

# The Past, Present and Future of Gear Manufacturing

## Celebrating 30 Years of Gears

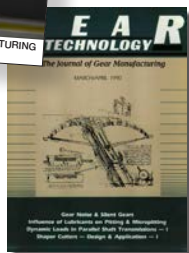
Matthew Jaster, Senior Editor

The gear industry is full of storytellers. It's a niche market that boasts a remarkable cast of characters that have been sharing their stories with us for 30 years. In that time, the editors and staff of *Gear Technology* magazine have had the privilege to report the ins and outs of this highly-specialized industry. From technical

articles to case studies and features, the main focus of this magazine has been to "provide a forum of discovery and innovation for you, the gear manufacturing industry." Our Publisher, Michael Goldstein, said as much in our inaugural issue of May/June 1984.

For our 30 year celebration, we turned it over once again to our advertisers, contributors and extended *Gear Technology* family to discuss the past, present and future of this exciting and innovative market. While the information both readers and advertisers have contributed over the years has been instrumental to the success of both *Gear Technology* and its "younger sister" publication, *Power Transmission Engineering*, I'd argue that the "off-the-record" stories are quite possibly more interesting in the grand scheme of things. Getting to know the people and the personnel responsible for making wind turbines spin, helicopters fly, cars shift and rovers rove has been equal parts educational and entertaining.

"Whenever someone wants to connote mechanical precision and complexity, invariably they use among other things, imagery of gearing," says Alan R. Finegan, director of marketing, Gleason Corporation. "Gears are mathematically complicated to design and are relatively difficult to manufacture. The final analysis of their quality and performance is not as a single component but as part of a moving mechanical device. Despite numerous innovations aimed at eliminating gears and all their complexities, gears remain as key drivers of power and motion *simply because they work.*"



## How has technology changed in gear manufacturing in the last 30 years?

"In the days before high-technology machine tools, workers typically were required to have approximately seven years of experience to be optimally productive, with top pay. The machine tools of today allow workers to be highly productive without the same level of experience. Along with technology innovations, over the past 30 years the quality assurance paperwork has quadrupled. As an example, for some of the aerospace gears we manufacture, the paperwork outweighs the parts."

**Joseph L. Arvin, President and COO, Arrow Gear**



"Machining technology and cutting tool technology have been nipping at each other's heels over the last thirty years. Driven by base materials, PVD coatings, CBN grains and grinding wheel technology, the speeds in which these tools can be operated have increased exponentially. Machine tool technologies have been forced to keep up with these changes by utilizing CNC controls, high-speed linear guide ways, high-precision ball screws and highly precise, high-speed, direct-drive work spindles."

**Thomas Kelly, Senior Vice President-Machine Tool Division, MHI America Inc.**

"Everyone is aware of the inroads lean manufacturing has contributed to improved productivity and faster changeovers. Even though this has been going on for years, many of us are still only in the beginning stages of implementation. In order to keep up with our foreign competition's cheaper labor rates, we must incorporate lean in everything we do in manufacturing."

**Fred Young, CEO, Forest City Gear**

"Computers and gear grinders! In 1984, we were just getting desktop PCs and commercial software. Gear grinding was an exotic aerospace/high-speed technology."

**Charles D. Schultz, Beyta Gear Service and Gear Technology Technical Editor and Blogger**

"The fundamentals haven't changed in that quality is still directly related to runout of the tool and the workpiece. What has changed dramatically was humorously summarized by an engineer who offered that 'poor quality can now be produced incredibly fast.' Of course quality is improved as well as productivity due to the precision of modern CNC machines."

**Bill Miller, Vice President, Kapp Technologies**

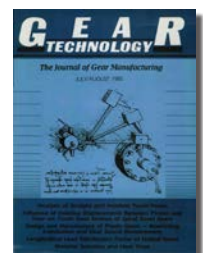


"(There has been a) significant growth of design software. Early on, most design software was generated within a gear company, and so its underpinnings and theory were well understood by the users, as they were also the program developers. Today, some believe that is lost on engineers that use off-the-shelf design software."

