gear TECHNOLOGY®

SEP/OCT 2019

MPT EXPO 2019

MAP AND LISTINGS
BOOTH PREVIEWS

HEAT TREAT 2019

POWDER METAL AND 3-D PRINTING

ASK THE EXPERT LIVE!

GET ANSWERS LIVE AND IN PERSON

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Star SU
Solutions for all your gear cutting tool needs


Star
NXT

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Vol. 36, No. 7 GEAR TECHNOLOGY, The Journal of Gear Manufacturing (ISSN 0743-6858) is published monthly, except in February, April, October and December by Randall Publications LLC, 1840 Jarvis Avenue, Elk Grove Village, IL 60007, (847) 437-6604. Cover price $7.00 U.S. Periodical postage paid at Arlington Heights, IL, and at additional mailing office (USPS No. 749-290). Randall Publications makes every effort to ensure that the processes described in GEAR TECHNOLOGY conform to sound engineering practice. Neither the authors nor the publisher can be held responsible for injuries sustained while following the procedures described. Postmaster: Send address changes to GEAR TECHNOLOGY, The Journal of Gear Manufacturing, 1840 Jarvis Avenue, Elk Grove Village, IL, 60007.

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November 19–21: Power-Gen International 2019, New Orleans, Louisiana;
November 19–22: Formnext 2019, Frankfurt, Germany;
December 3-5: AGMA Epicyclic Gear Systems—Application, Design and Analysis, Seattle, Washington;
December 9-12: CTI Symposium Germany 2019, Berlin, Germany.

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THE GEAR INDUSTRY'S INFORMATION SOURCE

www.geartechnology.com

Gleason Power Skiving

Gleason's Power Skiving concept is suitable for the highly productive manufacturing of cylindrical internal and external gears with outstanding gear quality and significant reductions in cost per piece. Learn more here:

www.geartechnology.com/videos/Gleason-Power-Skiving/.

Sandvik Coromant Machine Tool Monitoring

Markus Eriksson, business development manager, uses monitoring solution CoroPlus Machining Insights to demonstrate how data from the machine tool can offer insights into the machining processes, and how these can be used to create improvement actions. Learn more here:

www.geartechnology.com/videos/Machine-Tool-Monitoring-with-Sandvik-Coromant-/

Event Spotlight:

K 2019 in Düsseldorf, Germany, features over 3,000 exhibitors in the entire plastics and rubber industry to demonstrate the industry's capabilities, discuss current trends and set the course for the future. The event takes place October 16–23. Learn more here:

www.geartechnology.com/news/9860/K_2019_/

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Get Answers LIVE and in Person

Publisher & Editor-in-Chief
Michael Goldstein

You have challenges. We all do. If your challenges are related to any aspect of gear design, manufacturing, inspection, heat treating or use, the solutions can be found at Motion + Power Technology Expo, which takes place October 15–17 in Detroit.

So come and ask your questions about how to implement the latest gear manufacturing technology. Ask about how best to solve you latest design challenges. Ask about cutting tools, gear rating standards, lubrication and bearings.

This is a unique opportunity to ask and get answers from the very top people in all facets of our industry.

In fact, we've lined up panels of experts—the who's who of our industry—to answer those questions for you, live and in person. As we've done at previous shows, we're hosting four sessions of our popular "Ask the Expert LIVE!" series at our booth (#3826). Each session will be video recorded and become part of our permanent video library on *Gear Technology TV* (found at *www.geartechnology.com/tv/*). Each session covers a specific topic, and we've lined up an appropriate panel of experts for each one:

Gear Manufacturing—Tuesday, October 15, 10:30 a.m.

- Dr.-Ing. Andreas Mehr, Gear Grinding and Shaping Technology Development, Liebherr.
- Dr.-Ing. Hartmuth Müller, Head of Technology and Innovation, Klingelnberg.
- Dr.-Ing. Deniz Sari, Sales Manager Middle Europe, Samputensili
- Dr. Hermann J. Stadtfeld, VP Bevel Gear Technology and R&D, Gleason

Gear Design—Tuesday, October 15, 2:30 p.m.

- Charles Schultz, President Beyta Gear Services (also Gear Technology technical editor and author of Gear Talk with Chuck on the geartechnology.com blog).
- Prof. Dr.-Ing. Karsten Stahl, Director of the Gear Research Center (FZG) at the Technical University of Munich.
- Frank Uherek, Principal Engineer, Gear Engineering Software Development, Rexnord.

Lubrication—Wednesday, October 16, 10:30 a.m.

- Paul Conley, Chief Technologies, SKF.
- Sib Hamid, VP, Director of Operations and Corporate Director of Technology, Lubriplate.
- Dr.-Ing. Thomas Tobie, Head of the Department Load Carrying Capacity of Gears at the Gear Research Center (FZG) at the Technical University of Munich.

Bearings—Wednesday, October 16, 2:30 p.m.

- Mike Allega, Application Engineer Specialist, Timken.
- George Lutzow, Manager Application Engineering, SKF.
- Jitesh Modi, Engineering Director, Transmission Applications North America, Schaeffler Group USA Inc.
- Chris Napoleon, President, Napoleon Engineering Services.

We're counting on you to come to the show and participate. We've lined up top-notch experts who are sure to have the experience and insight to help you solve your gear-related problems. So come to the show and participate. Even if you don't have questions, just sitting in the audience is a great way to learn. Come to booth #3826 and absorb the knowledge!

Even if you're not coming to Motion + Power Technology Expo, you can still participate in Ask the Expert Live! Just e-mail your question to *publisher@geartechnology.com*, and we'll pose it to the appropriate panel during one of our live segments. Then, you can watch and listen to the answers after the show on *Gear Technology TV*.

In addition to *Ask the Expert LIVE!* we'll also be recording episodes of *Revolutions* at the show. Our booth will be pretty busy throughout the three days. We'll be interviewing experts from Advanced Heat Treat Corp., AGMA, ERS Engineering, Gleason, KISSsoft, Helios Gear Products, Klüber Lubrication, Ovako, THORS, TimkenSteel and many others. We'll be asking about the latest technological innovations from the leading companies in our industry. We hope you'll be there to hear what they have to say.

Hope to see you in Detroit.

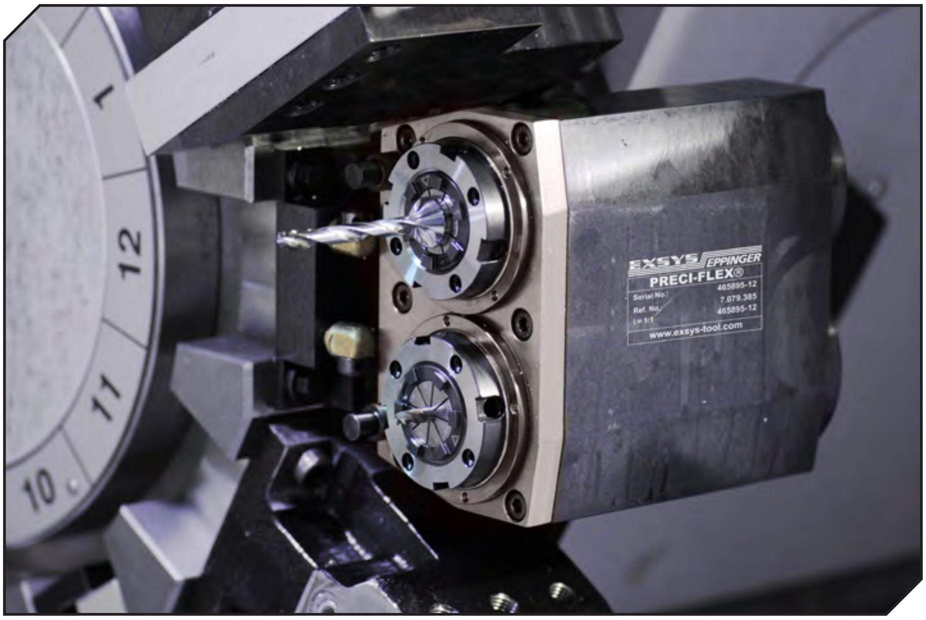
P.S. Don't forget to renew your FREE subscription when you visit our booth.

EXSYS

OFFERS TOOLING TECHNOLOGY AT SOUTHTEC 2019

Exsys Tool, Inc. will offer attendees at Southtec the chance to experience its comprehensive range of tooling technology for turning machines and innovative gearbox solutions at the Greenville Convention Center in Greenville, South Carolina, October 22–24. Visitors to Booth 1829 will have the opportunity to learn how Exsys' modular toolholding solutions and Eppinger's gear-making expertise offer exceptional cost-savings and greater manufacturing efficiency.

In addition to its Preci-Flex modular toolholding system, which speeds turning center tooling changeovers and improves productivity with longer tool life, Exsys will showcase the Deco-Flex tooling interface, which adds flexible precision for small-part manufacturing and includes holders for all generations of Star CNC brand Swiss-style machines. Exsys will also highlight Eppinger gear solutions and their German-made precision, including standard spiral bevel, planetary, planetary bevel, hypoid and cycloidal gearboxes, along with custom gear-making services.



For more information:
Exsys Tool, Inc.
Phone: (800) 397-9748
www.exsys-tool.com

GMTA

EXTENDS ITS PRODUCT OFFERING TO INCLUDE BASKETS, TROLLEYS AND LIFT TABLES

GMTA is adding to its product line. Known for gear cutting and honing, parts washing, special machine tools, tooling, laser welding, surface grinding, deburring machines, multi-spindle lathes and multi-station vertical machinery, GMTA is now selling baskets, trolleys and lift tables.

Walter Friedrich, GMTA's president said, "We felt that we needed to have an intermediate step between the machining and cleaning processes."

Products available include bearing turntables, lift tables, custom carts and conveyor systems. Lift tables include single position lift tables, single position lift and rotate tables, single position lift and tilt tables, rotate tables, hydraulic lift tables, air spring lift tables and fork free lift tables for cart access. In addition, custom carts for manufacturing and production operations are available. These include 4-wheel carts, 6-wheel carts, low profile carts, flat top carts, rotate carts and tilt carts, fork free carts and custom part sequencing carts.

Besides being a link between gear-making machines and parts washers, GMTA makes these products available to users in the material handling industry.

For more information:
GMTA
Phone: (734) 973-7800
www.gmtamerica.com

Mitutoyo America

INTRODUCES SHOP FLOOR CNC MACHINE

Mitutoyo America Corporation is pleased to announce the release of the MiSTAR 555 CNC Shop Floor Coordinate Measuring Machine to its CMM product line that operates without compressed air and on conventional 120V 20 AMP electrical service with movement speeds of 606mm/s and acceleration of 2,695mm/s^2 (3D).

The MiSTAR 555 is a compact, space-saving in-line or near-line CNC coordinate measuring machine designed for high-speed, high-accuracy measurements with accuracy assurance from 10°C to 40°C. It features an open-structure design with a single support moving bridge enabling users to mount workpieces from the front, rear and right for installation and a walk-up inspection station for easier operability.

The modular control unit and PC are stored in the base of the main body structure, making the MiSTAR more compact, reducing the installation area to approximately 70 percent from a conventional moving bridge model for location flexibility. The MiSTAR also uses a Mitutoyo-designed and manufactured robust scale detection system with a high resistance to airborne contaminants, eliminating the need for costly environmental controlled enclosures.

The MiSTAR features several Industry 4.0 integrations, including the Mitutoyo-developed Smart Measuring System (SMS), which enables monitoring the operation state required by smart factories and a Status Monitor that retrieves current CMM status features using the MTConnect protocol. Condition Monitor provides a system that collects and evaluates different operational information such as measuring, movement lengths, machine error, probe functions, and many more for long-term preventative maintenance and machine use statistics.

For more information:
Mitutoyo America Corporation
Phone: (630) 820-9666
www.mitutoyo.com

From Design to Finished Gear

A visit to the Gleason booth connects you to powerful gear and transmission design tools, economical Chamfer Hobbing, hard finishing innovations like Combi Honing™ and polish grinding, in-process laser inspection as well as productive new tooling and services. All working together to connect your gear manufacturing to maximum efficiency, from design to finished gear.

www.gleason.com/emo2019 **www.gleason.com/mpt2019**

EMO
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MOTION+POWER TECHNOLOGY EXPO
BOOTH #3400

Total Gear Solutions Gleason

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HIGHLIGHTS LATHE AND TURN-MILL CENTER AT CMTS 2019

At CMTS 2019, Index and Mitcham Machine Tools recently demonstrated how to increase output per operator via integrated automation and single-machine production of complex parts.

The TNL20-11 features eleven linear axes, frontworking attachment with six stations, autonomous counter spindle and two turrets, each with eight stations providing up to 12,000 rpm and 2.0 kW of power. The TNL20-11 can apply up to four tools simultaneously, and the lower turret can be equipped with a backworking attachment capable of allowing independent machining of the rear of a part. The machine offers identical, twin liquid-cooled spindles with up to 10,000 rpm, 5.5 kW of power and 17.2 Nm of torque.

When integrated with the iXcenter robot cell, the TNL20-11 becomes even more productive. With compact vertical storage of up to 14 pallets, this cell uses an articulated arm to load and unload parts.

The G220 features fluid-cooled, identical main and counter spindles that provide power of 31.5/32 kW (100%/40%), torque of 125/ 170 Nm and maximum speed of 5,000 rpm. The fluid-cooled, five-axis motorized milling spindle is available in both HSK-T40 and HSK-T63 configurations. The HSK-T40 version offers power of 11 kW, torque of 19/30 Nm and speed of up to 18000 rpm, while the HSK-T63 version offers power of 17 kW, torque of 62/90 Nm and speed of up to 12,000 rpm. Both milling spindle options feature hydrostatic bearings in the Y and B axes, and a stable circular guide further ensures excellent rigidity and damping. The Y axis features a ±80 mm stroke, while the B axis is driven directly by a torque motor and has a swivel range of –50/+230 degrees. With a large travel distance in the X direction, machining at up to 30 mm below the turning center height is possible.

The G220's motorized milling spindle operates using a one-row tool chain magazine which features space for 70 tools for the HSK-T40 configuration or 50 tools for HSK-T63. An optional double-row tool magazine enables setup during machining and accommodates twice as many tools as the standard solution.

For more information:
Index Corporation
Phone: (317) 770-6300
www.index-usa.com

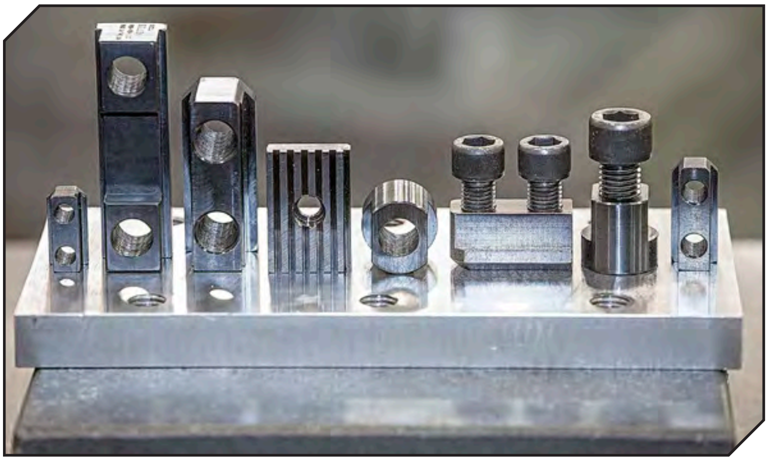
Dillon Manufacturing

OFFERS JAW NUTS AND KEYS TO IMPROVE CHUCK SAFETY, ACCURACY AND PERFORMANCE

As machine tool technology continues to advance, including greater horsepower, larger material cuts, and higher machine tool speeds, the stress and mechanical forces upon jaw nuts and t-nuts being used within these operating conditions has also increased. Jaws nuts and keys made from case hardened 1018 CRS can fracture, crack, and break under high speed machine stress loads causing damaged workpieces and chucks, and endangering operators. Dillon Jaw Nuts and Keys, manufactured from 4140 heat treated steel, provide superior wear resistance, impact resistance, higher tensile strength, and extended jaw nut life. Operator safety and chuck life are greatly improved by eliminating the use of low carbon jaws nuts and t-nut in the machining process.

Dillon Jaw Nuts, T-nuts, and Keys are available to fit all popular power chucks from 6" in diameter to 24" in diameter including Forkhardt, Gamet, Howa, Kitigawa, Matsumoto (MMK), Nikko, Pratt Burnerd, Rohm, Samchully, Schuck, SMW, SMW-Autoblok, and more. Standard sizes are stocked for immediate shipment. They are ideal for workholding applications requiring durability and high strength such as high speed machining. Dillon also offers a special T-Nut design and manufacturing service for custom workhlolding requirements.

For more information:
Dillon Manufacturing
Phone: (800) 428-1133
www.dillonmfg.com



Klüber Lubrication

OFFERS HEAT TRANSFER OILS FOR OPEN OR CLOSED HEATING AND COOLING SYSTEMS

Klüber Lubrication, a worldwide manufacturer of specialty lubricants, introduces heat transfer oils for use in open or closed heating and cooling systems in the wood-processing industry.

Lubricants used in wood processing must withstand extreme temperatures, high loads and aggressive media. The excellent thermal properties of new heat transfer oils from Klüber Lubrication make them ideal for wood-processing applications. Specially formulated for use in indirect closed heating units, the high resistance of these oils to thermal degradation ensures reliable, lasting performance. With good oxidation stability, the oils protect equipment and prevent deposit formation. They maintain viscosity, even in low temperatures, and have a long service life.

Klüberfluid HT 1 Series is a highly refined mineral oil heat transfer fluid that offers excellent thermal stability. Its advanced formulation supports long service life without viscosity changes or deposit formation.

Klüberfluid HT 4 US Series is a synthetic heat transfer oil designed to overcome heat stress that high-temperature heat transfer mediums endure. Its synthetic hydrocarbon base stock combats issues related to carbon formation as well as extends fluid life compared to petroleum-based fluids. The extremely low vapor pressure and subzero pour points of the oil increase efficiency and reduce pressure buildup and evaporation losses.

The tough requirements of the wood-processing industry demand high-performance lubricants. The advanced formulations of new heat transfer oils from Klüber Lubrication ensure reliable performance under extreme heat-related stress.

For more information:
Klüber Lubrication
Phone: (603) 647-4104
www.klueber.com

MOTION + POWER TECHNOLOGY EXPO

October 15–17,
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Detroit, MI
www.MOTIONPOWEREXPO.com

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Advanced Heat Treat Corp.	www.ahtcorp.com	4600	
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Great Lakes Industry	www.greatlakesind.com	3141	

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Hanik Corporation	www.hanikcorp.com	2407	65
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IPM, Inc.	www.ipminc.com	3240	
J.G.Weisser Söhne GmbH & Co.	www.weisser-web.com	4434	
James Engineering	www.james-engineering.com	2726	
JRM International Inc.	www.jrminternational.com	3222	
Kapp-Niles	www.kapp-niles.com	3607	11, 20
KISSsoft AG	www.kisssoft.ch	3400	65

Company	Website	Booth#	Ad
Klingelnberg	www.klingelnberg.com	3631	Back Cover
Knoll America	www.knollamerica.com	3441	
Laser Marketing Technologies	lasermarktech.com	4627	
LEAX Group	www.leax.com	4032	
Liebherr Gear Technology, Inc.	www.liebherr.com	3413	5
Linamar Forgings Carolina, Inc	www.linamar.com	4431	
Louis Belet	www.louisbelet.ch	3033	
Lucrescent Bearing	lucrescentbearing.com	2836	
Machine Tool Builders Inc.	www.machinetoolbuilders.com	3407	22
MachineMetrics	www.machinemetrics.com	3044	
Magnetic Inspection Laboratory	www.milinc.com	3831	
Makishinko Co., Ltd.	www.makishinko.com	3937	
Matrix Design, LLC	www.matrixdesignllc.com	4022	
Matrix Precision Co., Ltd	www.luren.com.tw	2613	
MB Metal Technologies LLC	www.mbmetaltech.com	3541	
McInnes Rolled Rings	www.mcinnesrolledrings.com	2922	15
Meritor	www.meritor.com	2818	
MESYS AG	www.mesys.ag	3933	
Metalcastello	www.metalcastello.com	3735	
Mitsubishi Heavy Industries America, Inc. Machine Tool Division	www.mitsubishigearcenter.com	4418, 3044	8, 48
Mohawk Machinery Inc.	www.mohawkmachinery.com	3920	
MTI	www.slmti.com	4307	
Nagel Precision Inc.	www.nagelusa.com	4308	
Napoleon Engineering Services	www.nesbearings.com	3620	
National Fluid Power Association	www.nfpa.com	2731	
New England Gear	www.newenglandgear.com	3422	
Nichiei Co. Ltd.	www.nichiei-ind.com	3326	
Nichols Portland, LLC	nicholsportland.com	3040	
Norton/Saint-Gobain	www.nortonabrasives.com	2607	46
Oberlin Filter Company	www.oberlinfilter.com	3334	
Oelheld U.S., Inc.	www.oelheld.com	3803	48, 58
OEM Controls, Inc	www.oemcontrols.com	2939	

Company	Website	Booth#	Ad
OEM Off-Highway	www.oemoffhighway.com	3539	
Ohio Star Forge Co.	www.ohiostar.com	4040	
Omni Gear & Machine Corp.	omnigear.us	3939	
OSG USA, Inc.	www.osgtool.com	4234	
OTEC Precision Finish	www.otecusa.com	2626	
Ovako North America	www.ovako.com	2413	
Peening Technologies	www.peeningtechnologies.com	4402	
PEE-WEE Kaltwalz- und Rohrbearbeitungsmaschinen GmbH	www.pee-wee.de	2921	
Peninsular Cylinder Company	www.peninsularcylinders.com	2835	
Penta Gear Metrology LLC	pentagear.com	3607	20, 56
Perry Technology Corporation	www.perrygear.com	3107	
Philadelphia Gear, A Timken Brand	www.philagear.com	4033	
Piselli Enterprises inc	www.pisellient.com	4500	
Positrol, Inc.	www.eworkholding.com	4031	
Power Transmission Engineering magazine	www.powertransmission.com	3826	
Pragati Transmission Pvt. Ltd.	www.pragatigears.com	4231	
Precipart	www.precipart.com	3003	
Precision Gage Company, Inc.	www.precisiongageco.com	4222	
Preco, Inc.	www.precoinc.com	2408	
Premier Thermal Solutions	www.premierthermal.com	4039	
Presrite Corporation	www.presrite.com	4200	59
Profiroll Technologies USA Inc.	www.profiroll.com	4000	
Proto Manufacturing	www.protoxrd.com	4328	54
R&J Cylinder and Machine	www.rjcylinder.com	2936	
Radix Technology Solutions	www.aistechgroup.com	4344	
Rave Gears LLC	www.ravegears.com	3839	
Razzaq Engineering Works	www.razzaqengg.com	4334	
REGG Rolling Corporation	www.reggrolling.com	4027	
Reishauer Corporation	www.reishauer.com	2953	53
REM Surface Engineering	www.remchem.com	4510	
Riley Gear Corporation	www.rileygear.com	3622	
Romax Technology Inc.	www.romaxtech.com	3110	

Company	Website	Booth#	Ad
Rotec Tools Ltd.	rotectools.com	3131	21
Rubig Engineering	www.rubig.com	2409	
RUF Briquetting Systems	www.ruf-briquetter.com	3208	
Russell, Holbrook & Henderson	www.tru-volute.com	4226	
S.L. Munson & Co.	www.slmunson.com	2800	
Schnyder SA	www.schnyder.com	2407	65
Schunk	www.schunk.com	3231	
Scot Forge	www.scotforge.com	2809	
Senjo Seiki Gear Chamfering	www.dynamicdetroit.com	4509	
Shanthi Gears Ltd.	www.shanthigears.com	3133	
Sinto America	sintoamerica.com	3039	
SMT	www.smartmt.com	4227	55
SMW Autoblok Corp	www.smwautoblok.com	2821	
Somaschini North America LLC	www.somaschini.com	4203	
SONA BLW Präzisionsschmiede	www.sona-blw.com	3439	
Southern Gear & Machine, Inc	www.southerngear.net	4228	49
Specialty Ring Products, Inc.	specialtyring.com	4133	
Specialty Steel Treating	www.sst.net	2426	
Speedgrip Chuck Company	www.speedgrip.com	4601	
Star SU, LLC	www.star-su.com	4013	IFC-1, 56
Stresstech	www.astresstech.com	4218	
SuperAbrasives, Inc.	superabrasives.com	3226	
Supreme Industrial Works	www.gearsupreme.com	3535	
Synergy Additive Manufacturing	synergyadditive.com	3227	
TEC - Materials Testing	www.tec-materialstesting.com	3032	
Techmode LLC		3737	
Techniques Surfaces USA, Inc.	www.hefusa.net	2839	
The Estell Group LLC	www.theestellgroup.com	2728	
The Modal Shop, Inc.	www.ndt-ram.com	4220	
The Tekfor Group	amtektekfor.com	4403	
THERMTECH	www.thermtech.net	4126	
Thors, LLC	www.thors.com	2928	
Thyssenkrupp Rothe Erde USA, Inc	www.thyssenkrupp-rotheerde.com	3228	

Company	Website	Booth#	Ad
TimkenSteel Corporation	*www.timkensteel.com*	3431	
Toolink Engineering Inc.	*www.toolink-eng.com*	4003, 3903	
Toyoda Americas Corporation	*www.toyoda.com*	3832	
Tribute, Inc	*www.tribute.com*	2733	
Trojon Gear, Inc.	*www.trojon-gear.com*	2528	
Trumpf	*www.trumpf.com*	4326	
TTP-API Heat Transfer	*www.apiheattransfer.com*	2531	
Tuson Corporation	*tuson.com*	2934	
Ty Miles, Inc.	*www.tymiles.com*	4607	
United Gear & Assembly, Inc.	*www.ugaco.com*	4207	
United Tool Supply	*www.unite-a-matic.com*	4614	45
Vantage Corporation	*vantage-corp.com*	4414	
ViewTech Borescopes	*viewtech.com*	4415	
Viking Forge Corp.	*www.viking-forge.com*	2610	
Virgo Communications & Exhibitions	*www.virgo-comm.com*	3936	
Visual Knowledge Share	*www.vksapp.com*	4239	
Walker Forge, Inc.	*www.walkerforge.com*	3031	
Weiler Abrasives Group	*weilercorp.com*	3335	
Weldon Solutions	*weldonsolutions.com*	4131	
Western Michigan University's Center for Advanced Vehicle Design and Simulation (CAViDS)	*wmich.edu/vehicledesign/consortium*	2837	
WFL Millturn Technologies GmbH & Co. KG	*www.wfl.at*	4309	44
WS GearDynamics GmbH	*www.ws-geardynamics.com*	4603	
Xubi Engranajes, S.L.	*www.xubi.com*	3931	
Yates Cylinders	*www.yatesind.com*	2636	
ZEISS Industrial Quality Solutions	*www.zeiss.com/metrology*	4405	
Zerust Corrosion Solutions	*www.zerust.com*	4026	
Zoller Inc.	*zoller-d.com*	3739	

MPT Expo 2019 Booth Previews

MPT Expo takes place October 15–17 at TCF CENTER (formerly the Cobo Center) in Detroit. Here are booth previews of some of the exhibitors most relevant to the gear industry.

