Carbide Hobbing Case Study

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Introduction

Bodine Electric Co. of Chicago, IL, has a 97-year history of fine- and medium-pitch gear manufacturing. Like anywhere else, traditions, old systems, and structures can be beneficial, but they can also become paradigms and obstacles to further improvements. We were producing a high quality product, but our goal was to become more cost effective. Carbide hobbing is seen as a technological innovation capable of enabling a dramatic, rather than an incremental, enhancement to productivity and cost savings.

Nowadays, no one denies that carbide hobbing is feasible. Many questions remain, however, regarding the best applications, carbide material, hob sharpening, coating and recoating, hob handling, hob consistency, optimum hob wear, best cutting conditions, concerns for the initial cutting tool investment and production cost. In short, "the devil was in the details." The industry had few, and sometimes conflicting, recommendations on these details. This is why many companies, manufacturing in small to medium lot sizes, have not rushed to implement carbide hobbing. Also, some companies tried and then abandoned this technology altogether.

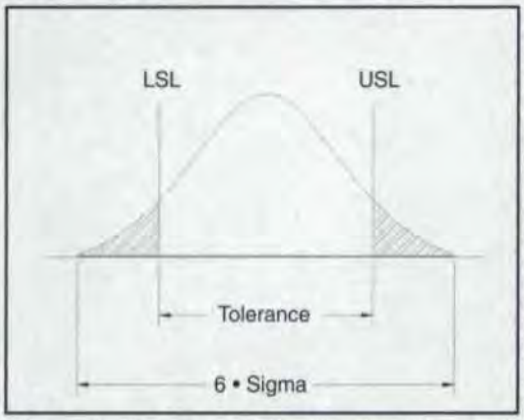

Figure 1—Process variation for the "flat gear" family was out of control.

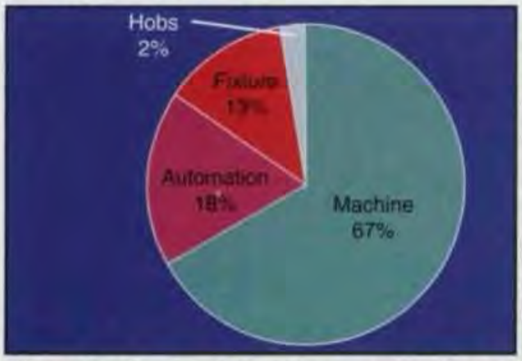

Figure 2—Cost breakdown by percentage for new carbide hobbing cell.

This article is a case study featuring one manufacturing cell solely implemented with carbide hobbing technology. The annual output is 250,000–300,000 gears, with an average just-in-time lot size of about 200–300 gears. Approximately 150 different sizes and pitches are produced, with an average of four setup changes over two shifts. Most of the gears are finish hobbed to AGMA 9 quality level. The pitches range from 12–64 DP.

The successful performance of carbide hobbing is predicated on various contributing factors, such as machine, fixture, blanks, hob maintenance, and process management systems. These factors will also be discussed.

Application and Historical Perspective

Bodine Electric produces a large variety of parts with gearing elements—spur and helical gears and shafts, solid- and bore-type pinions, worms, and worm gears. For the introduction of carbide hobbing, we decided to select the "flat" gear family because of its large volume.

Machines. Initially, we had only outdated hobbing machines in the flat gear cell. The average machine age was 20 years. The use of longer- and higher-performance hobs was limited by the machines' rpm and shifting capability. Only two (out of five) hobbing machines had an automatic shifting feature. There was not precise control on hob positioning relative to the workpiece or the hob shifting distance. These machines were in constant need of maintenance.

Fixturing and Automation. Only two machines in the cell had automatic loaders. Fixturing and automation documentation was not readily available. Some of the fixture items were reverse engineered and not always compatible with each other. Our company relied mostly on the experience of setup people. This led to a wide variation in setups, fixture, and cutting conditions.

Cutting Tools. A long-standing tradition in fine-pitch gear manufacturing was the use of so-called "square" hobs made out of high-speed steel (HSS). Use of carbide and longer hobs was limited by each machine's rpm capability and shifting length, respectively.

Cutting Conditions. Our practice was to use very conservative cutting conditions that were outdated. Different machines had different limitations with respect to rigidity and rpm capability. The performance of each machine was not monitored. The cutting conditions and cycle times could vary depending on the setup person, machine, inspection results, and cutting tool used at the time.

