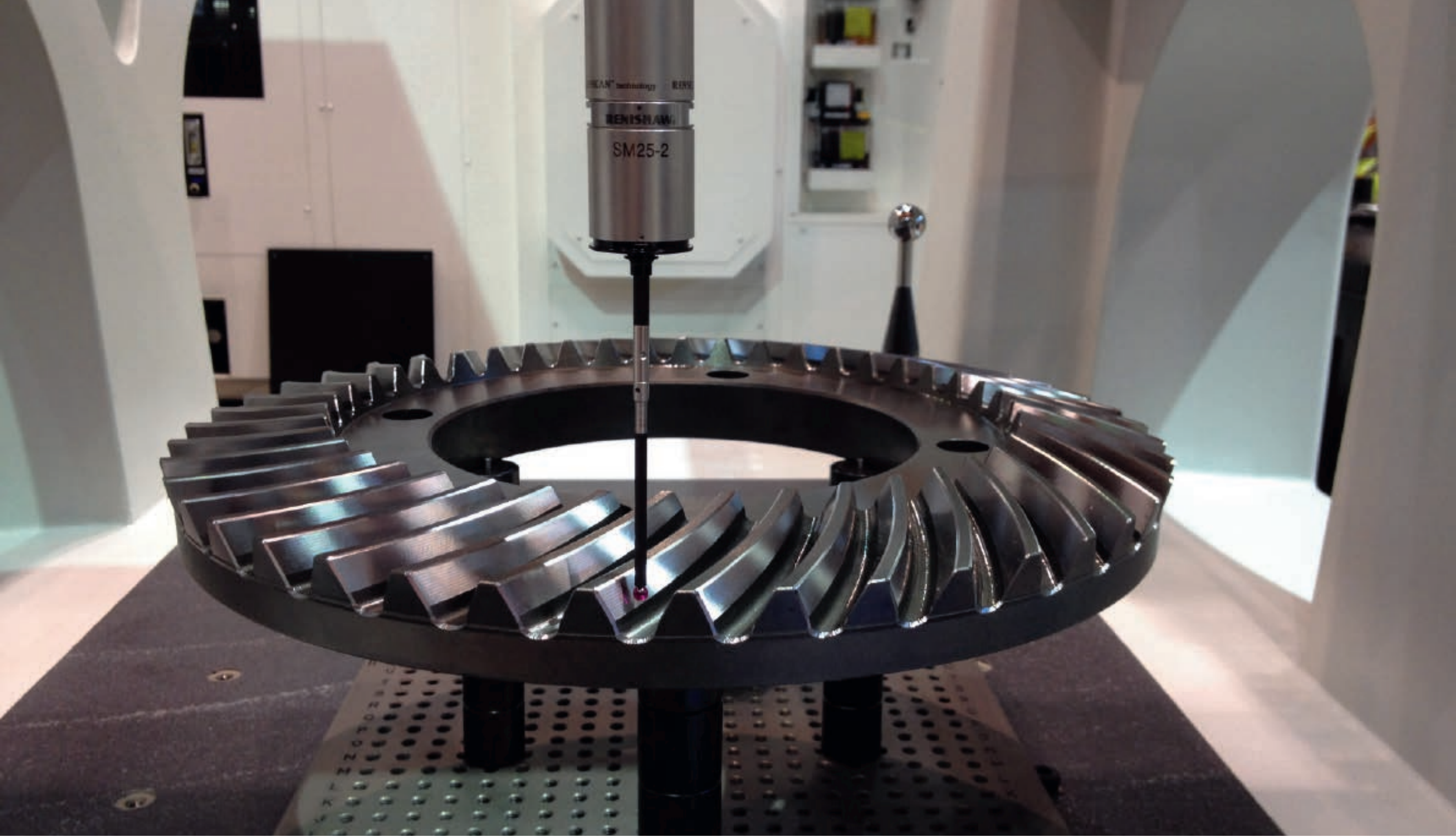

Figure 1 Surface Data Collection of Hardened Spiral Bevel Tooth Flanks on CMM

Past gear manufacture was expensive utilizing dedicated equipment. CLGM is a new way to make gears and control gear production.

Closed Loop Gear Machining (CLGM) – 5 Axis CNC Gear Process

Most gears require dedicated machines and tools for design, manufacture and inspection. Improvements in modeling and CNC machining accuracy eliminate this requirement, increasing flexibility and reducing cost.

- Dr Mike Fish, Director and Rich Easley, US Business Manager, Dontyne Systems
- Mike Finn, Applications Development Engineer, Mazak Corporation

Historical Gear Manufacturing Processes

In the past a gear development and manufacture process was, in many ways, considered "black magic". Only a select few gear engineers, working with highly specialized and expensive software and equipment, could develop the processes necessary to produce gears with certainty. Nearly every phase of the process required specialized equipment and/or software: the initial design, cutting of teeth, part finishing and final part inspection. This equipment is generally expensive, inflexible and leaves the manufacturer dependent on outside sources for much of the tooling and overall process development. In addition many of the processes need to be completely re-developed, taking many months and significant expense, when a new or different part is manufactured.