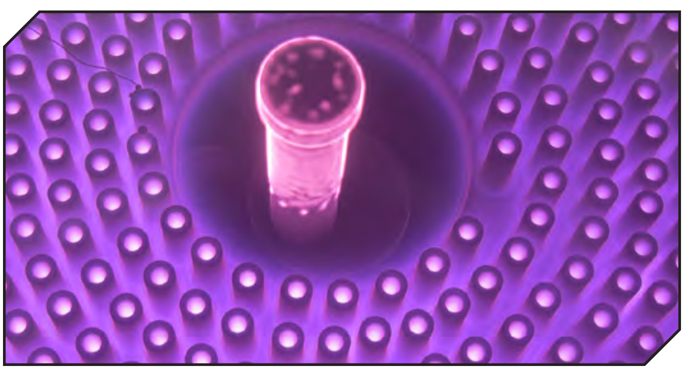
ADVANCED HEAT TREAT

BOOTH 4600

Advanced Heat Treat Corp. (AHT) will feature its heat treat solutions to help manufacturers and engineers solve wear, fatigue and corrosion challenges.

AHT will have both technical and operational personnel available to help MPT Expo attendees get their heat treat and metallurgy questions answered on-the-spot. Exhibitors include Vasko Popovski, P.E. with over 25 years of metallurgy experience and Chad Clark, 16-year AHT veteran and plant manager at the AHT site located in Monroe, MI.

The Monty recently recognized AHT founder and chief executive officer, Gary Sharp, as "the man most responsible for making plasma nitriding a mainstream process in North America."



Aside from ion/plasma nitriding, AHT also offers gas nitriding, ferritic nitrocarburizing, UltraOx, through hardening, carburizing, induction hardening, stress relief and more. Their 20+ surface treatments, multiple locations and dozens of accreditations/certifications make AHT well-equipped to provide the capabilities and expertise engineers and buyers desire.

www.ahtcorp.com

ALD VACUUM TECHNOLOGIES

BOOTH 3200

Six years ago, "One-Piece-Flow" (OPF) for case hardening processes was introduced into the gear industry for the first time, using SyncroTherm technology. Based on low-pressure carburizing (LPC) and high-pressure gas quench (HPGQ), advantages include high quality parts, short process times, less part distortion and high environmental compatibility.

In the meantime, SyncroTherm technology has expanded to include other processes such as tool hardening, annealing, brazing and sintering. In addition, another possible use is flexible heat treatment of small batches or lots, the so-called "Small Batch Production" (SBP).

The new SyncroTherm 2.0 now offers additional control features in order to meet all the requirements of a modern Internet of Things (IoT) setting. These include standardized interfaces for simple integration of external plant components into the SyncroTherm 2.0 furnace system and IoT-compatible interfaces (XML) for data transmission to superior customer-ERP-systems.

Target markets include the automotive industry and their suppliers, especially parts for electromobility in the OPF. The SyncroTherm technology is also used successfully in the aviation industry. The use of flexible "Small Batch Production" (SBP) broadens the application range for captive heat treaters and commercial heat treaters.

www.aldtt.net

AMERICAN GEAR MANUFACTURERS ASSOCIATION

BOOTH 3426

The American Gear Manufacturers Association will be in the center of the inaugural Motion + Power Technology Expo (MPT Expo). Everyone is invited to the booth to discuss the thought process behind the all-inclusive show and the future direction of the power transmission industry. You can direct questions to AGMA's staff or board about standards, education, emerging technology, membership, committees and the strategy that AGMA and its members are using to move the future.

And although they want everyone to stop by their booth, AGMA encourages attendees and exhibitors to walk the entire show floor to see all the new and different companies that have come to showcase their importance in our industry. With the new Fluid Power Pavilion, the Emerging Technology Pavilion and 250 exhibitors — including over 50 new companies — attendees will be connected to the top manufacturers, suppliers, buyers and experts in the mechanical and gear power,

electric power and fluid power industries. This is the place where you can do real business.

When attendees and exhibitors need a break from making deals, AGMA highly encourages them to take an educational seminar, attend a Fall Technical Meeting session or sign up for the new Motion + Power Technology Conference (MPT Conference), where they will learn from the experts. Whether you are new to the business and want to take the "Basics of Gearing" course or are looking to expand your knowledge by taking the "Fundamental Understanding of Electro Fluid Power Technology" class, there is something for everyone across all industries. Not an engineer or operator? That is okay, the two-track MPT Conference boasts presentations from leaders on cybersecurity, IIoT, workforce, supply chain management, 3-D printing, automation, economics and more. These development tools make taking that extra person an easy choice when you can check off training for the year in just three days.

www.agma.org

BENZ
BOOTH 4608

Since 1898, Benz has been a leader in supporting manufacturers by developing industrial fluids and lubricants. During this time, their products and offerings have evolved along with the industry.

To guarantee all your metalworking and machining processes are running as smoothly and proficiently as possible, machining fluids and coolants are a necessity. Since each fluid is formulated to work with particular metals in different conditions, be sure and contact a Benz representative for the details and specifications of the appropriate lubricant for your metal cutting application.

Benz manufacturers and distributes the best coolants for CNC Machines to keep your metalworking products, machines and operators in the absolute best condition! Contact Benz today!

www.benz.com

BEVEL GEARS INDIA
BOOTH 4210

Bevel Gears India has been manufacturing bevel gears and bevel gearboxes for over 40 years. The range of bevel gears, from 0.40" to over 70", is broad by international standards and serves several industries. They also manufacture a select range of fine pitch spur, helical and worm gears.

The bevel gear expertise has broadened over the years from custom gearing to include stock bevel gears and standard cube bevel gearboxes.

The stock bevel gear program is offered in both metric and imperial versions. Customers can select from ground or lapped spiral bevels, ground or lapped Zerols and soft or hardened straight bevel gears. Customization of stock products is an option to provide more flexibility.

Bevel gearboxes are available in standard ratios and sizes with the option to customize gear ratios, gearbox mounting requirements or housing materials for demanding applications. For power-dense applications, Bevel Gears India provides customers with high ratio hypoid gears with very high single-stage reductions. Their engineering department will be glad to review your requirements.

Applications include medical, robotics, packaging and positioning.

www.bevelgearsindia.com

BOURN & KOCH, INC.
BOOTH 3813

Bourn & Koch, Inc. will feature their newly designed 100H-T horizontal gear hobbing and turning center. Capable of producing high quality gears in a compact footprint, the 100H now features a 12-station turret to allow for turning and hobbing of workpieces in one setup. The 100H-T also features the latest BK-HMI conversational programming. The Bourn & Koch 100H has standard single- and multiple-cut cycles, Fanuc 0i-F CNC control, a power-programmable CNC hob swivel, automatic hob shift, along with crown and taper hobbing cycles. With the addition of turning, the 100H-T is designed for "one and done" gear manufacturing.

Also on display will be the fully remanufactured CNC Fellows 10-4 with electronic guide and CNC backoff allowing for crown and taper. Numerous mechanical guides and cams are no longer required to shape a wide array of gears on a Fellows 10-4. Bourn & Koch has long provided quality OEM remanufactures of Fellows 10-4 gear shapers, but has now engineered their electronic guide and CNC backoff software into the machine, which is operable through their conversational programming. The addition of electronic guide and CNC backoff offers an efficient and affordable entry into the world of advanced gear shaping.

Bourn & Koch will also feature their 25H gear hobber in their booth. Designed for the economical hobbing of fine pitch gears up to 25 mm, the 25H is a compact machine capable of producing high quality gears for a wide variety of applications and industries.

www.bourn-koch.com

CINCINNATI GEARING SYSTEMS

BOOTH 3018

Cincinnati Gearing Systems is recognized for precision gear and transmission design and manufacturing. More than just a gear manufacturer, CGS offers customers 100 years of gear design and manufacturing experience, producing reliable, high quality, cost effective products for a wide range of power transmission applications.

cincinnatigearingsystems.com

CIRCLE GEAR AND MACHINE COMPANY

BOOTH 4318

Circle Gear specializes in quality custom gearing in small to medium lot sizes. They are one of the only companies in the country that will reverse engineer and manufacture spiral bevel gear sets. Circle Gear services include bevel gears (straight and spiral up to 36" diameter), spur gears, helical gears, herringbones (up to 60" diameter), internals, racks, sprockets, worm and worm gears and all other types of power transmission products. Circle provides servicing on splines (involutes and straight-sided, internal and external). They offer reverse engineering as well as breakdown services on many products. Circle Gear currently resides in a 125,000 sq. ft. full service production facility. They also house a full service gearbox rebuild division, QRS (Quality Reducer Service). QRS specializes in rebuilds of all major brands of gear reducers as well as manufacturing of custom designed units.

www.circlegear.com

CUMI AMERICA INC.

BOOTH 4139

Achieve higher precision and productivity with high performance ceramic grains for gear grinding. Time tested and compatible with all major gear grinding machines, CUMI grinding wheels are now represented by a dedicated North American sales office.

www.cumiusa.com

DTR CORPORATION

BOOTH 3818

DTR is a supplier of high-performance, long-life gear manufacturing tools for small and large gear cutting applications. Established in 1976, DTR is one of the world's largest producers of cutting tools, shipping to more than 20 countries. DTR offers a full line of gear cutting tools, including hobs, carbide hobs, shaper cutters, milling cutters, chamfering and deburring tools, broaches and master gears.

Every tool is precision-made using high speed steel, premium powder metal or carbide, along with the latest in coatings, to achieve superior cutting and long life.

www.dtrtool.com

DURA-BAR

BOOTH 2937

Dura-Bar continuous cast gray and ductile iron is an alternative to steel, castings and aluminum that offers reliability and improved profitability for many applications, including gears.

Engineered to machine fast and consistently, Dura-Bar is customizable and available in a wide variety of sizes and shapes in the standard ASTM A48 and ASTM A536 gray and ductile iron grades.

Recently, Dura-Bar has added a tube portfolio with the launch of Dura-Tube. The new tube portfolio, produced utilizing either a proprietary continuous cast process or trepanned process, is now available in a selection of sizes and grades. The flexibility to choose Dura-Tube provides customers with options to select tube products to specifically meet requirements such as wall thickness, concentricity and even volume.

www.dura-bar.com

DVS TECHNOLOGY AMERICA

BOOTH 4007

Präwema internal gear honing machines offer significantly higher quality for internal gears. Finer tooth flank surfaces provide for gear noise level reduction and are ideal for gear parts running at high torque. Twin-spindle machines are available for higher output or further machine processes like hard turning or grinding.

The Pittler SkiveLine machines offer turning, milling, drilling, gear cutting, deburring and more in one machine. Stable gear cutting with Pittler skiving technology can be used for ring gear and step pinion machining, as well as many other applications.

www.dvs-technology.com

EMUGE

BOOTH 3307

In addition to Emuge's portfolio of rotary cutting tool solutions, they also design and build precision clamping devices for specific customer applications. Emuge's workholding division specializes in providing highly accurate, almost maintenance-free customized solutions for applications from low volume job shops to high volume automotive production environments.

Due to its interchangeable clamping element designs, Emuge can adapt its installed precision clamping devices to meet new, evolving customer

requirements. Adaptable workholding solutions eliminate the need for an entirely new workholding device, saving cost and streamlining the manufacturing process. Attendees can learn more about these adaptable workholding solutions, and discuss any of their custom clamping application needs at the Emuge booth. (*www.emuge.com/products/precision-workholding*)

"Our workholding group stays close to our customers to learn about their unique challenges and production environments. Doing so helps us develop the best solutions for their applications," David Jones, precision workholding product manager, Emuge Corp., said.

www.emuge.com

ERS ENGINEERING

BOOTH 3741

ERS Engineering Corp. will present Through Surface Hardening (TSH) technology — a unique metallurgy process that makes it possible to replace carburizing with induction hardening for a wide range of complexly shaped components, including parts previously thought to be unsuitable for induction hardening.

"The implementation of this technology provides a unique opportunity to the manufacturers who produce case hardened components to achieve two major goals," Semyon Brayman, president of ERS, said. "First, to substantially reduce the production cost; and second, to significantly improve the quality of produced components."

TSH is well suited for induction surface hardening helical bull gears, spiral bevel gears, crown wheel style hypoid gears, helical side gears and other gears and gear-like components. Applicability of the TSH technology is not limited to gears. Bushings, transmission shafts, kingpins, ball joints, driveshafts and differential crosses and bearings are also good candidates.

www.ersengine.com

EURO-TECH CORP.

BOOTH 3209

Featuring Mytec mechanical & hydraulic expansion arbors & chucks; and Frenco spline gaging. Today's solutions for efficiency and power density are often a combination of mechanical, fluid power, electric, and hybrid technologies.

Today's gears and splines are precision items produced through special tools with very tight tolerances. When you need to inspect manufactured work pieces you need even more accurate measuring and inspection equipment. For over 40 years Frenco has committed itself to the challenge of providing customized solutions for individual gear and spline inspection requirements.

Euro-Tech is the exclusive North American distributor of the Frenco product line including master gears and master wheels, setting masters, artifacts, profiled clamping systems and gear and spline production; also instruments for size production including measuring pins and ball inserts, indicating gages including rocking type, face stop and profiled guiding body and special indicating gages.

eurotechcorp.com
www.frenco.com

FOREST CITY GEAR

BOOTH 3418

Forest City Gear is a family-owned and operated business and has been in the gear manufacturing industry since 1955. Industries across the globe have placed their trust in Forest City Gear and their ability to do what others can't. Every day they manufacture custom gears across a diverse array of industries covering an equally diverse range of applications. These applications span land, sea, air and space. Forest City Gear was chosen to produce all the gears and splines in the Mars Rover where failure simply wasn't an option. Forest City also regularly supports everything from telescopes, artificial elbows, aircraft, automotive, racing, medical implants, industrial equipment, marine applications and more. Be assured that when your gears made at Forest City arrive on your dock, they will not just meet your expectations; they will exceed it.

If you'd like to learn more of what they can do for your organization, contact them to arrange a "walk through the forest," where you can tour their plant and see for yourself the difference a Forest City Gear will make in your application.

www.forestcitygear.com

FVA

BOOTH 4237

The *FVA-Workbench* is a manufacturer-neutral software solution for the modeling, parameterization, and calculation of transmission systems. It bundles more than 50 years of research and development from the FVA (German Research Association for Drive Technology) expert network into a single platform and makes this accumulated knowledge directly available for practical application

This unique software includes the latest results from the FVA research network — new calculation methods for fast, precise results. Thanks to powerful performance and intuitive operation, the new *FVA-Workbench* is easy to use and accelerates development processes significantly. Individual gearbox components and complete systems can be developed in the shortest time possible.

www.fva-service.de

GALDABINI

BOOTH 3339

Galdabini's PAS vertical straighteners are electromechanical machines designed for straightening short and medium length shafts. Their innovative C-shaped frame and the movable table holding

workpieces are two important features which are ideal for producing large quantities of parts as small batches.

The electromechanical technology enables energy saving and reduced floor space, flexible layout, low noise level, accessibility from three sides and reduced maintenance. PAS machines are the best technical straightening solution to achieve accurate tolerances in short cycle times.

The straightening process is fully automatic and 100% of parts are monitored and controlled; production statistics generated by machine software allow all the most significant production data (cycle time, initial and final tolerance..) to be recorded.

www.galdabini.us

GEAR MOTIONS

BOOTH 3531

Gear Motions will introduce new, non-backdriveable gearbox technology. Attendees can view demonstrations of the never-before-seen, patented technology at their booth.

Gear Motions will also unveil its plan for a substantial new equipment investment. The precision manufacturer plans to add three new Reishauer robotic gear grinders to its facilities in Syracuse, New York, and Buffalo, New York, over the next two years. The first, a Reishauer RZ 260, is expected to be installed by the end of 2019. The new machines will further expand the company's gear grinding capacity and add new capabilities such as twist control and super finishing.

Gear Motions' top sales and engineering staff will be on-site and available to discuss customers' precision manufacturing needs and project specifications.

www.gearmotions.com

GLEASON

BOOTH 3400

Gleason Corporation will showcase a wide array of new design, manufacturing and inspection technologies for cylindrical and bevel gears.

KISSsoft's Release 2019 includes: *KISSdesign*, an instrument that allows intuitive concept design at system level; an interface to the latest bearing data from SKF; and power skiving manufacturability evaluation based on workpiece and tool data. The interface between *GEMS* and *KISSsoft* provides an exchange of gear and system information between the two software packages. This allows the user to realistically evaluate and optimize every type of bevel and hypoid gear—with a closed loop between the design and manufacturing software.

Gleason will demonstrate the 260GX Threaded Wheel Grinding Machine with twist-control and polish grinding, software-guided single tool setup and "closed loop readiness" with a multi-functional automation system including Gleason's new GRSL Gear Roll Testing System with laser technology for fast and reliable 100% in-process gear inspection. The completely integrated solution interfaces directly with the grinding machine for automatic correction of tooth size, profile and lead angle as well as lead crowning.

Gleason's new GRSL Gear Rolling System with laser technology provides both double flank roll testing as well as analytical index and involute measurement and a new lead measurement feature on all teeth for full, analytical and functional in-process inspection. The GRSL can be employed as either a stand-alone or a fully integrated, automated solution. Real time analytics and process trend analysis are clearly visible over the production run, allowing for automatic closed loop corrections on Gleason process equipment. Users can also sort by defect so gears for rework or scrap are tracked by characteristic.

The 300GMSL Gear Metrology System combines standard tactile probing methods for cylindrical and bevel gears with the power of non-contact laser scanning of tooth flank forms. The integration of laser scanning and associated 3-D graphics with a CAD interface considerably expands both the functionality and the range of applications for the machine platform and is designed for thorough gear analysis and development. Achieving a more complete analysis of process variable changes becomes much more intuitive with the high-resolution topographical surface mapping capability. A new host of tools for the detection and analysis of gear noise makes the 300GMSL well suited to addressing noise in today's eDrive transmissions. The 300GMSL is "Closed Loop ready" to network to many of Gleason's Hard Finishing Machines.

The latest edition of the Genesis gear hobbing machine family incorporates the newly developed chamfer hobbing, which produces precise chamfers according to customer specifications while minimizing tool cost-per-piece. Gleason will also demonstrate the integration of tool and machine workflows, reducing manual data input and minimizing input errors, tracking every aspect of tool information from supplier to machine, to crib, to sharpening, to end of tool life.

Gleason presents two new workholding products: The new generation of expanding and contracting hydraulic production arbors; and new, modular standard workholding featuring quick-change workholding solutions for cylindrical gear bores ranging from 18 to 100 mm in diameter.

Gleason diamond dressing tools can be re-plated multiple times to extend tool life and maintain the highest precision. With 30+ years of experience in diamond plating technology, Gleason can address every gear related dressing solution in the market including solutions for polished surfaces or asymmetrical gears. Tools can be equipped with RFID, barcode or QR technology to integrate in 4.0 tool management environments.

Gleason will present a host of new service offerings: The Gleason SPN Program (Safety-Productivity-Networking), a simple and economic field service alternative to a complete re-control of old Siemens 840D pl and many models of Gleason Metrology Inspection machines; Gleason Fingerprint, which diagnoses machine problems and potentially prevents downtime of installations; Tool-to-Machine communication adds intelligence to tool management, reduces manual data input and minimizes input errors; The new Gleason Academy platform of theoretical training classes and operator training in tutorial style.

www.gleason.com

GMTA – GERMAN MACHINE TOOLS OF AMERICA

BOOTH 4439

GMTA will feature its Profilator line of gear pointing, rounding, cutting, Scudding, Hard Scudding, deburring and polygon machine tools for North America. The highly modular machines are used for polygon and slot facing, shifter stop machining, chamfering and deburring of highly complex automotive and other powertrain gears. "Hard Scudding" allows the machining of green and hardened gears on the same machine, using the same programs.

While Profilator GmbH & Co. KG introduced the concept of Hard Scudding in 2015, it expanded scudding technology with "Micro-Finishing." Micro-Finishing takesplace after the Hard Scudding process has been completed. The process takes a high quality Hard Scudding part and improves its surface quality. Additionally, this is a completely dry machining process and requires no cutting fluids or MQL technology. The total cycle time for finishing a ring gear via Hard Scudding and Micro-Finishing is approximately 64 seconds, but the cycle time could be decreased by 10%, keeping it under one minute for all automotive gear rings.

Micro-Finishing technology is aimed at making at quieter gear and the superfinishing process reduces friction, increases pitting resistance and the life of gears. This process uses a high quality diamond plated tool, designed to remove only a small amount of part material. The resulting part greatly increases surface quality on the gear teeth.

The Micro-Finishing technology can be applied as a "stand-alone" process on a Scudding machine, a sequential process where Hard Scudding and Micro-Finishing are completed using a tandem tool set-up or it can be applied on a double Profilator machine. The processes of Hard Scudding and Micro-Finishing can be completed simultaneously.

gmtamerica.com

GWJ

BOOTH 3934

GWJ Technology offers professional software development for mechanical engineering to support engineers and designers in their daily work — from standard software for classical machine elements with 3-D CAD integration modules to the determination of whole systems up to a complex special software for 5-axis milling of gears. Several of GWJ's various software suites will be on display.

GWJ will introduce a lot of features, including a new and enhanced calculation for cylindrical gear pairs. The new version now supports the strength calculation of plastic gears. Ultra-clean steels and plastic materials were also added to the material database. In addition, the profile modifications can be dimensioned and the user gets recommendations for the flank modifications. The definition of load spectra has been extended and new options for the dimensioning of the profile shift coefficients were integrated. A calculation with a fixed center distance independently of the profile shift sum is also available. Additionally, the calculation of the load capacity according to AGMA has been updated.

Furthermore, a new calculation module for Hirth couplings will be introduced. Besides the generation of several gears and shafts, the 3-D CAD plugins offer the possibility to import shaft geometries in the calculation.

There is also a new version of the *SystemManager* software. The new version provides multiple enhancements that make the life of engineers easier than ever before. For example, the support of 3-D elastic gear bodies and 3-D elastic bearing rings, the import of background graphics of shafts, the import of shaft geometries such as 2-D DXF, 3-D STEP or the direct link between the face load coefficient with load capacity calculation with the load spectrum, extended parameter variation, new diagram functions, template file directory, periodic gear forces in the harmonic response, advanced results for planetary gear trains, and updated bearing database for SKF and Schaeffler (INA/FAG) bearings or the new exchange format REXS for the data exchange of systems between different software solutions like *Bearinx*, *SystemManager* and, in the future, e.g. multiple-body simulation tools.

During the exhibition, GWJ will give insight into the new calculation module for face gears, a part of the special software *GearEngineer*.

www.gwj.de

HAINBUCH AMERICA
BOOTH 3203

Stop by booth 3203 to see Hainbuch's lineup of job shop mandrels for gear cutting, hobbing, grinding and shaping. The Mando G211 segmented mandrel for gear cutting features a slim interference contour; rigid radial clamping with pull-back effect; large clamping range and vibration damping due to vulcanized clamping bushings; integrated flushing channels and more.

www.hainbuchamerica.com

HANIK CORPORATION
BOOTH 2407

Hanik Corporation is your source for Schnyder precision gear cutting tools, made in Switzerland. Schnyder hobs are available in up to 4A Quality.

www.hanikcorp.com
www.schnyder.com

HELIOS GEAR
BOOTH 3213

Helios solutions include the Helios Hera series of CNC gear hobbing machines from YG Tech. Hera machines offer several attractive features: Fanuc or Siemens CNC; high-speed hob heads with automatic retraction during power failure; direct-drive torque motors; friendly dialog programming for easy operating and quick training; re-hobbing (skiving); world-class construction and components; and compact footprints.

Helios will show the Hera 90 CNC gear hobbing machine. This machine features a unified, versatile gantry automation system for easy and productive hobbing of spur gears, helical gears and splines. It also features a high-swivel head for worm and thread milling. Manufacturers of parts up to 90 mm (3.543 in) diameter and 3 module (8.5 DP) should visit the Helios booth to see the machine in action.

Gear manufacturers can also see the Hera 350 CNC gear hobbing machine. With the series' same high-quality feature set, the Hera 350 enables profitable vertical hobbing of spur gears, helical gears and other hobbed profiles. The machine is rated at 6 module (4.3 DP) and 350 mm (13.780 in) diameter for automatic loading (additional capacity is available for manually loaded parts).

The Helios TM 200-R3 gear deburring machine from Tecnomacchine deburrs parts up to 200 mm (7.874 in) in diameter with high-speed tool spindles. With five workstations and a unified, flexible automation system, the TM 200-R3 offers manufacturers a productive brushing, deburring and/or chamfering solution that enables consistent quality and reclaimed labor. Manufacturers can visit the Helios booth to see this machine produce deburred parts in as little as every 20 seconds.

Lastly, as part of Helios's partnership with Kapp Technologies, the PGM 165 gear inspection machine will also be demonstrated. This CNC analytical measuring machine can inspect parts up to 180 mm (7.087 in) diameter using Renishaw 3-D probe technology and *Penta Gear Metrology* software.

