How Many Mice Does It Take to Design a Gear?

or the Manager's Guide to Gear Design Software

You can use anything from pencil and paper to an "expert" system. Which is best for you?

William R. Stott

Gear design has long been a "black art." The gear shop's modern alchemists often have to solve problems with a combination of knowledge, experience and luck. In many cases, trial and error are the only effective way to design gears. While years of experience have produced standard gearsets that work well for most situations, today's requirements for quieter, more accurate and more durable gears often force manufacturers to look for alternative designs.

Many have hoped that faster computers and more powerful software would prove to be the philosopher's stone that could turn so much guesswork into design gold. While no computer program can replace a qualified gear engineer, many software packages can help him or her calculate equations, perform stress and materials analyses, produce computerized gear prints andeven suggest ways to optimize a design.

Most of the manufacturing design world has embraced the computer age wholeheartedly, but the gear industry has lagged behind. One reason is the esoteric nature of gear design—only a handful of people across the country know and understand it. Most of the programs that are useful for gear design have been developed by this handful for their own use.

But no matter how hard its members kick and scream, the gear industry is being drawn into the computer era. While many smaller gear shops—and a fair number of large ones—still calculate gear designs with pencil and paper, a lot of high-end, high-volume shops have gone to full automation, with CNC machines, PCs, CAD programs and other computer design tools.

Two of the engines driving these changes are the automotive and aerospace industries. Earlier this year, Chrysler announced a new corporate-wide strategy centered on IBM's CATIA software package. One of the goals of the strategy is to design their automobiles completely on the software. Already, Chrysler exchanges CAD data with more than 300 suppliers and produces several of its models entirely on the CAD system. Also this year, Boeing unveiled its new 777 airplane, the first commercial airliner designed entirely on a CAD system.

Computer programs that would be of use to gear designers can be divided

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into three basic categories: CAD programs, gear calculation programs and gear analysis or "expert" systems software.

A CAD Software Primer

Essentially, CAD programs computerize the drawing board. Instead of drawing mechanical blueprints with a pencil and paper, design engineers use a mouse, electronic stylus or other input means to draw a part on the computer screen. Some of the more popular software packages include *AutoCAD* from AutoDesk, IBM's *CATIA* and *CADAM* programs, Intergraph's *Engineering Modeling System* and *CADDS* from Computervision. Versions are available for PCs, workstations and mainframes.

This digitization of the drawing process enables the designer to save a design, modify a portion of it and print it without having to redraw the entire part each time. It also allows direct downloading to machine tools via CAM software.

In addition to standard two-dimensional drawings, many CAD programs today are capable of 3D solid modeling, which allows the designer to fully visualize the part from any angle, making obvious such errors as interference.

CAD systems have definite benefits to someone laying out a transmission or an entire gearbox. By placing the gears, shafts, bearings and seals with a CAD system, the designer can determine whether proper clearances are given for each part and ensure that the entire product is manufacturable and easily maintained once produced.

Some vendors have developed add-on modules for gear design in conjunction with CAD programs. One example of this is CIMLOGIC's *Power Transmission* package, which works with the popular *AutoCAD* program. *Power Transmission* selects appropriate standard gears based on the user's specifications, including horsepower, speed ratio and input rpm. However, this program will not perform calculations to determine load, stress and life capabilities of the gearset. *Power Transmission* requires the CIMLOGIC *Toolbox* program, a general-purpose geometry design enhancement for *AutoCAD*. The price for the package is $1,595 for DOS-based PCs.

However, the consensus among gear experts is that CAD systems are not all that useful for designing gears. While these programs are extremely powerful and have been a boon to mainstream manufacturing design, they do not come equipped with the formulas necessary to compute gear geometry. Given the appropriate geometry, a CAD system can draw the gear, but this is an unnecessary step, says Kent Reece, vice-president of Van Gerpen-Reece Engineering in Cedar Falls, IA. "There is no use for each tooth drawn on a gear drawing," Reece says. "There's nothing you can do with it. It's a waste of the engineer's time."

What's Out There?

The number of kinds of software available to design engineers may seem overwhelming. Prices can range anywhere from $100 to $10,000 or more, not including the required hardware, which can range from PCs to workstations to mainframes. There has been no effort to produce a standardized gear design package for computers. A number of gear shops, universities and consulting firms have developed their own software over the years to suit their own needs. The result is that there is a great variety of gear design software available, each package with its own approach to the gear design problem. With so many choices, and with so few of them aimed directly at gear manufacturers, computerizing the design process can be a daunting and confusing task.

