Wind Turbines: Clean Energy, but Energy-Efficient?

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Green Energy (stock photo by Dimitri).

It has often been reported that when the legendary—but true-to-life—bank robber and certified colorful character Willie Sutton was asked why he concentrated on robbing banks, his simple, reasonable reply was, "Because that's where the money is." But that's not quite accurate. What he did say—in an autobiographical sketch—was "Go where the money is. And go there often."

So it is no surprise that the manufacturing sector—the products they make and how they make them—is a prime target for efforts—both governmental and private—to enhance energy efficiency, reduce consumption and maintain or exceed current productivity levels.

But beyond the big-picture state of energy consumption in America, we talked energy efficiency with some major players in the lubricants industry—but with a focus on their products' impact regarding energy efficiency of gears and gearboxes in wind turbines—a much narrower universe than gear drives in general. We also gathered some insights from an expert in the gear/wind turbine sector relative to gears and gearboxes (*see sidebar*).

A question that immediately comes to mind is, what, in general, is happening with lubricants and their role in energy efficiency in a wind turbine gearbox application—and the gears that go in them?

"Most gearboxes in wind turbines today are designed around a single planetary and two parallel-shaft helical gears," explains Felix Guerzoni, product application specialist and team leader for Shell Global Solutions U.S. Inc. "The process of gears meshing and un-meshing results in a combination of rolling and sliding contacts. With spur and helical gears, much of the contact is rolling contact and as a result the efficiencies are quite high. For worm gears, where the majority of the contact is sliding contact, these tend to be much less efficient. It is for this reason that PAG-based (poly-alkylene glycol) gear oils with lower coefficients of friction relative to PAO (poly-alphaolefin) are favored for worm gear lubrication. The efficiency losses in a spur or helical gear

Table 1-Types of Gears.

Types	Gears	Position of the shafts	Tooth Flank Contact	Gear Components	Type of Movement	Sliding Percentage (%)
	Spur Gears	Parallel	Line	Cylinders	Rolling and Sliding	10 - 30
	Bevel Gears	Intersecting	Line	Cones	Rolling and Sliding	20 - 40
	Crossed Helical Gears	Crossing	Point	Cylinders	Increased Sliding	60 - 70
	Hypoid Gears	Crossing	Line	Cones	Increased Sliding	60 - 70
	Worm Gears	Crossing	Line	Cylindrical and Globoid Element	Mainly Sliding	70 - 100

(Courtesy Klüber)

Wind Turbine Gearing: Moving Towards Energy Efficiency?

Following is a Q & A with Charles D. Schultz—PE and chief engineer with Beyta Gear Service (*www.beytagear.com*) and Gear Technology technical editor.

What are the most common issues regarding gear/gearbox energy efficiency in wind turbine gearing? Efficiency improvements will require improved accuracy and better surface finishes on both gears and bearings. Extending super-finishing technology to larger gears will be challenging.

What is the gear industry doing to address those issues?
Huge investments will be needed to keep advancing the technology. Some companies are not in a position to make those investments and will fall behind. Whoever has the latest equipment will have an advantage.

Does it all begin with the design engineer or is that an over-simplification? There are big advances possible even on existing designs. (But) good design makes the task easier.

What renders worm gears useless for wind turbines? By their nature worms have more sliding action and therefore lower efficiency. They will still have their place due to simplicity and high-ratio-per-reduction-stage, but there is tremendous room for improved efficiency in worms simply because they have so much farther to go. (Even) low-tech helicals are perhaps 97 percent-efficient while worms might be 60 to 70 percent-efficient. Improving from 97 to 98.5 will be possible, but getting that last 1.5 percent will be challenging. Getting a 5 percent improvement in a worm set will become commonplace once the very talented engineers get on the task.

What improvements have been made to date in energy-efficient wind turbine gears? Better bearing and gear accuracy.

Which processes—heat treat, lubrication, grinding, etc.—need improvement most? Or are already being improved for energy-efficient turbine gearing? It depends on how you define energy efficiency. If you consider 'cradle-to-grave' energy costs you have to look at things like heat treat. If a furnace cycle could be reduced from 60 hours to 48 it wouldn't show up in operating efficiency but it certainly reduces the product's carbon footprint.

Do you see direct-drive replacing gearbox-driven power for wind turbines at some point? I'm not as optimistic as many direct-drive proponents. The geopolitical situation on rare earth magnets is not favorable and the cost-per-pound of the material far exceeds that of the materials it displaces.