In addition to machine tools, Helios offers manufacturers cutting and abrasive tools, including hobs, milling cutters, shaper cutters, generating grinding wheels, form grinding wheels, bevel gear grinding cups, diamond dressing gears and more. Gear manufacturers can also benefit from Helios's services, such as gear cutting tool resharpening and recoating, contract inspection and application engineering.

www.heliosgearproducts.com

HOBSOURCE
BOOTH 4401

HobSource delivers quality tools whether you hob, shape, skive, shave, broach or mill. Each tool is manufactured to exacting quality standards in ISO/QS facilities from the latest grades of high speed steel and carbide using CAD/CAM technology and state of the art CNC equipment. If you demand performance, reliability and dependability from your tools and vendors, HobSource challenges you to try their tools.

www.hobsource.com

INDEX TECHNOLOGIES INC.
BOOTH 3327

Gear manufacturers need tools returned quickly. Index Technologies sharpens your perishable assets to meet or surpass original sharpening specifications. Offering hob sharpening and skive cutter sharpening. Visit the booth to see the company's skive cutter sharpening machine in action.

www.indextechnologiesinc.com

INNOVATIVE RACK & GEAR CO.
BOOTH 2907

Innovative Rack & Gear Co., Inc. is a custom manufacturer of gear racks and gears to OEMs and suppliers in a variety of industries, including machine tool, automation, construction, mining, healthcare, aerospace and others. Investments in the latest technologies for precision gear rack manufacturing and highly skilled craftsmen are the reasons

why Innovative Rack & Gear should be your quality source for gears, especially precision hard-cut and precision soft-cut gear racks. The recent acquisition of a Wenzel CMM ensures the accuracy and quality that customers have come to expect as well as being certified to ISO 9001:2015.

www.gearacks.com

JAMES ENGINEERING

BOOTH 2726

Robots and full-time CAD/CAM programmers are not required to achieve fast, consistent, precise results. James Engineering will highlight the variety of part types, shapes and sizes the MAX System can easily be programmed to process and execute in seconds using the simple Select—Enter—Cycle—Start interface to its unlimited number of part-processing recipes.

Today's MAX System is a tested and proven innovation, which routinely applies its patented Focused Deburring skillset at speeds and production volumes that not only keep up with, but surpass CNC milling rates, while also producing finish quality and structural enforcements no other finishing solution can deliver. James Engineering's CNC-style, multi-axis MAX System was first introduced in 2008, and a prototype of today's second-generation series was first demonstrated at AGMA's 2017 Gear Expo.

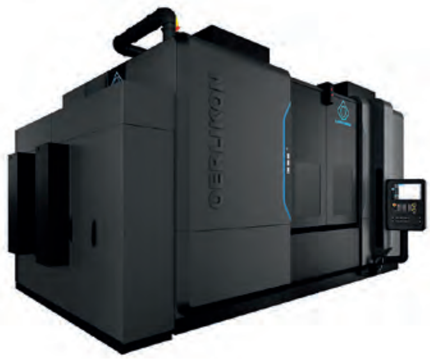
www.james-engineering.com

KLINGELNBERG

BOOTH 3631

Klingelnberg will unveil leading-edge technology with the P 26 precision measuring center and optical measuring technology. At the same time, Klingelnberg will demonstrate its expertise in the "non-gear" sector.

To be equipped for all measurement tasks, Klingelnberg combines Hispeed Optoscan optical measuring technology with the established, high-precision 3-D Nanoscan probing system. This system incorporates maximum precision with the required robustness for a production environment. Thanks to the high-speed changeover feature, the optimal measurement system can be used for every task. Optical measuring technology can be used for digitizing an entire, possibly unknown component or measuring splines quickly yet completely. The high measurement speed of the optical system with a high point density allows for measurements that would be time-intensive if performed with a tactile system. The tactile 3-D Nanoscan is designed to capture individual, high-precision measured values. For a rapidly generated, dense point cloud, Hispeed Optoscan is available. Roughness measuring technology is also available.



Klingelnberg also offers solutions in the "non-gear" sector. Whether turning blanks, ground workpieces or rolling bearings — Klingelnberg G variant precision measuring centers are specifically designed for use in the production process of axially symmetrical components.

The G series precision measuring centers are suited to production processes that require not just dimensional measurement tasks, but also complex form and surface measurements in large numbers.

Klingelnberg G variant precision measuring centers are designed for use on the shop floor, including applications in the automotive and commercial vehicle industries, machine building and plant engineering, and the manufacture of rolling bearings.

The expo team will also be informing visitors about the exhibit highlights presented at EMO Hannover 2019. Among others, these include the Oerlikon G 35 Bevel Gear Grinding Machine for the aviation industry and the Höfler Viper 500 MFM cycloid grinding machine, which is of special interest to the robot industry.

Specifically tailored to the requirements of the aviation industry, the newly developed Oerlikon G 35 bevel gear grinding machine incorporates two vertical grinding spindles.

The Viper 500 MFM makes it possible to mass-produce high-precision cycloid gearings without requiring complex pairing of components. In combination with the precision measuring centers and closed loop technology, Klingelnberg now has a complete system for the production of highly accurate cycloid gearings. In the

cycloid grinding cell, the processing machine and the precision measuring center are connected by automation. Thanks to the use of *GearEngine*, this cycloid grinding cell is "fit" for Industry 4.0 processes. Combined with closed loop, this gives rise to an autonomous, self-optimizing production system that makes it possible to utilize the machining and measuring capacity of the machines to optimal effect.

www.klingelnberg.com

LIEBHERR

BOOTH 3413

Based on the proven LGG 280 generating grinding machine, Liebherr is presenting the larger LGG 400 M model at Motion + Power Technology Expo. Furthermore, Liebherr will showcase its line of gear measuring machines.

The LGG 400 M has been developed with an eye towards aerospace and job shop customers. It fits into the same footprint as its little sister, the LGG 280, but has grown in height. With a different housing and a column extension, it is capable of machining long shafts because the travel of the main and counter column has been extended.

"Our users can utilize a variety of grinding heads for internal and external gears," says Oliver Kraft, Manager Development and Design of Gear Cutting Machines at Liebherr-Verzahntechnik GmbH. "They can perform generating grinding with high productivity on workpieces up to 280 millimeter in diameter or profile grinding on even larger components up to 400 millimeters. This means even greater flexibility then its sister machine."

Long shafts with small diameters have come into demand, required by customers in the aerospace and jobs hop industries—often for short runs. Liebherr offers an optional crane for optimal handling of large parts. "We have ergonomically adapted the machines overall," Kraft explains. "Due to the height, we have incorporated fold-out stair steps so workers are better able to reach the working area. Large viewing windows provide the operator with the best possible overview of the working area and the process."

For the first time, Liebherr will be presenting its extended product portfolio in the US. The WGT series of measuring technology closed the gap in the closed-loop sector. The four-axis measuring devices are equipped with high-precision mechanic and electronics, which are controlled by intelligent and user-friendly software. The combination of granite guides and air cushioning creates maximum precision with wear-free mechanics. In addition to the gear inspection machine options available as standard, customer-specific solutions are also available, such as extending the travel range on the Z-axis, longer tailstocks to accommodate long shafts, and rotary tables adapted to the payload. Liebherr will exhibit the gear measuring machine WGT 280.

www.liebherr.com

LOUIS BÉLET

BOOTH 3033

Facing a demand from the watchmaking world for gear cutting solutions, Louis Bélet started producing tools with special profiles in the late 1980s. Currently, the profiling sector at Louis Bélet consists of several dozen machines, allowing customer requests to be met within very short lead times, even for special profiles!

"Today's world is moving in the direction of miniaturization. Coming from the watchmaking world, Louis Bélet is ideally positioned to face these challenges, both in terms of dimension of course, but also in terms of lead time and quality," Pierre Falbriard, R&D manager at Louis Bélet, said.

"Markets such as medical, connectivity, aeronautics and automotive are facing this megatrend on a daily basis and Louis Bélet can give them the necessary expertise in the field of cutting tools," Hervé Baour, international BDM at Louis Bélet, said.

Louis Bélet's know-how allows them to produce the highest quality tools for cutting gears exceeding 2500 DP, 25 being the largest dimension currently achievable.

They will also present a lecture on the theme of micro-skiving. Of course, power-skiving is a proven technology, but for a fine toothing, no solution was available on the market so far.

The product expertise offered by this company of 150 employees doesn't just cover gear cutting tools. Louis Bélet also markets more traditional precision cutting tools such as drills, mills or shape tools, with the same quest for perfection and precision.

www.lbsa.ch

MACHINE TOOL BUILDERS

BOOTH 3407

Originally established in 1995 as a service organization, MTB has since evolved into a world class machinery rebuilder, and has begun to move towards the new machinery business.

As a technology driven firm, the staff of MTB offers a wide array of experience in mechanical and electrical engineering, electronic controls, and software design. This knowledge is coupled with an eye for innovation and a genuine desire to provide the service you need when you need it.

MTB represents Burri grinding and dressing machines, Donner+Pfister measurement and gear grinding products, Senjo-Seiki deburring and chamfering machines, and Diablo Furnaces (stop by their booth at the co-located ASM Heat Treat show in booth #1318).

www.machinetoolbuilders.com

MCINNES ROLLED RINGS

BOOTH 2922

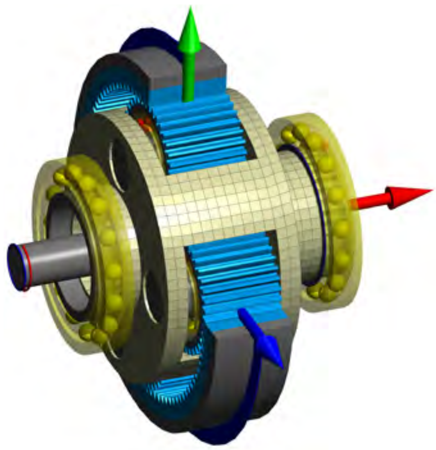
McInnes Rolled Rings specializes in seamless rolled rings from 4"–144" diameter and forged discs up to 54"diameter in carbon, alloy and stainless steel. Their ISO 9001, AS9100 and ABS certified plant in Erie, PA combines the latest in ring rolling technology with experienced people, aimed at providing the best value and the fastest deliveries in the industry.

www.mcinnesrolledrings.com

MESYS

BOOTH 3933

Mesys will show new features of its shaft system calculation version *07/2019*. The fully coupled system calculation has new features in its FEA integration which allows elastic gear bodies and elastic



bearing rings in addition to elastic housings, shafts and planet carriers. In the latest version centrifugal expansion and contact for elastic bearing rings were added.

Harmonic response can now be calculated using periodic displacements in addition to periodic forces. One use case is the calculation of dynamic gear forces based on transmission error. Another use case is considering a base excitation from the housing.

The parameter variation has a new optimization step allowing to maximize or minimize parameters based on multiple constraints. This can be used to let the software calculate maximum permissible forces for example.

The REXS data exchange format version 1.1 allows to exchange data with other CAE programs.

Bearing databases with catalog data from Schaeffler and SKF were updated, several databases for spindle bearings including internal geometry are available on request from GMN, IBC, CSC and HQW.

www.mesys.ag

MITSUBISHI HEAVY INDUSTRIES

BOOTH 4239

Mitsubishi Heavy Industries will follow the world debut of the new ZE26C at CIMT in China with the market launch of the new model in North America.

The ZE26C will respond to needs for higher speed and precision especially in the transmission systems of electric vehicles and the reduction gears used in robots. The ZE26C was developed to finish hardened and tempered gears with outer diameters up to 260 mm. Superior performance has been achieved by making improvements to the ZE-B series of widely acclaimed gear grinding machines. Specifically, the ZE26C's grinding precision and stability have been enhanced by increasing the rigidity of the column, table and grinding wheel head, coupled with revamping of the spindle structure. In addition, by increasing cutting speed and reducing idle (non-cutting) time by roughly 50% compared to earlier models, the ZE26C boosts high-volume production capability and promotes lower running costs.

Furthermore, by expanding the maximum wheel width to 160 mm, frequency of wheel replacement is reduced and simultaneous mounting of standard and polishing grinding wheels is simplified, enabling response to a variety of in-factory needs and higher operational performance. Also, adoption of water-soluble coolant (optional) improves environmental performance while also enhancing energy savings.

The new ZE26C will be on display and perform a gear grinding demonstration (dry run). A demonstration will also be given of Mitsubishi's Diascope monitoring system, which uses IoT technology to give visibility of real-time production status.

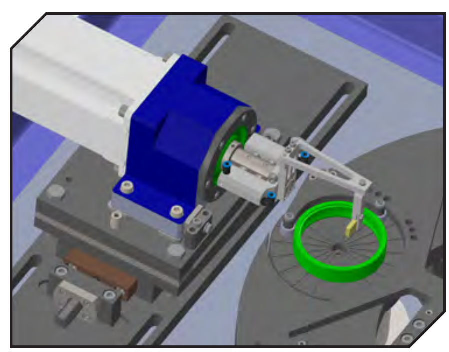
www.mitsubishigearcenter.com

NAGEL PRECISION

BOOTH 4308

Nagel will showcase their comprehensive line of honing, superfinishing, face grinding and deep hole drilling equipment.

Nagel has developed a new series of flexible stone superfinishers to finish inner and outer bearing races. The machines are custom designed to meet customer specifications and can be equipped with either Siemens or Allen Bradley controls. The ultra light finishing stone holder is mounted directly on a heavy duty servo oscillator and can attain oscillating speeds of up to 45 HZ. Directly coupled servo part driver can reach speeds of up to 3000 rpm. Multiple finishing heads can be mounted to achieve desired quality and output.



The key features of the new machine are: ability to change over rapidly from one part type to another and minimize non cutting idle time (part load/unload) during the machine cycle. The superfinishing heads are mounted on an X and Z servo axis for automatic positioning to accommodate part diameter and thickness change. Patent pending part drive system can handle a range of part diameters without any changeover. The new system encompasses a number of industry features to make the machine more flexible and productive.

www.nagelusa.com

NORTON | SAINT-GOBAIN ABRASIVES

BOOTH 2607

The new Norton Xtrimium range of gear solutions is designed for high performance gear grinding in extreme, tight tolerance environments. The newly structured portfolio of gear grinding products is specifically designed by category to provide higher profile accuracy, supreme form holding and burn-free grinding in worm, profile, and bevel applications. Highlighting the new range is an innovative dual-worm wheel design that enables two operations in one grinding wheel, substantially saving time and cost.

"In today's increasingly stringent industry requirements for higher accuracy and improved surface finishes, our new high performance Xtrimium grinding wheels are engineered to deliver the highest quality gear grinding solutions," said Jim Gaffney, senior product manager, Norton | Saint-Gobain

Norton Xtrimium Dual-Worm Grinding Wheels feature a unique design with a high-performance vitrified bond section for grinding and a fine-grit resin section for polishing the gear teeth, enabling one wheel to perform what traditionally required two wheels. Substantial savings in wheel costs and productivity via the elimination of wheel swapping, can be achieved with the Norton design. In addition, improved surface finishes of Rz = 1.0 mm and Rpk = 0.05 mm, and reduced harmonics (noise) are realized. The Norton Xtrimium Dual-Worm Grinding wheels can also be adapted to existing machines.

www.nortonabrasives.com

OELHELD

BOOTH 3803

Oelheld is adding SintoGrind TC-X 630 as the new entry level product to its flagship and perennial best-selling SintoGrind series. SintoGrind TC-X 630 is made from the latest generation of GTL base oils. GTL stands for Gas to Liquid. GTL technology converts natural gas — the cleanest-burning fossil fuel — into high quality liquid products that would be otherwise be made from crude oil. GTL base oils are colorless and odorless. They contain almost none of the impurities found in crude oil, such as sulfur, aromatics and nitrogen.

SintoGrind TC-X 630 will set new standards in its product and price class. The product is designed for flute grinding, profile grinding and outside and inside diameter grinding. SintoGrind TC-X 630 works on a wide variety of materials including tungsten carbide, HSS, PCD, CBN, cermet and ceramics. SintoGrind TC-X 630 contains no hazardous elements and exhibits stable viscosity over a wide temperature spectrum.

www.oelheld.com

PENTA GEAR METROLOGY LLC

BOOTH 3607

Penta Gear Metrology, a brand of Kapp-Niles, offers analytical gear inspection machines for workpieces up to 450 mm diameter, as well as a wide variety of master gears, spline gages and functional inspection equipment, including double-flank testers and gages for measuring dimension-over-pins or dimension-over-balls.

In addition, Penta Gear's ISO 17025/A2LA-accredited laboratory offers contract inspection services, reverse engineering and gage certification.

Ask about Penta Gear's REPOWER program to find out how your older analytical inspection machine can be given new life.

pentagear.com

PHILADELPHIA GEAR

BOOTH 4033

Philadelphia Gear and other experts that are a part of the Timken Power Systems team join forces to feature seven brands that combine to provide an entire industrial drivetrain solution. Drawing on a global pool of engineering expertise and technological advancements, Timken Power Systems provides end-users with a single trusted source for comprehensive electro-mechanical equipment support. From designing custom control systems to gearbox expertise to comprehensive

bearing repair solutions, they can maximize your powertrain and rotating equipment's reliability and performance.

Through a network of independently ISO-certified regional service and manufacturing centers, they focus on providing local expertise at a national level to minimize your downtime and reduce your cost of repair.

www.philagear.com

PRESRITE

BOOTH 4200

Presrite specializes in the near-net forging of gears. Typical stock allowances range from .004" to .060" on the gear flanks. With presses up to 6,000 tons of capacity and a state-of-the-art tech center, Presrite offers design, engineering and die-making production solutions.

www.presrite.com

PROTO MANUFACTURING

BOOTH 4328

Proto offers laboratory as well as portable and ultra-portable x-ray diffraction systems for the measurement of retained austenite and residual stress.

www.protoxrd.com

REISHAUER

BOOTH 2913

Reishauer presents a sophisticated gear grinding process monitoring system. All process data of each workpiece are recorded and remain 100% traceable.

The dressing and grinding process are measured and monitored by smart real-time data processing and tested algorithms. For each workpiece, all data generated during dressing and grinding are recorded and stored in a database and remain 100% traceable. Using the stored process and tooling data, including workpiece identification via DMC, offers

the means of comprehensive analysis. Due to process interaction, and using preset evaluation limits, workpieces that exceed or fall short of these limits are automatically removed.

Recurring automatic testing cycles measure and evaluate all the relevant grinding machine axes involved in the process, thus enabling early detection of electromechanical deviations. Maintenance costs are optimized both in terms of planning and diagnosis, and some potential EOL anomalies may be avoided.

www.reishauer.com

REM SURFACE ENGINEERING

BOOTH 4510

REM Surface Engineering, the inventor of the ISF Process, the Rapid ISF Process, the Extreme ISF Process, and the REM Process, provides surface engineering solutions for aerospace, heavy equipment and off highway and industrial gearing.

REM's isotropic superfinishing technologies are value adding and performance enhancing improvements to conventional machining operations such as grinding and lapping. Founded in 1965 in Southington, CT by Robert Michaud, REM Surface Engineering is a family-owned company that has proudly been serving their partners and customers for over 50 years. REM Surface Engineering operates four locations in Brenham, TX, Southington, CT, Merrillville, IN and St. Neots, UK that provide products and services globally.

www.remchem.com

ROTEC TOOLS LTD.

BOOTH 3131

Learn more about Affolter's line of compact hobbing machines, including the AF110Plus, the most powerful gear hobbing center in Affolter's GEAR line. The 7-axis AF110Plus is designed for parts up to 90 mm length and 60 mm diameter, with modules up to 1.5 mm.

rotectools.com

SMT

BOOTH 4227

SMT is a globally integrated provider of mechanical transmission engineering services and software development. Over the past 16 years SMT has grown from a collective of experienced and passionate engineers into an international enterprise serving all sectors of the transmission and driveline development industry.

SMT engineers have knowledge of the full development process of automotive, industrial, aerospace, energy and marine transmissions and are able to advise on all aspects of transmission design, analysis and optimization. Having worked with leading international companies on a wide array of engineering projects, SMT can deliver fully integrated technical solutions for the design, development and manufacture of entire drivetrain, gearboxes and transmission systems.

MASTA is a complete suite of CAE software for the design, simulation & analysis of driveline systems from concept through to manufacture.

www.smartmt.com

SOLAR MANUFACTURING

BOOTH 2013

Since 2002, Solar Manufacturing has introduced technology in the heat treating industry with advances in hot zone designs, improved energy efficiency, state-of-the-art furnace automation and control systems and high-performance gas quenching. They will be showcasing their SolarVac control innovations at ASM Heat Treat 2019 for the benefit of their customers — a new, thermally efficient and extremely strong hot zone design and a new integrated furnace control system.

www.solarmfg.com

SOUTHERN GEAR

BOOTH 4228

Southern Gear is a custom precision gear and gearbox manufacturer providing quality gears to demanding industries including aerospace, defense, marine and medical. Their AS 9100- and ISO 9001-certified facilities house nearly 150 machines ready to manufacture precision gears and gearboxes including bevel, helical, spur, face, ring, internal, anti-backlash, worm and worm gears, racks, splines, sprockets and more.

Southern Gear is equipped to perform every type of machining at their plant including: turning, milling, grinding and gear cutting/grinding. Parts are manufactured in their plant, under their control and under their AS 9100 D quality system and lean manufacturing processes. Southern Gear's total management of the entire production sequence allows them to increase efficiency and optimize quality in order supply mission-critical parts to the aerospace and other demanding industries on time and

on budget.

Southern Gear's engineers and machinists have an average of 26 years of experience, and their employees have been with the company an average of 17 years.

A veteran-owned company in business for more than 60 years, Southern Gear offers a wide variety of precision gear manufacturing, from bevel to worm gears, from prototype to assembly, from aerospace to medical.

www.southerngear.com

STAR SU

BOOTH 4013

Star SU will present advanced manufacturing solutions from both machine tools and cutting tools.

Star SU will introduce their hobbing and shaping machine portfolio through the newly created company Samputensili CLC S.r.l. Star SU will interactively display the CLC 260 H and CLC 500 H — two high performance modular horizontal gear hobbing/milling machines, which can be customized for any type of gear, shaft and worms up to a total length of 5000 mm.

The new Star NXT linear CNC tool and cutter grinding machine sharpens both straight and spiral gash hob designs up to 8" OD × 10" OAL. With a small footprint and maximized grind zone, the NXT also sharpens disk, shank and helical type shaper cutters, Scudding cutters

and a wide range of round tools, making it a versatile tool room machine.

In addition, Star SU's complete library of gear manufacturing machinery solutions will be available, including the Samputensili SG 160 Skygrind — the first gear dry grinding machine in the world

with a patented process, which totally eliminates the need for cutting oils during the grinding of gears after heat treatment with a significant reduction in the cost of consumables and a considerable improvement of environmental impact.

Star SU offers a wide variety of gear cutting tools, precision tool re-sharpening services, and advanced coatings from Oerlikon Balzers, including Alcrona Pro and Balanit Altensa, the high-speed coating solution that realizes productivity gains and efficiency.

Star SU will also feature their innovative Scudding cutters manufactured to produce gear and spline teeth for reduced cycle times and tool costs.

Also on display will be Star SU's complete round tool offerings, including gundrills, design and build solid carbide drills, and precision reamers. Addressing the fluid power industry, they will showcase a selection of cavity/port tool solutions including one shot cavity machining.

Lastly, Star SU offers a wide variety of tungsten carbide blanks and preforms from H.B. Carbide. Using only the highest quality raw materials and employing state-of-the-art, computer controlled vacuum sinter-hipping furnaces, these cemented carbide preforms can be used for cutting tools, dies and wear parts in a variety of specialized applications.

www.star-su.com

UNITED TOOL SUPPLY

BOOTH 4614

United Tool Supply's booth will be full of their latest product advancements, in combination with the products that have made their business what it's been for the last four decades. Showcased in their booth will be their Unite-A-Matic PD gauge, Surf-A-Matic surface finish gauge, and their newest product, the Roll-A-Matic PD Runout gauge. United Tool Supply's product lines will be proudly displayed and demonstrated to show the industry what they have to offer moving into the new decade.

The company's featured product this year, the Roll-A-Matic, is a shop hardened PD Runout Inspection gauge designed with the customer's needs in mind. A flexible design allows United Tool Supply the ability to use customer's existing masters and interchangeable locators to inspect multiple parts on one gauge. The gauge can be manually operated or motor-driven, with an indicator or paired with a linear gauge/LVDT probe to output the data digitally to a PC. This solution is a simple, accurate, repeatable gauge to facilitate in-process checks on the shop floor during the manufacturing process.

www.unite-a-matic.com

VIKING FORGE

BOOTH 2610

Viking Forge, LLC will display near net shaped and flashless forged gear blanks manufactured from their closed die, hot forging mechanical press lines. Producing high precision forged products from 1 to 95 lbs, 3" to 14" in diameter and up to 10" in length, Viking Forge is dedicated to using advanced technology to further the science of forging for the benefit of their customers.

Viking's proficiency begins with engineering, where their highly skilled and experienced staff develop forging designs that meet or exceed customer expectations. 3-D CAD modeling, material flow simulation and Solid Modeling System technologies allow engineers to calculate the exacting requirements of how the steel forging process will affect the final product. These process steps reduce multiple prototyping, controlling costs and lead times. Sales management and engineering staff will be in attendance to discuss these advantages with you.

www.viking-forge.com

WFL MILLTURN

BOOTH 4309

WFL focuses on complete machining with a full range of Millturn machines with the ability to machine complex parts up to very big components. More than twenty different machining methods can be performed.

The Millturn design concept is very robust and rigid with a massive cast iron bed. The main spindle as well as the high precision turning-boring-milling unit are extremely powerful. Gear manufacturing is all about keeping high quality demands, profile accuracy and reliability.

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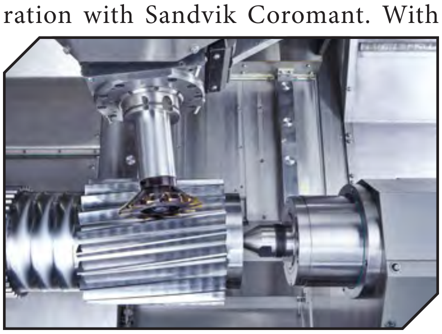

these manufacturing methods, virtually all machining challenges for gear manufacturing can be covered. Moreover, the ability to measure the gears in the machine improves the efficiency and reduces risk of error.