While no one has written a program that could be the industry standard, most of the commercially available gear design programs are based on formulas found in the AGMA standards. In addition, AGMA's Computer Programming Committee has been working for about a year and a half on a program that will perform calculations based on the proposed ISO 6336 standard. This program will make it easier for manufacturers to compare AGMA ratings with ISO ratings, said committee chairman Michael Antosiewicz of Falk Corp. It's important for AGMA to develop such a program because the standard itself is subject to interpretation, and different programs might produce different results, Antosiewicz said.

AGMA plans to sell the ISO 6336 software sometime after the standard is approved by ISO and the program itself is finalized.

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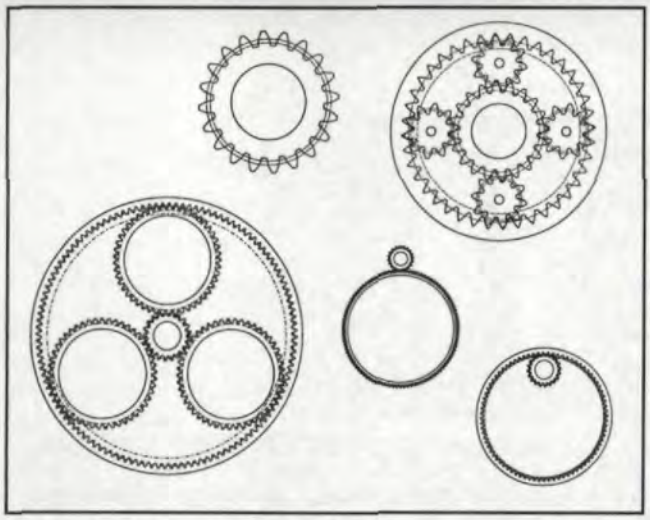

Sample gears drawn with *PC Gears* software.

Gear Calculation Packages

If you want to start small, there are a number of commercially available packages created to perform some of the routine calculations of the design process and provide easy answers to certain design-related questions.

One of the simpler programs available is the *Gear Professor* from Computer Sales & Maintenance, Inc., in Arden, NC. The program is primarily designed for manufacturers rather than designers. It calculates the appropriate change gears required on conventional gear hobbing machines according to the gear geometry provided. In addition, the *Gear Professor* will calculate the appropriate pin measurements of a gear, allowing the design department to better communicate with the manufacturing department the exact geometry of a gear. The program costs $595 for the first copy and $295 for additional copies. A new release that will perform calculations for bevel and worm gears as well as spurs and helicals is due out sometime in 1995.

PC Gears, from PC Enterprises in Sedona, AZ, takes gear geometry and cutting tool information and produces animated drawings of spur and planetary gearsets in mesh, providing the designer with an immediate idea whether there will be interference, backlash or undercut in the mesh.

PC Gears, at $250, is a relatively inexpensive tool that can be of help to gear engineers who need a fast and easy way to check for problems in their designs. In addition, a new release of the software, *GearWorks for Windows*, will be available early this year.

Another program that will handle many of the routine calculations involved in gear design is *Gearpack* from Software Engineering Service in Rockford, IL. *Gearpack* helps the engineer design single gears or mating gear pairs. The program will calculate tooth thickness, outside diameter, root diameter, gear lead and normal diametral pitch from the center distance and number of teeth for spur or helical gears meshing at parallel or crossed axes.

In addition, *Gearpack* presents a graphics screen showing the gears in mesh and demonstrates a step-by-step rotation of the gears in motion. *Gearpack* is available for $250. Software Engineering Service also offers software to select change gears, calculate the tooth form of a gear when the meshing gear form is already known, and perform many other functions related to gear hobbing, inspection, grinding wheel dressing and gear tooling. All the programs from SES run on a PC.

Expert Systems

While programs that perform calculations based on AGMA standards can be of great help to engineers, designing gears based on

these formulas might produce gears that are noisy, short-lived or prone to pitting, bending, breaking or fatigue. Several companies have produced more comprehensive, "expert" systems for gear design, which help designers produce the optimum gear design for specific applications.