From an historical perspective, what machinery has gotten bigger, heavier and slower as it 'advanced'? Auto motors and electric motors were much bigger in their early days than they are now. That huge armature does act as a great flywheel to smooth out the load spikes that occur with every blade rotation, but as knowledge improves on reducing those peak loads the gearboxes will become better able to survive.

What other factors affect gearing/energy efficiency in wind turbines? Every aspect of the machines will need continuous improvement. Blades, towers and controls have a long way to go. Energy conservation re-fits for existing facilities and equipment will become commonplace.

General Properties of Different Base Oils				
Properties	Mineral Oil	Polyalphaelefines	Polyglycol	Ester*
Viscosity-temperature Behavior	0	+	++	+
Aging Resistance	0	+	++	+
Low-temperature characteristics	---	++	+	+
Wear protection	0	+	++	+
Friction coefficient	0	+	++	++
Neutrality towards sealing materials and paints	++	++/	/+	
++ = very good; + = good	0 = satisfactory; --- = poor			

The Properties of esters depend on the specific type of ester and may differ strongly (courtesy Küber).

can be as low as one to five– percent per stage, while in a worm gear they can be up to 30 percent. Planetary gears minimize efficiency losses to just one percent per stage."

Put another way, "Efficiency is loss-per-mesh, says Chuck Schultz, licensed chief engineer for Beyta Gear Service and a member of this magazine's technical editors staff. "More meshes, more loss; oil churning and windage (A force created on an object by friction when there is relative movement between air and the object.) also contribute. Details of helical and spur gear design can make some improvement but it still comes down to rolling and sliding. Worms have more sliding and lower efficiency as a result."

With all that rolling and sliding to deal with, a chart provided by Klüber Lubrication North America L.P. helps break things down in some detail as to various gear characteristics.

"As the sliding percentage increases, the efficiency of the gearbox decreases," says Dennis A. Lauer, P.E. and Klüber vice president of engineering. "A gear unit performs rolling and sliding movements on the power transmitting flanks of the meshing teeth. The load on the tooth flanks is a function of the tooth geometry and the forces generated by the sliding movement. In gears mainly performing a rolling movement (spur and helical gears, for example), the load on the tooth flanks is generally lower than in gears mainly performing a sliding movement (such as worm and hypoid gears). The higher the sliding percentage and wear load on the tooth flanks, the higher the requirements a lubricant has to meet."

An obvious second question—at least when speaking with a lubricant expert—is what exactly can lubrication do to increase energy efficiency in wind turbines?

"Due to past reliability issues, it is extremely important that a lubricant is properly designed, says Lubrizol's Michelle Graf, product manager/hydraulic and industrial gears. "A balanced formulation will enhance the overall performance of the gearbox by providing optimum lubrication while also protecting all other components of the gearbox. Lowering friction helps to reduce energy consumption while optimizing oxidation resistance, and may allow oil drain interval extension."

"Research is ongoing to identify ways of designing gears and lubricant combinations which can increase the energy efficiency of wind turbine gears," says Guerzoni. "A major area of focus lies in bearing selection."

Klüber's Lauer points out that "Originally, mineral oils were used in wind turbine gears but we know that the synthetic gear oils can reduce friction over mineral oils, so many windmill operators are beginning to take advantage of this. Of course, if you can reduce the friction in a gearbox, the efficiency will increase. "But," he adds, "an increasing number of wind farms are using PAO synthetic oil. We have also introduced poly-glycol and rapidly biodegradable ester synthetic oils for their additional advantages over PAOs."

"The majority of wind turbine lubricants are usually ISO 320 viscosity grades," says Graf. "Although both mineral-based and synthetic formulations are utilized, synthetic lubricants tend to be more widely used due to their enhanced oxidation performance, wide temperature operating range and the potential for drain (replenishment) interval extension."

Shell's Guerzoni makes the point that, "As wind turbine technology has evolved, so too have the range of gear oils required to lubricate them effectively and reliably. The trend in the marketplace today and the gear oil types for most of the leading wind turbine OEMs are synthetic PAO-type ISO 320 gear oils. Some operators still specify the use of mineral oil, ISO 320-type gear oils; however this is not as widespread as previously. Synthetic biodegradable ester-type gear oils may be recommended on specific projects, but are not widely used in general.

So, non-synthetic or synthetic lubrication—what are the plusses and minuses? See Table 2 for a comparison.