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Gear Manufacturing, Tuesday, Oct 15, 10:30 a.m.

- Dr.-Ing. Andreas Mehr, Gear Grinding and Shaping Technology Development, Liebherr.
- Dr.-Ing. Hartmuth Muller, Head of Technology and Innovation, Klingelnberg.
- Dr.-Ing. Deniz Sari, Sales Manager Middle Europe, Samputensili
- Dr. Hermann J. Stadtfeld, VP Bevel Gear Technology and R&D, Gleason

Gear Design, Tuesday, Oct 15, 2:30 p,m.

- Charles Schultz, President Beyta Gear Services (also Gear Technology technical editor and author of Gear Talk with Chuck on the geartechnology.com blog).
- Prof. Dr.-Ing. Karsten Stahl, Director of the Gear Research Center (FZG) at the Technical University of Munich.
- Frank Uherek, Principal Engineer, Gear Engineering Software Development, Rexnord.

Lubrication, Wednesday, Oct 16, 10:30 a.m.

- Paul Conley, Chief Technologies, SKF.
- Sib Hamid, VP, Director of Operations and Corporate Director of Technology, Lubriplate.
- Dr.-Ing. Thomas Tobie, Head of the Department Load Carrying Capacity of Gears at the Gear Research Center (FZG) at the Technical University of Munich.

Bearings, Wednesday, Oct 16, 2:30 p.m.

- Mike Allega, Application Engineer Specialist, Timken.
- George Lutzow, Manager Application Engineering, SKF.
- Jitesh Modi, Engineering Director, Transmission Applications North America, Schaeffler Group USA Inc.
- Chris Napoleon, President, Napoleon Engineering Services.

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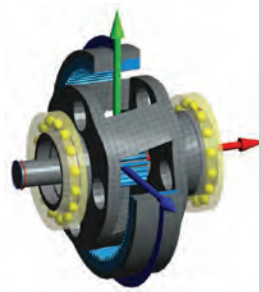

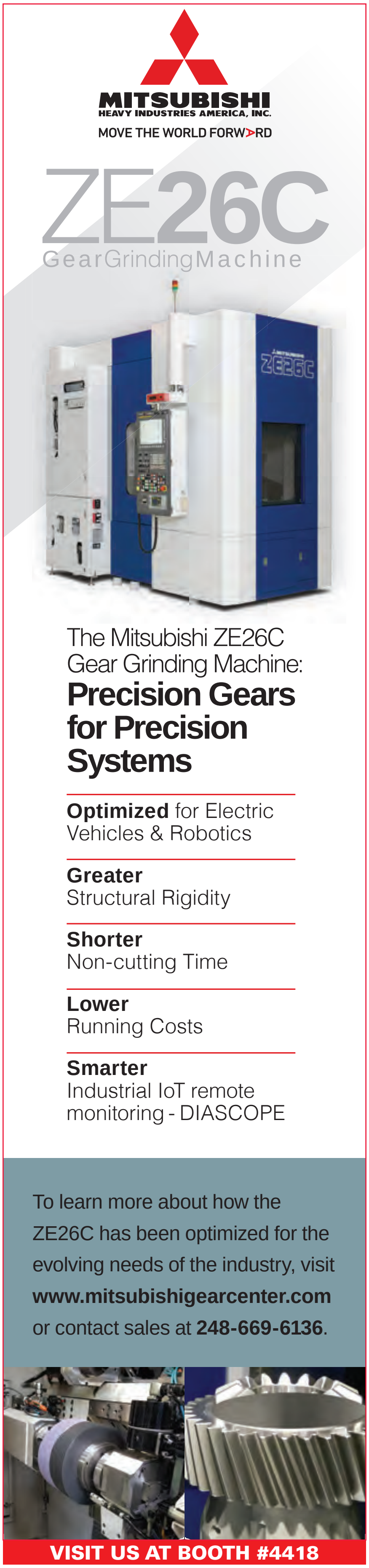
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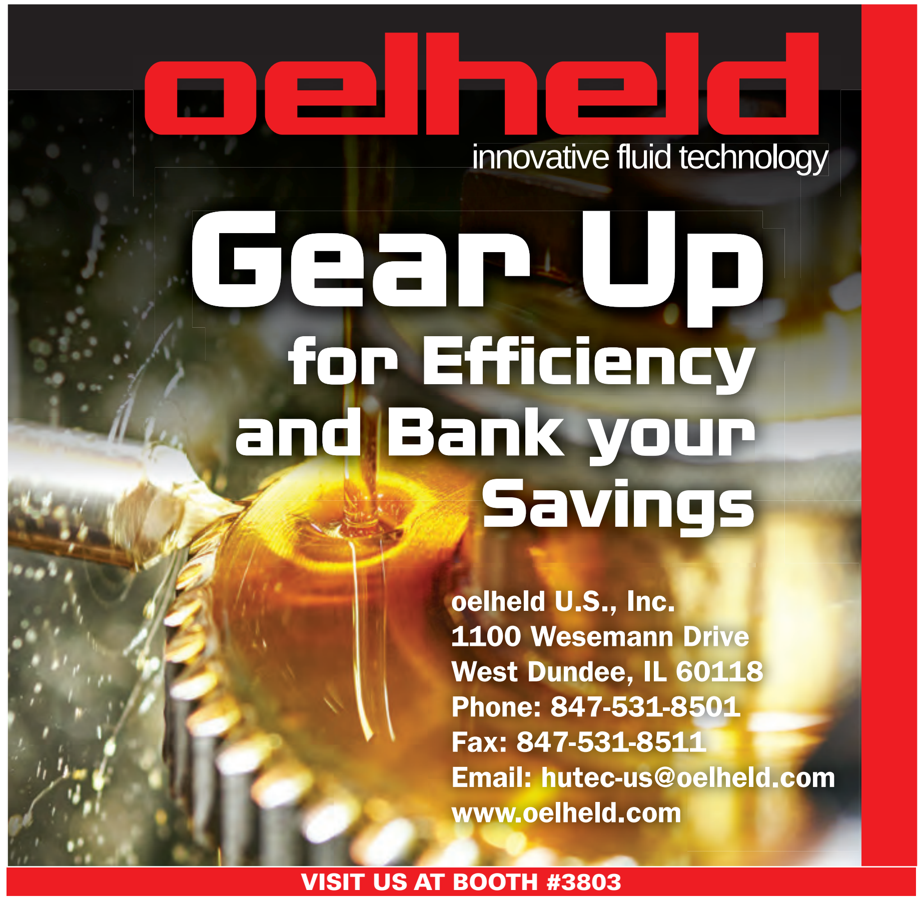
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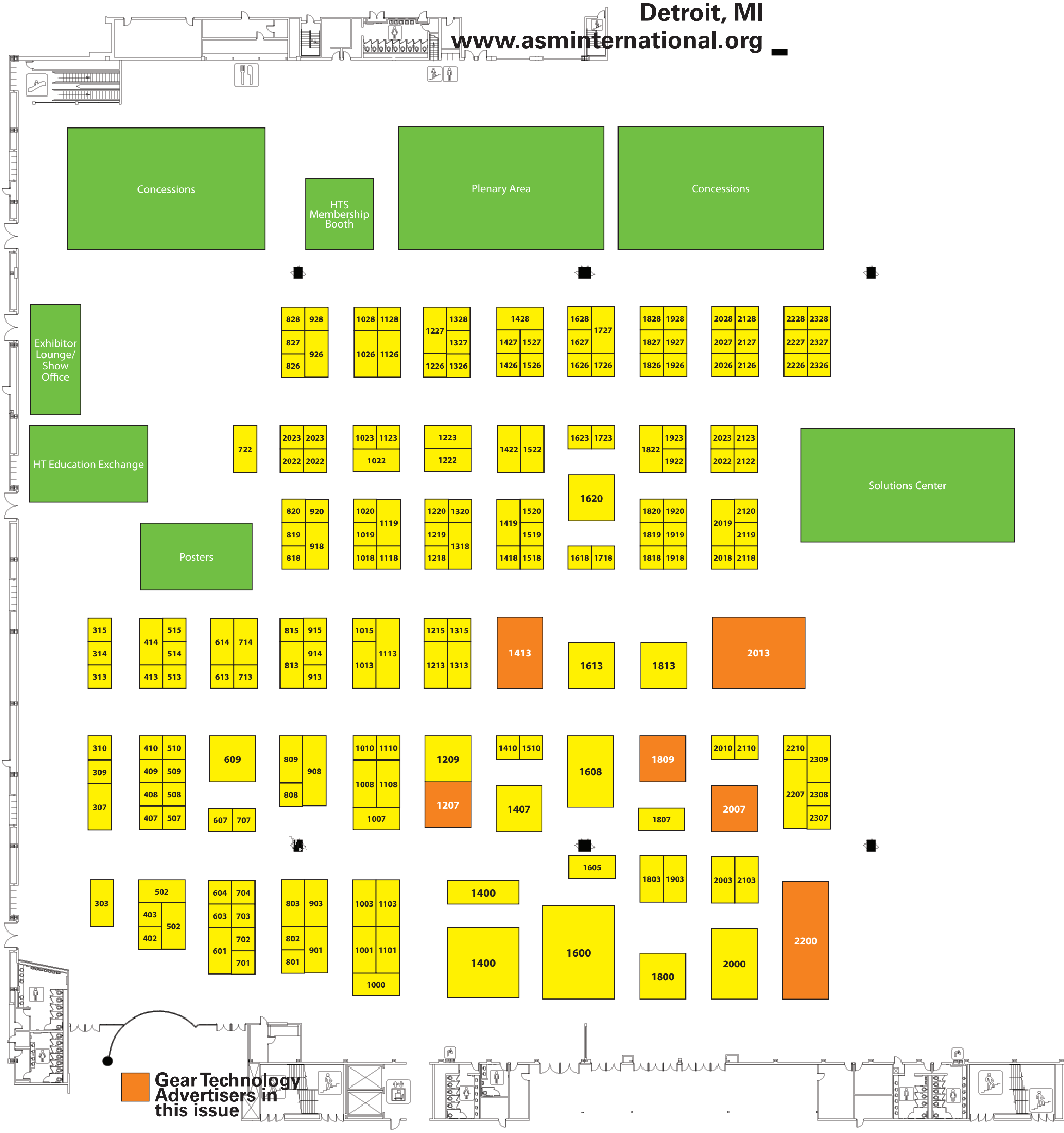

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The Additive Advantage

How 3-D Printing is Changing the Powder Metal Performance Game

Matthew Jaster, Senior Editor

A study released in the 1995 September/October issue of *Gear Technology* examined the advantages of powder metallurgy for new and existing gear applications. "The Beginner's Guide to Powder Metal Gears," written by George Shturtz at Carbon City Products, Inc., explored why PM deserved serious consideration for gear design in areas like automotive, hand tools, outdoor power equipment and office machinery applications.

It's a fascinating read — particularly in 2019 — when you compare the role PM plays today in gear manufacturing versus its potential back in 1995. And while the Metal Powder Industries Federation (MPIF) has championed the technology — offering technical papers on powder metal since the mid 1940's — additive manufacturing has given PM even greater visibility in recent years pushing its potential from prototyping into the production environment.

Matt Sand, president at 3DEO, said that metal additive manufacturing was always outshined by plastic 3-D-printing because the process of using powder metal is very complex. Some powder metals need to be handled in careful environmental conditions to prevent explosions and some processes require sintering in order to achieve final part density.

"Currently, metal additive manufacturing is used mainly for prototyping and one-off production of complex parts in industries such as aerospace and medical devices. However, companies like 3DEO are working hard to create new metal AM processes that are optimized for high-volume serial production," he added.

The Potential of 3-D-Printed Components

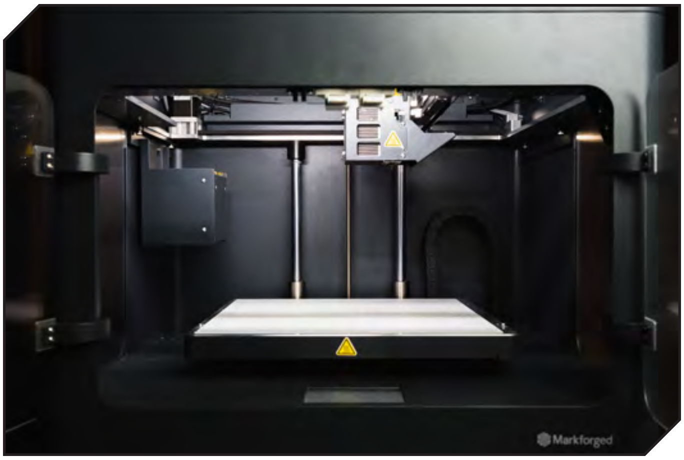
As 3-D-printing machines continue to increase their capabilities, PM components have the potential to become more than just one-off, customized solutions.

According to Tommy Lynch, senior applications engineer, additive manufacturing at Xometry, powder bed fusion metal systems have evolved to become more productive. Powder handling is becoming more user-friendly, and Lynch is seeing more systems emerge that have dual or quad laser setups that can increase build speed and through-put on smaller parts.

Lynch said metal binder jetting is also going through a revitalization stage with new players in the technology. Over the next few years, this technology could have a stronger foothold for making production metal parts with similar results as metal injection molding.

Concerning the potential of 3-D-printed powder metal components, Lynch believes that compared to traditional manufacturing methods the biggest advantage will be the speed of iteration.

A Metal X Print Farm (courtesy of Markforged).



Close-up of a MetalX bed (courtesy of Markforged).

"Engineers now have the flexibility to design, instantly quote, order, and have parts within a week. In addition, there may be cost savings by avoiding steep setup charges that typically occur with traditional methods such as CNC machining or metal casting," Lynch said.

For laser powder bed fusion, like direct metal laser sintering or selective laser melting, the ability to use the same process for both prototyping and production has provided a strategic advantage in part validation and revision releases. Lynch has seen many examples of Xometry customers solving challenges with their metal casting supply chain by moving to direct-printed metal options. Parts produced also have the benefit of being fully-dense and ready-to machine.

Additionally, Sand said that 3-D-printed metal components benefit from advanced designs and complex geometries such as internal cooling channels. These components can benefit from increased durability, reduced cost, shorter lead time and improved functionality.

Alex Crease, application engineer at Markforged, said that 3-D-printing applications have changed since the advent of high-strength metal parts and low-cost adoption. Take Markforged's Metal X, a metal 3-D printer, for example, as it introduces a safe and cost-effective method of producing parts quickly out of a variety of metals. The machine extrudes bound metal powder layer by layer to construct a part. Once built, it's sintered in a furnace, where the binder melts away and the final metal part solidifies.

"Additive technologies like the Metal X demonstrate that 3-D-printing can efficiently produce parts that can withstand the rigors and strain of the modern factory, but it also signals that such quality and effectiveness aren't just reserved for the largest manufacturers with the deepest pockets. The 3-D-printing landscape has further evolved with the introduction of artificial intelligence (AI), giving manufacturers the opportunity to make 3-D-printing more accurate and reliable.

Regarding Gear Production

While PM components come in all shapes and sizes, the readers of this magazine would probably be most intrigued by their future potential in gear manufacturing.

"Gears are very difficult due to the tight tolerances and high demands on the components," Sand said. "Most metal

3-D-printing technologies are NOT able to hit these component requirements in production quantities."

3DEO's Intelligent Layering process starts with a layer of metal powder that is then sprayed with a proprietary binder. A cutting tool is then used to cut out the 2-D design of one dimension of the part. This process continues layer by layer until the part is built. The green part is then sintered in a furnace to melt the binder and achieve final part density. 3DEO's process is able to achieve a superior surface finish which reduces post-processing.

"This is particularly beneficial for gears because gears have a complex shape with tiny grooves that may be hard to polish. In addition, gears require tight tolerances because the gears must fit together perfectly to function," Sand said.

On the polymer side, Lynch said there are significant advances in material science which include being able to print in epoxy and urethane materials through the Carbon DLS platform. Both polymer and metal powder bed fusion technologies tend to work well for medium to larger gears; and laser sintering and multi-jet fusion are great examples of this.

"There are still surface finish and resolution issues on finer features and thin gaps. Process tolerance, materials, and as-built surface finish should all be considerations when choosing additive for geared components," Lynch said.

The challenge of producing gears with additive manufacturing is two-fold: machines need to print with high enough precision to minimize backlash in the gear teeth, and the materials the machines print have to withstand torque transmission through the teeth. Plastic 3-D printers that have dominated the industry don't have the strength or the resolution to print effective gear teeth. While metal 3-D-printers have the material strength to do it, metal 3-D-printers, until now, were not affordable, according to Crease.

Metal 3-D printed gears from 3DEO.

"The Metal X offers a cost-effective solution for creating metal parts in a variety of metals, including stainless steel and tool steels. Since producing gears often requires some amount of tooling and overhead, like extrusion dies, broaches, and more, additive manufacturing has the potential to reduce some of those overhead costs to make both prototyping and production more efficient. Functional prototypes and small-scale production parts, like gears and similar components, can be created without worry over tooling or overhead costs," Crease said.

Once manufacturers are ready for larger scale production, Crease said they can use the Metal X to create the tooling and workholding needed to make gears and other components at scale. This allows gear manufacturers to iterate quickly through designs, optimizing both the gear design and its tooling design, all while keeping costs low.

Markforged's *Blacksmith*, the first AI-powered software that makes additive manufacturing machines "self-aware," allows users to automatically adjust programming to ensure every part is produced as designed. *Blacksmith* AI software connects additive manufacturing equipment to inspection equipment. This means that parts can be 3-D scanned and their information can be relayed back to the machines making them, which in turn update their settings to make the next part more precise. This closes the loop between manufacturing and inspection to make 3-D-printed parts more accurate and repeatable.

"Markforged's *Blacksmith*, has the potential to improve part precision and repeatability to ensure manufacturers receive accurate print gears or gear tooling with 'adaptive manufacturing.' Through 3-D scanning, this data is compared to the original design which AI then learns from and adapts the process settings to produce a more accurate final part. Ultimately, *Blacksmith* will produce the right part the first time and every time, and manufacturers can ensure that printers are hitting the necessary tolerances for gear components and can reduce the number of design iterations needed before a production run," Crease said.

Know Your Limits

Additive manufacturing has its own set of unique limitations. According to Lynch, this is primarily around internal stresses generated during the build process. Support structure is an absolute need in most cases, and post-processing adds additional challenges as well as surface inconsistencies.

"Educating and building reasonable expectations for our customers is a large part of working with metal printing," Lynch said. "Size and costs can also be prohibitive. Although this technology can scale, it is best optimized when a full build tray is utilized for an array of small pieces."

The greatest challenge with utilizing metal 3-D printing is the lack of quality control within the industry. "3-D-printing is mainly used for prototyping because when used for

The greatest challenge with utilizing metal 3-D printing is the lack of quality control within the industry (courtesy of 3DEO).

high-volume production, most technologies fail to achieve repeatability and typically have problems with degrading processes," Sand said.

Crease agrees that the number one challenge isn't the technology itself, but education in the industry around it. "When vendors introduce a breakthrough, new ways to make parts, it's naturally going to take time for everyone to understand the process and how it can be leveraged to improve and change their business," he said.

A Focus on Heat Treat and Surface Finish

Heat treating, specifically for stainless steel alloys, is basically controlled heating and cooling cycle(s) to obtain specific conditions or properties. Depending on a heat-treating condition, it is possible to increase hardness and tensile strength of a part and/or improve ductility and machinability. The condition is usually defined by the application and working environment of the part, according to Sand.

"Finishing processes such as media blasting improve the surface quality, as well as properties like surface hardness and fatigue resistance. Blasting also helps with removing contamination and providing a uniform surface appearance," he added.

Lynch added that heat treating is essential for many printed metal components to stress relieve the parts before removing from its supports and build plate. Post heat treating is available as well for hardening materials in built components. Typically parts are bead blast or shot-peened to remove any excess material on surfaces. There are abrasive and non-abrasive methods of surface smoothing, but each has trade-offs.

Just like with traditional metals, 3-D-printed metals can be heat-treated to certain temperatures to achieve different material properties, so the traditional processing methods for gears can carry over into modern technologies like 3-D-printing. "Smooth, precise surfaces on gear teeth allow the gears to mesh consistently without any slop or noise, which is why surface prep is so important. Any inconsistencies in the surfaces of the gear teeth make the gear less efficient: it becomes more likely to jam, and more power is needed to transmit forces through the teeth. Similarly, more backlash and slop will be introduced into the system if the gears are manufactured less precisely. So having a consistent, clean surface improves the performance of the gear and makes it more efficient. Parts printed on Markforged's Metal X can be cleaned up just like their traditional metal counterparts, making it easy to post-process if very high precision is needed," Crease said.

Taking Initiative

So where is the technology heading today?

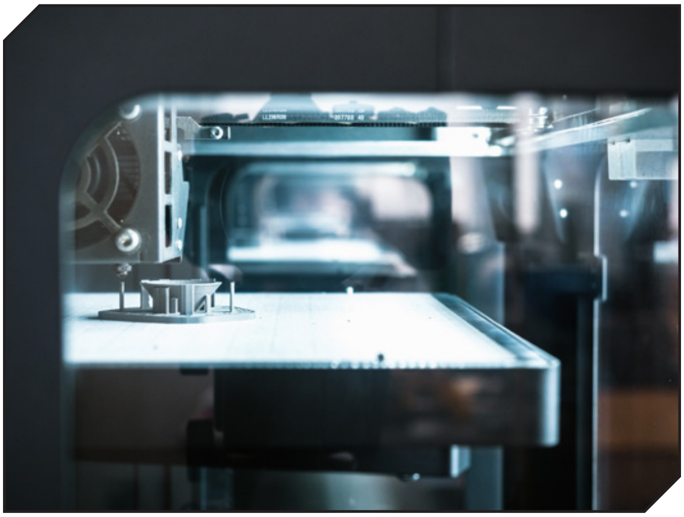
Sand said it's not trivial to move from prototyping to production. Additive manufacturing is great for rapid prototyping, but achieving the repeatability necessary for serial production is complicated. The reason being is that additive manufacturing lacks a standardized method of production. With additive manufacturing, there are hundreds of variables to control that can affect the outcome of a print. Each printer, operator, and even layer is independent of the other and can create serious problems with the predictability of performance.

"3DEO started with the idea of production in mind, so all or our systems have been developed around this. As we grow and take on larger orders, we continually discover how much additive manufacturing processes lack standardization in quality and process controls. As a result, we have to develop our own systems in order to compete with traditional manufacturing," Sand said.

Xometry is able to instantly price and provides lead times for seven 3-D printing technologies as well as traditional machining, sheet metal, and molding (courtesy of Xometry).

3DEO has a dedicated R&D team that continues to develop and improve the Intelligent Layering technology. We are currently working on expanding our available materials to others such as titanium and tungsten carbide.

Xometry continues to create meaningful engineering and design for manufacturing (DFM) tools for a variety of 3-D-printed processes and materials. We offer design guides, videos, a comprehensive online knowledge base, as well as continual release of new and revolutionary technologies. Because Xometry is a platform for manufacturing, it is able to instantly price and provides lead times for seven 3-D-printing technologies as well as traditional machining, sheet metal, and molding.



This metal test print is being run on the Metal X system (courtesy of Markforged).

Printing is only the first step of a multi-stage process when 3-D-printing metals. The best way to conceptualize the part is as a near-net-shape, meaning that additional processing is likely necessary to achieve specific tolerances or surface finishes. A great surrogate is that of metal casting, where the shape is made then typically post-machined.

"Simplicity and reliability are key for additive manufacturing, which is why we developed the full additive ecosystem -- from software to printers to materials. This tactic allows us to fine-tune every part of the process to give our customers the best user experience and reliability. We even launched *Blacksmith* to ensure customers can tell if they've printed in-spec parts. It's essential to align each part of the process under one group because one weak link will produce a poor result. For example, if a customer uses an inferior material, they'll have an inferior final part, no matter how high-quality the printer is," Crease said.

The Future of 3-D-Printed, PM Gears

Sand believes the future is bright for gear manufacturing, especially when it comes to lower volume production runs. 3DEO offers metal 3-D-printing technology in production today, but there are undoubtedly many other new, up-and-coming technologies that will make significant inroads in gear fabrication.

Lynch said that resolution and surface finish will continue to improve from direct-printed results. It may not be the case that powder bed fusion will be the primary way metal parts are additively manufactured.

"With new hybridizations of processes, both

Xometry continues to create meaningful engineering and design for manufacturing (DFM) tools for a variety of 3-D printed processes and materials.

"With new hybridizations of processes, both additive-to-additive, and additive-to-subtractive, there will be greater leveraging of strengths between processes. For example, growing a part and in-situ tuning of feature sets may be commonplace; pairing this with model-based definitions (MBD or PMI) will complement the blend of design intent, fabrication, and real-world implementation," Lynch said.

The capabilities of additive manufacturing technology are increasing at an incredible rate, especially with tolerancing and dimensional precision, according to Crease.

"Ten to 15 years from now, we expect to produce gears and energy transmission systems ranging from precision nano-drives and micro motors to extremely large-scale gears (such as mill and pulley gearing) all from a variety of 3-D printers," Crease said. "Additionally, the removal of current limitations in designs of teeth and grooves from subtractive manufacturing will create more possibilities for all new engagement and drive methods that were never considered before."