Expert systems help designers along the way by providing default values for certain gear geometry factors. Also, they are capable of performing stress, load and life analyses of gear pairs. Finally, expert systems will present the engineer with warning signals if obvious problems, such as low contact ratios or excessive interference, arise.

Fairfield Manufacturing Company, Inc., of Lafayette, IN, is one of the country's largest suppliers of gearing and power transmission systems. Over the past 25 years, Fairfield has developed its own *Gear Design Software*, beginning with simple calculation programs designed to run on a mainframe system and evolving to version 6.2, which runs on a PC and is available from the manufacturer or through AGMA for $850.

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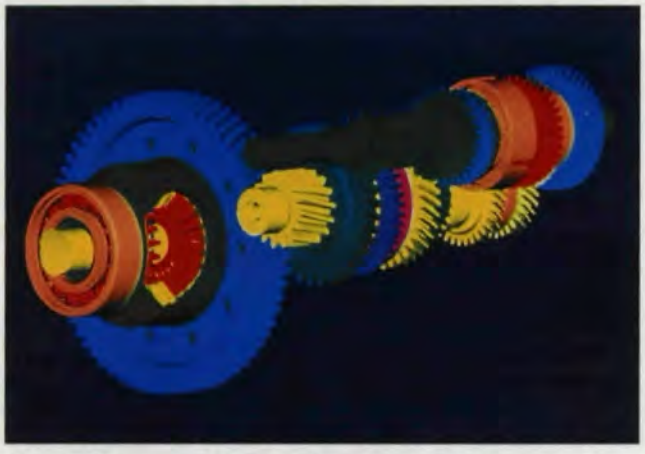

Many CAD programs can be adapted to the users needs. Above is a gear train designed on Intergraph's EMS. Below, a customized application for creating spur & helical gears.

Fairfield's *Gear Design Software* performs data, rating, stress and life calculations for spur, helical, planetary, bevel and spiral bevel gears. Calculations are based on AGMA 2001-B88 and publications of the Gleason Works. In addition, the program has a quick pin size routine, an AGMA quality calculation routine and a two-bearing shaft routine to estimate bearing life and help determine which bearings to use.

Despite its calculating abilities, however, *Gear Design Software* is not an automatic design tool, says Jim Dammon, vice president of engineering. The program will warn you, however, when obvious problems in the design come up—for example, contact ratios less than 1, excessive interference, etc. However, it is entirely possible to design faulty gears with the program, Dammon said. The gear designer still has to know what he is doing.

Geartech Software, Albany, CA, sells a trio of programs for designing and analyzing gears. *GearCalc* designs spur and helical gears for optimum surface durability and bending strength. *AGMA218* calculates power ratings and tooth pitting and bending fatigue life ratings for gears. Although the program uses AGMA standard 218.01, which has been superseded by AGMA 2001-B88, developers say the calculations are still acceptable for all gears except those made of Grade 3 carburized material. Finally, *Scoring+* analyzes the scoring and wear probabilities for a gear set.

Geartech's programs work closely in conjunction with one another. A single keystroke will take you from one to the next. For example, you could design a gear set with *GearCalc*, check to see that it will perform as required with *AGMA218*, and determine if there are likely to be any lubrication, scoring or wear problems with *Scoring+*.

Geartech's three programs are available in a single package for $2,490. The software will run on a DOS-based PC.

Like the other expert systems, *Diseng* gear design software from CIATEQ, Queretaro, Mexico, tries to make suggestions for the best possible gear based on the parameters provided by the user. First, the designer defines either a single explicit value or a range of possible values for gear parameters, including ratio, center distance, pressure angle, and so on. This allows the user greater flexibility in defining the design problem. When starting from scratch, there is even a subroutine to help the designer in the initial sizing of the gears when only factors such as power, torque or speed are known. Second, the designer defines the performance requirements of the gearset, including pitting life, bending life, scoring probability, reliability level and the potential operating conditions. Third, the software performs calculations based

on AGMA 2001-B88 and supporting standards to produce the gear design.

With the *Diseng* software, optimization of a gear design means going back to the first and second steps and changing the variables. The software saves the results for each iteration, and it will produce a graph showing the relationship between different iterations for each variable. This allows the designer to see exactly how changing each variable will affect the various aspects of gear performance.

The goal of the software from Van Gerpen-Reece Engineering Co., Cedar Falls, IA, is to produce gears that are quieter, longer-lasting, more efficient or less expensive. A typical approach for Van Gerpen and Reece is to take a gear set that works and make it better, Reece says.

