Gear Design Deconstructed

Jack McGuinn, Senior Editor

How difficult is it to design a gear? It depends upon whom you ask.

How difficult is it to choose the correct method for *making* that gear? Extremely difficult. Choosing the correct process is paramount in shepherding a job from blank page to the finished part print. Thus the gear engineer must ensure that what goes on the blank page is something that can actually be manufactured.

"Preparing the manufacture of (for example) a cylindrical gear is in most cases more complicated than the gear design," says Hermann Stadtfeld, vice president-bevel gear technology-R&D, Gleason Corp. "Picking the right manufacturing methods and calculating optimal machine settings regarding geometry, as well as productivity, is key and has significant influence on the physical properties of a gear."

Thus while stipulating that the role of the gear engineer (designer) in and of itself is not the most daunting job in gearing, it is certainly among those requiring the widest breadth of knowledge. The *design* process begins with four deceptively brief questions, the answers to which will help in determining the correct manufacturing process:

1. What kind of gears should you use?
2. What should they be made of?
3. How should they be made?
4. How should they be checked?

Adequately addressing each of the above questions requires expert knowledge over a range of gear making-related disciplines, including heat treating; materials; workholding, inspection; standards (both ISO and ANSI/AGMA); reverse engineering; gearbox and machine upgrades; custom gearbox design; specification development; project management; chamfering or deburring; and vendor qualification.

It is the responsibility for sorting out all of the above in the manufacture of a custom gear that makes designing a gear correctly the first time such a critical process.

In-House or Outsource?

You might be thinking — how many design (new part) projects are addressed on a daily basis? Do operations exist where it is all new gears, all the time? Or are they typically freelance consultants?

"Whenever gear design or manufacturing is a core skill for a company (e.g., gearbox manufacturers), they will try to get onsite employees for their gear design," says Thomas Tobie, head of the load carrying capacity of cylindrical gears department at the Gear Research Center (FZG) at TUM. "Due to the fact that gear design is often very application-specific, only an onsite employee is capable of dealing with every application-specific difficulty. Companies who are not focused on gear design or manufacturing as a core competence usually hire consultants for single projects."

Adds Alex Kapelevich, AK Gears — "Gear designers are typically onsite employees. There are not so many contracted gear consultants."

On the other hand, Charles Schultz, chief engineer, Beyta Gear Service; *Gear Technology* blogger, explains that "Traditionally, gear companies had in-house design-and-build capabilities. For a variety of reasons — aging workforce, changing business models, lack of trained engineers & designers — few still offer this one-stop shopping. Lots of custom equipment is still built, but machine builders frequently use off-the-shelf gears and gearboxes."

Stadtfeld states that "Companies that manufacture gears for a living on a daily basis usually have their own gear designers; (but) there are consultants that offer such a service. Also Gleason, KISSsoft, Romax, SMT, etc. develop gear design software which they sell, but also offer gear design services."

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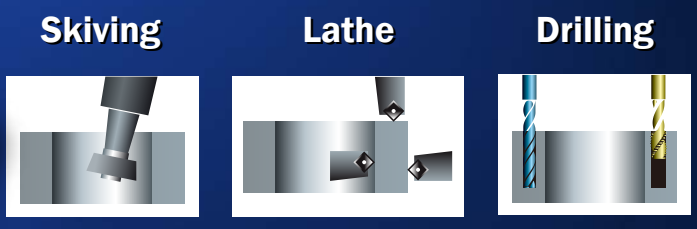

