Alternative Gear Manufacturing

Charles Cooper

The gear industry is awash in manufacturing technologies that promise to eliminate waste by producing gears in near-net shape, cut production and labor costs and permit gear designers greater freedom in materials. These methods can be broken down into the following categories: alternative ways to cut, alternative ways to form and new, exotic alternatives. Some are new, some are old and some are simply amazing.

Alternative Ways to Cut

Traditional gear manufacturing involves cutters, hobs and other tools that quickly remove metal from the piece being worked. These are not, however, the only ways to cut metal. Stamping, fineblanking, lasers, electrical discharge machining and abrasive waterjet are all being used for gear production, each filling its own market niche.

Stamping and Fineblanking. Stamping is a metalworking technique that has been compared to using a cookie-cutter. A cutting die is pressed down into the metal and pulled out again. When it comes up, the workpiece is ejected and the process begins again. Stamping is very fast, very efficient, but not terribly precise, with a great deal of clearance differences between workpieces common. Because of this, workpieces often require post-press grinding, shaving or other machining. Stamping is restricted by the thickness of the piece being worked and is used primarily for spur gears and other thin, flat forms.

Fineblanking shares certain similarities to both stamping and forging. The process takes metal from a sheet like stamping but differs from it in that it uses two dies and forms the workpiece by pressing it into the desired shape. In this way it is similar to forming techniques such as forging and powdered metal compaction. The metal is extruded into the die cavities to form the desired shape. Also unlike stamping, fineblanking offers the designer a limited three-dimensional capability and can thus be used to create bevels, multiple gear sets and other complex forms.

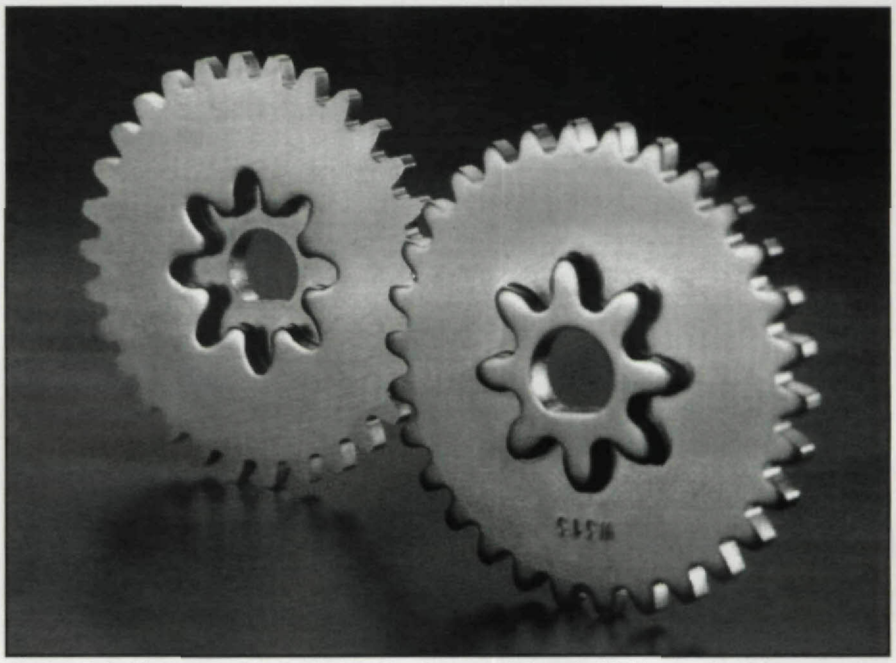

Fig. 1 — A double gear fineblanked in one hit using a semipierce by MPI International, Inc.

The double gear for an automotive seat shown in Figure 1 was made by MPI International, Inc. a Michigan-based fineblanking and stamping company. The part was traditionally manufactured by taking a stamped gear and welding a machined gear hub to it. This was expensive, the results inconsistent and, according to MPI, there were many rejects. Fineblanking's repeatability of the concentricity of the two gears as well as nearly distortion-free shaping was the answer. Tolerances were kept to .0005 inches and savings were realized on the elimination of rejects and the additional machining and welding required under the original design. The gear was strength tested prior to production and has successfully carried passengers in over 2 million vehicles.

"Fineblanking gives you a stronger gear than stamping or powdered metal," said Rick Eisele of MPI International. "In fact, many powdered metal gears are replaced by fineblanked gears. You get close to machined-gear quality with fineblanking." Stamped and fineblanked gears can be found in a myriad of applications including the automotive, appliance, office equipment, hydraulic and medical equipment industries.