Van Gerpen-Reece's complete gear design system calculates tooth beam strength factors, surface durability factors and all the dimensions required to manufacture the gears. The designer can create non-standard gears with either standard or non-standard tooling. In addition, modules are available for selecting the appropriate shaper, shaver or hob for a gear, designing new tooling, selecting the appropriate master gear for inspection or designing a new master gear if needed.

The basic Van Gerpen-Reece gear design module sells for $5995. A package that includes modules for cutting tool searching and design costs $10,000. Additional modules are available.

Universal Technical Systems in Rockford, IL, has more than 75 programs for the design, analysis and manufacture of gears. UTS's *Program #500* is its main program for designing gears. It can be modified according to the user's needs, with options for optimizing hobbed and shaped gears, for calculating sliding ratios and profile modifications, and for a number of other functions. In addition, the company offers an engineering calculation package called *TK Solver*, which can be combined with a large number of gear-specific calculation modules, including programs to calculate K Factors, determine tooth thicknesses, perform stress analyses, and calculate the load and life ratings of plastic or powdered metal gears.

UTS's software allows an engineer to modify existing gear designs to produce non-standard gears that are better than their off-the-shelf counterparts. The complete package for *Program #500* with all the options installed costs $12,000. The price for the basic hobbed gear and tooling design software is $1950. *TK Solver* sells for $595, with additional modules relating to gear analysis available for $50 to $1,200 per individual module.

In spite of the capabili-

Expert systems often use graphics to demonstrate potential problems. A screen image from UTS Software shows gears in mesh.

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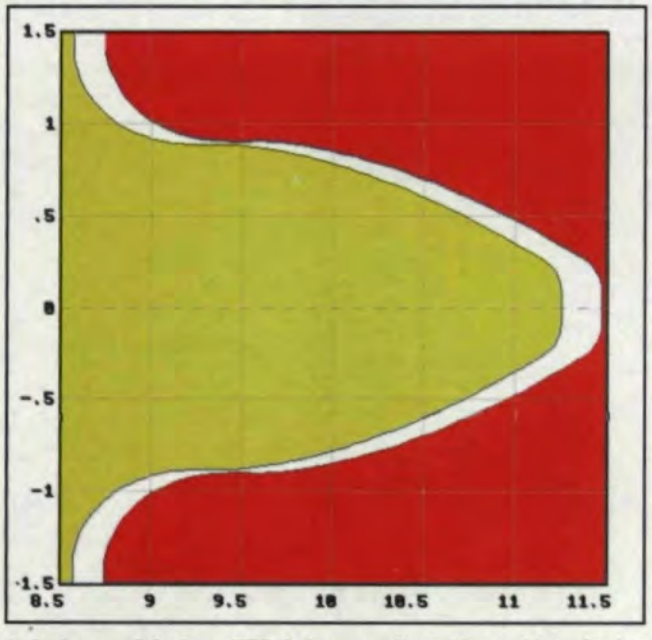
A blown-up section of the image reveals interference in the design.



A design module from UTS Software adjusts the mold cavity for plastic or powdered metal gears to allow for shrinkage.

ties of these "expert system," none of them is capable of replacing the gear design engineer. Too much of the gear design process relies on experience and knowledge of the field.

All Right. I'm Still Confused. How Do I Choose?

Unfortunately, choosing a gear design system is no easy task. The programs mentioned in this article are just some of the software packages being used today. Many individual companies use proprietary software in-house, and some consulting firms use their own software to design gears for clients.

What this means is that it's going to take some research to figure out exactly what will meet your needs. Not everyone needs to go out and buy an expert gear system. The engineers at your company may be doing just fine on their own, but a simple calculation program might help them do their jobs better. On the other hand, your company may be designing cutting-edge gears that require non-standard forms, in which case you might benefit greatly from an expert system. In any case, it's important to check as many sources as possible before deciding.

Once you have determined what type of software you need, choosing an individual package or combination of packages will also require a bit of research. Each piece of software is in effect a computerization of the design technique favored by the programmer, especially with the more advanced expert systems. It is important that you be familiar and comfortable with the approach taken.

Other factors that should be considered before buying software include the amount of training it will require and the type of hardware required to run it. While most gear-specific design programs are written for the PC, many high-level CAD programs require workstations or more powerful systems. ○

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