**Joe Mihelick, consultant and Gear Technology technical editor**

"The evolution of CNC gear manufacturing machines, as well as the CNC gear inspection instruments (have been significant). It is now possible to do higher speed cutting with carbide tools, as well as the ability to "hard finish" gears. These much simpler mechanisms have increased productivity as well as quality, and the modern CNC gear inspection instruments have also provided much better computer data analysis in line with the newer gear accuracy standards."

**Robert E. Smith, gear consultant**



## What are the key technologies/innovations driving the gear industry today?

“Although basic manufacturing technology has not changed much, process technology has changed a great deal. Changes in manufacturing are in the widespread use of CNC technology in all phases of manufacture, as well as much wider use of robotics and automation. Demand for better quality gears has increased the use of gear grinding also. Most manufacturers are now employing lean manufacturing principles as well as manufacturing cells.”

**Bipin Doshi, President, Schafer Gear Works, Inc.**



“A new generation of fearless manufacturing engineers is accelerating implementation of tool and machine technologies. Technologies (that) evolved over the last 10 years naturally take time to reach full potential, and perhaps to a greater extent in our industry, due to inertia of traditional conservative practices.”

**Bill Miller, Vice President, Kapp Technologies**

“In general we are seeing reduced cycle times and lower-cost-per-component. The competitive landscape of machines and tools can also be seen in gear manufacturing today where there’s more competition between conventional gear machining and multi-axis gear machining.”

**Mats Wennmo, Senior Technical Manager, Sandvik Coromant**



## 30 Years In, We're Still Here

By Jack McGuinn, Senior Editor

Thirty years is not a particularly long history for most industries. Take the gear industry; its beginnings go waaay back—like, B.C. back.

Regardless of perspective, quite a bit has happened in the last three decades in the industry, and this “whippersnapper” of a gear industry journal has been there right along to report on the who-what-when-where of it. And it has been quite a ride.

Following is a distillation of comments offered by individuals who have enjoyed long, successful careers in the gear industry—certainly long enough to back up any opinion they may offer as to what constitutes the “magic moments” occurring in the gear industry from 1984 to present. Their observations will

be plotted throughout the Timeline near the date in time cited in their opinions.

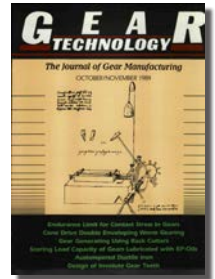
As you will see, each person offered up more than a few milestone-moments, although their “homework assignment” only asked for one or two. But let’s face it: that’s like being asked to name your favorite movie or your favorite child—can’t be done.

As you time-travel your way along, you are of course most welcome to disagree with our contributors’ choices; or if there is a glaring omission in our Timeline, please don’t hesitate to let us know at [geartechnology.com](http://geartechnology.com).



"I believe that power skiving will be extremely beneficial in the high-volume production of ID/OD gears, and multi-tasking machines are going to change the way small- to medium-volume gear manufacturing is done. Multi-tasking machines are doing many of the tasks previously done by special-purpose machines using sequential operations. This trend is seen not only in gear manufacturing but manufacturing in general."

**Nitin Chaphalkar, Manager, Advanced Solutions, DMG Mori ASI**



"In 2014 the continued improvement of form grinding machines is important, but not as important as the change to 3-D design software and improved thermal processing."

**Charles D. Schultz, Beyta Gear Service and Gear Technology Technical Editor and Blogger**



"There are some interesting advancements in the forging industry whereas gears that have traditionally been machined are now forged to a net or near-net shape. Heat treating still remains to be a challenge which many companies are addressing."

**Thomas Kelly, Senior Vice President-Machine Tool Division, MHI America Inc.**



**1984**

The publication of *Dudley's Handbook of Practical Gear Design*

**1984**

*Gear Technology* debuts.