Blanks. All blanks were outsourced. The suppliers would grind one face of the gear blanks, enabling us to stack three to five parts per load during the hobbing process. Despite this effort, the bore's quality and face parallelism were inconsistent.

Outsourcing. In addition to five machines making flat gears in-house, we were outsourcing hobbing and skiving at an annual cost of $281,000. Adding to that the annual blanking outsourcing of $563,000, our total flat gear outsourcing cost came to $844,000. Other concerns with outsourcing were quality and on-time delivery.

Quality. The flat gear process variation was out of control, as shown on the graph in Figure 1. Although we had extremely knowledgeable people who were able to produce quality parts despite using old technology, many setups would turn into development projects, which took its toll on our productivity and profitability.

The high quality of the product was maintained at a cost. Extra, non-value-added steps of 100% inspecting and sorting were necessary. In short, the cost of flat gear manufacturing was high. We wanted to improve the process and replace "product control" with "process control."

Productivity. Cycle times were very long. Frequently, to achieve the desired quality, setup personnel would use more conservative cutting conditions, thus further increasing cycle times and reducing productivity. On average, there was less than one setup per machine per day. The inexpensive, conventional, off-the-shelf "square" hobs had to be re-sharpened quite frequently, thus disrupting production flow. Lean manufacturing stresses the importance of just-in-time manufacturing and continuous reduction of work-in-progress. This leads to smaller lot sizes and greater setup frequency per day.

In summary, we had an abundance of opportunities:

Figure 3—New CNC hobbing machine.

Quality Improvements
- Process capability improvements.
- Further tightening of the tolerances to produce a higher quality product.

Productivity Improvements
- Reduce cycle times and increase production with the same number of people.
- Reduce setup time.
- Reduce process debugging time.

Cost Improvements
- Cost reductions as a result of productivity improvements.
- Lower cutting tool cost per gear or keep it the same as HSS.
- Reduction in rework cost.

Additional Capacity
- Skiving Capabilities.
- Reduction in outsourcing.

Considerations for New Technology

We could have benefited by improving the process in small incremental changes. Some examples are reworking the machines, buying better cutting tools, improving the fixtures, buying better blanks, and even stressing greater control of our processes. These would have all brought some semblance of success.

Nonetheless, we felt that we needed drastic, rather than incremental, improvements to bring the process under control and achieve cost reduction. This is why we decided to blow up everything, investigate new carbide hobbing technology, and bring a new spirit into the factory.

At the same time, we wanted to bring in technology that would work from the onset. We wanted to be conservative in our estimates, making sure that there would not be excessive process

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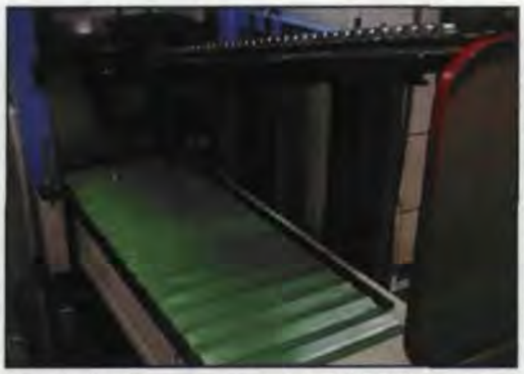

Figure 4—New system included flexible automation with gantry loader.

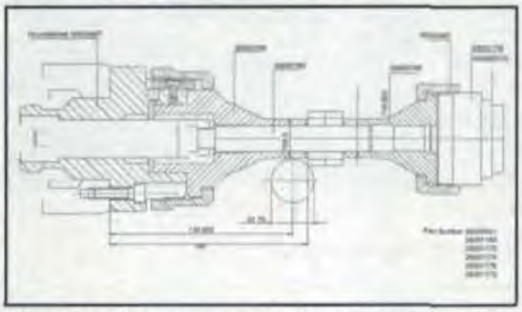

Figure 5—Precision quick-change, face-clamping fixture for clamping more than 150 types of parts.

debugging. So we decided that a test would be the ideal first step toward a successful implementation of new carbide hobbing technology.

Hobbing Test

Test Objectives

• To learn more about potential challenges.

• To understand the pros and cons of carbide hobbing as applicable to our pitch and size ranges.

• To have the process debugged prior to purchasing the machine.

• To specify the machine acceptance criteria based on challenges experienced during testing.

• To compare machine suppliers.

• To start developing carbide hobbing support systems.

