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Trends in wind turbine drive trains

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Abstract— The overall trends in wind turbines and their drive trains are opposing: multi unit offshore installations vs. local single units in local grids, small wind turbines vs. multimegawatt turbines, classical drive trains vs. regulated CVT drive trains, medium vs. high speed gearboxes and so on. Accordingly, the requirements on the drive train are getting more and more differentiated and the gearbox designs more and more diverse.

While the need for smaller gearboxes leads to the requirement for low cost yet noise optimized gears, the need for large gearboxes leads to technological challenges in gearing, large bearings and highly stressed structural members like planetary carriers. The Indian gear industry has considerable potential to address all these needs if some bottle necks are overcome and if it is willing to compete against international companies active in India.

Keywords—wind, gearbox, multimegawatt, large bearings

I. WIND TURBINE DRIVE TRAIN CLASSIFICATION

Wind turbine drive trains may be classified in different ways, here, two approaches are selected:

A. By gearbox ratio / generator speed:

- ratio of $i \approx 10e0$: direct drive where generator is directly coupled to the rotor, using low speed generator (e.g. Enercon)
- ratio of $i \approx 10e1$: drive with one or two gear stages and medium speed generator (e.g. Multibrid)
- ratio of $i \approx 10e2$: drive with two to four gear stages and high speed generator (classical concept).

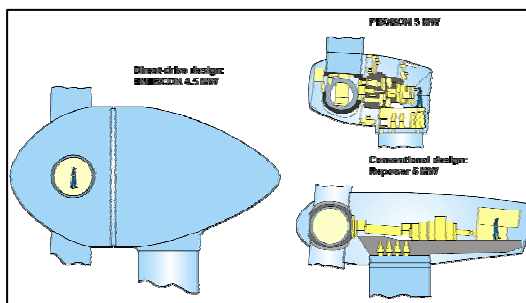


Fig. 1 Low speed, medium and high speed generator drive trains

B. By number of input and number of output shafts:

- single input, single output (one rotor / one generator),

- most commonly used design, see e.g. Fig 3 for example
- single input, multiple output (one rotor / multiple generators), e.g. by Clipper, see Fig. 5 for example
- multiple input, single output, e.g. by Kowintec, see Fig. 2 for example
- multiple input, multiple output (no operational design know by author)

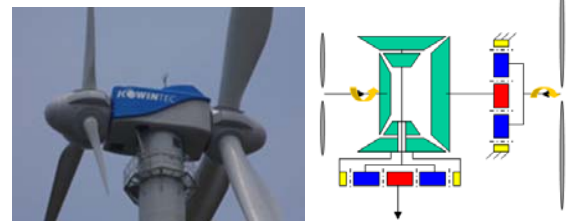


Fig. 2 Drive train concept featuring a summary gearbox with two input shafts and one output shaft (generator arranged vertically) [13]

II. MULTIMEGAWATT GEARBOXES

Today's multimegawatt gearboxes with more than 3MW rated power mostly are built in Europe or by European companies. The difficulties in these designs are related to gearing corrections, internal gear fabrication, lubrication management and bearing design. In all cases, planetary gears are used, however with different kinematics. Planetary stages may be arranged in series, where the planetary carrier is driven and thus the planets are rotating in space (see e.g. Fig. 3, left). Alternatively, planets may be stationary (see e.g. Fig. 3 right) or a planetary stage may act as a differential gear, summarizing the speed from one carrier and a non stationary ring gear on the sun gear (see Fig. 4)



Fig. 3 Worlds largest operational wind gearboxes. Left: Winergy 5MW gearbox. Right: Renk 5MW gearbox (during assembly).

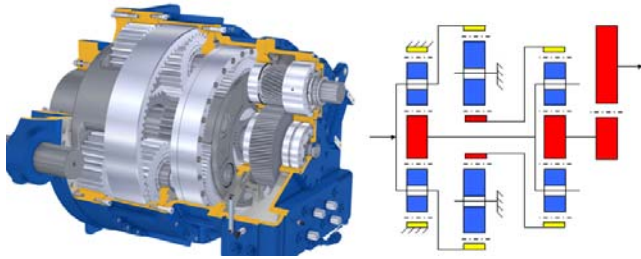


Fig. 4 Differential gearbox, Bosch Rexroth, working principle

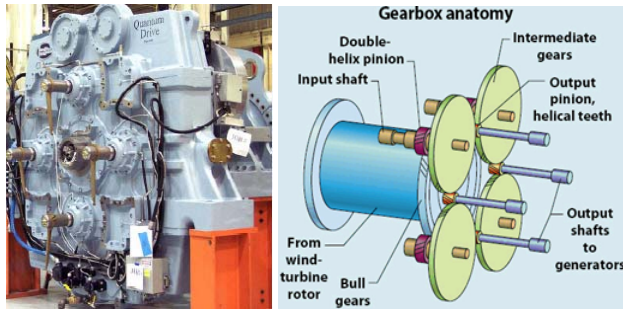


Fig. 5 Clipper Quantum Drive, gearbox architecture [8], [9]