## Mid-1980s

From **Dr. Robert Handschuh**, a 30-year NASA veteran with invaluable experience in DOD rotorcraft drive system analysis and experimental methods.

Through much of the entire **1980s**, "(Development of) coordinate measurement machine use for spiral bevel gear manufacture (Army-funded, Sikorsky Aircraft contractor, early **1980s**); Applying CNC technology to spiral bevel gear manufacture on Gleason 463 gear grinder led to full CNC Phoenix machine line (Army-funded, Bell Helicopter contractor, mid-to-late **1980s**); Linking the two above items together improved gear quality and reduced production costs; Face gear development from basic research—by Dr. Faydor Litvin and many Ph.D. students, as well as the Army-funded Adv Rotorcraft Transmission Project led by then-McDonnell-Douglas Helicopter company (now Boeing-Mesa), included technology development of gear load capacity at NASA Glenn to use in the Apache Block III Helicopters now being produced.

**1985**

The software *Load Distribution Program (LDP)* is first distributed to OSU GearLab sponsors, which now has over 1,000 license holders; OSU writes papers on incorporating *LDP* microgeometry analysis into many gear design analysis procedures, resulting in a great reduction in the noise of automotive transmissions.

## How will technology in gear manufacturing change in the next 30 years?

"Continuing changes in materials, including plastics and carbon fiber. A continued emphasis on designs and processes for ever-quieter gear sets, including more and improved fine finishing processes, integration of system solutions as part of smart factories. In 30 years there is no way to predict the needs of the applications and end users, much less the manufacturing technology. That's what makes the role of a solutions provider challenging and exciting."

**Alan R. Finegan, Director of Marketing, Gleason Corporation**



"We will see even more flexibility in gear design and gear machining, as well as increased power density and a considerable change in end user sustainability. Another advancement we'll see is improved end user control and influence in gear design/gear machining ratio."

**Mats Wennmo, Senior Technical Manager, Sandvik Coromant**

"Of course new turning equipment has been appearing for years that incorporates gear cutting in the blanking phase. This is especially beneficial to those with little gear work and little time to satisfy demands for faster throughput. Just as hard turning is a supplement for cylindrical grinding, I believe these equipment developments will continue to flow down the processing chain. I foresee the addition of gear inspection on this equipment to satisfy the need for quality documentation just as it has been implemented on gear grinders."

**Fred Young, CEO, Forest City Gear**



### 1985

From **Dr. Hermann J. Stadtfeld**, Gleason Corporation vice president, bevel gear technology, R&D. By **1985** coordinate measurement of bevel gears with electronic master (nominal data file) including machine corrections is developed by Gleason & Zeiss; From **1989-1995**, single flank technology becomes the world standard in bevel gear quality evaluation (T20 by Oerlikon and 500HCT by Gleason); The first bevel gear dry cutting process is introduced in **1997** at EMO in Hannover, Germany by Gleason; From **1998-2005** bevel gear grinding in automotive becomes a worldwide standard and replaces lapping widely (Gleason and Kingel-berg); The first bevel gear cutting machine without machine bed for first true dry chip removal (Phoenix II by Gleason) is introduced (**2001**) at EMO in Hannover.

### 1987

From **Dr. Donald Houser**, Professor Emeritus at Ohio State University; Houser is the founder of the Gear Dynamics and Gear Noise Research Laboratory (GearLab), an industrial research consortium with 45 participating companies. The **1987** PhD thesis of Ohio State University graduate student Sandeep Vijayakar provided the basis for his Calyx contact analysis algorithm that has been used by numerous companies to solve contact problems of multi-mesh gears.

### 1988

From **Alan R. Finegan**, director of marketing for the Gleason Corporation. Gleason Corp. introduces Phoenix (**1988**), the world's first 6-axis CNC bevel gear cutting machine, a genuine game-changer that rocked the foundations of bevel gear manufacturing.