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Influence of Thermal Distortion on Spur Gear Tooth Contact

Dr. Jon Larrañaga, Dr. Ibai Ulacia, Aurea Iñurritegi, Dr. Aitor Arana, Jon German, and Julen Elizegi

Introduction

The increase of efficiency in automotive gear transmissions has been a key subject of research in the past decade (Ref. 1); to this aim, dip-lubricated gearboxes have been designed with minimized oil levels in search of reduced churning power losses (Ref. 2) and maximum power-to-weight ratios. However, when such gears' running conditions reach the highest pitch line velocities and torques, bulk temperatures increase rapidly, resulting in reduced oil film thickness, higher surface shear stresses and an increased number of asperity contacts — all of which may lead to a premature failure of the gear pair. Moreover, in such cases, not only high temperatures are reached but also significant temperature gradients are found between pinion and gear. Figure 1 shows a sample of the aforementioned operating case. As can be seen, the optimal conditions lie between a relative immersion depth of $H/D = 0.1$ to 0.25, where power losses are minimal. However, with these oil levels the temperature difference between pinion and gear reach 20°C to 30°C because the small size of the pinion results in a lower convection heat transfer due to the reduced oil-lubricated area and its increased rotational speed (with respect to that of the gear) increases the amount of heat flowing inwards, resulting in a higher bulk temperature of the pinion. This phenomenon leads to relative pitch deviations and thermally induced profile distortions (Ref. 3).

Several experimental results regarding the effects of thermal distortion on the gear mesh can be found in literature — primarily related to turbo-gears running at high pitch line velocities (close to 100 m/s) (Refs. 4–6) — where the differential thermal effects are known to cause large variations of contact and root stresses (Ref. 7). At lower tangential speeds, only thermal effects of plastic gears have been analyzed in scientific literature (Refs. 8–9) because the material properties are temperature-dependent and the increased thermal expansion coefficient causes significant profile distortion. Nevertheless, plastic gears do not reach the bulk temperature levels of their steel counterparts (Ref. 10) and, therefore, metallic gears may also show appreciable geometry distortion when they are subject to operating conditions such as those shown (Fig. 1).

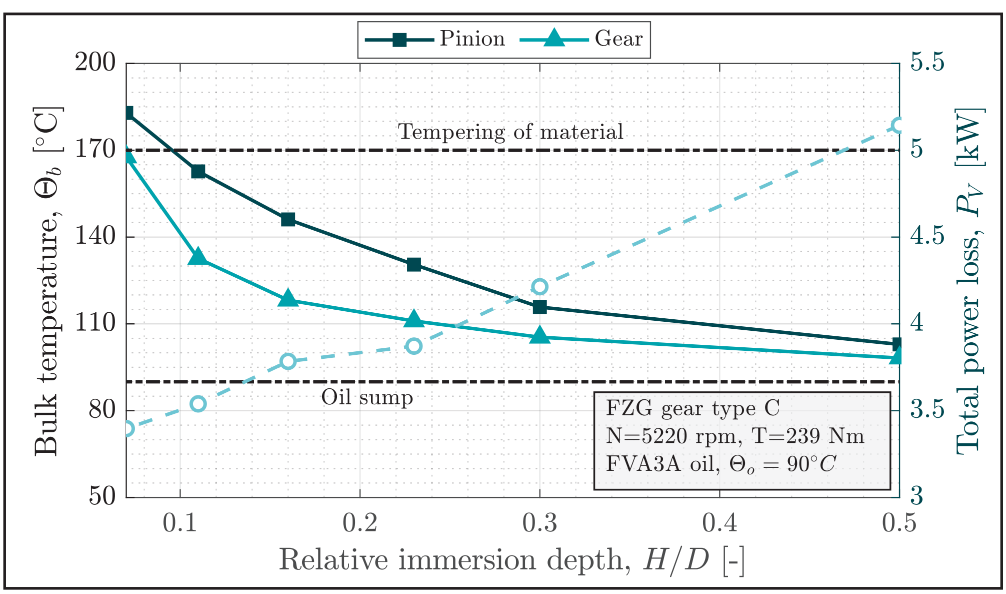


Figure 1 Influence of oil level in gear pair bulk temperature and thermal gradient (Data from Ref. 2).

In the present work, predicted steady-state temperature distributions from a thermal-lumped parameter model developed by the authors in (Ref. 11) are used as inputs for a 2-D finite element model. Geometry distortion and tooth contact parameters in the transverse plane are numerically computed where load distribution, transmission error and available backlash are studied. Narrow face width spur gears with b/d<0.5, running at high speeds and low oil levels are analyzed, and it will be shown that even with thermally favorable operating conditions with high immersion depths, profile deviations are appreciable. The results of the study will allow setting the limits of design backlash to avoid gear jamming and to size the initial profile modifications to reach the desired contact behavior at operating temperatures.

Thermo-Mechanical Model

The thermo-mechanical model developed in the current work is a combination of a simple thermal-lumped parameter model of the gear pair (Ref. 11) and a 2-D finite element model (FEM) (Ref. 12). The former allows calculating thermal gradients in the gear body as well as the temperature differences between pinion and gear; while the latter is used to compute geometry distortion and perform the loaded tooth contact analysis (LTCA).

Thermal-lumped parameter model. Unlike other thermal network models in gear literature that represent the complete

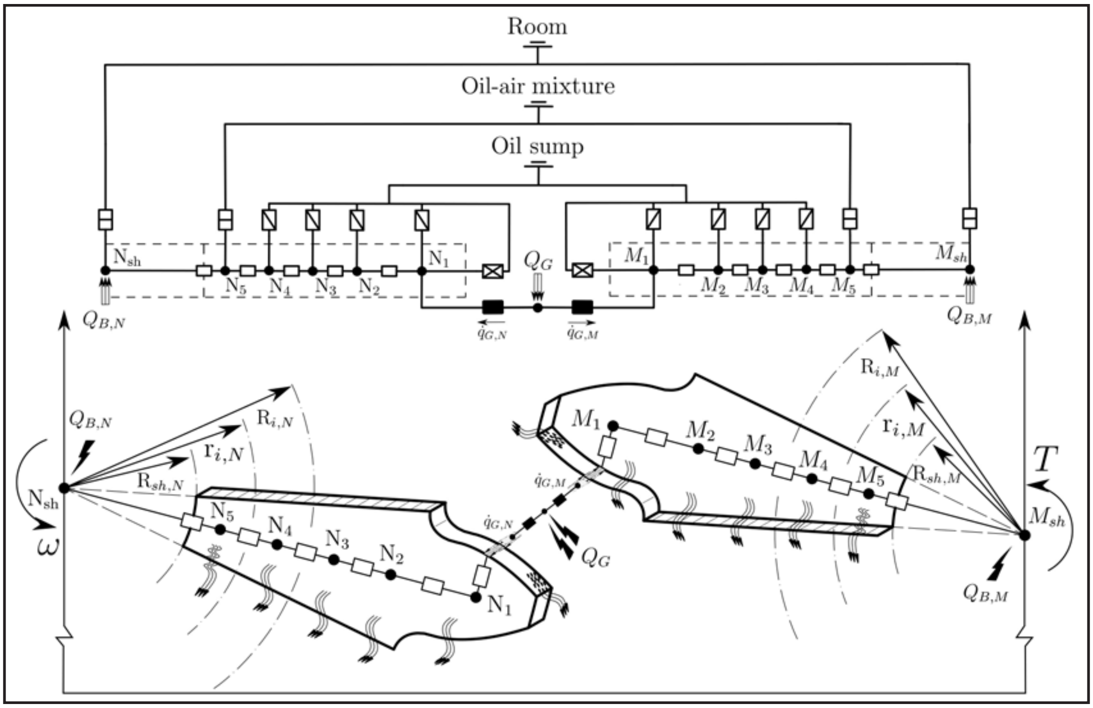


Figure 2 Thermal network model of a gear pair.

gearbox, the thermal network model developed herein focuses on the temperature field of the gear pair. The main underlying assumption is that it is possible to compute the steady-state temperature distribution within the solids, considering only the heat flux coming from the gear mesh and the shaft, as well as the steady-state temperatures of the surrounding fluids (oil and air inside the gearbox).

As it can be seen (Fig. 2), pinion and gear are discretized radially and each individual control volume is linked to its neighbors by means of thermal resistances. Circumferential thermal gradients within the gear body are neglected and therefore pure radial conduction is considered. This means that the control volumes are represented as annulus, where conduction resistances are computed from the classical one-dimensional cylindrical approach. The relative immersion depth being different for the pinion and gear, some of individual annulus are permanently in contact with the oil sump, while others only exchange heat with the oil-air mixture inside the gearbox. Therefore, convective heat transfer resistance between the external surfaces of the gear and the surrounding fluid depend on the local Nusselt number, *Nu*, which is evaluated considering the thermo-physical properties of the fluid at the boundary layer temperature. Heat exchange due to radiation is neglected because the temperature levels of the elements inside the gearbox are not high (usually below 200°C).

Two heat sources are considered: i) power losses from the gear mesh; and ii) heat from the bearings and sealings. The former is described in detail (Ref. 11), while the latter is computed from classical equations in gear literature (Ref. 13) where only a third of the total power loss is introduced in the gear axis nodes; the remaining two thirds are assumed to be dissipated through the housing and oil bath. If constant, steady-state oil/air temperatures are considered, it is not necessary to compute churning and windage power losses because the heat generated within the fluid no longer increases its bulk temperature.

Finally, the solution of the model is given by the system of equations assembled in matrix form in Equation 1, in which C is the capacity matrix; K is the conductivity matrix (where $K_{i,j} = R_{i,j}^{-1}$); Q is the heat input vector; Θ is the temperature vector; t denotes time; and the superimposed dot indicates time differentiation. In order to avoid instabilities due to non-linearities in fluid properties and convection coefficients, the Picard iteration method is used to solve the initial value problem.

$$C(\Theta,t) \times \dot{\Theta} + \mathrm{K}(\Theta,t) \times \Theta = Q(t) \quad (1)$$

The resulting radial temperature distribution of pinion and gear is loaded in a 2-D finite element model which computes the thermal growth of each point of the mesh following Equations (2) and (3).

$$r_y'(x) = r_y(x) + \Delta r_y(\Theta) \quad (2)$$

$$\Delta r_y(\nabla\Theta) = \alpha_L \cdot \sum_{i=1}^{i=n} (r_{i+1} - r_i) \cdot \left(\frac{T_i + T_{i+1}}{2}\right) - T_0 \quad (3)$$

Finite element model. A thermo-mechanical quasi-static and two-dimensional model of a gear pair is developed to analyze the effect of the thermal distortion on gear mesh behavior — namely, load distribution and transmission error. The numerical models are automatically generated using a custom gear mesh generator and the FEM models are calculated using *MSC.Marc* solver.

The gear and pinion mesh are generated following the methodology used by Litvin (Ref. 14). This methodology is characterized by defining a greater density of elements in the teeth than in the body of the gear (Fig. 3). Additionally, a progressive mesh density (i.e. — bias factor) has been determined from the symmetry axis of the tooth to the contact area (Ref. 15). A four-node, isoparametric, arbitrary quadrilateral element for plane stress applications is used (element type 3 of the *MSC.Marc* software (Ref. 16)).

The numerical model considers two load cases: in the first

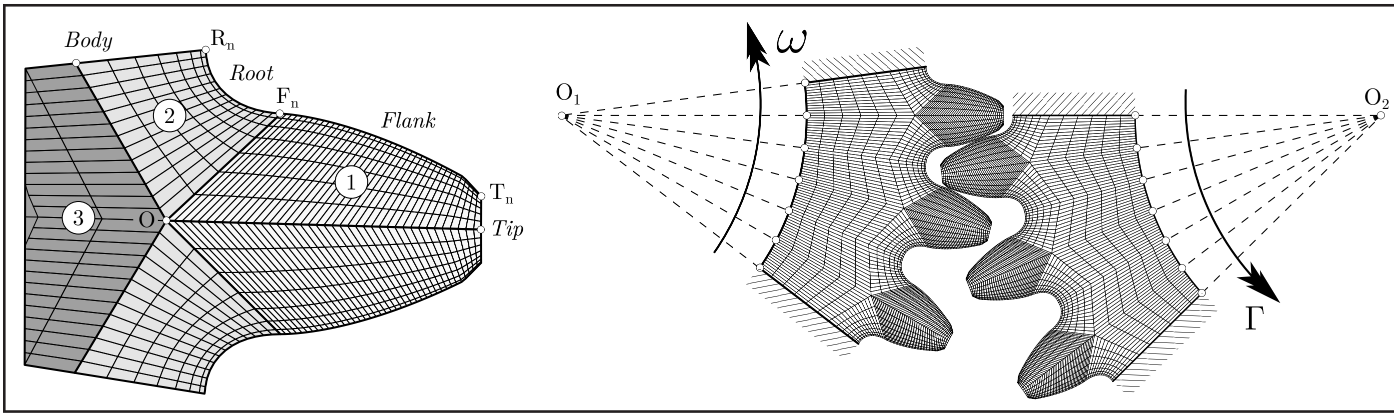


Figure 3 Mesh detail and boundary conditions of the numerical model.

step, the temperature of the gears as computed by the lumped thermal network model are introduced and then thermal growth is computed. In a second step, the expanded gears rotate and the contact between pinion and gear is computed. The rotation is applied in the pinion and the torque in the gear, both counter-clockwise. Rigid connectors are introduced between the point representing the gear axis centerline and the body, which are also used to apply the rotation and torque boundary conditions (Fig. 3). As it has been described by the authors in a previous work (Ref. 12), the complete gear was modelled in order to minimize the effect of boundary conditions in the results.

Case study. With the aim of studying the influence of thermally induced geometry distortions on contact behavior, a reference gear pair with identical teeth geometry has been selected. Such gears are characterized by having the same length of approach and recess, as well as the same thickness along the tooth height (i.e. — same manufacturing profile shift coefficients 'X_E', ensuring that they have the same bending and rotational stiffness at any point). With this approach, any difference in contact behavior can be easily identified from the horizontal and vertical displacements in the corresponding diagrams.

Table 1 summarizes the geometrical characteristics of the gear set under consideration. Five different torque levels are applied — from 100 Nm to 500 Nm at two different pitch line velocities — 10 m/s (2,000 rpm) and 20 m/s (4,000 rpm). The gears are lubricated with FVA3A mineral oil which is an ISO VG100 oil with 4% Anglamol EP additive. The numerical simulations consider oil levels from H/D = 0.5 to 0.1 at a constant oil sump temperature of 90°C. The material selected for the gears is a 16MnCr5 steel, 206 GPa Young modulus, 0.3 Poisson coefficient, 7,830 kg/m^3 and a thermal expansion coefficient of 12.5 µm/m K.

Results

First, resulting temperatures from the thermal network model are summarized and then thermally distorted geometry will be presented. Loaded tooth contact analysis results will be displayed at the end where the influence of different parameters

Table 1 Geometry parameters of the spur gearset

	Symbol	Value
Number of teeth	$z_{1,2}$[-]	25, 25
Normal module	m_n [mm]	4
Normal pressure angle	α_n [°]	20
Face width	b [mm]	15
Profile shift coefficient	$x_{1,2}$ [-]	0, 0
Operating center distance	a_w [mm]	100
Reference profile acc. ISO 53	[-]	C (1.25/0.25/1)
Tolerance field acc. DIN 3967	[-]	cd25

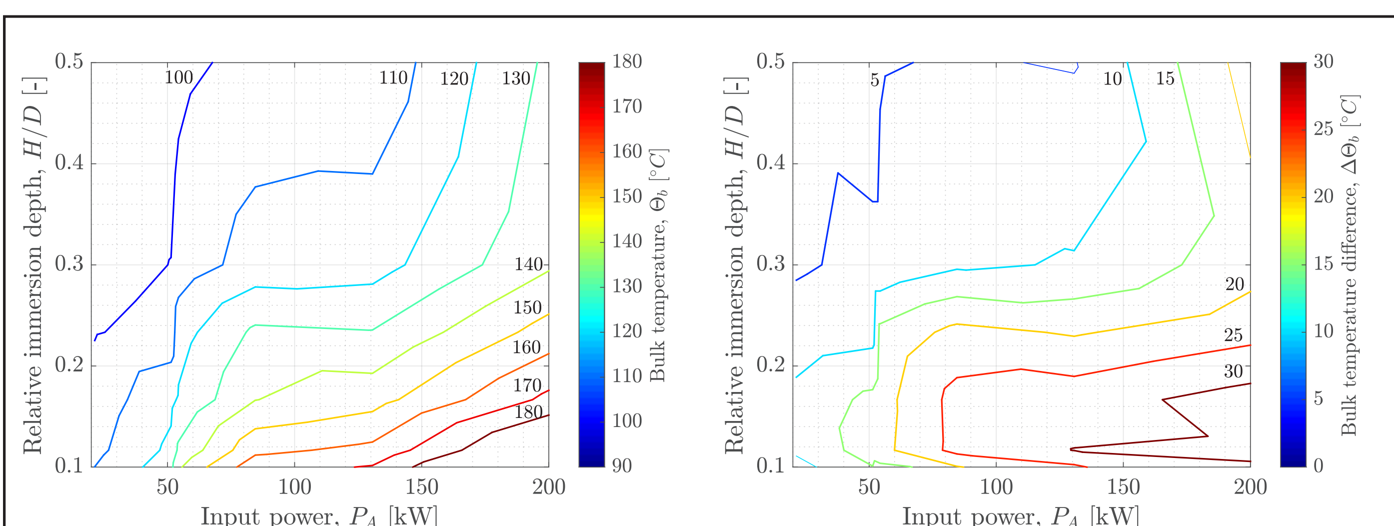


Figure 4 Predicted temperatures and gradients for different input powers and immersion depths.

will be analyzed in depth.

Temperature distribution. The different combinations of torque, speed and immersion depth result in bulk temperatures in the range between 90°C to 160°C. No appreciable thermal gradient has been found between pinion and gear because the speed ratio is 1 and the oil level covers the same area in both gears; therefore, the convection heat transfer is identical, which explains the absence of temperature differences.

In order to simulate unfavorable thermal conditions, two additional situations have been studied: i) idler gears with additional heat inputs from multiple meshes; and ii) reduction gear units. Figure 4 presents the results of the latter with $z_1 = 20$ and $z_2 = 30$, while the rest of the parameters are maintained. As it can be seen, significant temperature gradients exist at the highest input powers and lowest immersion depths.

Thermally induced geometry distortion. Figure 5 depicts the degree of distortion of the gears described in Table 1 with respect to the original geometry manufactured at 20°C. Distorted geometry at the oil sump temperature of 80°C is calculated along with the geometry change at a sufficiently high temperature, 140°C. In both cases, it is seen that a constant temperature increase of the gear (without temperature gradients in the direction of the radius), increases the tip diameter, reducing the manufacturing allowance that approaches zero. However, the difference at the root is not that important.

Such a difference between the tip and the root indicates that a considerable profile slope deviation exists. This is explained by the thermally induced base diameter increase, f_b, which is interrelated to the pressure angle deviation, f_α, by means of the following equation.

$$f_b = f_\alpha \cdot d_b \cdot \tan(\alpha) \tag{4}$$

Furthermore, profile form errors are also present because the diagram on the right (Fig. 5) shows a slight curvature that deviates from the mean shape of the profile. However, such differences seem to be strictly located in the root region and they will not be addressed in the current paper. Finally, tip diameter increase is also shown, which may act on the length of the line of action and the contact ratio. All of these parameters are further analyzed in the next sections.

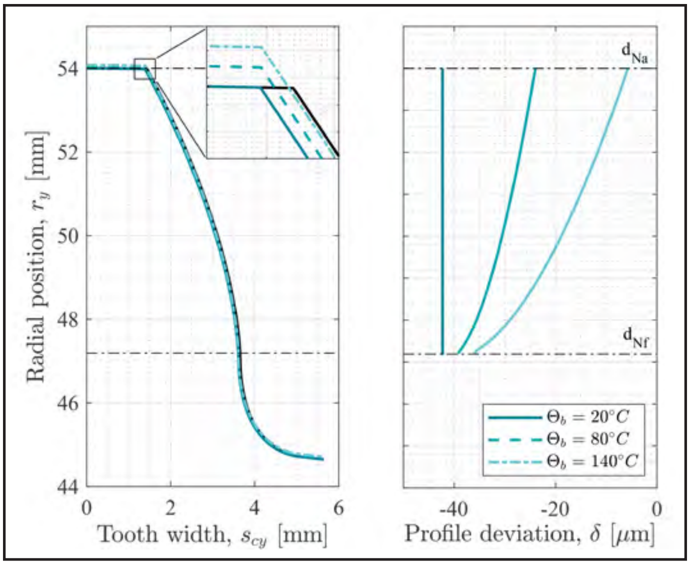


Figure 5 Profile geometry distortion at different operating temperatures.

Loaded tooth contact analysis without thermal effects. In order to understand the effects of thermally induced geometry distortions on contact parameters, the reference calculations with variable torque (and ambient temperature) are presented (Fig. 6). Loaded tooth contact analysis shows the normal behavior under load, with a non-dimensional load sharing factor, *R*, between 0.4 and 0.6. Significant contact outside the theoretically defined phase of mesh is also observed, where the simulated start/end of the active profile takes place 1.5 degrees before/after expected. On the other hand, loaded transmission error (Fig. 6b) shows an increasing peak-to-peak value with torque, but also decreasing mean values — indicating that the driven gear lags behind its theoretical value due to the increased tooth deflection.

Moreover, both Figures 6a and 6b show a symmetrical

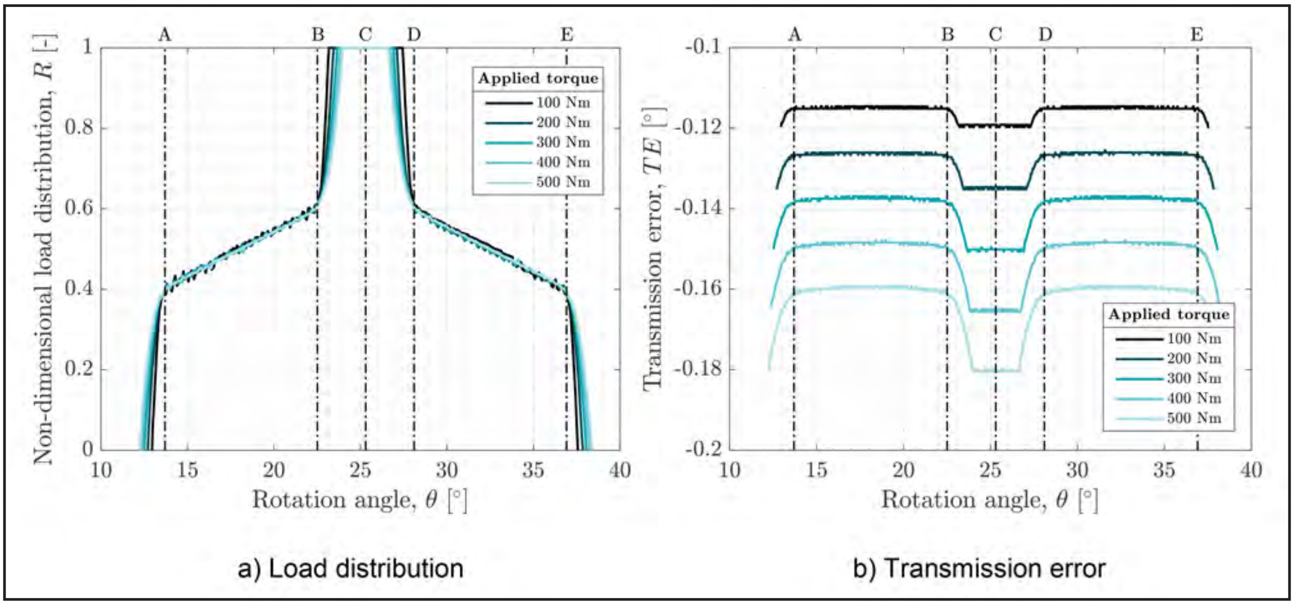


Figure 6 Influence of torque on load distribution and transmission error.

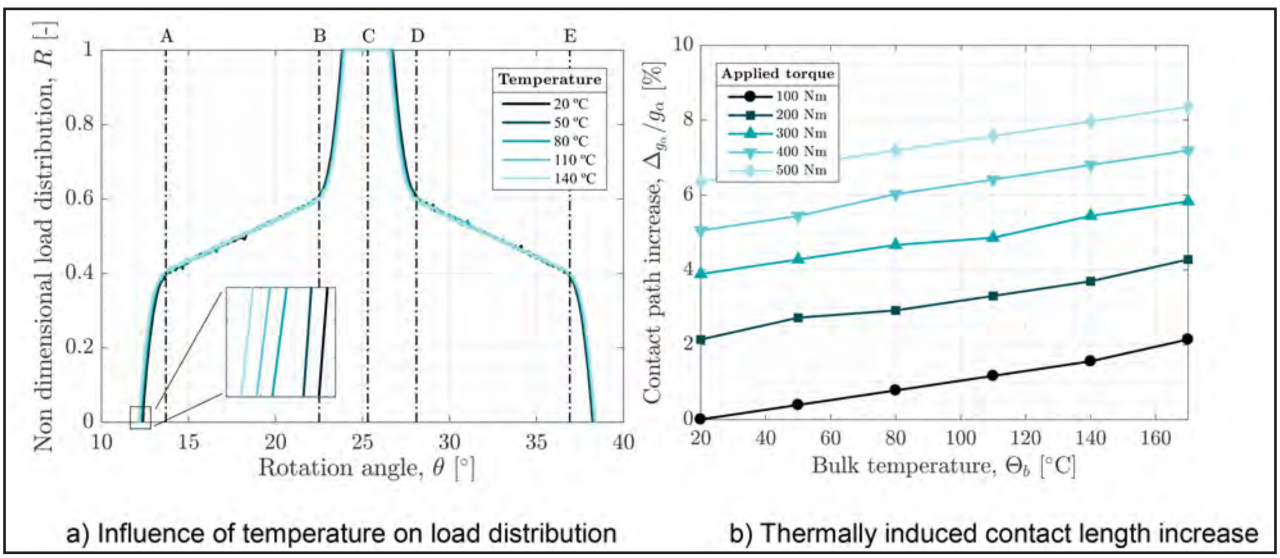
behavior with respect to the pitch point, C, indicating that both geometries are identical. That is to say, the length of approach equals the length of recess. Table 1 also shows that no design profile shift has been considered and the same tolerance field is applied to both gears, resulting in equal manufacturing profile shift coefficients $X_E = -0.0309$. Therefore, pinion and gear are geometrically identical and, as a result, have the same stiffness.