A major investment required for any supplier of multimewatt gearboxes is the erection and operation of a back to back test stand. Considering that overload factors up to 3x should be achieved, the power rating of such test rigs is reaching 14MW in the world largest test rig. Only few companies worldwide offer gearbox testing as a service, typically, gearbox companies have to build their own test rigs. While electrical back to back testing is the most commonly used arrangement, the below test stand shows a mechanical back to back arrangement.



Fig. 6 Back to back testing of multimewatt gearboxes [14]

III. INTEGRATED GEARBOX – GENERATOR SYSTEMS

A trend can be observed, with prominent examples being the Multibrid M500 rated at 5MW, that higher speed generators are combined with two stage gearboxes. Typically, then, the generator and gearbox are arranged co-axially, featuring planetary gears. The advantage is that the mass and size is reduced.

Such combinations are also intended for use in offshore wind turbines. There, efficient sealing of the gearbox to prevent moisture and salt accumulation in the gearbox is critical. Furthermore, the use in hot and cold climates requires an

extensive cooling and heating capability, while space made available for heat exchangers is reduced.



Fig. 7 GE Transportation Integradrive, aerodyn SCD

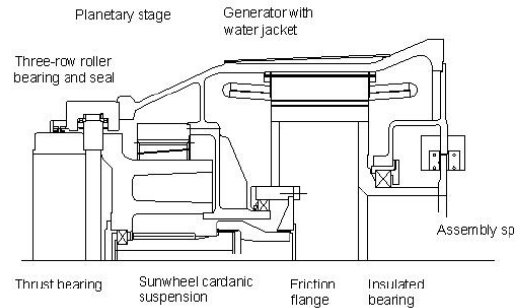


Fig. 8 WinWinD drive train with integrated single stage planetary gearbox and generator [12]

IV. GEARS FOR SMALL WIND TURBINES

Less developed areas e.g. rural villages, hilly areas and sparsely populated areas are a suitable environment for small wind turbines as the wind flow typically is not obstructed by large structures and buildings. Alternatively, small wind turbines are used in cities, being installed on top of buildings along roads and bridges. From the above, contradicting requirements on the drive train result: the drive train should be cheap so that the turbine is affordable for private persons, it should be low noise design as it may be used in densely populated areas and it should be manufacturability by an average quality gear supplier. Typically, single stage gearboxes with a relatively high ratio are used only, the pinion directly integrated with the generator shaft. The resulting technical requirements are therefore

- through hardened gears only to avoid costly secondary machining
- standardized gear geometry without profile or lead modifications so that standard tools may be used
- high contact ratio gears using helix angle and standardized high addendum reference profile to reduce noise levels
- optimized profile shift so that scuffing risk is low and standard mineral oils may be used as lubricant
- minimized module to increase contact ratio improving noise characteristics

Below, a non optimized gear and an optimized gear are compared. It is to be noted that manufacturing cost for both gears is comparable as in both cases, standard tools as per ISO / DIN standard are used. The key to such optimized

design for small wind turbine is not a capital investment in expensive production facilities but a basic understanding of gear geometry optimization. Such know how should be promoted in the Indian gear industry by universities or through the formation of an Indian Gear Manufacturers Association responsible for sharing know how.