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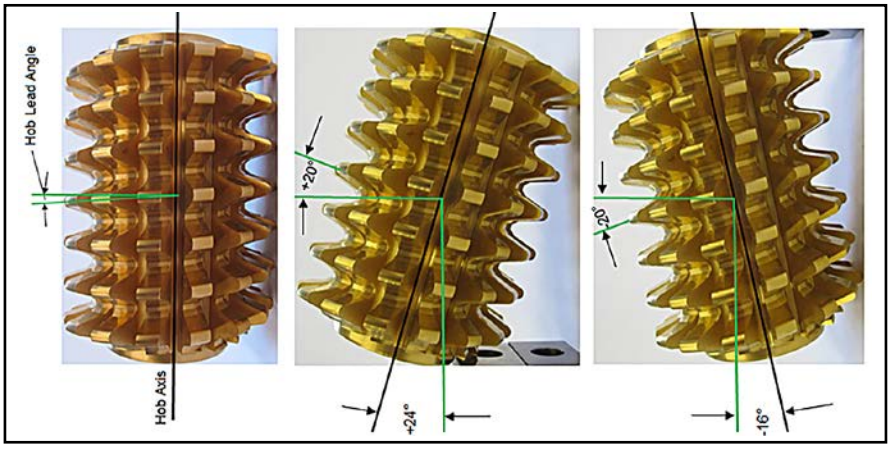
It's All About the Manufacturing

Given the breadth of knowledge required for designing — and manufacturing — a gear, an ability to work seamlessly within other disciplines in making that happen is crucial.

"The gear design is done by applying some software tools, says Stadtfeld; "given the fact that a cylindrical gear can be defined with 5 values — number of teeth, module, helix angle, profile shift factor and edge radius — the design is not as complicated as preparing the right manufacturing scenario."



The choice how to set up a hob has consequences for surface and productivity. (Courtesy Gleason Corp.)

Schultz believes that "Good designers understand the process capabilities of each manufacturing step and incorporate them into the design. It is always great to get "buy-in" from the rest of the team that confirms your understanding of their work."

"A good gear designer is a mechanical engineer whose background is all of this," says Stadtfeld, adding, "A gear designer is always considering the kind of manufacturing and heat treatment which is available for a certain new gear design and factors those practical manufacturing aspects into a new design."

Standards and the Bigger Picture

For FZG's Tobie, the process is about much more than geometry: "For gear designers, it is very essential to have deeper knowledge, or at least experts, alongside who have knowledge about machining, lubrication, material properties or heat treatment processes, as the requirements on a good gear design are very versatile. In recent years the general trends towards increased power density, high reliability, good efficiency and adequate noise behavior require the design of optimized gears. This optimization has to be done at a very high technical level and requires consideration of many — sometimes even contrary — effects."

And then of course there are standards — ISO and ANSI/AGMA to sort out.

"Good design is compliance with specifications and robust service life," Schultz says. "While there are differences in stan-

dards, a 'good' design will 'rate' in any of them. In the future expect to see more 'convergence' between the standards."

It is Tobie's belief that "For many fields of application, it is common practice that the verification of the load carrying capacity is made according to relevant standards (ISO, AGMA), as it is often specified and required by the customer. Therefore, a fundamental knowledge about current standards is often required. For other fields of application, different in-house specifications may be given (e.g., car industry). In such cases standardized methods often are not so important for the gear design."

Training & Education

This is as good a spot as any to wonder what kind of training gear engineers typically receive. Given how many things there are to deal with, one wonders where to begin.

"In (those) companies focused on special products (e.g., automotive gearboxes), it is common to develop a new product based on former products using the gained experience," Tobie points out. "Thus, the gear designer is gaining knowledge on the job. This is a great benefit — especially for young engineers. Besides that, seminars and trainings focused on gear design can be helpful for more experienced employees to get a new perspective on well-known processes."

"There are few "typical" designers," Schultz declares. "Some have an academic background, others are engineers by training. Others come up 'through the ranks' of machinists, drafters, or other positions. The job requires a variety of skills along with an interest for seeing how gears work. Leonardo da Vinci did not have an engineering degree and still managed to do some amazing gear designs."

Is there a "most difficult" gear to design and manufacture?

