Long-Life, Low-Cost, Near-Net-Shape Forged Gears

Years of research pay off for Presrite.

John Mullally

Near-net gear forging today is producing longer life gears at significantly lower costs than traditional manufacturing techniques. Advances in forging equipment, controls and die-making capability have been combined to produce commercially viable near-net-shape gears in diameters up to 17" with minimum stock allowances. These forged gears require only minimal finishing to meet part tolerance specifications.

"It's been a long, technically challenging process," advises Chris E. Carman, Operations Manager, Bessemer Division, Presrite Corporation, Cleveland, OH, but the effort has paid off in the development of a viable, cost-effective production technique for gears.

Carman cautions that near-net forging is not the process of choice for all gears. "Some small, fine-pitched gears aren't suited to this process yet," explains Carman, who has led the precision forging company's near-net gear development effort since 1989. His multi-disciplined engineering and production team worked in conjunction with a major off-highway equipment supplier to overcome the technical problems evident in early near-net gear forging attempts.

Fig. 1 — Forging dies are produced in-house from CAD programs on a precision wire EDM machine.

Fig. 2 — Near-net forged gears have an envelope of material around the tooth profile, which is removed by single-pass grinding.

Fig. 1

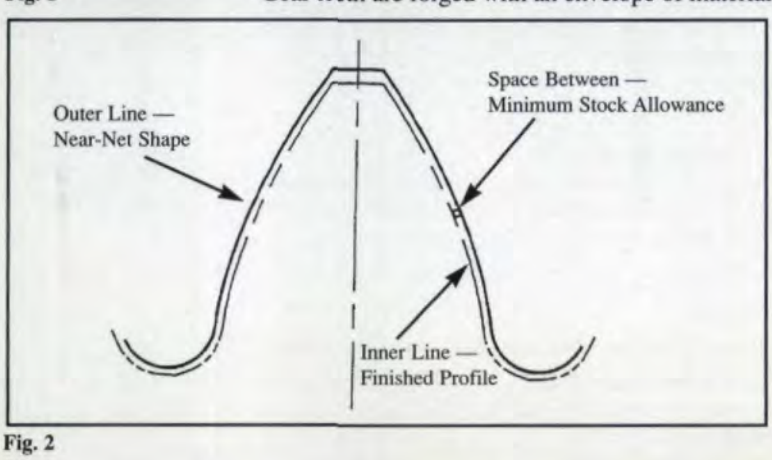

Fig. 2

What is "Near-Net"?

Near-net forged gears come from the forging press in almost the exact shape of the finished gear. Gear teeth are forged with an envelope of material around the tooth profile, unlike near-net blanks, which are forged cylinders into which the teeth must be cut by hobbing. Near-net gears have teeth forged with a thin envelope of excess steel, which is removed by single-pass grinding, resulting in a finished gear that is more accurately machined than if hobbed and shaved.

Straight bevel, spiral bevel, helical and spur gears have been produced with the new forging process. Maximum diameter for the forged gear is under 20". Most production gears are within a range of 3–17" in diameter, limits determined by current press and processing equipment capacities.

Lower Net Cost Gears

The driving force behind the effort to develop a commercial near-net gear forging process is cost reduction. In theory, the near-net forging process reduces work-in-process and eliminates the need for some specialized, high-cost capital equipment, expensive expendable tooling and high labor rate machining steps.

Because the near-net process produces a gear shape complete with teeth, no rough and finish hobbing is required. Instead, finish hobbing, shaving or grinding can be used. Grinding speeds product flow through the manufacturing process and avoids the cost of specialized shavers and attendant high labor rates. The increase in product throughput reduces the amount of work-in-process and shortens delivery times.

However, putting this theory into practice proved very challenging. Initial attempts in the early 1990s produced excessive scrap, high tooling costs, short tool life, high cycle and poor delivery times.

However, notes Presrite's Carman, the potential benefits of the program could be seen through the challenges as the technical problems with the process became more clearly defined. This definition helped plot the path to correcting the process deficiencies at each step.

Early Benefit

Despite production problems, one benefit of the forging process became quickly apparent—

Fig. 3

Fig. 3 — Presrite is able to near-net forge a variety of gear shapes, including straight bevel, spiral bevel, helical and spur gears, in diameters up to 17".

Fig. 4

Fig. 4 — A fully equipped gear lab checks dimensional accuracy of near-net gear forgings using a Zeiss coordinate measurement machine (CMM).

longer life gears. Customer-run B-10 gear life tests of the forged gears showed them to have almost double the world average field life of a conventionally produced gear.

This long life is attributed to the lack of stress induced into the gear as it is forged. A forged gear has improved mechanical properties because of the consistent, unfractured grain structure of the forged steel. Furthermore, the steel is stable with the workpiece kept under 2200°F, reducing heat distortion. The elimination of traditional gear cutting reduces machine stresses, resulting in a more stable heat-treated product.