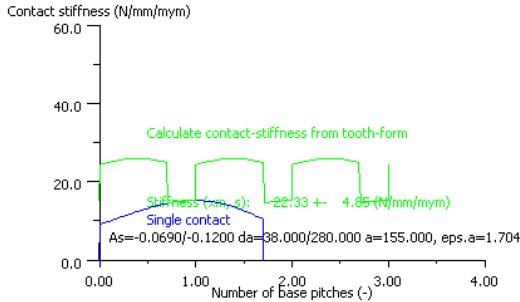


Fig. 9 Stiffness variation (green line) / vibration of non optimized spur gear

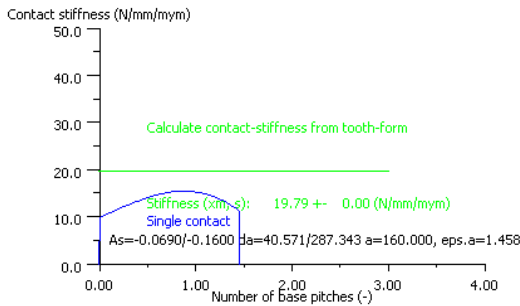


Fig. 10 Stiffness variation (green line) / vibration of optimized helical gear

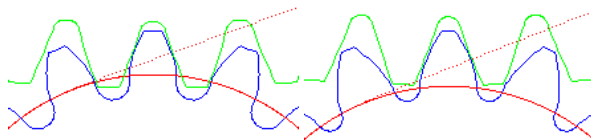


Fig. 11 Left: non optimized gear. Right: optimized gear of comparable cost.

V. CVT GEARBOXES

CVT gearboxes are typically arranged between the primary gearbox (which acts as a speed increaser) and the generator. Their purpose is to control both speed and torque on the input shaft for the generator faster than may be achieved by blade pitching. This may be achieved by splitting the mechanical power into a hydrodynamic, hydrostatic or electrical power path and a mechanical power path. While the later has a constant ratio, the ratio of the hydrodynamic, hydrostatic or electrical path is variable and may be changed quickly. The principle is well know e.g. in the tractor industry where CVT transmissions with hydrostatic units are common in higher power ranges. Newer concepts try to replace the gearbox

through a combination of a large hydro pump with a hydro motor, the package being arranged between main shaft and generator. This eliminates the need to split the power input into a hydrostatic/hydrodynamic/electrical and a mechanical path. However, cooling and the size of the hydro motor and pump may be difficult to handle.

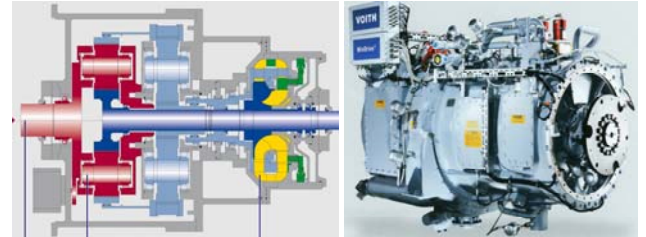


Fig. 12 Hydrodynamic CVT gearbox used in wind turbines between main gearbox and generator [5]

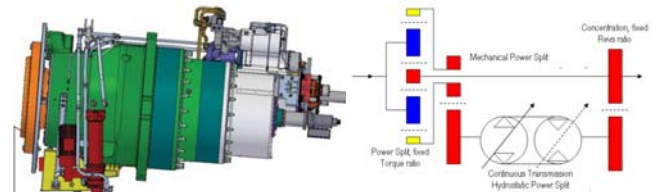


Fig. 13 Hydrostatic CVT gearbox attached on output side of main gearbox, working principle [6]

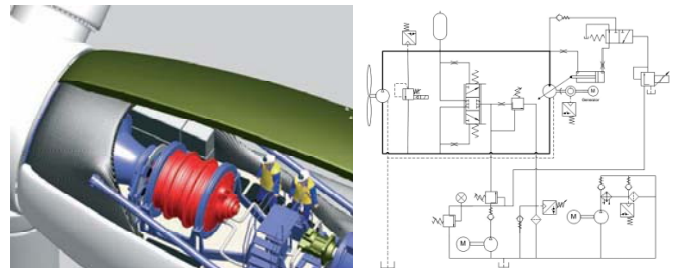


Fig. 14 Hydrostatic drive without mechanical gearbox [7]

The use of CVT gearboxes does have an influence on the load spectrum experienced by the gearbox and thus on the design of the main gearbox. Analytical models for gear and bearing design should allow including CVT transmissions.

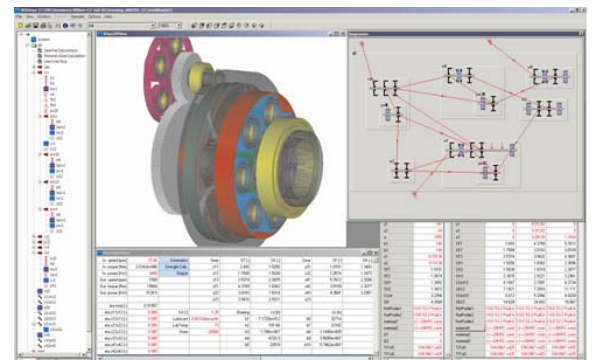


Fig. 15 Gearbox design software including the effect of CVT transmission on gear and bearing loads [11]

VI. DESIGN FEATURES

Detail design solution with respect to bearings, planetary carriers, lubrication and gearing are becoming more and more important as the power density of the gearbox increases.