And while synthetic certainly appears to be the lubricant of choice, there are caveats. One has to do his homework before making a choice.

"Not all synthetic gear oils perform the same," Guerzoni advises. "It is still critical to formulate a product having a balance of the appropriate base fluids and additives to provide synergistic benefits from the product in use. Synthetic PAO fluids (ISO VG 320) are now the most commonly used within the wind turbine industry. Some consider the up-front cost of the synthetic gear oils prohibitive; however, on a life-cycle cost basis and the fact they offer extended lifetimes relative to mineral oils, the payback on the return of investment is rapid.

“Well-formulated products offer benefits in the area of robustness to contamination from water, excellent rust and corrosion inhibition, very good low-temperature fluidity and low-foaming tendency. Synthetic PAO-type gear oils can also lead to reduction in operating temperatures relative to mineral oil-based gear oils of equivalent viscosity grade. This further helps extend oil life and equipment reliability.”

Yet with all of the above understood, the question remains—Which synthetic lubricant is best for wind turbine gearing? It depends; it’s not like you can just draw up an equation.

Says Guerzoni, “Given the remote location of many wind farms, the desire for improved reliability and the challenges involved in conducting a gear oil change (in a wind) tower—not only logistics but crane rental as well—the selection of gear oils which can extend oil life, improve reliability and reduce the costs associated with oil change-outs are critical. Gear oils must be able to provide not only extended service periods (with demands today for four years and upwards), but protect gears from common failure modes such as micropitting and scuffing wear. They must be robust to contamination from salt-laden water preventing rust and corrosion to gears and bearings. They must operate without the formation of deposits which can plug filters and impact efficiency. Based on the lowest and highest ambient operating temperatures, consideration must be given to the low temperature fluidity—i.e., how easily the product will flow under cold temperature start-ups. Compatibility with seal materials and paints used in the gearboxes is also important. The fact that industry specifications for wind turbine gear oils today include such a significant number of separate laboratory and rig tests before they are even subjected to a field trial is testament to the desire to select products which will improve reliability for the wind farm operator.”

Or, as Lauer puts it, “First we need to select the proper viscosity and additive package to protect the gears and the bearings. We want to provide a chemistry that will achieve the longest possible life in the gearbox—like polyglycol—and strongly recommend oil condition monitoring to maximize the change intervals.”

Photo (courtesy Lubrizol).

“Consult with the manufacturer of the turbine who may or may not refer the end user to the gearbox manufacturer for their recommendation on proper fluid selection,” says Lubrizol’s Graf. “Because of the gearbox reliability issues in the past, wind turbine and gearbox manufacturers tend to be con-

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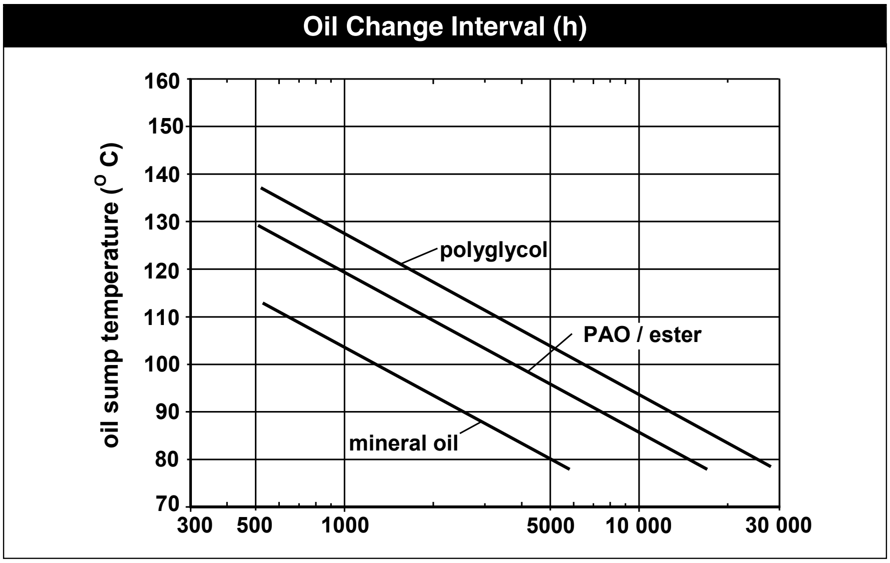

Polyglycol provides the best aging resistance, providing the longest oil change intervals (Courtesy Klüber).

servative relative to establishing lubricant requirements and require extensive laboratory and field performance validation. A fluid for wind turbine gearbox lubrication must be a balanced formula which provides protection for all gearbox components across a wide range of operating conditions (see above)."

