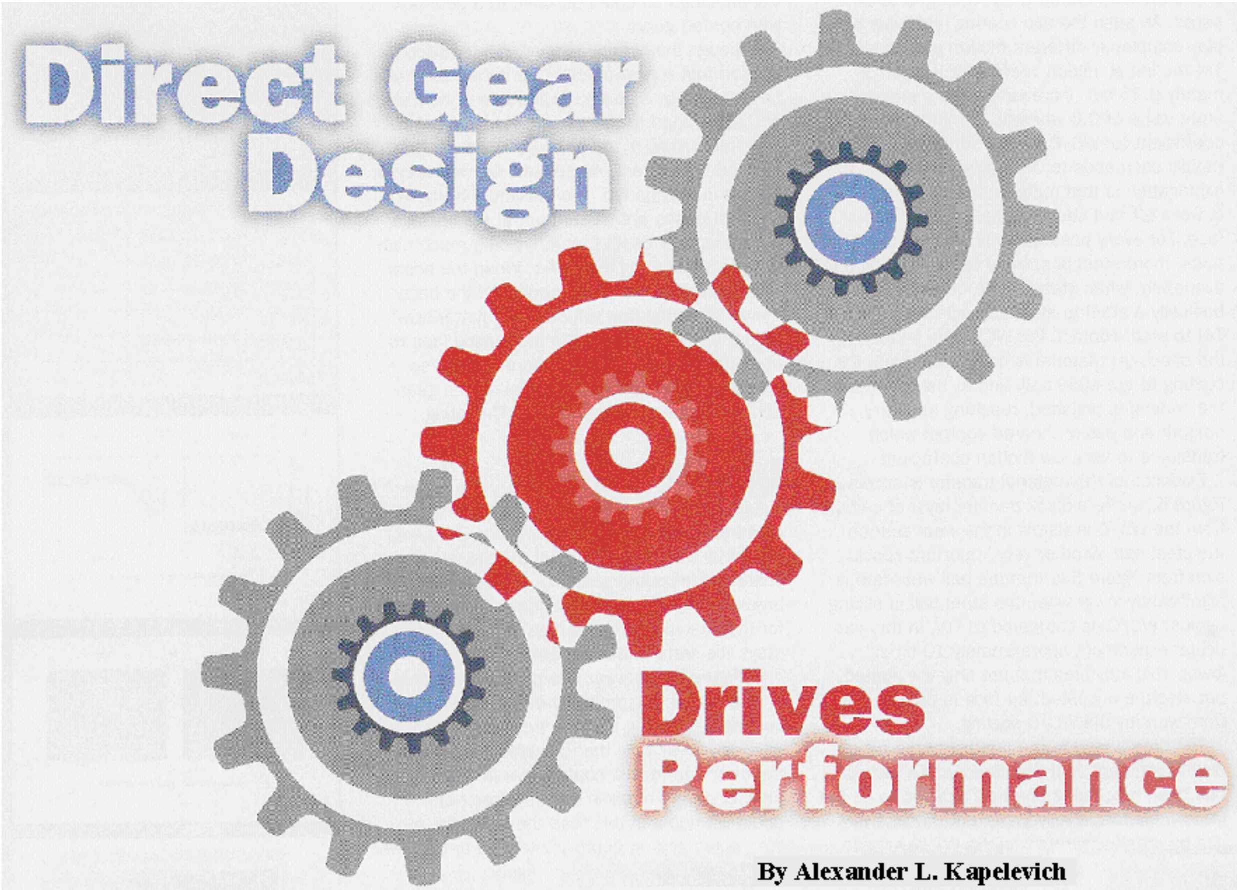


Direct Gear Design^{SM} - an application-driven gear development process with primary emphasis on performance maximization and cost efficiency.

Modern gear design based on the gear rack generating process was introduced in the 19th century and remains the predominant way of designing gears today. It considers the gear rack profile as the cutting edge of the tool. In order to define the gear geometry, the designer must select the generating rack parameters such as pitch (or module), tool profile (or pressure) angle, and proportional tooth addendum, and dedendum. It makes gear design *indirect,* dependent on pre-selected (typically standard) tool parameters, which limits the range of possible gear solutions and gear performance.

There is a distinct difference between gear design and design of other mechanical components. Other components are designed based on the desired product performance under defined operating conditions. Tooling selection, in this case, is a secondary concern.

