


AN ALTERNATIVE DESIGN FOR SPEED INCREASERS

Unlike traditional gear design, which is based on the rack generating process and driven by manufacturing convenience, Direct Gear Design is driven entirely by application requirements.

By Alexander L. Kapelevich, Ph.D.



Alexander L. Kapelevich is a founder of the consulting firm AKGears LLC. He can be reached at ak@akgears.com, or go online to www.akgears.com.

THE AWEA WINDPOWER SHOW always provides impressive demonstrations of the latest and greatest achievements in all the areas of science and technology that are related to wind-power generation. Wind turbine gearbox suppliers present the very best gear alloys, forging and cutting processes, the mirror-like tooth surfaces achieved by the isotropic superfinish technology, and the best bearings and lubrication systems, etc.

In contrast with these innovations, the gear tooth geometry of almost all gearboxes has become outdated. In most cases it presents century-old tooth proportions produced by the standard 20° pressure angle generating racks with some addendum modification. This tooth

geometry is universal and good for general gear applications because of gear interchangeability and the availability of standard tooling. It does not fit to the specific operating conditions and requirements of wind turbine gearboxes, however, which include a long lifetime of some 20 years, relatively low speeds, high static loads, size and weight constraints, high efficiency, noise and vibration limitations, and low cost of fabrication and maintenance, etc. The gear tooth geometry must be customized to satisfy all of these conditions.

Unlike the traditional standard gear design, the proposed alternative Direct Gear Design® method does not use the basic rack parameters. It uses desired performance parameters

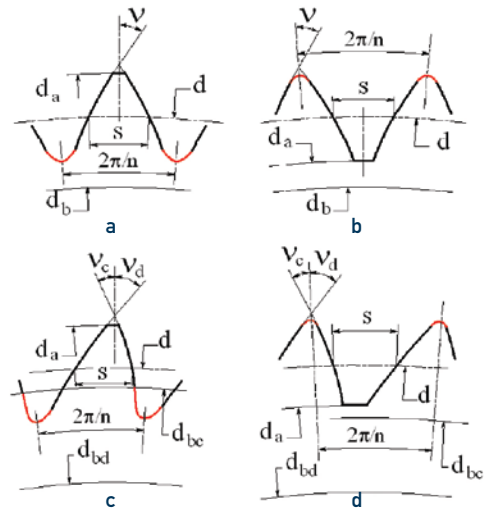
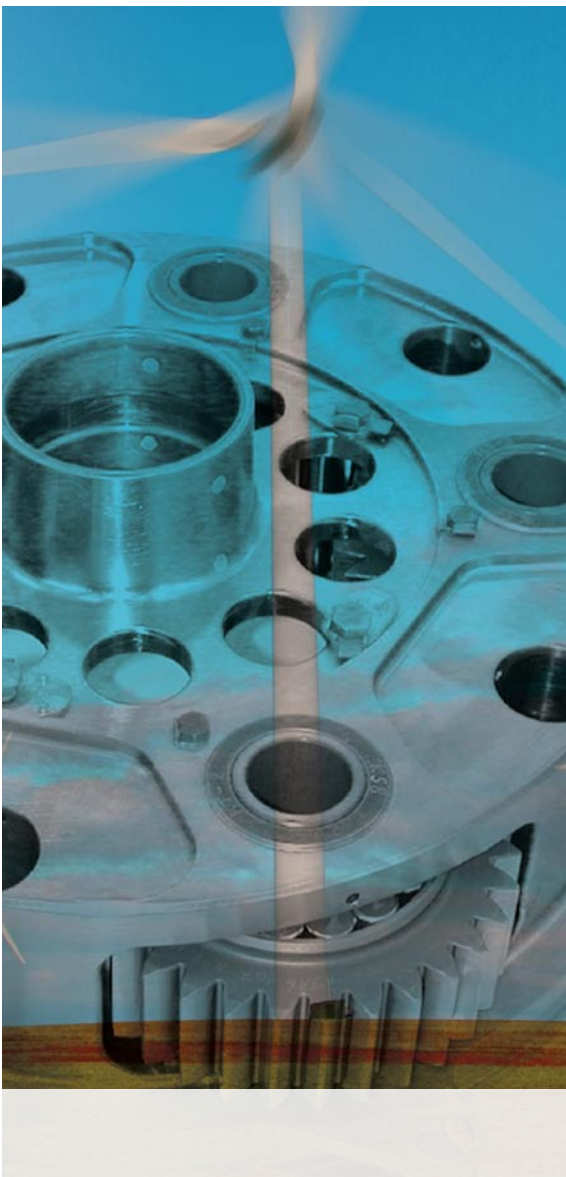


Fig. 1: Tooth profile (the fillet portion is red); a, b—with symmetric, and c, d—asymmetric teeth; a, c—external teeth, and b, d—internal teeth; d_a —tooth tip circle diameter; d_b —base circle diameter; d —reference circle diameter; s —circular tooth thickness at the reference diameter; v —involute intersection profile angle; subscripts “d” and “c” are for the drive and coast flanks of the asymmetric tooth.