We anticipated a need for a better engineering support system as well as a simpler, more disciplined process monitoring system that would give us reliable feedback. We knew that after the major investment, the flat gear cell would be scrutinized.

Test Findings & Potential Challenges.

• This is an emerging technology, although it started 30 years ago.

• Many tried but abandoned carbide hobbing.

• Greater engineering support will be required.

• There was no industry consensus on recommendations.

• The mistakes are much more expensive.

• The tool cost per gear was an unknown factor.

• The initial cutting tool investment is much greater.

• We found three vendors all capable of achieving our tighter quality requirements.

• The selection was based on business reasons rather than technical reasons.

Dry or Wet—That Was the Question. We tested both wet and dry hobbing. Eventually, we selected the wet process because we felt it was a safer approach to the introduction of new technology. At that time, our perception was that dry hobbing required more engineering involvement and R&D. Each pitch and size had to be tested and fined-tuned for optimum hob geometry and cutting conditions. The machine was to be placed in a gear-manufacturing cell that was producing more than 150 different sizes and pitches. So, the testing and development of every part could become quite overwhelming. Also, we experienced less tool wear with wet carbide hobbing. Nevertheless, we acquired a dry hobbing option. This was just in case the process is further developed and better information about dry hobbing becomes readily available.

Best Carbide Hobbing Applications? It seems that the fine- and medium-pitch finish hobbed gears are the best candidates for the carbide hobbing technology. The finish hobbing feed rate is restrained by the feed scallop limitations; thus, productivity improvements cannot be achieved by increasing the feed rate. Another option for productivity improvement—multistart hobbing—cannot be employed for precision hobbing either. The only viable option for productivity improvement was increasing the hob speed.

Support Systems Needed. We came to the conclusion that in-depth engineering support systems would be needed for successful carbide hobbing. Mistakes with carbide hobs cost much more than they do with traditional HSS hobs.

Those systems would include:

• Database with simple means of extracting setup data for every part.

• Ease of database maintenance.

• A detailed hob monitoring system, which is unprecedented in a production environment.

• Detailed production and value-added monitoring.

New Hobbing Technology

The Initial Investment. After conducting tests and selecting a vendor, we purchased the equipment with cost distribution as shown in the graph in Figure 2. The total package included machine, automation, quick-change fixture, and carbide cutting tools. In addition, we purchased a new turning machine and developed corresponding support systems.

New CNC Hobbing Machine Highlights (Fig. 3).

• 8 CNC axes, including gantry.

• Higher cutting speed available.

- Longer hob shifting capability.
- Capable of wet and dry hobbing.
- Hydraulic hob arbor clamping.
- Skiving capability.
- Flexible Automation with Gantry Loader (Fig. 4).
- Six seconds load/unload.
- Capable of handling both bore- and shaft-type parts.
- Large unload storage capacity.
- CNC controlled loader positions.

The Fixturing. Because the fixture quality is critical to process capability, we acquired a precision, quick-change, face-clamping fixture (Fig. 5). The fixture had a modular design for more than 150 parts. The design was also based on the consideration of clamping the parts as close as possible to the cutting action. At most, there are three fixture items that need to be replaced when changing over from one part to another: backing, clamping and arbor.

The number of parts per load was reduced to two. CNC hobbing diminishes the effects of stacking gears per load because: a) a higher feed rate can be used during the hob approach travel, and b) the load/unload time is minimal. Incidentally, a smaller number of parts per load improved the gear quality. All fixture drawings were computerized and became a part of setup documentation.

The Blanks. A turning process was developed on a newly purchased CNC lathe. It provided 0.0002–0.0005" face parallelism and bore-to-face perpendicularity. This kind of turning quality eliminated the need to grind gear faces. In fact, the blank quality coming out of our CNC lathe was more consistent than our outside-purchased blanks having the one face ground.

The new turning machine also made it possible to tighten the tolerances of the bore size. The lathe was strategically placed next to the CNC hobbing machine to enable one-piece flow.