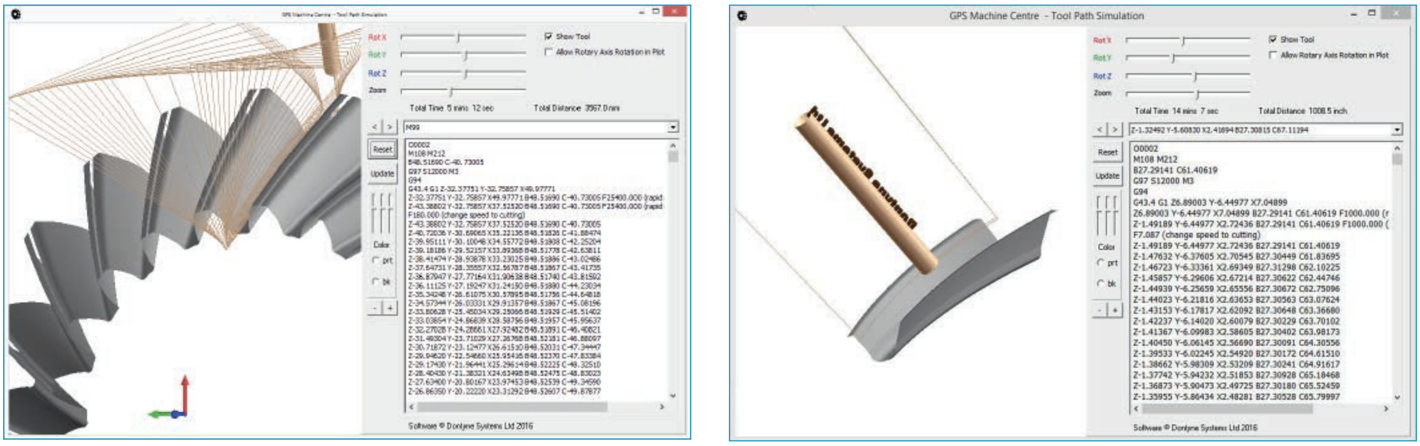

Figure 2 Toolpath Simulation of Spiral Bevel Gear

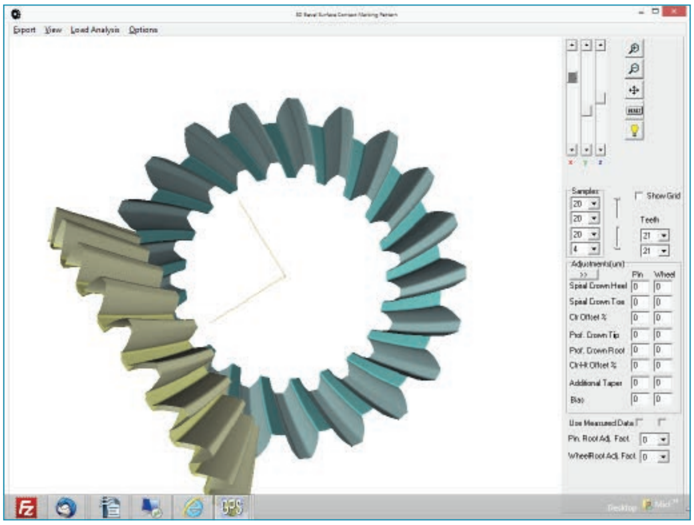

Figure 3 Spiral Bevel Miter Gear Set

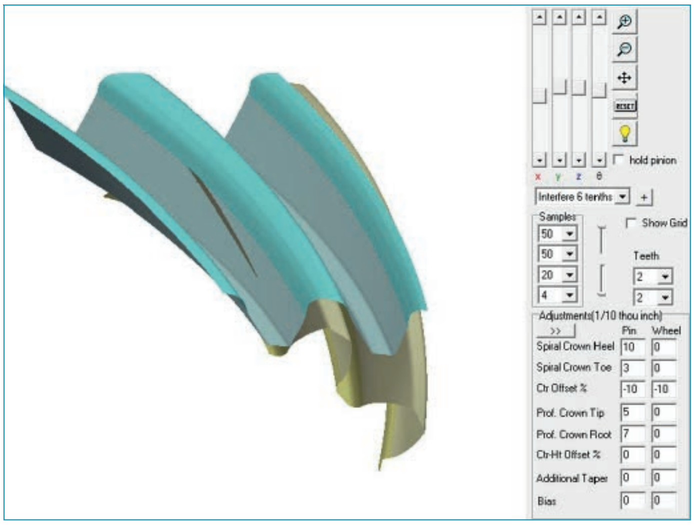

Figure 4 Tooth Contact Simulation

Over time, many gear manufacturers have looked to increase their manufacturing flexibility by better simulating part operation in the development phase, utilizing multi-task machines to minimize part movement and processes, implement standard end mill tooling and feedback part inspection data for comparison to the simulated initial design. The closed loop gear machining process (CLGM) developed by Mazak and Dontyne Systems enables gear manufacturers to design, manufacture and inspect gears to these expectations.

What Is CLGM?