"Hybrid manufacturing is a big trend on everyone's mind. While it is hard to imagine that process being used for production volumes, I think it definitely will change the design of parts and make the designs more optimized. It will reduce the product development times. On the heat treatment side, I think laser heat treatment methods offer the best promise. These methods enjoy a strong advantage due to selective hardening and energy efficiency point of view."

**Nitin Chaphalkar, Manager, Advanced Solutions, DMG Mori ASI**

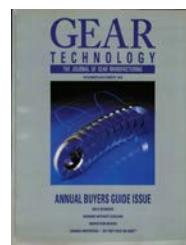
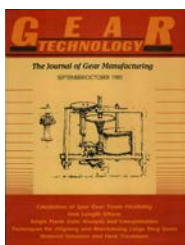
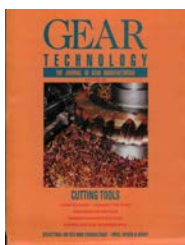
"I see non-traditional rough cutting as the emerging technology of the next ten years. Between wire cutting, 3-D printing and CNC milling, companies will have alternatives to hobbing and bevel cutting."

**Charles D. Schultz, Beyta Gear Service and Gear Technology Technical Editor and Blogger**



"Just as we've seen computer technology bring about sweeping changes in the past decade, I believe this will continue to evolve. I foresee an increased use of robotics in the gear industry, as well as multi-purpose machine tools."

**Joseph L. Arvin, President and COO, Arrow Gear**



**1991**

*Gear Technology* gets a makeover. Our first re-design.



**1995**

*Gear Technology* re-design #2. "Addendum" column is first introduced. Gleason acquired Carl Hurth Maschinen und Zahnradfabrik (1995).



**1993**

AGMA takes over as Secretariat of ISO TC-60.



## What sets the gear industry apart from other areas of manufacturing?

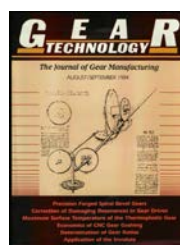
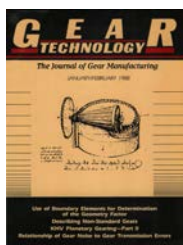
"Our current gear industry is anything but stagnant and will continue to offer many opportunities for aspiring engineers to reach levels of productivity and quality unimaginable today. I feel truly rewarded to have rubbed shoulders with brilliant people in our industry who for years have advanced the state of the art. I would remind us that whenever we think there is no room for improvement, our children (who don't know what is currently impossible) will figure out a way to (overcome) the current limitations we have."

**Fred Young, CEO, Forest City Gear**



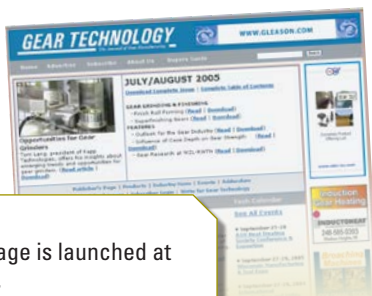
"Technically, one can still draw on and apply lessons learned 30 years ago and nearly every day brings a new challenge. Personally, the relationships developed can flourish for an entire career as the people in our industry are generally not transient."

**Bill Miller, Vice President, Kapp Technologies**



**1996**

The Gear Industry Home Page is launched at [www.geartechology.com](http://www.geartechology.com).



**2003**

*E-GT (Electronic Gear Technology Magazine)*  
Launched with the January/February printed issue.

**2005**

*Gear Product News* begins publishing in alternating months with *Gear Technology* (*Gear Product News* ceased publication after 2006).



**1997**

The Power Transmission Home Page is launched at [www.powertransmission.com](http://www.powertransmission.com).