Carbide Cutting Tools. We started with K-grade hobs and TiN coating (Fig. 6). However, in addition, we purchased a few P-grade hobs with TiAlN coating (Fig. 6). Carbide hobs were run at 600 surface feet per minute (SFM) of circumferential speed. The feed rate was just as conservative as in the case of HSS hobs. The conservative feed rates were necessary because of feed scallop depth limitations. The first peek at the carbide hob life provided impressive results. The first run resulted in 765 parts without a hob change. Making 3.4 times as many gears meant that the tool cost per gear would be approximately the same as in the case of HSS. We were glad that we were able to reduce the cycle time threefold while enjoying approximately the same tool cost per gear. (Note that carbide hobs were three to five times more expensive when compared to traditional "square" HSS fine-pitch hobs.) However, we continued to use the same hob. Before we sent it for sharpening, we achieved the hob life improvement of elevenfold (2,639 gears) as compared with HSS "square" hobs.

Figure 6—K-grade, TiN-coated carbide hob (left) and P-grade, TiAlN-coated carbide hob.

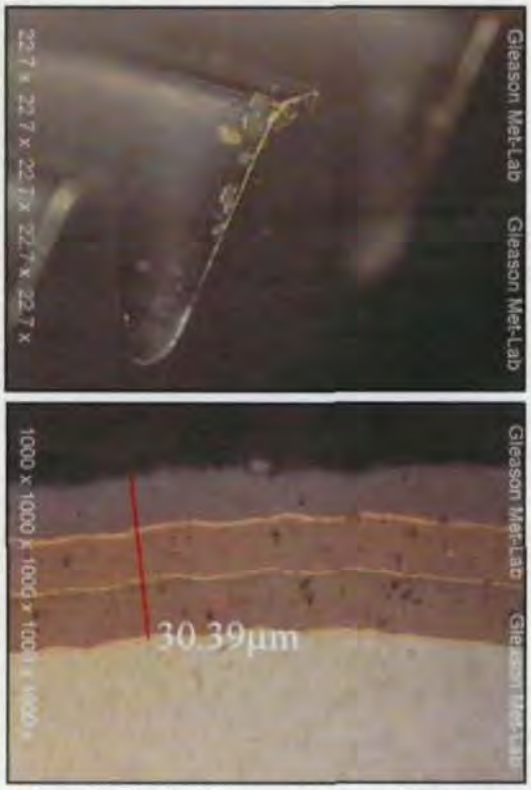

Figure 7—Coating fractures can contribute to poor hob performance. Multiple coating layers chipped on the outer surface (top), while the lower coating layers have remained intact (bottom).

After the first hob sharpening, we realized there was work to be done in mastering this technology. Lesson #1 learned: Without recoating the hobs, they failed miserably. We also learned that, with respect to the cutting tools, our limited initial test provided few comforting answers. Recommendations from hob suppliers and machine builders continued to be inconsistent and, at times, even contradictory. We still had a lot of questions. Should we use P-grade or K-grade? What was the best coating for our application? What was the

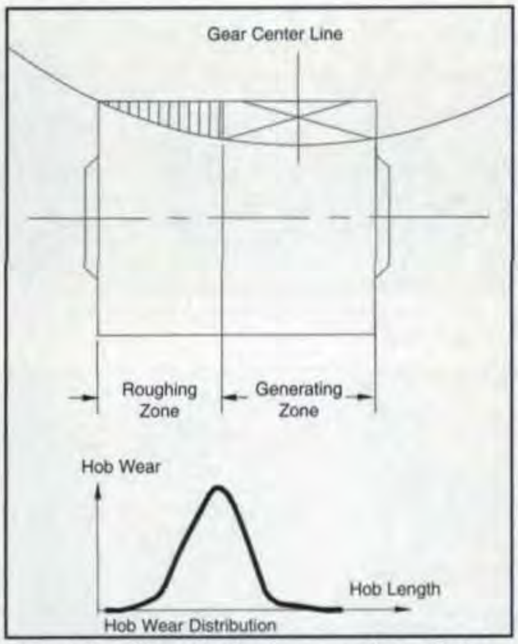

Figure 8a—Wear distribution on a shorter hob.

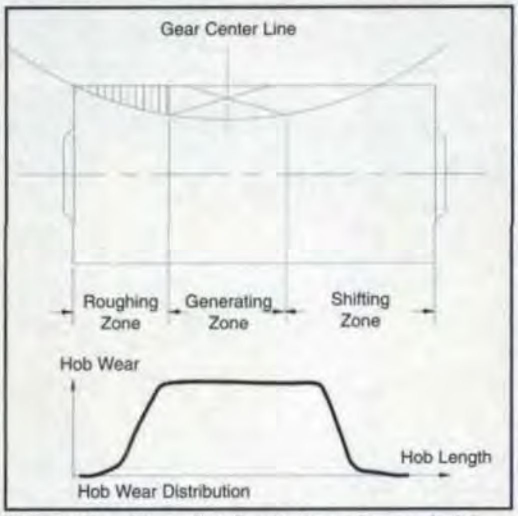

Figure 8b—Wear distribution on a longer hob.

optimum wear? What were the sharpening nuances (i.e. edge preparation)? When was the right time to strip the coating, and was it possible? What was the hob life and tool cost per gear? Was there any predictability in carbide hobbing?