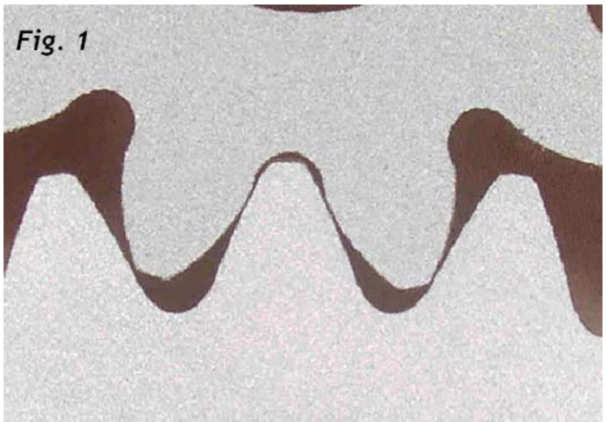
The rack generating process is not the only common gear manufacturing process anymore. There are high productivity machining methods (e.g. gear milling, broaching, form grinding) and gear forming processes (e.g. powder metal manufacture, injection molding, forging). Although these processes do not use a gear rack for the tool profile, they are traditionally designed by the rack generation method.

Customization is one of the recent trends in gear transmission development. It is driven by market demand for competitive and high performance products. Modern gear design based on rack generation does not meet these exacting demands.

AKGears, LLC has developed a design method that is free from the limitations of the rack generating process - Direct Gear Design. It means "gear design is primary; tool definition is secondary," not vice versa.

The rack generating based design can be applied to one single gear. Direct Gear Design, however, must be applied to at least two gears as all gear drives have at least two gears. It defines the tooth profile by two involutes and the angular distance between them. If the involutes are unwound from the same base circle, the gear has symmetric teeth (Figure. 1). If the involutes are unwound from two different base circles, the gear has asymmetric teeth (gears with asymmetric teeth are used to significantly improve the

performance of gear drives with unidirectional load application such as propulsion gear transmissions, Figure. 2). The outside circle provides the necessary top land to avoid pointed tooth tips. The bottom portion of the tooth or fillet is the area of the maximum bending stress that is initially described as a trajectory of the mating gear tooth tip. The fillet is later optimized to minimize the bending stress concentration. The direct designed gears can work together, if they have the same base pitch. This is necessary to define all gear mesh parameters, such as operating pressure angle, contact ratio, and backlash,



without any tool parameters.

Direct Gear Design can be defined as an application driven gear development process with primary emphasis on performance maximization and cost efficiency without concern for any predefined tooling parameters.

Direct Gear Design includes the following stages:

- Gear Mesh Synthesis – defining the initial gear geometry for the gear in tight mesh (backlash is zero).
- Efficiency Maximization - equalizing the specific sliding velocities for mating gears. Unlike in the rack generating method this can be done without compromising tooth strength and stress (or safety factor) balance.
- Bending Stress Balance - achieving equally strong gears by adjusting the tooth thinknesses at the operating pitch diameters. An iteration method combined with FEA is used.
- Fillet Profile Optimization - minimizing bending stress concentration along the fillet. A random search method combined with FEA is used. It provides 15 – 30% maximum stress reduction compared to the best rack generated gears.
- Tool Design, - tool parameter definition for the selected manufacturing process. If the rack generating machining (hobbing, for example) is selected, the gear profile defines the cutting edge of the tool by reversed generation.

Direct Gear Design optimizes the gear tooth in the normal section, making it suitable for any kind of involute gears: spur, helical, bevel, worm, face, etc. It expands the current limits of the following involute gear parameters:

- The minimum number of teeth is just three for spur symmetric gears and just one for helical and spur asymmetric gears. The maximum number of teeth is unlimited.
- Operating pressure range of 5 – 85^{o}.
- Face contact ratio range of 0 – 5 and higher.
- The range of 0 – 1 is for helical gears with axial contact ratio > 1.0.

- One stage gear ratio from 1:1 to 50:1 and higher.
- One planetary stage (at least three planets) gear ratio from 1:1 to 300:1 and higher.

The creativity, freedom, and flexibility of Direct Gear Design allows for the optimization of custom gear drives. This design approach provides the following benefits:

- 15 – 30% increased load capacity.
- 3 – 5 times longer life.
- 10 – 20% reduced size and weight.
- Cost reduction.
- Increased reliability.
- Noise and vibration reduction.
- 1 - 2% increased gear efficiency per stage.
- Maintenance cost reduction.
- Other specific benefits for particular application.

About the author

Alexander L. Kapelevich, Ph.D. is owner of consulting firm AKGears LLC, developer of the Direct Gear Design method and software. He can be reached at 651-308-8899 or via e-mail at ak@akgears.com.