"Custom manufacturing in the gear industry, vs. large OEMs' involvement in production of gears, is a small and intimate network. It is rewarding to be working in a competitive environment with like-minded people. Niche markets do reduce cutthroat competition, yet offer an exciting place for innovation and improvements."

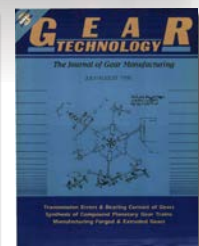
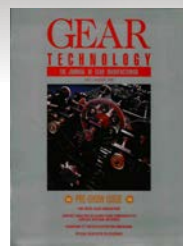
**Bipin Doshi, President, Schafer Gear Works, Inc.**

"I feel that gear manufacturing offers the highest level of metal cutting, and this industry produces gears with a high standard of quality that is simply amazing. It is very rewarding to be a part of an industry which is trying to achieve what was once considered impossible and always pushing the boundaries."

**Kenneth Sundberg, General Manager Gear Milling Solutions at Sandvik Coromant**

"The gear industry is a special and unique industry with its AGMA platform. This platform allows everyone to participate and learn from each other. The camaraderie between rivals seen in this industry is unparalleled. This also comes from the good natured people and talented engineers that work in the gear industry. I have been involved in AGMA activities for the past two-three years and everyone in the industry has always treated me as family."

**Nitin Chaphalkar, Manager, Advanced Solutions, DMG Mori ASI**



**2007**

Power Transmission Engineering magazine is born. Gear Technology redesign #3, and increased frequency to eight issues per year.



**2013**

Gear Technology re-design #4 — It's tough getting old!



**2014**

30 years and we're still here!



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## Development of Wind Turbine Standards

By Robert Errichello, Owner, Geartech and Gear Technology Technical Editor)

**“My most memorable story begins in the early 1980s, when the wind turbine industry started in California.** Many of the wind turbines were Danish machines that were designed to operate in the perfect wind environment of the steady, non-turbulent winds at the Danish coastline. When they were installed in the California mountain passes of the Altamont, Tehachapi, and Palm Springs, the wind turbines were subjected to severely turbulent winds. Consequently, there were thousands of failed gearboxes literally overnight. Some users made the mistake of designing their own gearboxes or purchasing off-the-shelf gearboxes that lasted no longer than the European gearboxes.

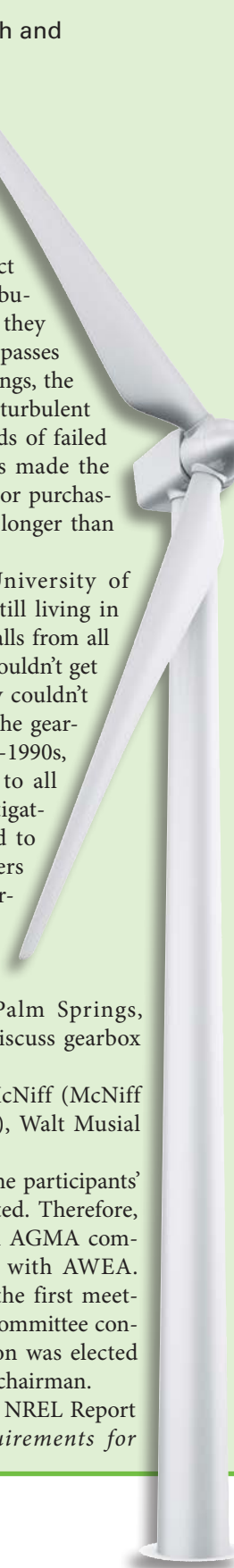
I had finished my studies at the University of California at Berkeley in 1978 and was still living in Berkeley. Suddenly, I received telephone calls from all three wind sites from frantic people who couldn't get their government tax credits because they couldn't keep their wind turbines running due to the gearbox failures. For many years up to the mid-1990s, my partner, Jane Muller, and I traveled to all three wind sites and inspected and investigated the gearbox failures. We also traveled to Europe to visit wind turbine manufacturers and gear manufacturers to resolve the gearbox failures.