	Pinion	Gear	
Diametral Pitch	10		
Module, mm	2.54		
Pressure Angle	25°		
Number of teeth	20	20	
Face Width, mm	12.7	12.7	
Torque, Nm	11.3		
FEA results			
Fillet Profile	Tooth Profile	Stress Chart	Bending Stress
Standard			44 MPa
Optimized			34 MPa

Table 1: Fillet profile optimization and achievable maximum bending stress reduction.

and operating conditions to define the optimized gear tooth shape. This design approach is developed for involute gears and based on the theory of generalized parameters created by E.B. Vulgakov [1], and it can be defined as an application-driven gear drive development process with primary emphasis on performance maximization and cost efficiency without concern for any predefined tooling parameters.

GEAR TOOTH AND MESH SYNTHESIS

There is no need for a basic gear rack to define the gear tooth profile. Two involutes of one base circle—or, in case of asymmetric gears, two different base circles—the arc distance

between them and the tooth tip circle describe the gear tooth (see fig.1) and the equally spaced teeth form the gear. The fillet between teeth is not in contact with the mating gear teeth. This portion of the tooth profile is critical, however, because this is the area of maximum bending stress concentration.

In a wind turbine gearbox the tooth load on one drive flank is significantly higher and is applied for longer periods of time than for the opposite coast one. An asymmetric tooth shape reflects this functional difference. The design

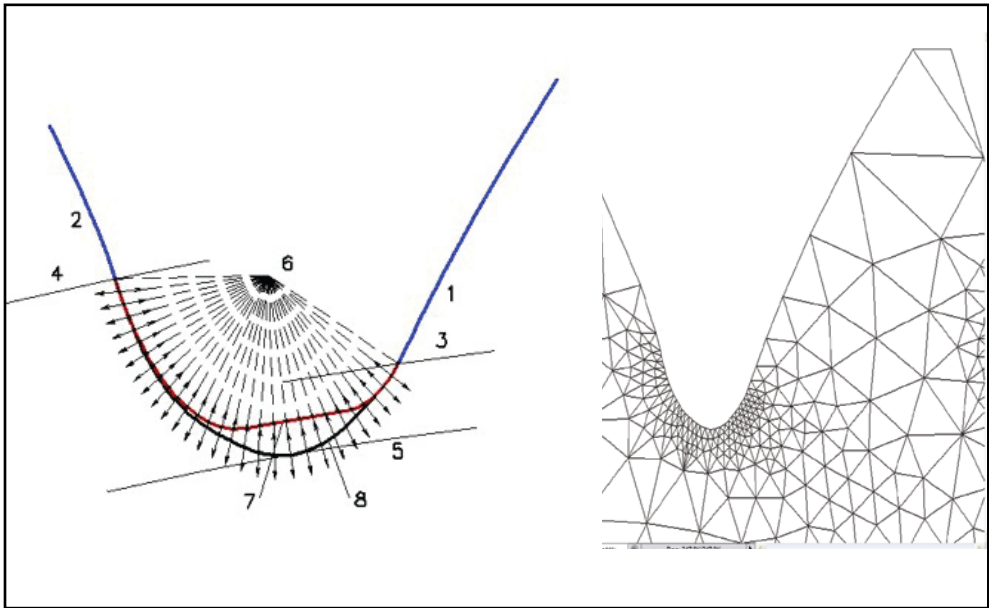


Fig. 2: Fillet profile optimization: a-random search node location; 1 and 2-drive and coast involute tooth flanks, 3 and 4-drive and coast form circle diameter, 5-root diameter, 6-fillet center, 7-initial fillet profile, 8-optimized fillet profile; b-FEA mesh

STAR Global Forum 2010
Simulation for Energy Engineering
www.cd-adapco.com/events Hotel Derek, Houston, TX, June 22-23

STAR-CCM+: Simulation for Renewable Energy

STAR-CCM+ : POWER with ease.

