. With this arrangement, the space available for a maximum number of planets is not restricted with unnecessary braces. The outside circles of the planets can be shifted together to within a few millimetres. Basically, identical planets can be built into different stages. This simplifies the manufacturing batches and reduces the diversity of components.”

A third trick enables Giger to design a particularly compact transmission: He integrates the gearing into the shaft. “My solution is to use a hollow shaft as a rotating gearbox. The gears are here integrated radially into the shaft, which permits a shortening of the overall length.” According to Giger, this alone has resulted in savings of about one metre in length and 10 tonnes in weight in the prototype calculations. “Even so, the safety factors are significantly higher than for a conventional system”, he emphasises. To pre-empt an expected objection, he goes on to add: “For repairs, dismantling or maintenance, all the components can be drawn from the shaft axially.”

The concept has already attracted the interest of gear manufacturers. “We are currently working on economic optimisation of the solution, so that it will become affordable for everyone”, is how Giger describes the status quo. “Trial series have already reduced manufacturing costs by 30 %. At the end of the day, it should be possible to produce a flex-pin gear around 20 % cheaper, and that with higher toothing safety factors and a longer bearing life than with conventional power gears.”

**Compact system from W2E**

Rostock-based developer W2E, who is prominent on the market with his patented “Larus Compact” drive train, has adopted a different approach. The drive train does without a main drive shaft in the normal sense. The W2E engineers have borrowed an idea from tunnel boring machines and have connected the hub directly to the machine frame via a large rotor bearing. “To be able to safely divert the arising forces, the front section of the machine frame is extremely rigid”, says development engineer Sven-Erik Rosenow. “That saves mass and relieves the drive train of the shearing and thrust forces which come from the rotor.” Subsequently, the rotor torque is transmitted to the drive shaft of the gears via a shaft coupling. The shaft coupling weighs almost 2 tonnes, compared to the 12 tonnes of a typical rotor shaft. The more or less complete elimination of undesirable shearing forces is just as important as the weight reduction. Through the double elastic decoupling in the power train from the rotor to the gearbox the drive train assumes the properties of a cardan joint – firstly by way of the elastomer elements between shaft coupling and gear input, and secondly with elastomer bearings around the whole circumference of the gearbox. It essentially excludes any remaining shearing forces and bending moments in the drive train after the main bearings. “Consequently, the load placed on the gearbox is effectively only that of the drive moment necessary for energy generation, which is a much more favourable load situation for the gearbox components and results in a much longer service life”, is how Rosenow sums up the benefits of the Larus Compact concept.
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Practice confirms expectations

According to the company’s own reports, extensive finite element calculations confirm the suitability of the drive concept. W2E engineers constructed an FE model comprising rotor blades, hub, drive train and gearbox. The load input was defined at the free ends of the rotor blades. The objective of the analysis was to calculate the shearing forces on the planet carrier bearings, which are considered to be of “prime significance for the service life of the gear system”. Rosenow on the results of the calculations: “The results indicate very low shearing forces at the planet carrier bearings, and the resulting loads on the gearbox from the bending stresses in the drive train are negligible.”

All well and good – but what does that mean in practice? The Larus Compact concept has now been proving itself as the drive unit for the Fuhrländer FL 2500 for around three years. In the meantime, over 40 turbines have been sold – including a spectacular W-90 lattice-tower turbine near Laasow, Germany, at a height of 160 metres. Fuhrländer’s Head of Marketing Walter Lutz is satisfied with Larus: “We are having no problems, it’s a good system.”

Measurements appear to confirm the functional feasibility of the concept. To obtain drive-train-specific load data, the similarly Rostock-based company Wind-Consult is performing deformation measurements within the elastic shaft coupling. With the aid of inductive displacement sensors, the technicians are able to determine the relative movement between the shaft coupling and the gearbox input decoupled by way of the elastomer elements. The measurements have been running for the past year and cover all the various load scenarios encountered on the turbine.