Influence of temperature increase on LTCA. In the same way as torque, temperature increase also extends the length of the path of contact. Tip diameter is increased proportionally to temperature and therefore the start of the active profile comes earlier and the end of it arrives later. In general terms, the trend of temperature increase is comparable to that of load. Figure 7a depicts this phenomena at a constant torque of 400 Nm and variable temperature (in the range of the numerically predicted values). However, as it can be observed (Fig. 7b) the influence of temperature on the length of the line of action is lower than that of torque. An increase of 100 Nm extends the path of contact 2%, while a 100°C increase implies approximately 1%.

If the shape of the thermally affected load distribution diagram (Fig. 7a) is compared to that of load (Fig. 6a), it is seen that temperature increase does not influence the symmetry. Thermal expansion affects pinion and gear shape in the same manner and therefore there is no geometrical difference; hence, no stiffness difference either.

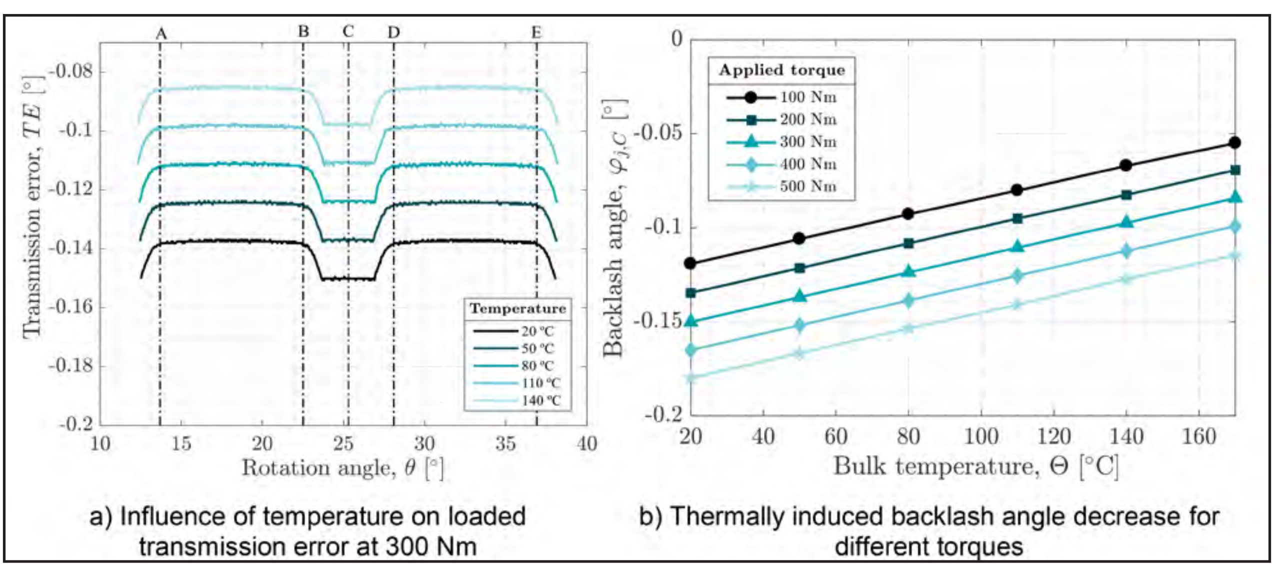
On the other hand, the increase of temperature affects transmission error appreciably (Fig. 8a). The reduction of the mean level of transmission error is fully explained by the reduction of the available backlash angle (Fig. 8b). For instance, at 300 Nm the decrease of the backlash angle from 20°C to 140°C is 0.0527 degrees, which corresponds to the mean step between both curves at the same operating temperatures (Fig. 8a).

Influence of temperature gradient on LTCA. In order to analyze the effect of the temperature gradient, the pinion temperature is maintained constant at 140°C, while gear temperature decreases. This case, with different temperatures for identical gears, represents multi-mesh transmissions where a gear could be engaged with multiple others and consequently the



a) Influence of temperature on load distribution
b) Thermally induced contact length increase

Figure 7 Influence of temperature increase on load distribution at T = 400 Nm.



a) Influence of temperature on loaded transmission error at 300 Nm
b) Thermally induced backlash angle decrease for different torques

Figure 8 Influence of temperature increase on transmission error at T = 300 Nm.

temperature of the former would be higher than the rest.

When a temperature gradient exists, the thermal expansion affects in a different manner on the gear and the pinion; therefore the load distribution and the transmission error are no longer symmetrical. Figure 9 shows the influence of temperature gradient between pinion and gear on the load distribution and transmission error.

The asymmetrical behavior of the load distribution and transmission error slightly increases as the temperature gradient rises. Additionally, it is noticed an increase of the overall transmission error while in the double tooth contact region (between points A–B and D–E), transmission error shows an increasing slope. The increase in transmission error is explained by the differences in the profile deviations of the pinion and the gear caused by different temperatures.

Influence of gear ratio. Dissimilar gear pairs compose most gear transmissions; therefore, the temperature levels reached in each body are also different. Figure 10 shows the load distribution and the transmission error of a gear pair with a reduction factor of 1.5.

First, the case of no temperature gradient is analyzed (140°C) in order to account for the effects of the gear size. In this case the increase of the temperature produces a larger expansion on the gear than on the pinion, inducing an asymmetrical load distribution. Similar load distribution is observed when identical gears are subjected to thermal gradients, as has been seen in the previous section. If the thermal expansion of the pinion is larger than the gear's, the load distribution decreases in the approach double contact region and is increased in the recess double contact part.

However, when temperature gradients are introduced in a reduction gear unit, the load distribution asymmetry is compensated (Fig. 10a).This effect is fully explained with the compensation of pinion and gear thermal expansions. The pinion has a smaller size than the gear, but larger temperature, thus

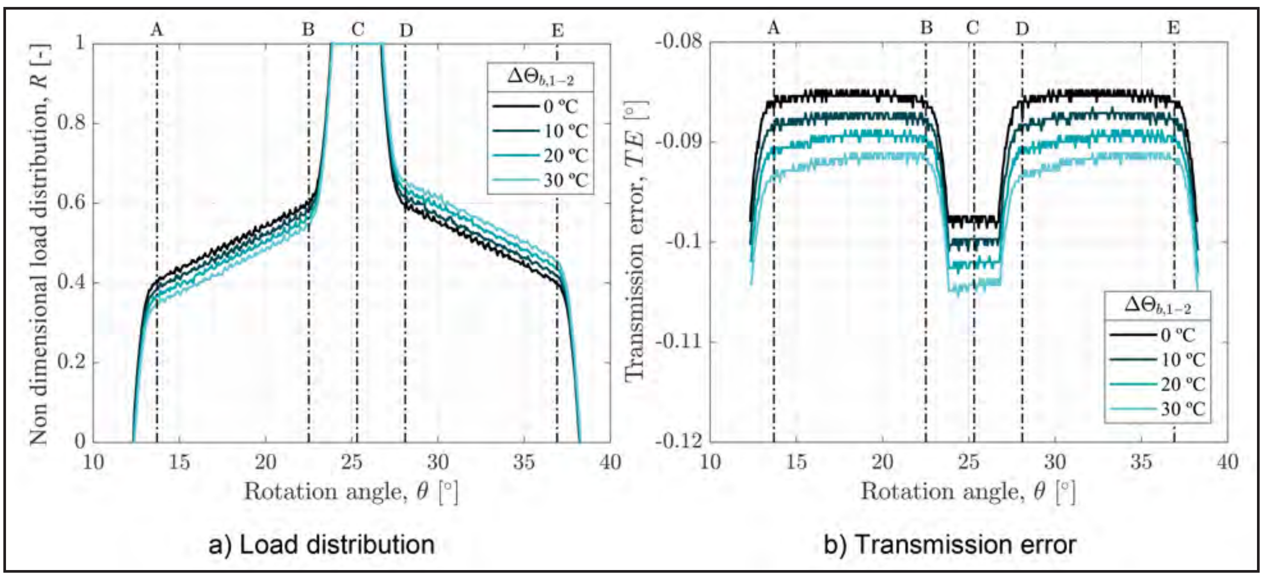


Figure 9 Influence of temperature gradient between pinion and gear on load distribution and transmission error at T = 300 Nm and Θ_1 = 140°C.

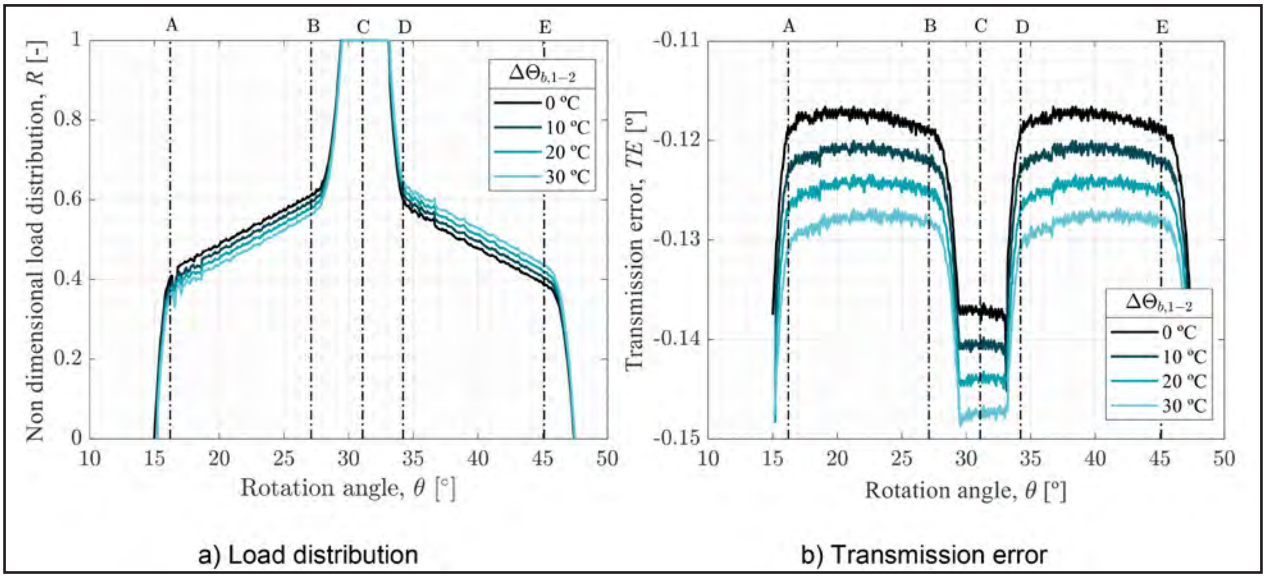


Figure 10 Influence of temperature gradient between pinion and gear on load distribution and transmission error at T = 300 Nm and Θ_1 = 140°C; case of reduction unit.

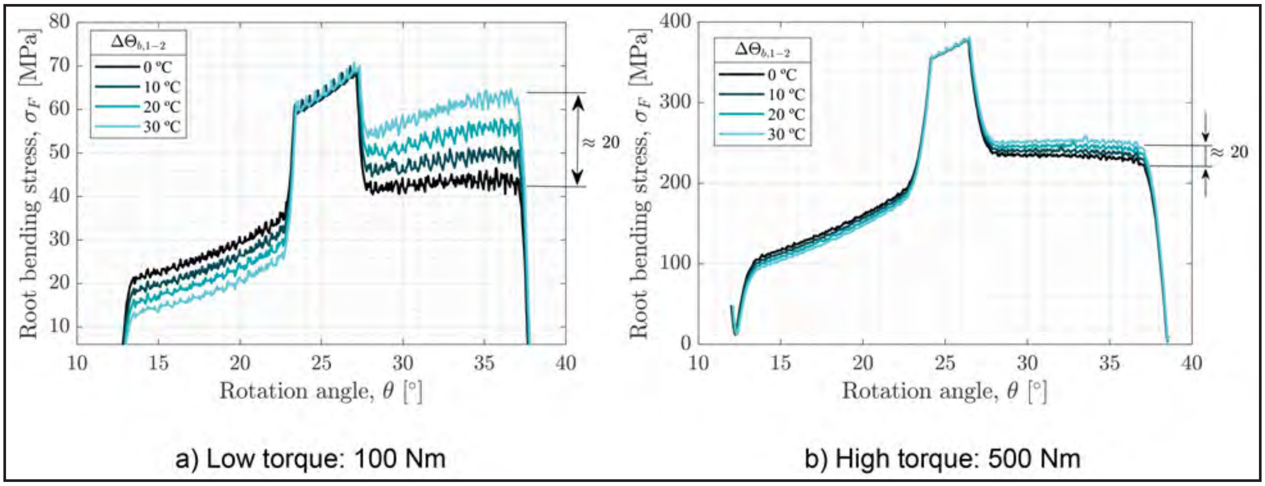


Figure 11 Influence of combined thermal and mechanical loads on root stresses at $\Theta_1 = 140°C$.

balancing the difference on thermal expansion and its effects.

Regarding the effects of thermal gradients of reduction transmissions on the transmission error, an increase of the transmission error is observed when the temperature gradients are higher (Fig. 10b). In this case, the decrease of the temperature on the gear increases the backlash while the transmission error increases.

Discussion

From the observation of Figures 6–10, it can be concluded that the most significant phenomena involved in the thermally and mechanically loaded gear behavior with respect to the simply loaded case is the reduction of transmission error; this is due to the available backlash angle decrease and the shift in the load distribution diagram when thermal gradients or relative pitch errors are present. However, in the preceding simulations load has been kept constant while varying temperature and their influence have not been interrelated.

Combined elastic and thermal deflections. In general, in cases where there is a differential base pitch increase, the geometry distortion is partially offset by elastic tooth deformations. However, when thermal loading is such that the expansion in the direction of the line of action is larger than the elastic deformation, load distribution can be significantly affected. This situation may affect mean tooth stress level and the position of the maximum value.

Figure 11 shows an example of such a situation. When the pinion drives the gear, the existence of torque reduces the base pitch of the pinion proportionally to the deflection of the loaded pinion tooth, which increases the base pitch of the gear by an amount equal to its deflection. The sum of both deflections determines the load distribution, and therefore tooth stresses. However, when thermal effects are considered, the existence of a temperature differential increases the base pitch of both the pinion and the gear proportionally to the tooth expansion. As a consequence, the load distribution diagram is altered beforehand. If thermally induced deformations are as large as elastic deflections, the load distribution diagram turns symmetrical because both phenomena compensate each other. Figure 11a shows the tooth root stress levels when thermal distortions are larger than elastic deformations, while Figure 11b shows compensated deflections. At 100 Nm the distortion of the bending stress diagram for a temperature difference of 30°C is as large as 30% in the recess, while at 500 Nm it barely represents 5%.

It is interesting to note that in both cases the stress difference between the isothermal case and that with maximum temperature gradient in the recess path of contact is approximately equal. This happens because in both cases the thermally induced pitch error is equal, as it is a function of the temperature gradient and not the torque. Therefore the additional deflection that the gears must overcome in both cases is the same, and the local load difference is almost equal — resulting in the same stress differential.

Design recommendations for enhanced contact behavior. In order to compensate the dissimilar root bending stresses (Fig. 11a), profile modifications need to be applied. To this aim, the amount of deviation at the operating temperature is computed and represented (Fig. 12). It is observed that pitch deviations increase proportionally to temperature, while profile slope decreases — both of which are the expected behaviors. For a pinion temperature of 140°C and a gear at 110°C, pitch differentials are 13 µm and 17 µm, respectively and the profile slope decrease corresponds to 27 µm and 20 µm. Therefore pinion and gear are applied to these modifications at ambient temperature to enhance contact behavior at steady-state operating conditions (assuming that the generated heat is not affected and the steady-state bulk temperature is the same).

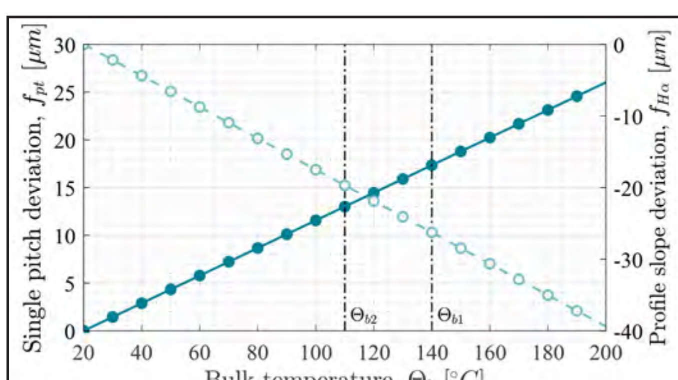


Figure 12 Profile deviations as a function of temperature and corresponding modifications.

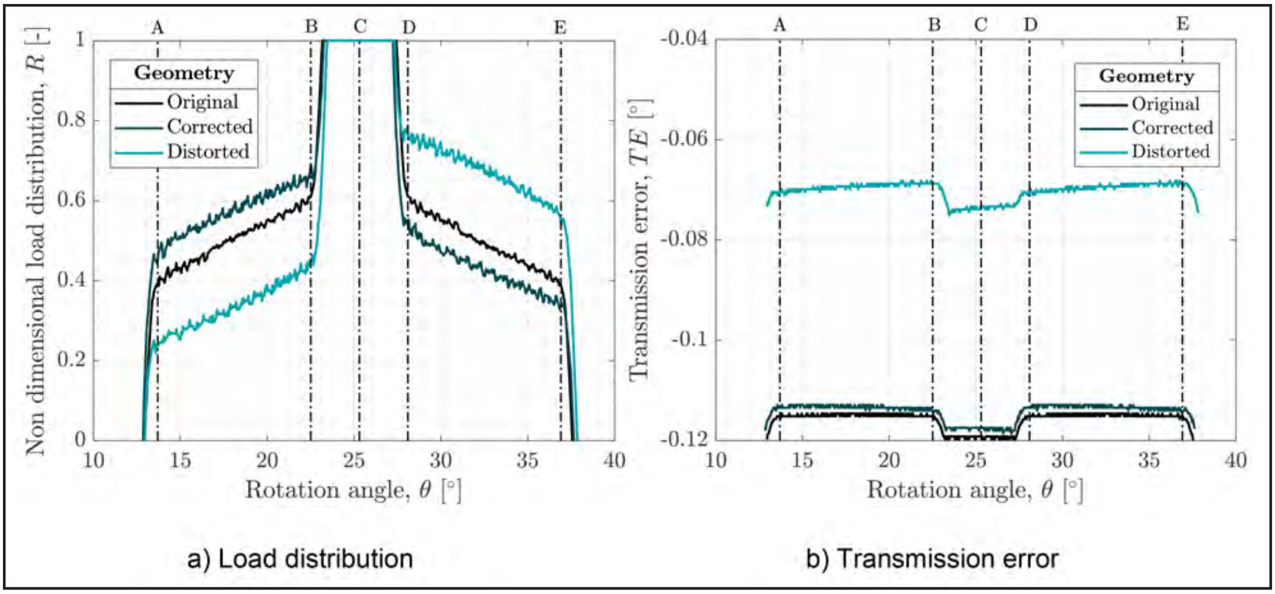


Figure 13 **Comparison of load distribution and transmission error between profiles at T = 100 Nm and $\Theta_1 = 140°C$ and $\Theta_2 = 110°C$.**

Figure 13 shows the contact parameter comparison between the reference state at ambient temperature, the thermally distorted one, and the corrected geometry. As can be seen (Fig. 13a), the load distribution has been improved but a significant difference of up to 10% is still present, indicating that profile form errors may not be negligible. On the other hand, it is shown (Fig. 13b) that the initial transmission error levels are recovered with small differences due to the aforementioned form errors.

Conclusions

In this paper the effects of thermally induced geometry distortions on load distribution and transmission error have been analyzed. A thermal-lumped parameter model accounting for radial temperature distribution has been coupled to a two-dimensional finite element model. Analytically predicted temperatures have been loaded on the FEM model to compute geometry distortion, and tooth contact analysis has been carried out. The results show that at high input powers and low oil levels, temperature differences arise between pinion and gear, resulting in pitch errors and profile slope deviations. Such profile distortions affect load distribution — especially at low loads and high temperatures — leading to a non-symmetrical diagram that affects bending stress levels. Transmission error is fundamentally influenced by the backlash angle decrease shifting the mean level towards zero. Profile modifications have been proposed and it has been shown that mechanical and thermal deviations can be predicted and compensated at the manufacturing stage.

For more information.

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Design Parameters for Spline Connections

Dr. Hermann J. Stadtfeld

Introduction

Splines are machine elements that connect a shaft with a rotor. Next to transmitting torque, the spline might also be utilized to center the rotor to the shaft. It is interesting that the spline's tooth profiles are involutes, although the involute profile does not contribute to the torque transmission, nor is it linked to the centering function. The reason for the involute profile is the fact that most external splines are manufactured by hobbing with a standard straight-sided, symmetric hob tooth profile that is fast and delivers good accuracy results. The internal spline has to be manufactured with shaping or broaching, using an involute cutting tooth profile. The nomenclature and parameters of a typical spline connection are presented (Fig. 1). The spline connection in Figure 1 is neither centering on the flanks nor on its major or minor diameters.

The exception to the involute profiles is the parallel straight profile spline that requires a planning operation for the external member and a single tooth shaping or broaching of the internal member. Splines can be organized into 2 main categories and 4 sub-categories that are defined by national and international standards; an overview is given (Fig. 2).

Studying the literature teaches that many large OEM's pick the design proposals, the tolerances and function features for one particular spline design from several standards. Here it will be proposed to use metric units for all calculations, applying the addendum/dedendum recommendation by DIN and following the ANSI guideline for side fit and major diameter fit. In order to eliminate the confusion that the design by picking dimensions and tolerances from different standards might cause, the following sections present a firm guideline for each step of the design, tolerancing and cutting tool definition.

The Different Spline Functions and the Required Fits

If a splined shaft that is, for example, the output of a transmission drive with a rotor that is mounted on its own bearings, then the function of the spline is not the centering of the rotor but merely torque transmission. In this case, a centering function would just cause the transfer of misalignment and runout between shaft and rotor, which leads to vibration and bearing wear. The described connection should have backlash between the flanks and clearance between the top of the internal and external teeth and their adjacent roots, and use a profile fit with backlash (Fig. 3).

If a splined shaft is connected with the internal spline, for example — at the output of a transmission — and if the shaft is long in relation to its diameter, then a flank-centered fit as shown (Fig. 4) is preferred. In order for correct flank centering, the backlash between the internal spline teeth and the shaft spline teeth must be zero. To achieve such a transitional fit, the tolerances according to ISO 7H (shaft spline) and 7n (internal spline) are recommended.

In a case where a rotor like a sprocket is radially centered by the spline connection, then major diameter transition fit (or interference fit) according to ISO (outside shaft diameter tolerance H7 and major internal diameter tolerance n7 (or H7/p7 for a press fit) can be used (Fig. 5). The profiles can be made with backlash or as transition or interference fit (see tolerance recommendations in connection with Figs. 3 and 4). The decision regarding the flank fit depends on the operation schedule

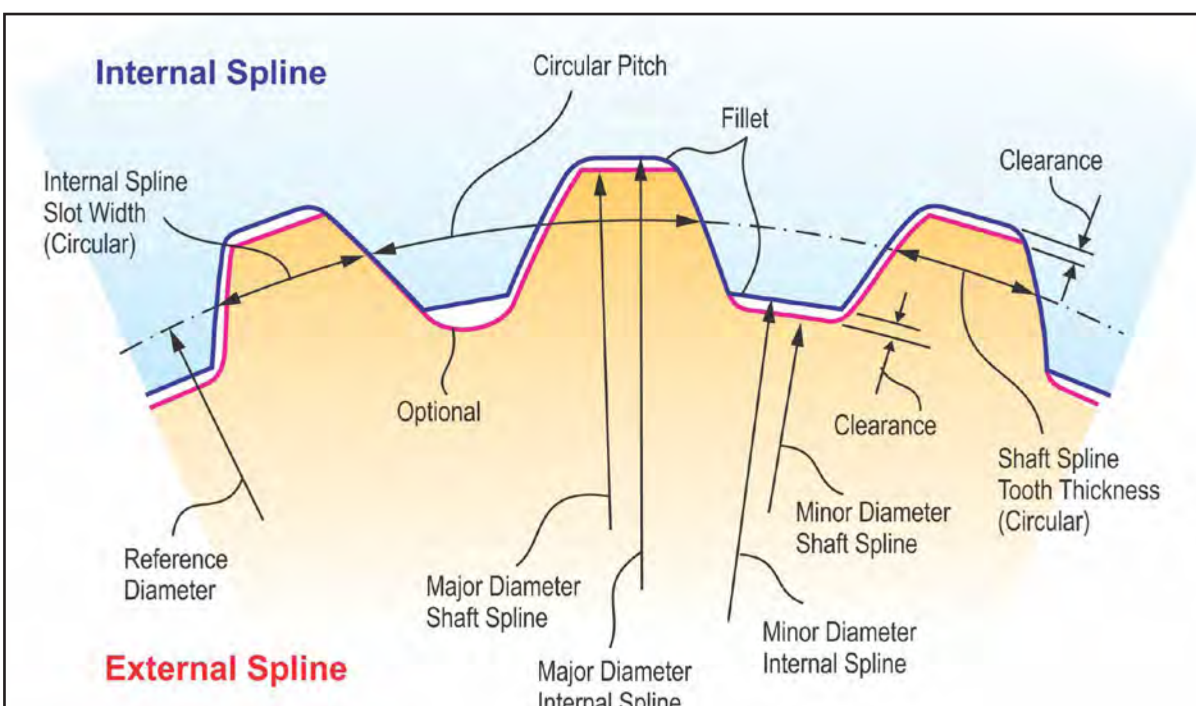

Figure 1 **Design parameters for splines.**

Involute Splines with Pressure Angle Splines with Parallel Straight Profiles			Parallel Straight Profiles with Corner Checks
ANSI B92.1	DIN 5480 & ISO 4156	JIS B1603-1995, D2001	AGMA 945-A18 & ISO 14
α = 30º, 37.5º, 45º	α = 30º, 37.5º, 45º	α = 20º, 30º, 37.5º, 45º	Pressure Angle Formula see Standard
Addendum Formula see Standard	Addendum = 0.45·m Dedendum = 0.55·m Broaching Dedendum = 0.60·m Hobbing	Addendum and Dedendum Definition lean towars DIN & ISO	Use ANSI or ISO Standard for Addendum and Dedendum
Min space width equal max tooth thickness, in case of Interference fit in-crease internal spline tooth thickness	ISO "H" tolerance for external shaft diameter. For internal major diameter use "a to h" for clearance fit, use "h to p" for a gentle fit and "p to z" for press fit	Regarding fit lean towards DIN & ISO	Regarding fit use ANSI or ISO Standard
Root fillet radii with either profile side fit or backlash and always clearance at the major and minor diameter			
Flat root with sharp fillet corners with major diameter fit, backlash and clearance at minor diameter (DIN-ISO also covers a minor diamater Fit)			
Flat root with sharp fillet corners with either profile side fit or backlash and always clearance at major and minor diameter			

Figure 2 Overview of different spline categories [1 through 7].