Lasers. While sometimes slower than traditional techniques, depending on the material, lasers can easily cut complex shapes such as gears with great precision and very little waste. This conservation comes from the ability of the CNC machines controlling the lasers to reuse cutting paths, getting as many gears from a single sheet of metal as possible. According to Matt Kalina, Director of Marketing for the LAI Companies, specialists in laser and abrasive waterjet technology, this fine nesting capability makes laser cutting one of the most economical ways to make certain types of gears. Also, the computer control means laser cutting is also low maintenance. The setup and first runs are always closely supervised, but the actual production runs don't need any real supervision due to the CNC programming.

The trade-off for this speed, precision and ease of use is that pieces cut with lasers have heat affected zones, areas where the metal is heated beyond a critical transformation point and recast. These zones are limited, however, to the edges of the cuts—minimizing, but not eliminating heat distortion and the need for further machining. Post production grinding and hobbing are common.

The type and thickness of the metal being cut is also at issue with lasers. "Lasers have trouble cutting metal more than 3/4" thick. To cut anything over that would require too much power," said Kalina. "They are also limited to non- or semi-reflective materials. Metals like aluminum and brass, that are highly reflective, are difficult to cut because the laser has trouble focusing its beam."

While lasers are, like stamping, traditionally limited to flat forms such as spur gears, newer five- and six-head CNC controlled machines are changing that. LAI has used them to cut more complex gear forms such as spiral bevels, worms and helical gears. "We've done a few jobs like these," said Kalina, "everyone was very happy with the results."

Electric Discharge Machining. EDM uses electricity to melt or vaporize the material being cut. Depending on the application, the electrode can either be a wire (wire EDM) or a pre-shaped solid used as a vertical "sinker" EDM.

Like laser cutting, EDM causes heat affected zones in the workpiece that could require later machining. However, it also eliminates many of the other problems associated with traditional gear cutting methods. The metal can be pre-hardened and then EDM processed to eliminate the need for any further machining. Also, wall thickness, and cutting and clamping pressures are not considerations since the piece is being cut with electricity instead of steel.

According to James Spalding, CBC, Marketing Manager for Charmilles Technologies, "for gear manufacturers, the biggest advantage of EDM is unattended machining. A group of machines can be programmed and left to work."

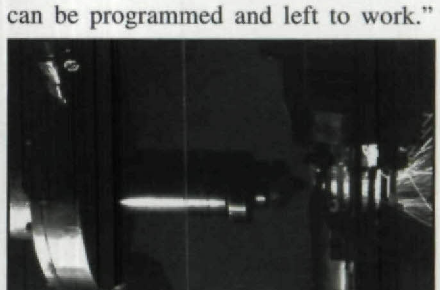

Fig. 2 — An LAI laser cutter in action.

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Fig. 3 — An LAI five-axis waterjet uses a 55,000-p.s.i. stream of water mixed with garnet abrasive to trim an aircraft screen panel made of titanium for Lockheed-Martin's new F-22 Fighter.

This translates into a savings in terms of labor because a machinist does not have to be present during the entire production cycle. Additionally, because the gears produced are near-net shaped, costly post-production machining can also be avoided. EDM can provide pieces with tolerances up to AGMA class 10 right off the machine.

Abrasive Waterjet. Abrasive waterjet, introduced to manufacturing in the early 1980s, has evolved into a versatile method for cutting and drilling any material and continues its rapid growth as a viable option for making gears.

"The technology's key attributes—flexibility, quick setup and simple tooling—make it a good match for making prototypes and small runs of custom gears," said LAI's Matt Kalina. "However, waterjet's dual head capability, quick cycle time and ability to produce an excellent surface finish (125 r.m.s. typical) also distinguish it as a feasible alternative for medium to large production runs."

Here's how abrasive waterjet technology works: High pressure water (50,000-60,000 p.s.i.) runs through a jewelled orifice ranging from .005 to .013 inches in diameter and into a nozzle ranging in size from .015 to .05 inches in diameter. The water stream creates a vacuum, drawing finely ground abrasive (i.e. garnet) into the nozzle's mixing chamber and out to make contact with the work material.

For gear manufacturers, the main advantage is the ability to cut a ready to use part quickly and, depending on the level of precision, at a lower cost per unit than conventional machining. It is frequently the method of choice since it typically produces burr-free edges without heat affected zones, can easily handle heat-treated materials, and, unlike lasers, can cut through stacks of materials to create multiple parts at the same time, saving money and time.