Visit us at:
WINDPOWER 2010
 Dallas, TX
 23-26 May 2010
 Booth 10143

- Wind Farm Siting Analysis
- Turbine & Blade Design
- Nacelle Thermal Management

For more information: info@us.cd-adapco.com
www.cd-adapco.com/energy

CD-adapco
www.cd-adapco.com

intent of asymmetric gear teeth is to improve performance of the primary drive profiles at the expense of the performance for the opposite coast profiles. The coast profiles are unloaded or lightly loaded during relatively short work period. Asymmetric tooth profiles also make it possible to simultaneously increase the contact ratio and operating pressure angle beyond conventional gear limits. The main advantage of asymmetric gears is contact stress reduction on the drive flanks, resulting in higher torque density, or load capacity per gear size. Another important advantage is the possibility to design the coast flanks and fillet independently from the drive flanks, managing tooth stiffness and load sharing while keeping a desirable pressure angle and contact ratio on the drive profiles. This allows reducing gear noise and vibration level. Asymmetric gears make it possible to simultaneously increase the transverse contact ratio and operating pressure angle far beyond conventional gear limits [2].

TOOTH FILLET PROFILE OPTIMIZATION

The tooth fillet design begins when the involute flank parameters are completely defined. The initial fillet profile is a trajectory of the mating gear tooth tip in the tight, zero-backlash mesh. The fillet optimization process [3] utilizes three methods: random search method locating fillet points; trigonometric functions for fillet profile approximation; and FEA for stress calculation.

The first and the last fillet profile points of the initial fillet profile lay on the form diameter circles (fig. 2) and can't be moved during an optimization process. The random search method is used to move the fillet finite element nodes along the beams that connect the fillet center and the nodes of the initial fillet profile.

The bending stresses are calculated for every new fillet profile points' combination. If the maximum bending stress is reduced, the program continues searching in the same direction. If not, it steps back and starts searching in a different direction. After the given number of iteration steps the optimization process is stopped, resulting in the optimized fillet profile that provides minimum bending stress concentration. Table 1 illustrates fillet profile optimization and the achievable maximum bending stress reduction for standard AGMA 201.2 gears.

The 20-25 percent bending stress reduction provided by the fillet profile optimization can be used directly to increase the tooth bending strength if it limits the gear drive load capacity. However, the gear drive load capacity and its size and weight are typically defined by the contact stress, or tooth surface durability. In this case the benefit of the bending stress reduction can be converted to reduce the contact stress and simultaneously increase gear mesh efficiency [4]. This is possible by increasing the number of teeth and applying the finer diametral pitch (lesser module) for the teeth with optimized filler, keeping the given center distance.



2010 WINDPOWER CONFERENCE & EXHIBITION

BARS & RESTAURANTS

Dakota's Steakhouse
600 N. Akard St.
(214) 740-4001
www.dakotasrestaurant.com

The French Room
1321 Commerce St.
(214) 742-8200
www.hoteladolphus.com/dining

Jeroboam
1501 Main St.
(214) 748-7226

Chipotle
208 N. Market St.
(214) 939-5272
www.chipotle.com

Campisi Restaurant
1520 Elm St. #100
(214) 752-0141
www.campisis.us

Tavern City
1402 Main St
(214) 745-1402
www.citytaverndowntown.com

Pyramid Restaurant and Bar
1717 N. Akard St
(214) 720-5249
www.pyramidrestaurant.com

Angry Dog
2726 Commerce St.
(214) 741-4406
www.angrydog.com

Mc Kinney Avenue Tavern
2822 Mckinney Ave.
(214) 969-1984
www.mckinneyavenuetavern.com

Purgatory of Dallas
2208 Main St. #10
(214) 651-8850
www.purgatorydallas.com

Uptown Bar & Grill
2523 Mckinney Ave. #A
(214) 969-9433
www.uptownbarandgrill.com



Fig. 3: Example of the asymmetric gear application.

TRADITIONAL VS. DIRECT GEAR DESIGN

Table 2 presents a comparison of the traditionally designed gear pair with the 27-tooth pinion and the 49-tooth gear, the 3 mm module, and the 32 and 30 mm face widths for the pinion and gear accordingly created by Direct Gear Design with the symmetric and asymmetric tooth profiles. This table illustrates the contact and bending stress reduction and increased mesh efficiency for direct design gears. Figure 3 presents the carrier assembly of a two-stage planetary turboprop engine [5]. Application of asymmetric gears allowed significant weight-output torque reduction in comparison with similar gearboxes with conventional symmetric gears.

Custom Spray Booths



Available in all sizes!

Global Finishing Solutions (GFS) specializes in building custom spray booths, ovens and finishing systems for liquid and powder coating of large equipment. Many companies that manufacture wind towers, blades and castings are satisfied customers.

Call for details today.