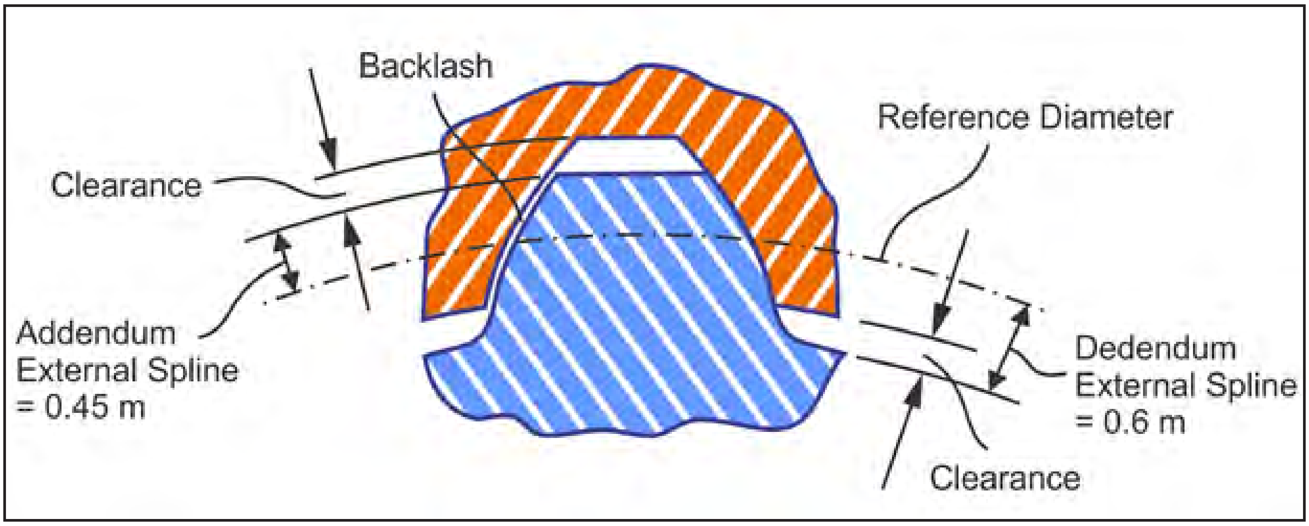

Figure 3 Not centering connection.

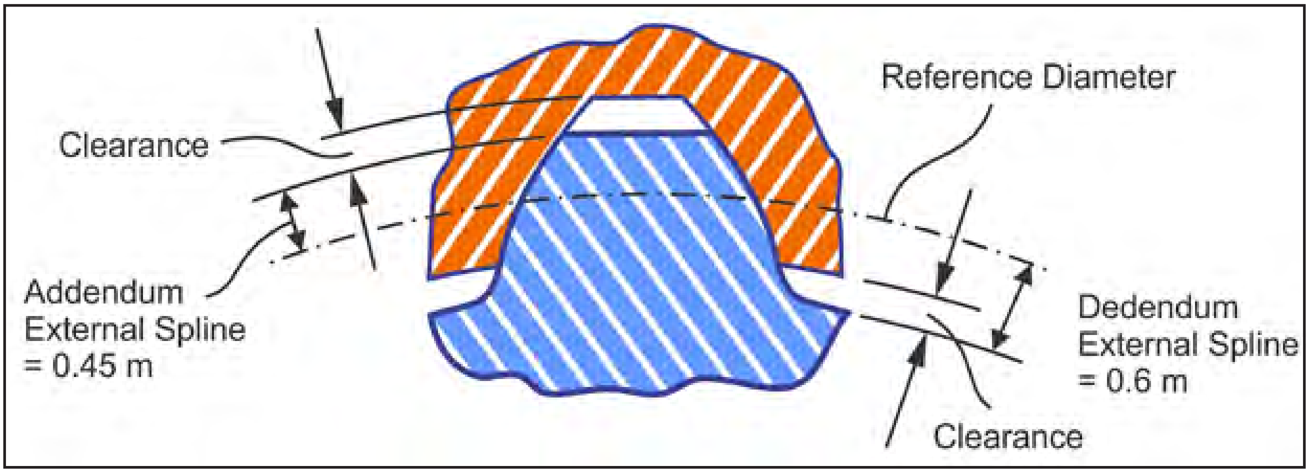

Figure 4 Flank centered connection.

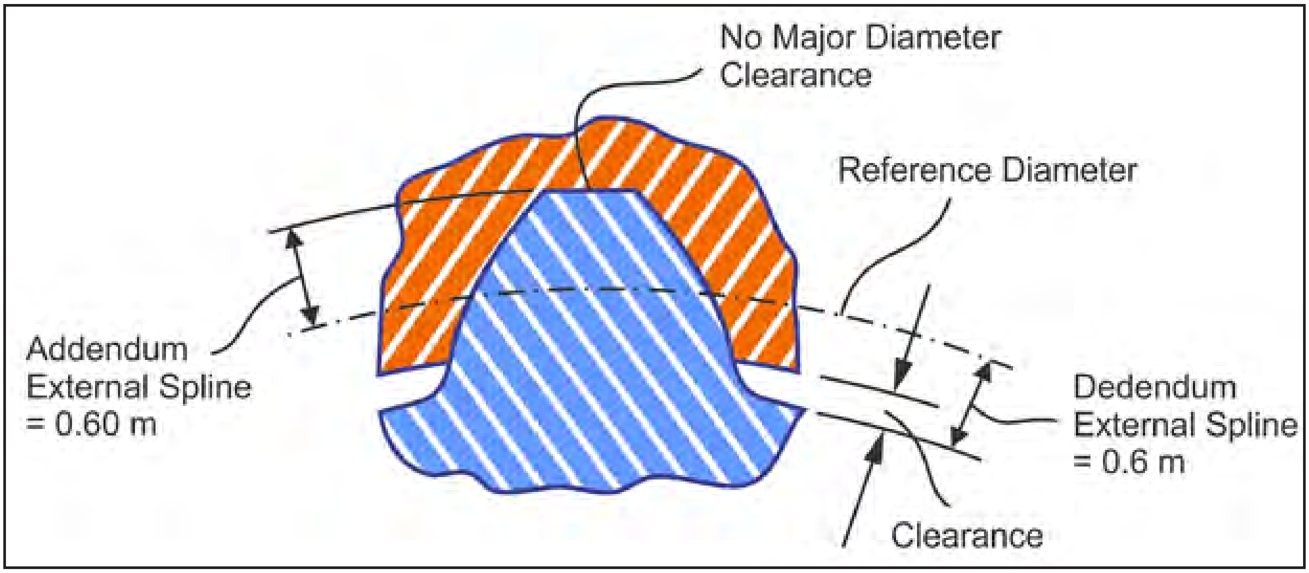

Figure 5 Major diameter centered connection with gentle flank fit.

(one-directional or two-directional torque transmission).

The parallel straight-sided spline has straight-sided teeth on the spline shaft and straight-sided slots on the internal spine. To calculate addendum and dedendum, the formulas either from the ANSI or the ISO standard can be used. In a metric calculation like that shown before, the ISO tolerance recommendations are appropriate for diameters and tooth thickness versus slot width. An example for a straight-sided spline is shown (Fig. 6).

The effective pressure angle can be calculated from the triangle in Figure 6, using the reference diameter as hypotenuse and the tooth thickness as the opposite side. The straight-sided spline according to AGMA has checks at the root fillets (Fig. 6). There is no particular preference in the standards regarding diameter fit or flank fit. Also, for the parallel-sided spline it is common to either use a major diameter fit with clearance on the flanks or a major diameter fit with a gentle fit or press fit on the flanks. Flank fit without major diameter fit is uncommon because a radial misalignment due to a press fit is more likely than is the case of splines with non-parallel flanks.

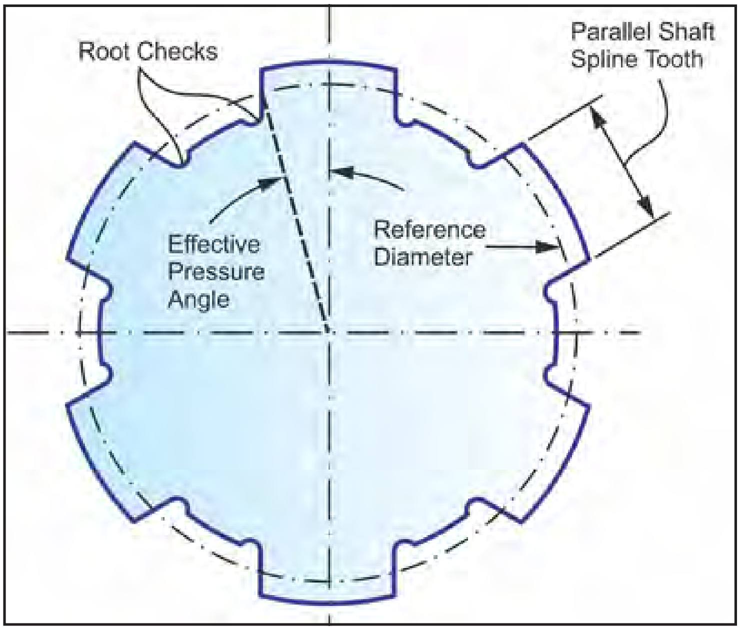

Figure 6 Parallel straight sided spline.

Defining Spline Dimensions

The example spline (Fig. 7) transmits the torque of a sprocket to the splined shaft (or vice versa) and centers the sprocket radially. The example sprocket spline has metric dimensions. Although it is proposed in this article to use metric dimensions for all calculations, later, for the search of a suitable standard hob, the module can be converted into diametral pitch in order to find the closest hob — either in the metric or in the imperial system.

The tooth depth is calculated using the difference between major and minor diameter divided by two:

$$\text{Depth} = (d_{Major} - d_{Minor})/2 = 2\,\text{mm}$$

The tooth proportions addendum and dedendum relate the depth to the still-unknown module:

$$\text{Depth} = h_K + h_F = 0.45 * m + 0.60 * m$$

This relationship allows to calculate a module of:

$$m = \text{Depth}/1.05 = 1.905$$

With the known module it is now possible to calculate addendum and dedendum:

$$\text{Reference addendum: } h_K = 0.45 * m = 0.857\,\text{mm}$$
$$\text{Reference dedendum: } h_F = 0.60 * m = 1.143\,\text{mm}$$

Both dimensions, h_K and h_F, are reference values that split the tooth depth into the reference addendum and the reference dedendum. This means that neither of the values is related to the pitch circle. The pitch diameter is calculated like for a standard spur gear by multiplying the module with the number of teeth:

$$d_0 = m * z = 22.857\,\text{mm}$$

It can be recognized that the pitch diameter is smaller than the minor diameter of the spline. Because the spline is not a meshing gear member, there is no working pitch diameter and the meaning of the pitch diameter is primarily important for the choice of the hob cutter and/or the broach. However, it is meaningful to calculate a reference diameter that separates the reference addendum and the reference dedendum:

$$d_{Ref} = d_{Minor} + 2 * h_F = 26.286\,\text{mm}$$

The difference between the pitch diameter and the reference diameter can now be used to calculate the profile shift, which is:

$$x * m = (d_0 - d_{Ref})/2$$
or:
$$x = (d_0 - d_{Ref})/(2 * m) = -0.9$$

The initially calculated module of 1.905 mm will not allow utilizing a standard broach for the internal sprocket spline. If the module is now rounded to a number from the DIN/ISO table of preferred modules, then the rounding to 2.0 mm is proposed.

Rounded module: $m_{Final} = 2.0\,\text{mm}$

This module rounding is without any tangible consequence if the spline shaft, as well as the sprocket spline, are together in the design and manufacturing planning stage. If the sprocket design is done for an aftermarket purpose, and has to fit on an OEM shaft spline, then the working pressure angle at the reference diameter might show some mismatch. In the present case the rounding was only small and pressure angle mismatch will be within an acceptable tolerance.

With the new, rounded module the previously calculated addendum and dedendum values have to be preserved. However, the original factors for the calculation of addendum and dedendum ($h_K = 0.45 * m$ and $h_F = 0.60 * m$) have changed by the module rounding. This fact is not relevant, because the *mm*-value of the sum of addendum and dedendum remain the same, as well as the top-root clearance.

After the module rounding, the pitch diameter and the profile shift factor have to be recalculated:

$$d_{0Final} = m_{Final} * z = 24.00\,\text{mm}$$
$$x_{Final} * m_{Final} = (d_{0Final} - d_{Ref})/2$$
$$x_{Final} = x_{Internal} = (d_{0Final} - d_{Ref})/(2 * m_{Final}) = -0.572$$

The spline set always has a V0 profile shift relation which means:

$$x_{Internal} + x_{External} = 0$$
and
$$x_{External} = -x_{Internal} = +0.572$$

Defining the Spline Pressure Angle

If the splines are being designed, then one of the preferred pressure angles from the standards should be used. ANSI and DIN offer the choice between 30°, 37.5° and 45°. In the JIS standard also a pressure angle of 20° is proposed.

If the spline is designed for an aftermarket product (for example the sprocket shown Fig. 7), then a simple measurement — preferably on a CMM or with a Vernier caliper as shown (Fig. 8) — can be conducted to obtain a first pressure angle estimation. If the aftermarket product is the sprocket (not the shaft), then it would be desirable to obtain the measurement explained in Figure 8 on the spline shaft.

The measurement results are used together with the depth of the spline tooth to calculate the approximated pressure angle:

$$\alpha_{approx} = \arctan[2 * Depth/(t_1 - t_2)]$$

For the example in Figures 6 and 7 with a topland $t_2 = 2.60\,\text{mm}$, a root width $t_1 = 7.30\,\text{mm}$, and a depth of 2.0 mm the

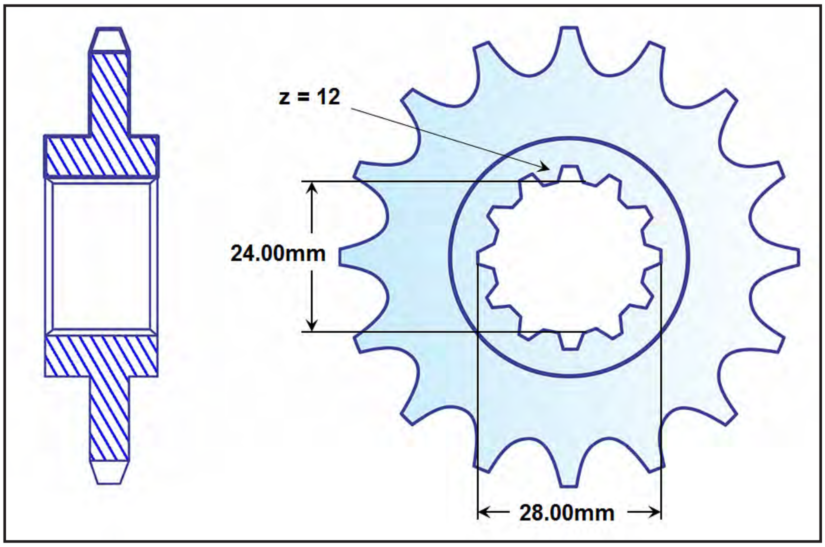

Figure 7 Example sprocket with internal spline.

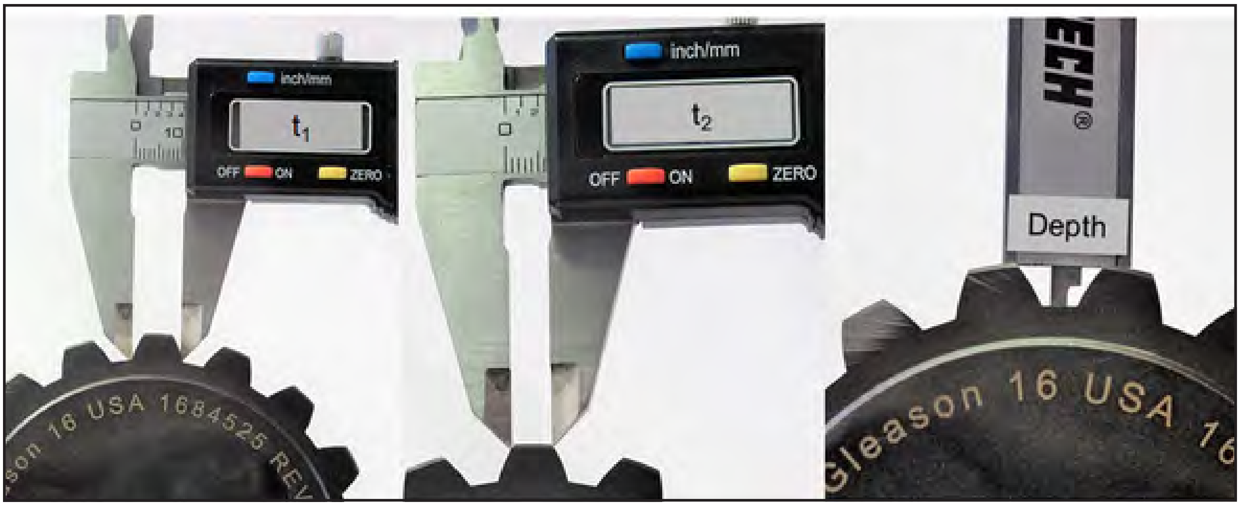

Figure 8 Measurement of topland root and depth.

approximated pressure angle is:

$$\alpha_{approx} = \arctan[2 \cdot 2.00/(7.30 - 2.60)] = 40.39°$$

The approximated angle is between the preferred angle 37.5° and 45° from the standards. The difference from 45° is 4.61° and the difference from 37.5° is only 2.89°. The decision therefore is 37.5°:

$$\alpha_{External} = \alpha_{Internal} = 37.5°$$

37.5° is a popular pressure angle for splines, which also indicates that the result of measurement and calculation is realistic. It is recommended that the major diameter of the sprocket is equal to the outside diameter of the spline shaft to assure a major diameter fit. If the sprocket is the transmission output of a uni-directional unit, then the flanks can receive a small backlash (e.g. — sprocket spline tooth thickness tolerance ISO 7H and shaft spline tooth thickness tolerance 7f). If sprocket and spline have to transmit torque in frequently changing directions, then a transition fit or a press fit of the spline teeth is recommended (sprocket ISO 7H, shaft ISO 7n).

The tolerance of the major diameter of the internal spline should be selected as a transition fit; for example, ISO H7 (the outside diameter of the spline shaft should be ISO j7).

Defining Tool and Cutting Parameters

The tool for the spline shaft can be a standard ISO spline hob cutter module 2.0 with a pressure angle of 37.5° and sharp corners at the hob teeth. Due to the profile shift of $x_{External} = +0.572$, the hob cutter must be retracted from the theoretical position by $x_{External} \cdot m = 1.144$ mm away from the shaft.

The tool for the internal spline can be a standard ISO spline shaper cutter, for example, with 8 teeth. The center distance between shaper cutter and internal spline is:

$$\text{Center Distance} = d_0/2 - x \cdot m - d_{0Cutter}/2$$
$$= 24.00/2 - (-0.572) \cdot 2.00 - (d_{0Cutter}/2 + m \cdot x_t)$$

A profile shift of the shaper cutter x_t might be required with the low number of cutter teeth, and is therefore considered in the center distance formula.

Summary

This article provides a guideline for the selection of a suitable standard in connection with the kind of spline to be designed and manufactured. Some basic formulae have been explained, together with a strategy on how to find standard tooling by calculating an appropriate profile shift factor for the spline to be designed. If an aftermarket part like a sprocket should be matched to an existing spline shaft, then the dimensions of major and minor diameter can be found on the shaft. Addendum and dedendum have to consider the recommended top root clearance (on the not-centering top root combination). If those facts are all taken into consideration, then it is not important to know if the mating, existing shaft was manufactured with an English standard hob and the sprocket is manufactured with a metric standard hob; this is as long as both members use the appropriate profile shift, which will assure that the reference diameters of shaft and internal spline are identical. Also, a simple method for determining the pressure angle of an existing spline has been presented. The result was compared to the ANSI and ISO table of recommended spline pressure angles which allowed a mature choice of the closest value.

The final section of the article aids in the selection of a hob cutter for the shaft and a shaper cutter for the internal spline. For the correct setup of the manufacturing machine the calculation of the center distances between work and tool was presented.

For more information. Questions or comments regarding this paper? Contact Dr. Hermann Stadtfeld at *hstadtfeld@gleason.com*.

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Dr. Hermann J. Stadtfeld is the Vice President of Bevel Gear References Technology and R&D at the Gleason Corporation and Professor of the Technical University of Ilmenau, Germany. As one of the world's most respected experts in bevel gear technology, he has published more than 300 technical papers and 10 books in this field. Likewise, he has filed international patent applications for more than 60 inventions based upon new gearing systems and gear manufacturing methods, as well as cutting tools and gear manufacturing machines. Under his leadership the world of bevel gear cutting has converted to environmentally friendly, dry machining of gears with significantly increased power density due to non-linear machine motions and new processes. Those developments also lower noise emission level and reduce energy consumption.

For 35 years, Dr. Stadtfeld has had a remarkable career within the field of bevel gear technology. Having received his Ph.D. with summa cum laude in 1987 at the Technical University in Aachen, Germany, he became the Head of Development & Engineering at Oerlikon-Bührle in Switzerland. He held a professor position at the Rochester Institute of Technology in Rochester, New York From 1992 to 1994. In 2000 as Vice President R&D he received in the name of The Gleason Works two Automotive Pace Awards — one for his high-speed dry cutting development and one for the successful development and implementation of the Universal Motion Concept (UMC). The UMC brought the conventional bevel gear geometry and its physical properties to a new level. In 2015, the Rochester Intellectual property Law Association elected Dr. Stadtfeld the "Distinguished Inventor of the Year." Between 2015–2016 CNN featured him as "Tech Hero" on a Website dedicated to technical innovators for his accomplishments regarding environmentally friendly gear manufacturing and technical advancements in gear efficiency.

Stadtfeld continues, along with his senior management position at Gleason Corporation, to mentor and advise graduate level Gleason employees, and he supervises Gleason-sponsored Master Thesis programs as professor of the Technical University of Ilmenau — thus helping to shape and ensure the future of gear technology.

A Precise Prediction of the Tooth Root Stresses for Involute External Gears with Any Fillet Geometry under Consideration of the Exact Meshing Condition

Tobias Paucker, Michael Otto and Karsten Stahl

Introduction

An efficient design with high power density characterizes a modern transmission, which leads, in many ways, to optimized constructions. Reaching a high utilization of material strength requires an exact prediction of occurring stress under given load carrying capacity to guarantee sufficient endurance.

Practically applied standardized methods to evaluate the load carrying capacity (AGMA 2101 (Ref. 1), DIN 3990 (Ref. 3), ISO 6336 (Ref. 4)) contain formulas to calculate the tooth root stress of standard profiles. At the same time, optimized profiles are designed that use more and more reserves of load carrying capacity (e.g.—optimized fillets, special tooth profile). Widely available FEM-calculations provide precise stress results, but are still laborious to apply for tooth contact analysis. Detailed, but fast and easy to use calculation methods are necessary to evaluate different types of tooth profiles in consideration of freely designed fillets. In addition, a more detailed analysis of standard tooth root profiles is required to increase power density. Also in many cases, expecting the maximum load and critical root stress at the tangent point of 30° (DIN3990 (Ref.3), ISO 6336 Ref. 4)) or the Lewis-Parabola (AGMA (Ref. 1) is not always right (Ref. 2.)

This paper shows a method to calculate the occurring tooth root stress for involute, external gears with any form of fillets very precisely within a few seconds. The following parameter variation uses a 2-D boundary element model to receive the notch stresses of the fillets. These calculated stresses are linked to a high-quality analytical tooth contact analysis to consider the exact relations of the gear mesh. This algorithm is implemented in the FVA software *RIKOR* (Refs. 5–6). The introduced model also allows a calculation of the occurring tension and compression stresses along the whole fillet for different mesh positions.

Calculation Method

The following section describes the calculation method that extends the standardized method of ISO 6336 (Ref.4).

Declaration of supporting points. Initially, a declaration of the supporting points of the tooth flank and the field of action is necessary to describe the calculation method.

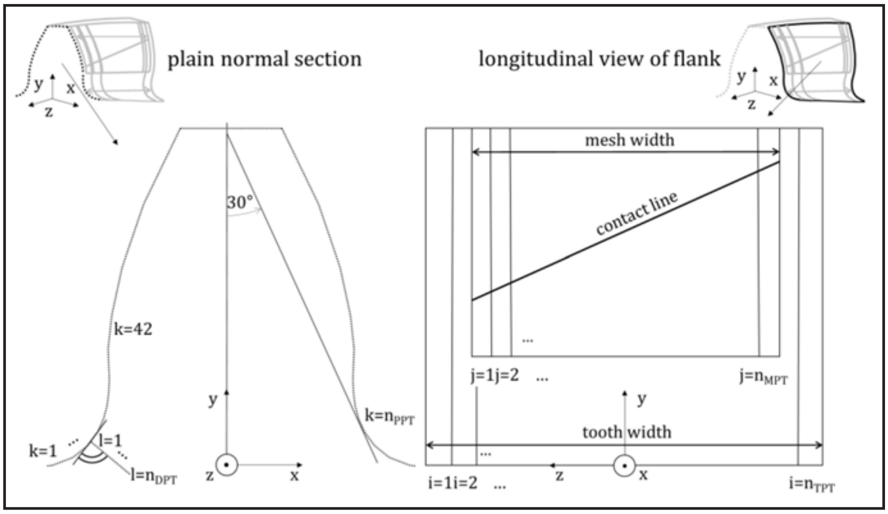

Figure 1 **Definition of supporting points for a tooth and a contact line.**

Figure 1 shows a definition of these supporting points for the plain normal section, and the plain longitudinal view of the tooth flank—including the root.