LAI has used abrasive waterjets to cut lapping machine gears from the difficult to machine G-10 plastic resin composite material; cut titanium rack and pinion components for commerical jet pilot seats; process phenolics into machinery gear components and cut spring steel into gears with tightly spaced teeth. According to Kalina: "Since abrasive waterjet machines can achieve tolerances of +/-.001 inches, depending on the thickness of the material, they can produce desirable characteristics in gears that do not require a high degree of precision, especially large gears since huge waterjet gantries can accommodate massive work pieces."

Alternative Ways to Form

These methods use dies to mold the metal into the desired shape. Casting and forging are both press work techniques using heat and pressure to form the final workpiece. Both are also near-net shape methods that leave little scrap metal and require little or no subsequent machining.

Casting. In its most basic form, casting is the process of pouring or injecting molten metal into a die, allowing it to cool, and then ejecting the finished or near-finished product. The major type of casting used in the gear industry today, for high strength and durability, is cold chamber casting.

Cold chamber casting begins with molten metal being ladled into the injection cylinder. A plunger pushes the metal into the closed die cavity where it is kept under pressure until it solidifies. The die is then opened, the piece is ejected and the plunger pushes the solidified slug from the cylinder.

One of the largest gear castings came out of Sivyer Steel of Bettendorf, Iowa. Their client, AmClyde, a manufacturer of mining and drilling platforms and machinery, needed a 62 foot diameter gear. It had to have a minimum ultimate tensile strength of 115,000 psi, a minimum 95,000 psi yield strength, minimum 14% elongation and minimum 30% reduction of area. Sivyer cast the gear in twenty segments, each 6 inches high by 6 inches wide by 117 inches long and weighing 1600 pounds using the cold chamber process. For the full story, read "A Huge Success" in the September/October 1995 edition of *Gear Technology*.

Forging. Forging can create stronger parts than casting or any other manufacturing method. The forging process is usually performed hot with the metal preheated to a desired temperature and then placed under intense pressure until it deforms and fills the die cavity. This can be done on a traditional press or by using dies mounted on rollers in a method pioneered in the old Soviet Union. The resulting part is referred to as a forging.

Forgings are used primarily as components in critical mechanical systems where great strength and durability are required. According to the Presrite Corporation, tests showed that forged gears last almost twice as long as conventionally produced gears. This great strength comes from the grain fiber structure of the metal following the outside contour of the part being forged into the forging's final near-net-shape. At the end of the forging process, there is usually only a small amount of metal around the teeth that needs to be ground off. Once that is done, the gear is finished.

Powdered Metal Forming. Compacting powdered metal into gears and other shapes is a materials innovation that uses powdered instead of molten or heated metals as in regular metal forming processes. The powder is usually a blend of metals which are compressed into a pair of dies at room temperature. This is usually followed by sintering, a process of heating the pressurized metal to just below the melting point of the base metal. Sintering binds the metal particles together, producing excellent tensile qualities which can be enhanced by further heat treatment.

Studies have been conducted comparing powdered metal gears to gears made by other processes. One such study, which can be found in the September/October 1995 edition of *Gear Technology* found that induction-hardened, sintered powder metal spur gears had slightly better dynamic tooth stress capacities than induction-hardened, melted steel spur gears but that for surface durability the steel gears were better. They also found that the steel gears, when they broke, would break suddenly, while the sintered gears would gradually weaken and break due to the porous nature of the material.

Fig. 4 — An assortment of gears forged by the Presrite Corporation.

Powdered metal compacting allows bevel, rack, face, spur, helical and compound gears to be made up to AGMA 8 standards with production rates of up to 1000 pieces per hour. Internal items like splines, keys and keyways can also be made to final shape with no post-press machining operations, eliminating scrap losses. Internal elements can be made simultaneously with the gear profile, again eliminating the need for subsequent machining and allowing an efficient use of dies and materials. All this makes powdered metal a popular alternative gear process with applications in the aerospace, automotive, home appliance and power and hand tool industries.

Exotic Alternatives—Chemical Etching and Microgears

Using chemicals to etch out gears is new. Developed originally for making integrated circuits, this technology is now being used at the Sandia National Laboratories in New Mexico to make experimental microengines, electric motors no bigger than a grain of sand.

The manufacturing process consists of laying down alternate layers of polycrystalline silicone (polysilicon) and silicone dioxide. Photolithography is used to set the patterns for the layers of the materials. Vias etched through the silicone dioxide provide anchor points between the mechanical layers and to the substrate. Finally, the silicone dioxide layers are etched away in a bath of hydrofluoric acid (HF), leaving a system consisting of one layer of polysilicon to provide electrical interconnection and one or more independent layers of polysilicon, which form mechanical elements such as gears.