Stadtfeld — "Cross axis helical, bevel gears and most complicated are hypoid gears." Schultz — "Probably worm gears, as there is no recognized 'system' and lots of variables to deal with." Tobie — "In general, there is a great diversity of gears (spur vs. bevel gears, module <1 mm gears vs. module >20 mm gears), of which every gear has its own specialties which have to be considered in the design process. Nevertheless, it is always a great challenge to design a gear, if different requirements, which are often contradictory, have to be taken into account. Consequently, the 'most difficult' gear has a very good power-to-weight ratio, low noise excitation, and is very cost-effective (as) it can be manufactured in single-part production."

Software

As software continues to evolve in various capacities as an essential tool for gearing, one wonders how it affects gear engineers (designers).

"A little knowledge is a dangerous thing," Schultz cautions. "Some of the more advanced software packages allow novices to 'design' gears and make beautiful 3-D renderings that are not the best solution to the problem. Software is a tool, and like any tool, the more experienced and skilled the operator, the better

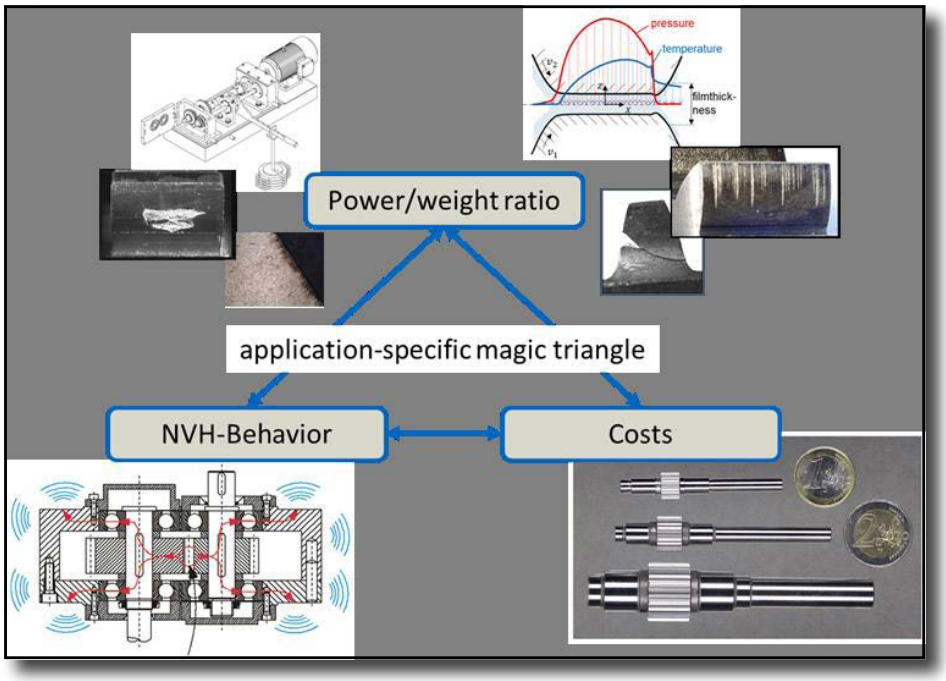
the results."

As for Tobie — "For today's gear designers it is absolutely indispensable to have a basic knowledge of how to use common calculation tools for designing gears. As the requirements — which have to be considered carefully — are steadily increasing, a computer-aided design is necessary. Besides using modern calculation tools, every gear designer should still be capable of understanding the basic principles of calculating the gear geometry and the load carrying capacity of gears without help of calculation tools, respectively."

The Latest Technologies

How are gear engineers affected by the latest technologies, things like 3-D printing and the Industrial Internet of Things (IIoT)?

"In general, new technologies will lead to new developments also for gear specifiers and designers," says Tobie. "In large companies these advanced technologies certainly already have an influ-



Despite the many considerations that must be addressed, it all begins with the application (Graphic courtesy FZG).

ence on the daily work of gear designers. Nevertheless, many gear manufacturers are companies of small to medium size, and for these companies at the moment the effect is still small because many of the named technology advances are still subjected to ongoing research projects. Regarding IIoT, an online monitoring of the gear condition and the remaining lifetime will be possible in near feature. Furthermore, 3-D printing will allow fast and cost-efficient manufacturing of individual gears made of different types of materials.