Critical design features currently include

- gear profile and lead corrections design
- bearing stress analysis considering bearing internal geometry
- lubrication system design, lubricant selection
- high strength bolting analysis
- FEM analysis of cast parts using load spectra

Future design features that may gain in importance include

- design and analysis of flexible planet support
- analysis of large main bearings including elastic bearing support
- FEM calculations of systems deformation
- dynamic system analysis
- on board (gearbox) CMS systems
- control of CVT gearboxes

Below, two design features that are gaining importance are shown as an example:

A. Flexpin: A flexible planet support, called flexpin, invented by Mr. Ray Hicks in the 60', allows for a one sided support of the planetary gears which in turn allows the use of up to eight planets. This reduces the load per planet and increases the gearbox power density.

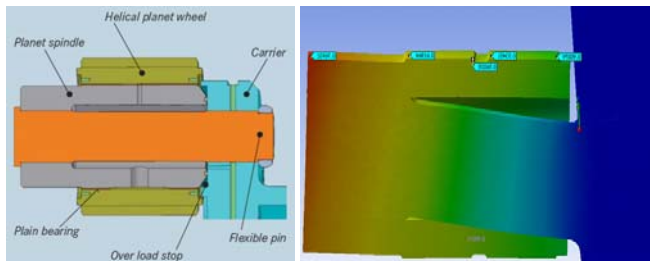


Fig. 16 Left: Flexpin design [6]. Right: FEM analysis of Flexpin

B. Large rotor bearings: Large bearings are used to support the rotor hub while integrating the gearbox, thus eliminating the main shaft. This leads to a much more compact design. However, as such bearings reach diameter of 2m and above, only few suppliers are available. Bearings are preloaded to maximize their stiffness and to ensure that ovalization does not lead to rollers being unloaded. Complex FEM analyses verify the load distribution among the rollers and the load distribution along individual rollers. Their analysis requires specific know how with respect to the bearing data itself (bearing macro and micro geometry), analysis methodology (FEM analysis with large number of contact conditions, multiple load steps, pre-tension effects from bolting) and fatigue analysis.

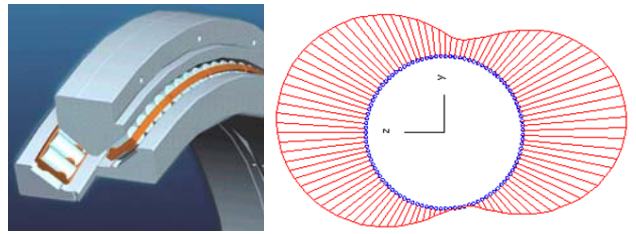


Fig. 17 Left: SKF Nautilus bearing [11]. Right: KISSsoft analysis assuming rigid bearings [12]

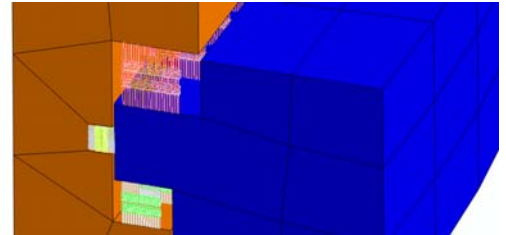


Fig. 18 Large bearing FEM model using non linear FEM elements to simulate the bearing rolling elements.

VII. CONCLUSION

Considering the increased variability in drive train requirements, the Indian gear industry will see ample opportunity to engage more and more in the design and production of wind gearboxes. Today, international companies, mainly from Europe, hold a large share of wind gearboxes produced in India. While the production of very large gearboxes remains a challenge only few companies will be able to handle worldwide, the demand for smaller gearboxes and CVT gearboxes should be addressed by the local suppliers.

The author feels that while India has the potential to be a global leader in gearbox production, know how to design and build wind turbine gearboxes is not readily available except among the top ranks in Indian gear industry. Considering the fact that the worlds two top wind turbine gearbox companies have plants in India, an effort among the leading Indian gearbox companies to share, build up and import know how for the design and manufacturing of tomorrows wind turbine gearbox seems advisable.

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