On September 23, 1991, during the American Wind Energy Association (AWEA) Windpower Conference in Palm Springs, California, the following people met to discuss gearbox failures:

Robert Errichello (Geartech), Brian McNiff (McNiff Light Industries), Jane Muller (Geartech), Walt Musial (NREL), and Brent Reardon (MSA).

At this ad-hoc meeting it was decided the participants' collective experience should be documented. Therefore, in October 1991, I asked the AGMA if an AGMA committee could be formed in cooperation with AWEA. Approval was subsequently granted and the first meeting of the AGMA/AWEA Wind Turbine Committee convened on October 19, 1992. Brent Reardon was elected chairman and Jane Muller was elected vice chairman.

In September 1994, Geartech completed NREL Report NREL/TP-442-7076: *Application Requirements for*



*Wind Turbine Gearboxes* (Ref. 1). The report documented Geartech's experience with wind turbine gearboxes and gave guidelines for selecting, designing, manufacturing, procuring, operating, and maintaining gearboxes for use in wind turbines. The report was accepted by the wind turbine committee as a working draft.

The wind turbine committee met ten times between 1993 and 1996. In 1996 they submitted their draft standard to AGMA for approval. In October of 1997 AGMA published

AGMA/AWEA 921-A97: *Recommended Practices for Design and Specification of Gearboxes for Wind Turbine Generator Systems* (Ref. 2). The wind turbine committee set a record for the shortest time from proposal of an AGMA standard to approval and publication.

In 1999, work began on the revision of AGMA/AWEA 921-A97. Because information sheets are less legally binding than standards, the committee decided to upgrade the document from an AGMA "Information Sheet" to an AGMA "Standard." They changed the document title to ANSI/AGMA/AWEA 6006-A03: *Standard for Design and Specification of Gearboxes for Wind Turbines* (Ref. 3). The wind turbine committee met nine times between 1999 and May of 2002, and the document was finally published in 2003. Once again, the committee set records for the first truly multi-discipline AGMA committee and the highest number of participants of any AGMA committee.

The knowledge gained from our failure investigations and our work in designing the wind turbine standard proved to be a very enjoyable experience for Geartech, primarily because we met so many wonderful people who were passionately committed to making wind turbines a viable source of renewable energy. Many of the people we met are now our close friends and we meet often to share colorful stories about our wind turbine experiences."

## References

1. Errichello, R., and J. Muller. "Application Requirements for Wind Turbine Gearboxes" NREL/TP-442-7076, Sept., 1994.
2. AGMA/AWEA 921-A97: *Recommended Practices for Design and Specification of Gearboxes for Wind Turbine Generator Systems*, 1997.
3. ANSI/AGMA/AWEA 6006-A03: *Standard for Design and Specification of Gearboxes for Wind Turbines*, 2003.

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## Share some of your most memorable moments in the gear industry:

"When MHI introduced their Superdry gear hob, it totally blew my mind. The tool was made from HSS, had a proprietary PVD coating and was cutting gears at 200 meters/min without the use of coolant. They broke all the rules that I was taught about cutting tools."

**Thomas Kelly, Senior Vice President-Machine Tool Division, MHI America Inc.**

"Many may not remember the origins of the AGMA's Gear Expo, but I was the one who first approached AGMA's Board of Directors in 1981, asking them to hold a trade show specific to the gear industry. Initially, they thought I was crazy, stating there would not be enough attendees for such a show. But my perseverance paid off; approaching them again in 1984, this led to the first show in 1985. The show was a table-top exhibit and was held in Chicago in the fall of 1985. Today, Gear Expo is now the leading show for the U.S. gear industry and is a major source of financial assistance for the AGMA."