Figure 7 is an example of one of the many challenges that we experienced. Coating fractures can contribute to poor hob performance. Coating on the illustration is breaking away from the tool. Close inspection within these areas reveals multiple coating layers that chipped on the outer surface, while the lower coating layers have remained intact.

Layer Buildup. Each coating is approximately 0.0004" thick. The top layer is a single layer of TiAlN. Underneath that are two layers of Futura coating, each composed of 27–35 alternating sublayers of titanium nitride (TiN) and titanium aluminum nitride (TiAlN). The yellow lines between layers are TiN. The light-colored substrate is seen near the bottom of the illustration.

We have yet to find overall consistency in hob performance. Although the greatest performance factor is probably how people use the hobs, other contributing factors are sharpening, coating quality, and the ability of the coating layers to stick to the previous layer.

Every single carbide hob has a history worksheet. Currently, we have more than 80 carbide hobs that service our flat gear cell. Every time the hob is used, the setup people record the date, the gear number, and the number of gears hobbed. The rest of the worksheet is calculated automatically. One of the important characteristics is material removal per cutting edge of the hob.

Hob Length Significance. In addition to changing the hob material to carbide, we introduced longer hobs. This further reduced the cutting tool cost per gear and reduced downtime caused by hob changes because longer hobs make more gears per sharpening. Conventional thinking implies that the improvement would be proportional to the hob length increase.

However, in reality, the improvement is proportional to the shifting increase. Figures 8a and 8b show the load and wear distribution on short and longer hobs. Short hobs may have little or no shifting length available. Frequently, a small hob length increase can result in manyfold hob performance improvements.

Cutting Tools Cost Reduction. A conservative estimate of per-gear tooling cost reduction is close to threefold (Fig. 9).

Support Systems

To understand and maintain the carbide hobbing process, our company introduced a system for monitoring process performance. A setup database was created to include all process documentation, such as fixture, cutting tools, gear parameters, cutting conditions, cycle time and other necessary setup information. For every setup, the database query creates a single sheet of paper with the latest setup information.

The original tooling has been expanded to process more than 180 different part numbers. Machine part programs are backed up periodically. Fixture and automation change parts are stored in a clearly marked storage area adjacent to the machine. As was mentioned before, every hob has a worksheet with a history of usage, sharpening, and recoating. Figures 10 and 11 demonstrate productivity over a three-month period.

Improvements Summary

Productivity Improvements. Major productivity improvements were realized due to carbide hobs having speed capabilities three times higher than HSS hobs. Other factors contributing to the productivity improvements were setup time reduction, CNC-controlled hob travels, more consistent setups and cycle times, a drastic reduction in process debugging time for lead/involute/runout problems, and precise calculations of hobbing cycles and goal setting.

Despite all of the challenges with carbide hobs, the productivity improvement made it possible for us to replace four machines. In addition, we increased production by in-sourcing all gear hobbing and skiving, with a $280,000 annual volume.

Quality Improvement. Prorated annual scrap savings was $47,000 as compared with three mechanical pinion cells using old machines and HSS cutting tools and producing approximately the same amount of parts (Fig. 12).

Other cost improvements resulted from process capability improvements. Figure 13 shows that the six-sigma process variation became smaller than the tolerance due to improving upon all of the process variables: new machines that were statistically evaluated for the process capability during the runoff, AA quality cutting tools, precision fixtures, better quality blanks, ISO-compliant quality systems, and having setup and cutting parameter consistency. The improvements in the process capability made it possible to reduce the inspection and rework expenses.