Realizing that their electrostatically-powered microengines didn't produce enough power to actually do anything, the engineers working on the project went on to develop a microtransmission to provide their engine with a lower gear. So far, they have been able to put enough of these gears together to give their tiny motors 3,000,000 times the torque of the motor alone, theoretically enough power to move an object that weighs a pound.

The gears in the microtransmission assembly are similar to the gears on a ten speed bicycle with a smaller gear mounted concentrically onto a larger one. The transmission consists of a pair of these multi-level gears, the first with a gear reduction ratio of 3:1 and the second with a gear reduction ratio of 4:1 to give a total of 12:1. Twenty-nine such gears together give a remarkable gear reduction ratio of 2,985,984:1.

The first uses of these microengines and gears will be as safety devices on nuclear weapons as well as in the next generation of "smart" weapons, moving tiny reflectors to channel light through on-board fiber-optic networks and performing other high-precision tasks. Later applications could include implanted drug delivery systems, control systems for automobile airbags, adaptive optical

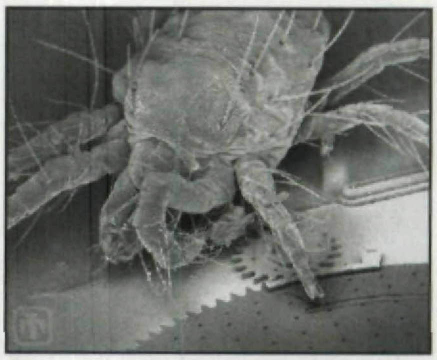

Fig. 5 — An electromicrograph showing a spider mite walking across microgears produced at Sandia National Laboratory.

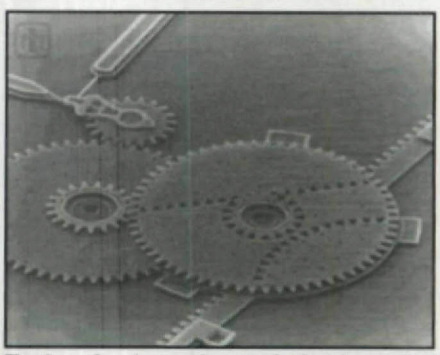

Fig. 6 — An electromicrograph showing part of the microtransmission built by Sandia National Laboratory.

technology, sensors for acceleration and rotation and as safety devices for conventional and civilian explosives. One major advantage will be ease of fabrication. According to project engineer Steve Rogers, companies will be able to download the basic transmission elements, and once they've done that, they can design as many as they need cheaply and easily.

Was the microtransmission able to move that one pound weight? According to Dr. J.J. Sniegowski, one of the inventors of the microtransmission, not yet. "The material isn't strong enough to take the strain and the gear teeth break," he said. " We are, however, experimenting with various methods to increase the strength."

Alternative gear processing is used to cut costs and waste and some techniques are better at it than others. Most promise to produce near-net shapes with little or no post production machining. With others some machining is necessary. Each, however, has its specific uses and produces gears with certain capabilities and applications and each has a place in the gear production marketplace.

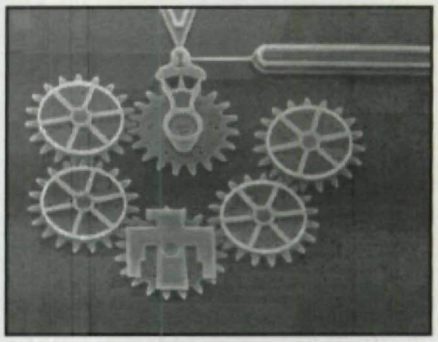

Fig. 7 — An electromicrograph showing six microgears. Sandia National Laboratory.

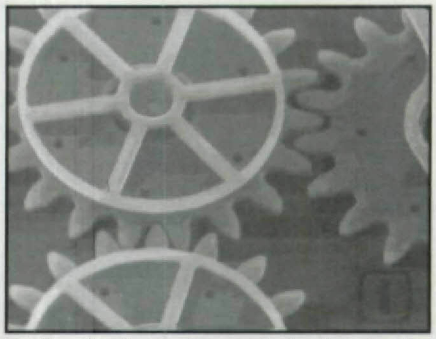

Fig. 8 — An electromicrograph showing showing details of the gears in Figure 7. Sandia National Laboratory.

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