The predictions made on the basis of the FE model have apparently been “confirmed fully” by the measurement results. Known factors, alongside the measurement displacement, are the radial and axial rigidity of the elastomer elements and a mechanical model of the cardan mechanism. “In this way, it is possible to determine the resulting shearing forces and bending moments at the gearbox input”, Rosenow sums up. “The experimental examination revealed a maximum shearing force load of around 12 kN and an introduced bending moment of max. 7 kNm. These values are significantly less than the comparable loads of a conventional drive train concept. The shearing forces acting on the gearbox in a classic arrangement, for example, can easily be greater by a factor of 100.”

Compact design with good figures

Recent figures presented by Multibrid, Germany, are testimony to the fact that gear systems without a classic main shaft are definitely suitable for practical use in the jumbo class of 5 MW and more. Already in 2001, the Bremerhaven turbine manufacturer awarded a design commission for a 5 MW gearbox to gear system specialists Renk AG in Augsburg, Germany. The result was a highly compact speed variator under the name “Aerogear”, which drives a synchronous generator with permanent magnet and full converter. The power-to-weight ratio of around 60 kg tower-top weight per installed kW is still unbeaten.

Especially with a view to the planned offshore deployment of the turbine, Renk and Multibrid – actually the French Areva group, to be exact – agreed to subject the prototype to an exhaustive inspection before series offshore installation, but after as long a period of operation as possible. Preference was given to partial dismantling without removal of the planet wheels. An inspection of the slide bearings was not deemed necessary, because none of the oil analyses had ever contained significant traces of the bearing metal – in particular tin and copper – and the temperature recordings had similarly shown no abnormalities or changes.

After 25,844 operating hours, the big day arrived in March 2009. Over the four years since its commissioning, the turbine had produced 47,000 MWh of electricity, which equates to an offshore-like average output of 1.7 MW – or 34 % of the nominal output. The results in detail:

- The sun pinion of the planet stage is the toothed component with the most rolling contact and is subjected to high loads. Consequently, it was a subject of special interest. Neither measurable geometry deviations nor wear were detected.
- The double-jointed toothed coupling of the sun pinion, which permits its free adjustability, is an essential benefit of the Multibrid gearbox. Toothed couplings are inherently subject to a certain wear. Thanks to the hardening and fine
machining, in combination with targeted and continuous lubrication, the rate of wear of the inspected couplings lies at the very minimum.

- Light deposits on the planet wheels had already been observed during previous inspections. The partial dismantling permitted final clarification of the cause: Minor surface corrosion, which could simply be wiped off by hand with a cleaning sponge. The teeth of the planets all displayed a very good lubrication film and are in “excellent condition”.

- The Renk Aerogears are the first large-size gear systems to use case-hardened and ground internal gears. The internal gear is here not held in the housing, as with a conventional planetary gear, but instead mounted under the rotor bearing and joined with the drive shaft. It was thus interesting to discover whether the calculated deformation of the environment had really occurred in operation and to assess the condition of the mesh with the stage planets. An endoscopic inspection showed that the teeth were in flawless condition and that the mesh contact pattern was homogeneous in both the height and width directions.

- According to Renk and Multibrid, neither the other bearings inspected nor the ESM elastomer elements of the torque arms gave any cause for complaint.

**Summary: Lots of secrecy, little trend**

For all the ground made up by the compact gearbox designs, it is still difficult to identify a clear trend – the signals being received from the industry are still too ambiguous. Vestas, for example, has chosen a classic design for its new 3 MW turbine, as has Repower – at least for the new 3XM model. Only the flagship 5M turbine possesses “modern” four-point bearings. GE is similarly unwilling to put a new integrated gearbox into series production.

It is generally pointless to address questions to the turbine manufacturers who are placing the development of alternatives on the agenda. There is no component of a wind turbine about which less is said than about the drive train. The typical reply of a German manufacturer to enquiries regarding new developments: “After consultation with our development department, I regret to inform you that all topics concerning the use and development of drive gear solutions are classified as extremely sensitive. We are thus unfortunately unable to issue public statements on these topics.” It seems that the “gearbox crisis” of a decade ago is not yet forgotten.

Jörn Iken

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