In closing, the investment in new carbide hobbing technology made us look at our operation under a microscope and improve upon other contributing factors that lead to successful gear manufacturing. These are fixtures, machines, cutting tools, blanks, and quality systems. The results are better quality gears at a lower cost. O

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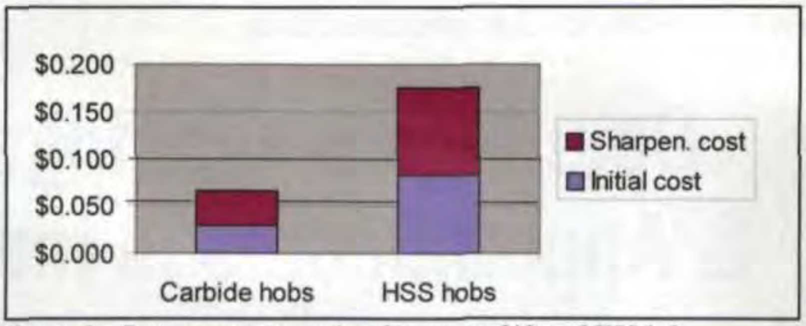

Figure 9—Cost-per-gear comparison between carbide and HSS hobs.

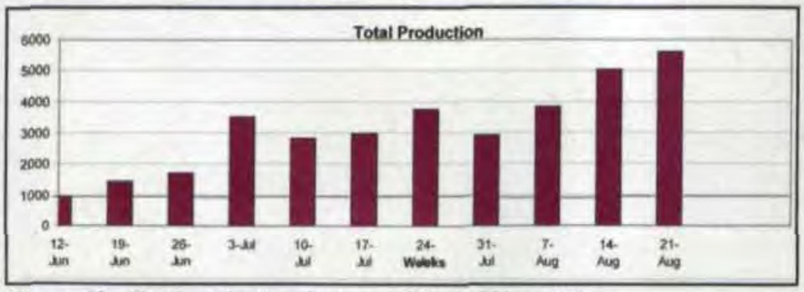

Figure 10—Total production during carbide hobbing trial.

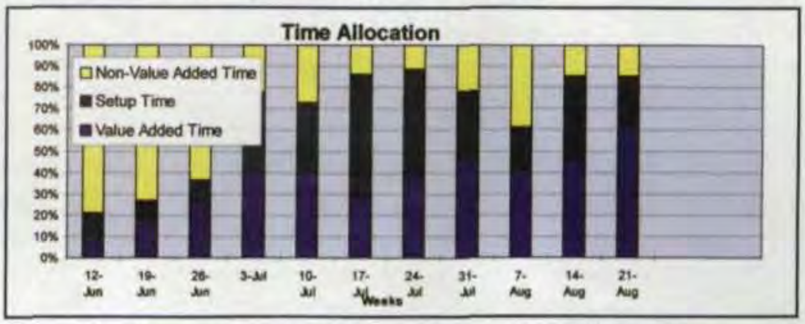

Figure 11—Time allocation breakdown during carbide hobbing trial.

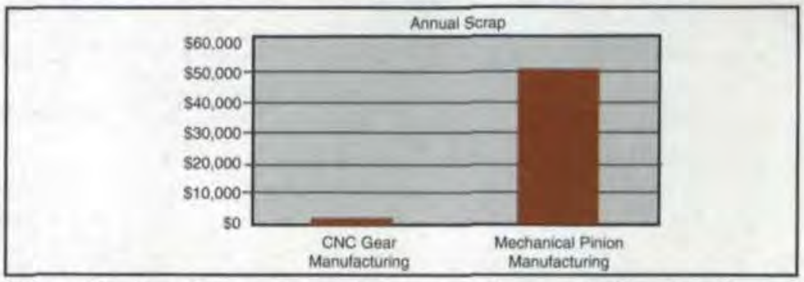

Figure 12—Comparison of annual scrap rates between CNC and mechanical manufacturing.

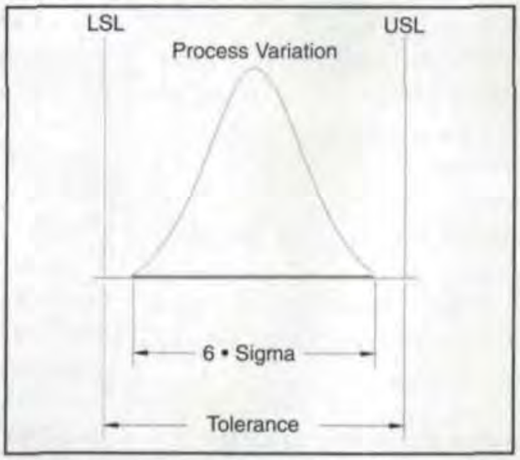

Figure 13—Improving process variables resulted in process variation becoming smaller than the tolerance.