Bearings, you'll notice, have been mentioned several times thus far as an element of lubricant-gear efficiency. And it's no wonder, given the role they play in turbines. And the fact that bearings are perhaps the most high-maintenance-demanding parts in the mix. Bearing failure is an accepted complication in wind turbine maintenance and repair, at least until such time that someone comes up with the "silver bullet bearing."

"In most gearbox designs the gear oil also lubricates the bearings within the gearbox, Graf explains. "Demonstrating bearing protection is integral to the performance of a gearbox lubricant. Gearbox manufacturers require lubricant approvals from their bearing suppliers to ensure suitable bearing protection."

"As gearbox bearing failures continue to undermine the reliability of wind turbines, much focus is now being placed on gear oil cleanliness and the role of contamination," says Guerzoni. "Studies on bearing life from other sectors have identified the negative role of contaminants including particulate and water on bearing life. This is now being translated to tighter cleanliness controls on wind turbine gear oils and the use of finer filtration. Current industry specifications require that gear oil be filtered to very low contaminant levels. ISO 81400 and the draft IEC 61400 (standards), for example, recommend a gear oil cleanliness of oil-added-to-gearbox at any location -/14/11 and < - /17/14 in service as measured by ISO 4406." (*ISO 4406:99 is the internationally recognized standard by which the number and size of solid particulate in 1ml of oil is quantified. The numbers represent the number of particles in a given particle size range against a standard scale of <4 micron, <6 micron, <14 micron—i.e., the smaller the number the cleaner the fluid.*)

Lauer believes that "The gear oil should always be tested on a rolling bearing test rig such as the FAG FE 8 rig to assure that the gear oil not only meets the demands of the gears but also protects the bearings. Oil contamination—particulate as well as moisture—is not good for the gears. But the bearings are even more sensitive."

Those companies involved in wind turbine manufacture are well aware that off-shore wind installations—already popular in Europe—are beginning to take hold here in the United States. One wonders how lubrication requirements might change in that scenario.

"As stated above in selecting the best lubrication, it is necessary to maximize the life of the oil in the gearbox," says Lauer. "A chemistry that is more resistant to moisture contamination would also be beneficial. Here again poly-glycol appears to be the best chemistry."

"There will continue to be interest in extending equipment maintenance intervals, including lubrication," says Graf. "This need certainly applies to turbines that are located in difficult-to-reach areas which increase the cost of maintenance significantly. For this reason some of the most recent designs for off-shore turbines are featuring direct-drive technology which eliminates the gearbox altogether."

"For offshore wind turbines," says Guerzoni, "there is increasing requirement on reliability, but also resistance to rust and corrosion. Wind turbine gear oils must stand up to the demanding SKF Emcor test when exposed to synthetic sea water with passing results. Long oil life is again critical."

When talking about energy efficiency in lubricants and gearing for wind turbines, the all-encompassing "green" is a word on most players' lips. Just how green are today's lubricants?

Ironically, given that they are used in a "clean energy production" application such as wind turbines—not much.

"In general there seems to be an increasing desire for fluids that can lubricate turbine components operating in environmentally sensitive areas," Graf states. "However the lubrication challenges for wind turbine applications make this extremely challenging. There are wind turbine lubricants commercially available that can minimize environmental impact, but there has been limited market acceptance due to their price premium."

"The term 'green' may be interpreted in many different ways," Shell's Guerzoni explains. "At this point in time very few projects call on the use of biodegradable gear oils, hydraulic fluids or greases. While such products do exist—offering a more environmentally considerate option for the operator—there are currently no regulations or industry requirements for more

Photo (courtesy Lubrizol).

widespread utilization of biodegradable gear or hydraulic oils for the wind turbine sector. As off-shore wind turbines move more towards direct-drive instead of geared units, the potential need for biodegradable gear oils reduces further."

Lauer is even more frank in his assessment. "If by 'green' you mean rapid biodegradability and sustainability, then I am afraid the current state of the art is not very 'green,' Lauer says, but adds, "Klüber has a rapidly biodegradable gear oil that has been used in one location for almost ten years, but we seldom get requests for this technology. 'Green' gear oils are available, but until it becomes a priority of the end user, I am afraid its use will not expand."

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