WWW.GLOBALFINISHING.COM

800.848.8738

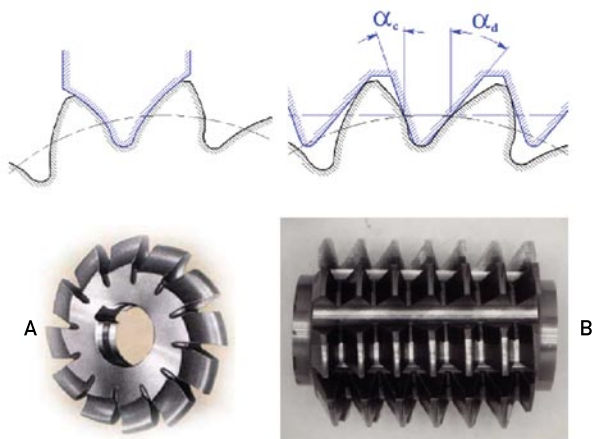


Fig. 4: Tooling options: a-profile gear machining, b-generating gear machining.

Optimized gear profiles require custom tooling. For profile machining process (fig. 4a) the tool profile is the same as a space profile between the neighboring teeth. For generating machining process like gear hobbing (fig. 4b) the tool profile is defined by reverse generation when the designed gear forms the tooling rack profile. In this case the rack profile (pressure) angles are selected to provide the best machining conditions.

SUMMARY

Unlike traditional gear design, which is based on the rack generating process and driven by manufacturing convenience, Direct Gear Design is driven entirely by application requirements, when technical and market performance of product is critical. It provides the ultimate in optimized gear geometry solutions for custom gear transmissions such as wind turbine gearboxes. The benefits of this approach include higher load capacity, reduced size and weight, extended lifetime, reduced noise and vibration, higher efficiency and reliability, and reduced cost. AKGears has implemented direct gear design in many high-performance gear drives, and we welcome your inquiries. ↵

REFERENCES:

- 1) E.B. Vulgakov, Gears with Improved Characteristics, Mashinostroenie, Moscow, 1974 (in Russian).
- 2) A.L. Kapelevich, "Geometry and design of involute spur gears with asymmetric teeth", Mechanism and Machine Theory, 2000, Issue 35, pp. 117-130.
- 3) A.L. Kapelevich, Y.V. Shekhtman, Tooth Fillet Profile

Leave the Heavy Lifting to Kalmar

Kalmar Reachstackers can lift up to 45 tons in tight spaces with the lowest possible lifetime costs. Kalmar has even designed special attachments for the Wind Energy Industry helping make us a leader in Wind Energy logistic solutions. We make the heavy lifting a breeze.

www.cargotec.com • www.kalmarind-northamerica.com

Design Method	Traditional Design*	Direct Gear Design	
		Symmetric	Asymmetric
Pressure angle, °	20	25	32/18**
Drive contact ratio	1.686	1.5	1.5
Driving torque, Nm	300	300	300
Pinion Bending Stress, MPa	225	167 (-26%)	171 (-24%)
Gear Bending Stress, MPa	225	167 (-26%)	171 (-24%)
Contact Stress, MPa	1265	966 (-24%)	887 (-30%)
Mesh Efficiency	98.47	98.62	98.62

Table 2: Contact and bending stress reduction (* standard 20° rack with the addendum modifications that equalize the maximum bending stresses. ** drive/coast flank parameters).

Optimization for Gears with Symmetric and Asymmetric Teeth, AGMA Fall Technical Meeting, San Antonio, Texas, October 12-14, 2008, (08FTM06).

4) A.L. Kapelevich. Direct Design for High-Performance Gear Transmissions, Gear Solutions, December 2008, 22-31.

5) A.S. Novikov, A.G. Paikin, V.L. Dorofeyev, V.M. Ananiev, A.L. Kapelevich, Application of Gears with Asymmetric Teeth in Turboprop Engine Gearbox, Gear Technology, January/February 2008, 60-65.

DEX *The Leading Repair Solution for Wind Turbines*

Failure is not an option...

Eliminate up to 70% of your electronic component replacement costs, let DEX repair instead.

ISO certified facilities in the US and Europe have extensive experience repairing Rotor Current Controllers, IGBT Racks, Controller Systems and more.

Learn what DEX can do for you
www.dex.com/renewables

Visit us at
WINDPOWER
 2010 booth #203

In the US
 (888) 678-9201

In Europe
 +353 - 1 - 8486555

**Use NDT to keep them turning...
 use TED for everything NDT**

- Digital X-Ray
- Magnetic Particle
- Liquid Penetrant
- Ultrasonic
- Eddy Current
- Visual – Borescopes
- Residual Stress Analysis
- Computed Tomography

www.tedndt.com

TED **Test Equipment Distributors, L.L.C.**
 Customer Care Center 800-962-1788
 Fax: 770-978-0115
 Service/Repairs 800-521-1730
 Fax: 248-528-8013