**Joseph L. Arvin, President and COO, Arrow Gear**

"I guess for a story I can only point to my own company. In 2015 Gleason will celebrate its 150<sup>th</sup> Anniversary, and I have spent a good number of years (more than I care to admit) here. Stepping back, I continue to be amazed by how Gleason has maintained a position of global leadership through so many years, adapting to change and thriving."

**Alan R. Finegan, Director of Marketing, Gleason Corporation**

"The journey working with indexable hobbing tools for small modules has been very eventful, and we have many unique and interesting stories from these projects. One specific case I recall very well is the time we implemented an indexable CM 176 hob on an old machine built around 1950 and reached a savings in machining time of 80 percent at the required level of quality. This was an amazing result for the owner of this small sub-contractor, giving him quite a competitive advantage and opening up new business opportunities for Sandvik Coromant."

**Kenneth Sundberg, General Manager Gear Milling Solutions at Sandvik Coromant**



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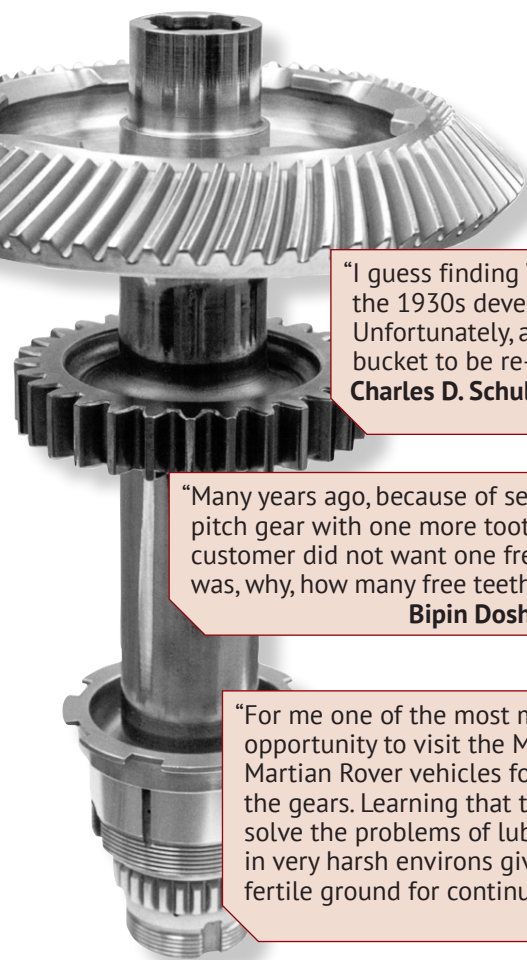
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"I guess finding Walter Schmitter's giant gear tooth with strain gages still intact from the 1930s development of AGMA's bending strength formula remains a high point. Unfortunately, at the direction of my supervisor – Walter's own son- I put it in the scrap bucket to be re-melted into another Falk product."

**Charles D. Schultz, Beyta Gear Service and Gear Technology Technical Editor and Blogger**

"Many years ago, because of setup error, we shipped a very fine pitch gear with one more tooth than the print called for, and the customer did not want one free tooth! Our foreman's comment was, why, how many free teeth do they want?"

**Bipin Doshi, President, Schafer Gear Works, Inc.**

"For me one of the most memorable experiences was the opportunity to visit the Mars Yard at JPL where they test the Martian Rover vehicles for which our company helped build the gears. Learning that the engineers are quite keen to solve the problems of lubrication and longevity of the gears in very harsh environs gives me hope that the USA will be a fertile ground for continuing development of our industry."

**Fred Young, CEO, Forest City Gear**

"I suggested to the chief engineer of our company, Manfred Lorenz, that perhaps our future business might be weighted towards non-gear components. His reply was 'Most certainly not. In fact, gear grinding will be more cost-effective than shaving.' That was in 1992. Quite prophetic, we now know."