"Nonetheless, gears are elementary mechanical components, and the basic requirements will remain unchanged in the next few decades. It is therefore very essential for gear specifiers and designers to keep in mind the fundamental basic knowledge about gears, in addition to the knowledge about new technologies."

Says Kapelevich, "A designer should be aware about new technologies and understand their requirements (mechatronics), capabilities (3-D printing), and potential efficiency (IIoT). Certain gear designs which had been impossible to manufacture have become possible due to 3-D printing, for example. Gear designers welcome the new opportunities and take advantage of them."

Schultz adds, "3-D printing has great potential for pattern and tool design, as well as 'proof of concept' on new products."

For more information:

AK Gears
316 Oakwood Drive
Shoreview, MN 55126
(651) 308-8899
ak@akgears.com
www.akgears.com

Gear Research Centre (FZG)
Institute of Machine Elements
Technical University of Munich
Dept. of Mechanical Engineering, Building 5
Boltzmannstraße 15
D-85748 Garching bei München
Germany
www.fzg.mw.tum.de

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1000 University Ave.
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When the Gearing Gets Tough

Sometimes semantics can get in the way of comprehension. We learned in the accompanying article that "gear design" is not *necessarily* at the top of the list of hair-on-fire, fire-in-the-hole scenarios. "Necessarily" is the keyword in this instance, as the following from Alex Kapelevich and Thomas Tobie provides scenarios of when gear design is indeed something that might keep a designer up at night.

Alex Kapelevich

Because gear design requires not only general knowledge of gearing, but also clear understanding of gear drive application, operating conditions (load, RPM, life, temperature range, etc.), dimensional and envelope constrains, specifics of selected gear fabrication technology (accuracy, production volume, productivity, cost, etc.), materials, lubrication, and many other aspects. Besides the gear design, there are other critical stages in gear drive development, e.g. — manufacture, inspection, assembly, and testing that must be done appropriately. But gear design is a major contributor to required gear drive performance.

Thomas Tobie

I think that designing a "standard" gear is no more difficult than designing some other machine elements; but for many applications a standard gear design is not sufficient.

In recent years the general trends towards increased power density, high reliability, good efficiency and adequate noise behavior require the design of optimized gears. This optimization has to be done at a very high technical level and requires consideration of many — sometimes even contrary — effects.

Some examples why such optimized gears are maybe quite unique:

Combination of high load, sliding motion, friction and temperature load that results in a complex stress condition and high stress levels leading to high requirements on material, lubricant and manufacturing quality

Elastic deformations under load which require modifications of a few microns during manufacturing to reach a good load distribution and noise behavior

Lubricant film with a film thickness significantly smaller than a human hair has to separate the loaded surfaces under the above described operating conditions (high pressure, sliding, temperature)

I think it is the combination of all these effects and requirements that makes the difference and makes it difficult to design an optimized gear for highest demands and reasonable costs at the same time.

In fact, our main goal and approach is still to improve gears as a whole and covering all the aspects — load carrying capacity, noise behavior, efficiency, costs, etc.

For this we try to understand the physical-mechanical — and sometimes also chemical mechanism — to quantify the relevant influence parameters and to bring this into calculation methods.

So I believe that there are three main topics of our continuous work: Developing improved calculation/simulation tools, try to develop standardized rating procedures and to establish standardized test procedure for influence parameters which cannot be covered by simulation only.

At the end, a good designed gear has to take into account many requirements from material, heat treatment, lubricant, manufacturing, gear geometry, etc., and in many cases compromises are needed to fulfil all requirements. The best selected lubricant will not help if an inappropriate material is used, and vice versa. Also, the best rating procedure for micropitting will not help if the gears fail by scuffing.