Although these finished gears performed exceptionally well, the manufacturing process was having development problems. Early forging scrap rates approached 20%. Forging die life was only 20% of a projected number of parts per forge setup.

"What near-net gear forging forced us to do," explains Carman, "was to tighten our traditional production forging tolerances by 400%. That was a challenge."

This forging tolerance improvement was required because of the one-step finishing process for gears. The forging process had to meet the minimal allowable stock envelope to match the capabilities of the grinding process, which also posed challenges. An early manufacturing cell producing forging and finish-ground gears generated scrap rates in excess of 25%. Grinding tool life was much less than anticipated, nearly tripling projected grinding costs.

Evolutionary Development

Equipment and tooling development were the initial targets of the Presrite team. The first major step was the shift from forging hammers to forging presses. "Presses make the forging process much more repeatable than hammers," notes Carman.

To take advantage of the repeatability of the newer presses, new controls had to be developed. "These controls had to be developed in-house, because they aren't available from forging press manufacturers," says Carman. "With them we brought the forging process from the 1940s right into the 90s with one step."

The problem of very short forging die life also had to be resolved. The design of this precision tooling was completely revamped with the addition of an in-house die design and manufacturing capability. Presrite introduced CAD and CAM to this function, which reduced design time and provided wide gear design flexibility.

For cost-efficient die manufacturing, the forger installed CNC W/EDM machines to tighten repeatable die tolerances and reduce tooling costs. "You have to have hands-on control of the die making and design to make this precision operation cost-efficient," states the development team leader.

To extend the life of the finished forging dies, Presrite engineers investigated a variety of die materials and coatings, including titanium and carbide, to find the right combination.

Another area that drew engineering attention was billet heating prior to forging. Carman notes that consistent, repeatable billet heating is critical to the process. With new controls and a switch to electric induction heating, billet heating is controlled to +/-25°F just prior to forging.

Attitude Adjustment

"A gear is a lot more than just a forging," admits Carman. In addition to the equipment and process changes to traditional forging operations, new people with new talents and perspectives were required. "You need 'gear people' involved in this forging process if it's going to be successful."

The specialty talents brought into the forging operation include gear designers and specialty gear quality technicians who understand gear technology and can use precision, gear-specific testing and quality control equipment in a dedicated, in-house gear lab.

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Fig. 5 — Precisely sawn and surface-improved billets are induction heated to about 2,100°F in preparation for the forging process.

Fig. 6 — A single stroke of the forging press produces the near-net gear profile with an engineered minimal stock allowance ready for grinding to final profile.

Fig. 6

The Process

Manufacturing begins with steel bar stock, usually turned and polished to improve the surface. Surface-improved billets are cut to exact weight. Because this process utilizes a "closed die," the weight is critical. The amount of steel must completely fill the die to produce the complete gear profile. However, the amount cannot be excessive or severe die damage may result.

The billets are heated in an electric induction furnace, and in a single stroke, standard mechanical forging presses in the 1000T–6000T range form near-net-shape gears with the complete allowable material envelope.

Mechanical presses provide the controllability required for process repeatability. The controls include a force monitoring and control system. With the addition of new controls, PLCs and other monitoring equipment, the process can be consistently repeated with minimal process variance.

Forging dies are designed and manufactured in-house as part of a concurrent, near-net gear design program.

A dedicated, climate-controlled gear lab is also essential to the die design and gear production process. Located within a 200,000 sq. ft. gear forging complex, the lab is responsible for quality audits for both gears and dies.

A Zeiss Model #UMM 550/500/450 coordinate measurement machine (CMM) runs custom programs developed by the customer/partner to provide dimensional analysis of forged dies and gears. Dies are checked before and after press runs and gears are checked during press runs to provide part deviation tracking.

Cost-efficient manufacture of forging dies, maintains Carman, can only be accomplished with in-house CNC machine tools. Having the capability in-house provided both cost and quality controls. He also cites advances in CNC controls for W/EDM machines for making the physical manufacturing of the forging dies both possible and economically reasonable.

Post-Forging Operations

The raw forged gear is hydraulically ejected from the press and allowed to atmospherically cool to ambient temperature.

To assure a complete and consistent allowable material envelope and provide a surface compatible with efficient finish grinding, the forged near-net gear is cold drawn through a finish sizing die. This die is also designed and produced in-house by Presrite.

The forged gears are then finish ground. Efficient precision finish grinding techniques for near-net gears have been developed by grinding wheel manufacturers working with machine tool builders. These grinding techniques make significant contributions to the cost efficiency of near-net-shape forged gears.

Production Reality

It's been a long, complex road at Presrite, but the effort has been worth it. Based on actual gear production, near-net-shaped forgings produce gears of longer service life at a lower cost per gear than traditional cutting techniques. Says Chris Carman, "Near-net-shape gear forging is a production reality and the low-cost production technique for most gear types." ○

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