**Bill Miller, Vice President, Kapp Technologies**



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## Closed-Loop Bevel Gear Development

### *Spiral bevel gears never had it so good*

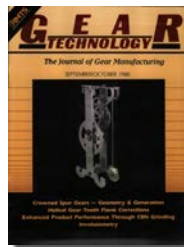
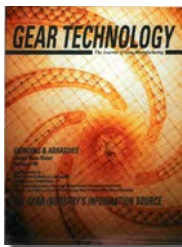
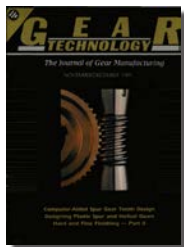
Joseph L. Arvin, President and COO, Arrow Gear

**I would have to say that the most significant change to the gear industry during the 30 years of Gear Technology has to do with the evolution of computer-based design, development, manufacturing, and inspection of gear teeth.**

Here is a brief background. The main challenge in producing high-precision gears is designing the gear teeth so the contact pattern of the meshing gear teeth will be correct when the gears experience various gearbox deflections during loaded operation. Historically, the process for getting this correct was that of trial-and-error; a process that would take many months and cost hundreds of thousands of dollars — especially in aerospace applications.

Then, in the mid-1980s, Dr. Dieter Wiener of West Germany developed and manufactured the first CNC spiral bevel gear grinding machine tool, which was later purchased by Klingelnberg. In 1988, I was invited to watch the operation of this original machine in Ettlingen; after viewing this technology in operation I was extremely impressed and I knew this had to be the future for the gear industry.

Meanwhile, Gleason was working with Zeiss in the development of software which could interface between CNC inspection systems and CNC tooth cutting and grinding machine tools. This software could send correction settings directly to the machine tool.



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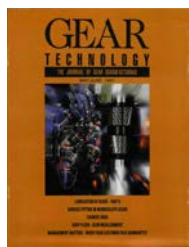


By the early 1990s, using Gleason's software and their new CNC Phoenix tooth cutting and grinding machines, Arrow Gear worked in developing and implementing the world's first hard-wired, integrated, closed-loop system for the design, manufacturing, and inspection of spiral bevel gears.

Using Gleason's software packages allowed Arrow's engineers to predict tooth contact pattern under various displacement conditions. This software also allowed for any settings changes required for the machine tools to be made automatically. By the mid-1990s Arrow's successful implementation was online and this allowed for the trial-and-error process to be eliminated.

Adoption of this new technology by the gear industry came slowly. Today, this capability is the standard among gear machine tool producers and is utilized extensively by gear makers. But I feel that this approach to high-precision gear manufacturing ushered in a new era for our industry and remains as the single most significant evolutionary step in gearing over the past 30 years.

Several years after this closed-loop system was successfully implemented, *Gear Technology* reported on Arrow's capability for advanced design and development in its January/February 2003 issue. I'm sure this article can provide you with all the details you would need.



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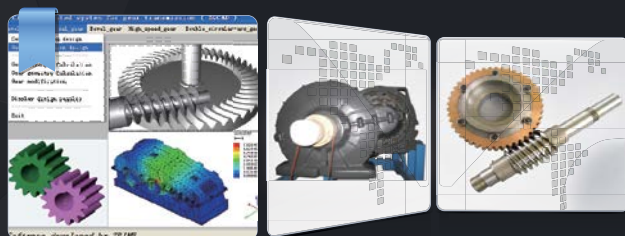
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Located in Zhengzhou, the capital of Henan Province, Zhengzhou Research Institute of Mechanical Engineering (ZRIME) has undergone 50 years of development. The company was restructured from a former research institute under the Ministry of Mechanical Industry into large-scale science & technology enterprise administrated by the central government of China. As one of the first high-tech enterprises in Henan Province and the pilot enterprise of scientific and technological renovation in Henan Province, ZRIME are authorized to grant the doctor's degree in field of machinery design and the master's degree in machinery design and engineering mechanics.

ZRIME are also authorized by the State for the planning and the administration of gear transmission technology in mechanical industry of China.



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