The CLGM solution enables clients to use 5 axis multi-tasking CNC machine tools to accurately cut gears. The upfront software functions include integrated graphics and industry standard (AGMA) engineering reports that enable a gear manufacturer to simulate how gear sets make contact, or conjugate, for different real life applications. Of particular interest to gear designers and manufacturing engineers is the contact marking pattern- the real life application of the gear set conjugation.

With CLGM the gear is designed and set conjugation evaluated and optimized in the software, the G-Code is created and the gear is then cut on a 5 axis CNC machine, the part is measured on an accurate CMM, the measured data is then compared to the original design and evaluated for acceptable conjugation. If the part is deemed to be within acceptable tolerance, the part is complete and production moves forward. If the part is deemed out of tolerance, due to tool deflection or other small manufacturing variation, corrections to the manufacturing model are made, the G-Code is re-calculated and the part recut to design.

Currently the software products sit offline of the CNC. All design, analysis, simulation and marking pattern definitions are made prior to the G-Code being posted on the machine. Inspection data is collected, imported back to the software for manufactured versus design part test/evaluation and the G-Code is then updated and reposted to the machine, if required, based on the inspection data results. Dontyne Systems expertise in modelling gear systems means that factors other than geometric accuracy can deem if the part is acceptable such as surface stress or transmission error level.

Design Phase

In the design phase the engineer can quickly design a new gear – or recreate a design to a gear that is currently in production. To recreate a gear the designer would import inspection data from a master part and check the mathematical model being used to generate the 3D gear surface. This is important to verify that any corrective settings give the desired effects. This creates the gear design including the definition of geometry and the rating of gears to ISO and AGMA standards, including tolerancing.

After the design is complete a load analysis is done to add surface modifications and to check that the design is correct under load. This also models deflections for examining performance with manufacturing or alignment errors. The evaluation uses measured data to assess whether the current surface condition is suitable under load.

The final design step is to calculate the cutting path for the CNC machine (machine and tool database), based on the design data. The result is G-Code to post on the CNC machine for a single gear tooth which can be looped to cut all of the gear teeth.

Figure 5 Hardmilling of Spiral Bevel Gear Carburized to 55 HRc on MazakVC500 5X

Part Manufacture

In most cases, with the use of a 5-axis Multi-Tasking CNC machine, the gear can be machined complete from the raw material using standard tools such as end mills and ball mills. The gear tooth cutting toolpath is combined with the cutting codes required for part manufacture. The benefits of machining the part complete on a single platform are reduction of setup time, reduction of work holding and improved accuracy.

Because all machining takes place on a single setup, the datums (bores, back faces and bearing diameters) and the gear pitch circle/cone have minimal runout with each other thus improving quality. Dontyne software gives control of the G-Code toolpath allowing the precise amount of stock on the flanks for hard-milling up to HRc62 after heat treatment.

Trials on Mazak Multi-Tasking machines have shown flank surface lead, profile and pitch accuracy to be Grade 10-12 per AGMA-A88 directly from the Dontyne export G-Code.

Tooth cutting cycle time on multi-axis machines is often stated as a major drawback. However, this is offset by including the entire machining process from turning the gear blank, to drilling bolt hole patterns and milling slots. This dramatically increases the break-even batch size relating to time up to 500 pairs with the added benefit of complete flexibility in design change.

Unlike dedicated gear cutting machinery, the tooth geometry is not limited by the cutting tool. Using common end mills and ball mills along with 5-axis motion, various types of gear teeth can be cut on a single Multi-Tasking machine ranging from spiral bevel and double helical to spur and straight splines. This flexibility is useful in a R&D and prototype environments.

Part Inspection, Feedback and Correction

Upon completion of the part machining, it is inspected on an accurate CMM machine. This inspection data can be compared to the measured data from the master part, as well as fed back to the inspection center module of the software. This link of the measuring system data to the design data provides 3D surface deviation reports and standard reporting to ISO and AMGA standards profile/lead/pitch/run-out. This 3D surface model data is then further evaluated by comparing the measured data of the actual finished part to the theoretical design part. The comparison data is then used to edit and update the original 5 axis paths for the gears and tools to improved accuracy if necessary. This corrected data is then output in G-code back to the machine to recut the corrected part- essentially closing the loop. A final inspection is then done to verify that the part is manufactured as designed.

Conclusion

Recent improvements in precision machine tool performance, computer simulation and modeling capabilities have enabled Dontyne and Mazak to develop a CLGM process for innovative gear manufacture. The CLGM process is currently being evaluated by several aerospace, automotive and other gear manufacturers to increase their manufacturing flexibility. The process has been used for both new and existing gear part manufacture.

CLGM helps satisfy increasing gear market trends demanding greater flexibility, rapid changeover speed, less special tooling, affordability and accuracy, which can now be achieved by performing all cutting operations on a single machine. Mass production requirements to feed dedicated gear equipment is no longer viable for many manufacturers. The utilization of realistic load simulation, flexible machining and accurate inspection feedback gives gear manufacturers new options to maximize the efficiency of their production machinery and processes.

More Information:

www.dontynesystems.com/
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