To illustrate the form of the fillet, it is most suitable to use a normal section of the tooth. For a spur gear, the normal and transverse sections are the same, located in a plane. But the normal section of a helical is curved in a 3-D area. To represent to actual fillet form precisely, a plain normal section is used. For later valuation, the plain normal section of the contour is indexed with a number of supporting points k (amount $= n_{PPT}$). At every point k of the contour, it is possible to define a number of supporting points l (amount $= n_{DPT}$) in normal direction to the inside of the gear material. For the analytical model, the tooth width is discretized in a number of supporting points i (amount $= n_{TPT}$). The mesh width is also discretized in a certain amount of supporting points j (amount $= n_{MPT}$), as it is not always the same size as the tooth width.

Figure 1 also shows the definition of a local coordinate system (x,y,z).

Influence function β_F ***of tooth root bending moment.*** To consider the tooth width and the bending lever, which varies in its longitudinal direction for helical gears, an influence function β_F is introduced that is based on investigations of Umezawa (Ref. 8).

This function describes the impact of a local tooth force at j to the bending moment, which occurs in i (compare to Eq. 1).

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When solving this function for a certain amount of supporting points and combining it with the local bending lever, a precise analytical calculation of the local bending moment (helical gears) is given.

$$\beta_{F_{i,j}} = \left(\frac{e^{-0.5 * \left(\frac{z(i)-z(j)}{\sigma_\alpha \cdot h} \right)^2}}{\sqrt{2\pi} \cdot \sigma_\alpha} \right) \cdot \left(\frac{h_0}{h} \right) + S_{L_{i,j}} + S_{R_{i,j}}$$

β_F	[-]	Influence function of tooth root bending moment
i	[-]	Index of supporting point (tooth width)
z	[mm]	Coordinate in lead direction
h_0	[mm]	reference tooth height (1mm)
σ_α	[-]	Influence function of pressure angle
j	[-]	Index of supporting point (mesh width)
h	[mm]	Tooth height
$s_{l/r}$	[-]	Influence of edge

Equation 1: Calculation of the Influence function $\beta_{Fi,j}$ at supporting point *i* caused by a load acting on supporting point *j* based on Umezawa (8)

Tooth root bending moment M_i. While solving the influence function β_F for every discretized load on the contact line, the local tooth root bending moment M_i can be solved at every supporting point i (compare to Eq. 2). The local bending lever h_F is referenced to the boundary point of the 30°-tangent and the fillet. This method also allows the consideration of the exact load distribution.

$$M_i = \sum_{j=1}^{n_{MPT}} \beta_{F_{i,j}} \cdot h_{F_j} \cdot p_{F_j}$$

M_i	[N·mm]	Tooth root bending moment at supporting point *i*
i	[-]	Index of supporting point (tooth width)
β_F	[-]	Influence function of tooth root bending moment
p_F	[N]	Local tooth force
n_{MPT}	[-]	Number of supporting points (mesh width)
j	[-]	Index of supporting point (mesh width)
h_F	[mm]	Local bending lever to 30°-tangent

Equation 2: Calculation of the tooth root bending moment M_i at supporting point *i* with certain load distribution

Figure 2 shows the impact of a single load (left figure) on the tooth bending moment. Also shown is the effect of a certain load distribution and bending levers (right figure) on the occurring tooth bending moment and its allocation.

Tooth root stress σ_i**.** Referring the bending moment to the bending section leads to the nominal tooth root stress of an equivalent beam (compare to Eq. 3). To consider the fillet it is possible to use the stress correction factor according to DIN 3990 (Ref. 3) or rather ISO 6336 (Ref. 4), which is referred to every loading point *j*. The calculated tooth root stress gives a maximum value without a specific declaration of the location of this stress. This stress correction factor does not allow considering any other root geometries than trochoids. The calculation of, e.g., grinding notches, asymmetric or otherwise optimized fillets is not possible. To determine the stress correction factor for such root geometries, it is necessary to calculate it with a numerical method.

$$\sigma_i = \frac{1}{W_b} \cdot \sum_{j=1}^{n_{MPT}} \beta_{F_{i,j}} \cdot h_{F_j} \cdot p_{F_j} \cdot Y_{S_j}$$

σ_i	[N/mm^2]	Tooth root stress at supporting *point i*
i	[-]	Index of supporting point (tooth width)
β_F	[-]	Influence function of tooth root bending moment
p_F	[N]	Local tooth force
W_b	[mm^3]	Bending section modulus at 30°-tangent
n_{MPT}	[-]	Number of supporting points (mesh width)
j	[-]	Index of supporting point (mesh width)
h_F	[mm]	Local bending lever to 30°-tangent
Y_S	[-]	Stress correction factor

Equation 3: Calculation of the tooth root stress σ_i at supporting point *i* with the exact load distribution p_{Fj} and the stress correction factor Y_{Sj} according to DIN 3990 (3) and ISO 6336 (4)

Local stress correction factor $Y_{Sj,k,l}$**.** To allow the calculation of local stress correction factors for any fillet forms, it is convenient to use a numerical method. A 2-D numerical method is adequate to fulfill this requirement, while it also calculates very fast. Within this paper, a 2-D boundary element method (BEM) is used (Ref. 5).

The local stress correction factor $Y_{Sj,k,l}$ calculates for every location of the acting force *j*, along the fillet *k*, and also in normal direction to the inside of the gear *l* (surface tension also possible). It correlates to the quotient of a local tooth root stress at the investigated location and the reference bending stress at the equivalent beam (bending lever of acting force to the 30°tangent) (compare to Eq. 4).

This reference is necessary for this calculation method, but does not influence the calculation accuracy. A reference to every other tangent is possible as only the distribution between local stress correction factor and root bending moment would change, while their product would stay the same. The reference of the local stress correction factor is a certain load acting point *j*. Therefore, the stress-increasing effect of the fillet is constant along the mesh width for a certain load acting position.

$$Y_{S_{j,k,l}} = \frac{\sigma_{2D_{j,k,l}}}{\sigma_{2D,ref,j}}$$

$Y_{S_{j,k,l}}$	[-]	Local stress correction factor
k	[-]	Index of supporting point (profile)
σ_{2D}	[N/mm^2]	Local tooth root stress with 2D numerical method
j	[-]	Index of supporting point (mesh width)
l	[-]	Index of supporting point (depth)
$\sigma_{2D,ref}$	[N/mm^2]	Reference bending lever to 30°-tangent

Equation 4: Calculation of the local stress correction factor $Y_{Sj,k,l}$

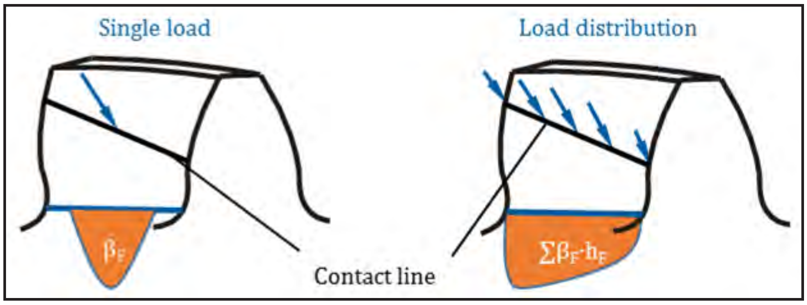


Figure 2 Illustration of the influence function β_F, local bending lever h_F and a certain load distribution p_F.

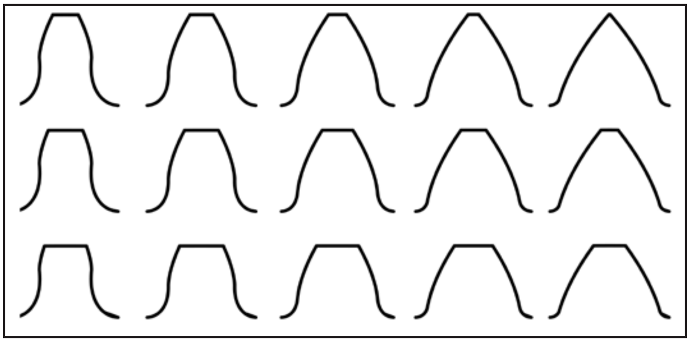


Figure 3 Tooth contours of varied parameters.

Table 1 Main geometry and 3-D model of investigated gear stage

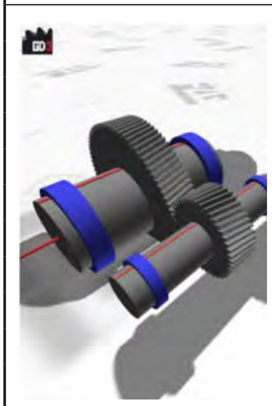
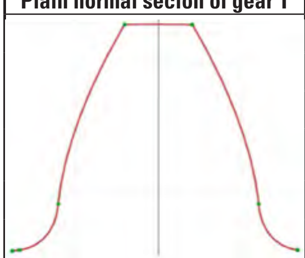
3-D Model	Geometry	Gear 1	Gear 2	Unit
	Module	1		mm
	Pressure angle	20		°
	Helix Angle	10	–10	°
	Number of Teeth	42	84	-
	Sum of profile shift	0		-
	Tip Diameter	*varies*		mm
	Root diameter	*varies*		mm
	Tooth width	18	18	mm
	Center distance	63.97		mm
	Contact ratio	*varies*		-
	Overlap ratio (nominal)	1.0		-

Table 2 Tool data and plain normal section of the investigated gear stage

Plain normal secion of gear 1	Tool Data	Gear 1	Unit
	Add. coeff. basic rack	1.5	-
	Ded. coeff. basic rack	1.6	-
	Tip radius	0.25	-
	Generating profile shift of this case	0 (*varies*)	-
	Protuberance angle	-	°
	Depth of protuberance	-	mm

Local tooth root stress $\sigma_{i,k,l}$. With exchanging the standardized stress correction factor with the local and numerical determined stress correction factor, it is possible to calculate a local tooth root stress at any location of the fillet (Eq. 5). This method also allows the prediction of the location of the highest occurring root stresses. With the requirement of very low calculation time, it would also be convenient to use this algorithm for optimizations. Within this paper it is used to compare the results to the standardized approach of ISO 6336 (Ref. 4).

$$\sigma_{i,k,l} = \frac{1}{W_b} \cdot \sum_{j=1}^{n_{MPT}} \beta_{F_{i,j}} \cdot h_{F_j} \cdot p_{F_j} \cdot Y_{S_{j,k,l}}$$

$\sigma_{i,k,l}$	[N/mm^2]	Tooth root stress at supporting point *i*
i	[-]	Index of supporting point (tooth width)
k	[-]	Index of supporting point (profile)
β_F	[-]	Influence function of tooth root bending moment
p_F	[N]	Local tooth force
W_b	[mm^3]	Bending section modulus at 30°-tangent
n_{MPT}	[-]	Number of supporting points (mesh width)
j	[-]	Index of supporting point (mesh width)
l	[-]	Index of supporting point (depth)
h_F	[mm]	Local bending lever to 30°-tangent
Y_S	[-]	Stress correction factor

Equation 5: Calculation of the local tooth root stress $\sigma_{i,k,l}$ at supporting point *i*, profile point *k* and depth point *l* with the exact load distribution p_{Fj} and the local stress correction factor $Y_{Sj,k,l}$

Parameter Variation and Results

The calculation method, introduced above, allows doing extensive parameter variations and studies and comparing the results to, e.g., standardized methods. In the following, a parameter study is shown, which investigates different trochoid fillet geometries and compares them to the corresponding results of ISO 6336 (Ref. 4). The variations are made with very stiff shafts and bearings, as the influence of these machine elements are not in focus for these calculations. The influence of the mesh stiffness is considered for these calculations.

Varied parameters. There are different possibilities to change the fillet geometry. The presented calculation study shows a variation of the profile shift x ($-1 \leq x \leq 1$) and the tooth height h_a (influences contact ratio $-1 \leq \varepsilon_\alpha \leq 1$). A different tooth height leads to changing contact ratio and, therefore, a variation of the critical contact line that is responsible for the maximum tooth root stress. The sum of profile shift is zero for every case to keep

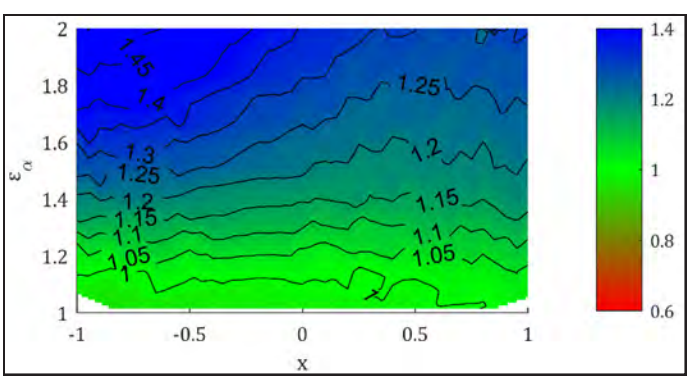


Figure 4 Relation of maximum tooth root stress σ_i according to ISO 6336 (Ref. 4) to maximum local tooth root stress $\sigma_{i,k,l}$ according to Eq. 5.

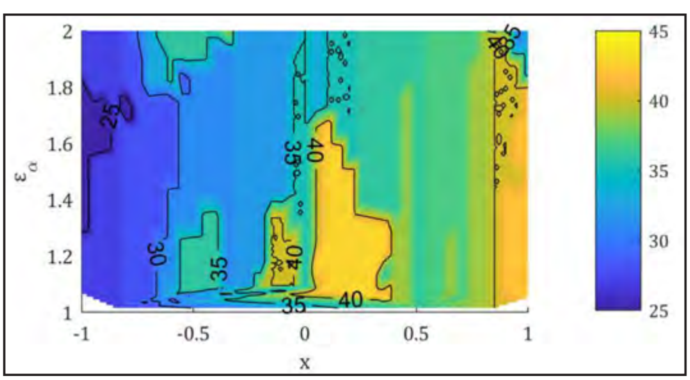


Figure 5 Location (in ° of tangent) of the maximum local tooth root stress $\sigma_{i,k,l}$ according to Eq. 5.

the same center distance. The plane normal sections of the different investigated tooth contours are shown (Fig. 3), while the focus of the calculations lies on the pinion ($z = 42$).

Table 1 shows the 3-D model with the geometrical data of the gears, and Table 2 shows the tool data for gear 1 of this model.

Influence of the contact ratio. Figure 4 shows the relation of the maximum tooth root stress according to ISO 6336 (Ref. 4) to the maximum tooth root stress according to Equation 5. A result above one means that the calculation according to ISO 6336 (Ref. 4) gives higher results as the local method of this paper. A main result is that for increasing contact ratios, the standardized method calculates very safely. Schinagl (Ref. 7) investigates the influences of the profile and contact ratio within his dissertation, while his results support this consideration.

Location of maximum tooth root bending stress. The method also allows an investigation of the location of the maximum occurring stress. The reference stress of the corresponding beam is at the 30°-tangent. Figure 5 shows the location (in ° of the tangent) of the maximum tooth root stress, depending on the profile shift and the contact ratio (critical contact line). With an increasing profile shift, the radius of the fillet decreases. The critical tension stress gets shifted nearer to the center of the tooth root fillet, which may lead to a more critical alternating load.

Further Calculation Possibilities

The discussed geometries of the variation are focusing on trochoid fillet geometries. Of course, the numerical method is not restricted to certain root geometries. Therefore, there are different calculations imaginable that are introduced in the following section. The pros and cons of each fillet geometry — especially of optimized forms — are not discussed.

Calculation of grinding notches. For case hardened gears, it is common to manufacture them with a certain amount of protuberance and finish the gears with a grinding process after hardening. An unfavorable behavior can be the occurrence of grinding notches. To evaluate these fillets forms there are different approaches, such as the investigations of grinding notches by Wirth (Ref. 9). To determine an exact or even measured contour, the approaches, which only describe the notches or protuberances analytically, are not promising. More productive is an investigation of the exact fillet form with numerical methods. Figure 6 shows a nominal contour compared to one with a grinding notch. An important point is to be able to evaluate these kinds of manufacturing deviations and to be able to react in an adequate amount of time without having to run extensive tests. Figure 8 shows a calculation of a gear with a grinding notch (normal section of the contour and tangential stresses); the 3-D illustration is shown for one tooth within Figure 9.

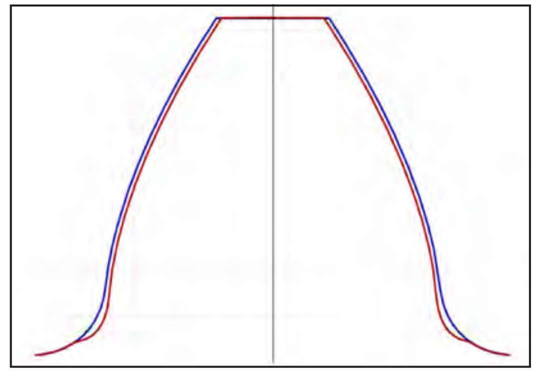


Figure 6 Nominal contour (outer, blue contour) and contour with grinding notch (inner, red contour).

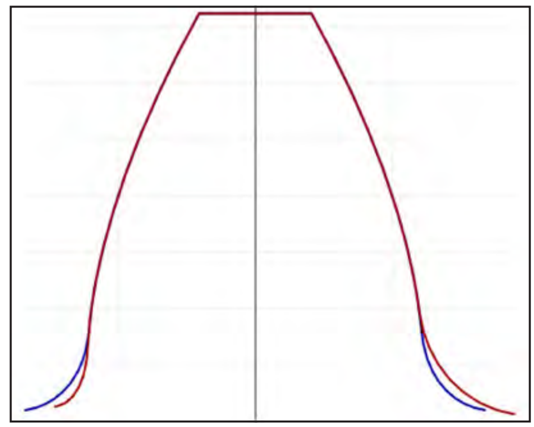


Figure 7 Nominal contour and asymmetric tooth root contour.

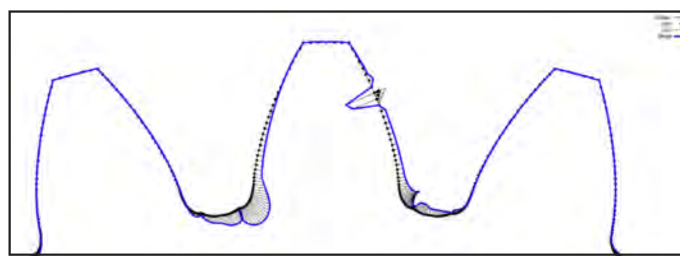


Figure 8 Illustration of the tangential stresses in plain normal section of protuberance (upper figure) and grinding notches (lower figure) on local tooth root stresses.

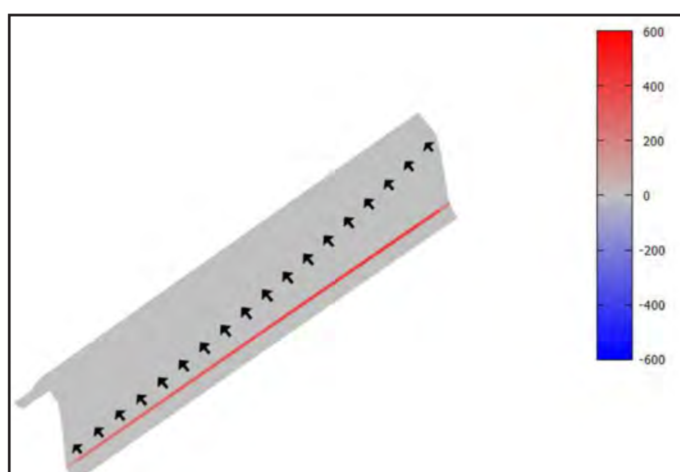


Figure 9 Illustration for one tooth of 3-D calculation of local tooth root stress $\sigma_{i,k,l}$ (along the certain tangent in N/mm^2) for full contact line of a helical gear (compression side is covered by the tooth flank)

Calculation of asymmetric root geometries. The critical tooth root stress according to DIN 3990 (Ref. 3) and ISO 6336 (Ref. 4) is represented as a tension at the side of the acting load. Therefore, it is possible to reduce the radius of the tooth root at the compression side in order to allow a wider radius at the side of the tension. An example of such an asymmetric root contour is shown (Fig. 7). To evaluate this sort of optimization it is possible to use the introduced algorithm. The distribution of the root stresses can be seen (Fig. 10) for a load acting at both sides.

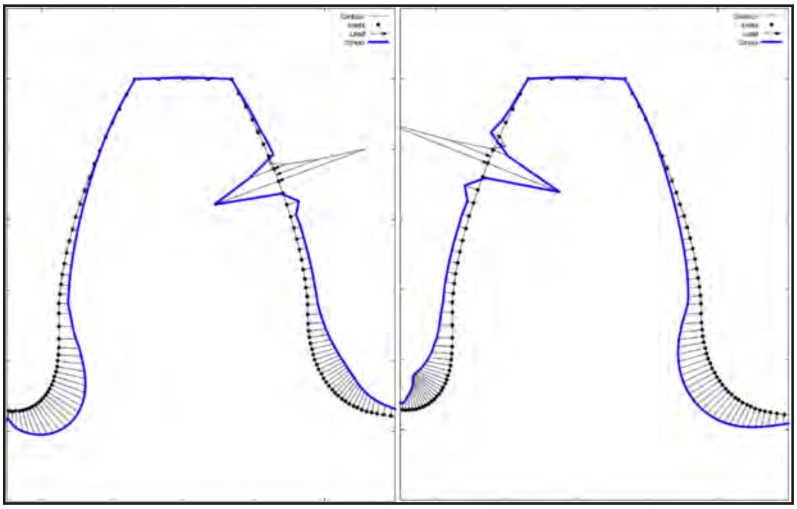


Figure 10 **Asymmetric root geometry with load acting at sharp (right figure) and wide radius (left figure).**

Conclusion

This paper introduces an algorithm to calculate precisely and quickly the local tooth root stress for involute external gears with any fillet geometry, and under consideration of the exact meshing condition. The formulas for this method and an extensive variation are introduced that show deviations between the simpler standardized approach and the presented local approach. A main result is that the standardized method according to ISO 6336 (Ref. 4) calculates the occurring maximum tension stress very safely for high contact ratios. By using this method the material utilization can be increased by up to 50%. The location of the maximum tooth stress deviates significantly for different profile shifts. Furthermore, examples of calculations for any root geometries are shown. On the one hand, with optimized fillet forms it is possible to decrease the occurring stresses up to 30%. On the other hand, an evaluation of manufacturing deviations is possible without test runs. All examples are calculated without the influences of shafts and bearings, which would lead to more unequal load sharing.

Future investigations should also cover these influences, as an unequal load sharing does not lead to an unequal stress distribution within the same amount. In addition, the introduced algorithm is suitable for root optimizations with any fillet geometry. To discuss and exercise this fact, further investigations are necessary.

For more information. Questions or comments regarding this paper? Contact Tobias Paucker at *paucker@fzg.mw.tum.de*.

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Tobias Paucker works as a Research Associate at the Gear Research Centre (FZG) at the Technical University of Munich.

Dr. Michael Otto joined FZG in 2000 as a research assistant and gained his position as head of department in 2006. He holds a Ph.D. in mechanical engineering; the topic of his research activities were load distribution and tooth root carrying capacity. Current research activities include gear geometry, tooth contact analysis and gearbox-related NVH. Another main focus is deformation and stress analysis of supporting shafts and bearings in the gearbox. He drives the development of various scientific programs that are available for companies that are members of FVA (German Research Association for Gears and Transmissions). He is also head of department—Calculation and Verification of Transmission Systems—at the Gear Research Center (FZG), chaired by Prof. K. Stahl, TU München.

Prof. Dr. Karsten Stahl is Chair, Machine Elements, Mechanical Engineering, at TUM. He leads and conducts research in the area of mechanical drive systems, with particular interest in investigating the load capacity, efficiency and dynamics of all gears types. His other areas of interest include applications in automotive engineering such as synchronization systems and multi-disc clutches. Stahl has developed methods for analysis that have been incorporated into international standards, together with the component strength values derived by means of these methods. He studied mechanical engineering at TUM and performed his doctoral studies from 1994 to 2000 in the Machine Elements Department. In 2001, he joined BMW, first as a gear development engineer, then as the manager of gear development in Dingolfing. In 2006 he transferred to the MINI plant in Oxford where he was initially quality manager for transmissions, then quality manager for powertrains and suspensions. In 2009 he took over responsibility for the initial development and innovation management of powertrain and vehicle dynamics systems at BMW in Munich. Stahl has been a full professor in the Machine Elements Department since 2011.

Octave LaBath

1941–2019

Octave LaBath, 77, of Blue Ash, Ohio, and former vice president of engineering at Cincinnati Gearing Systems Inc., died Thursday, August 8, 2019. LaBath was an active AGMA member, a member of ASME and president of Gear Consulting Services. He held a patent of a gearbox in wind turbines and worked on the LCAC for the U.S. Navy.

LaBath was active on nine AGMA technical committees at various points since the 1970s. He was the Chairman of the ISO TC 60, a member of the Technical Division Executive Committee (TDEC) and received the TDEC Award in 1982, Chairman of AGMA's Epicyclic Enclosed Drives Committee — where he led the completion of ANSI/AGMA 6123, Design Manual for Epicyclic Gear Drives — and published three papers through AGMA (AGMA 209.12, AGMA 209.15, and 02FTM10).

"We are saddened to hear about Octave as he was a great engineer that did so much for AGMA and the gear industry," said Amir Aboutaleb, vice president, technical division, AGMA. "He was a true steward for the development of standards and welcoming all who wanted to be a part of the process. His technical expertise, kind demeanor and willingness to include all committee members will be remembered."

Many members of AGMA attribute their participation in technical committees to LaBath, whom encouraged them to get involved.

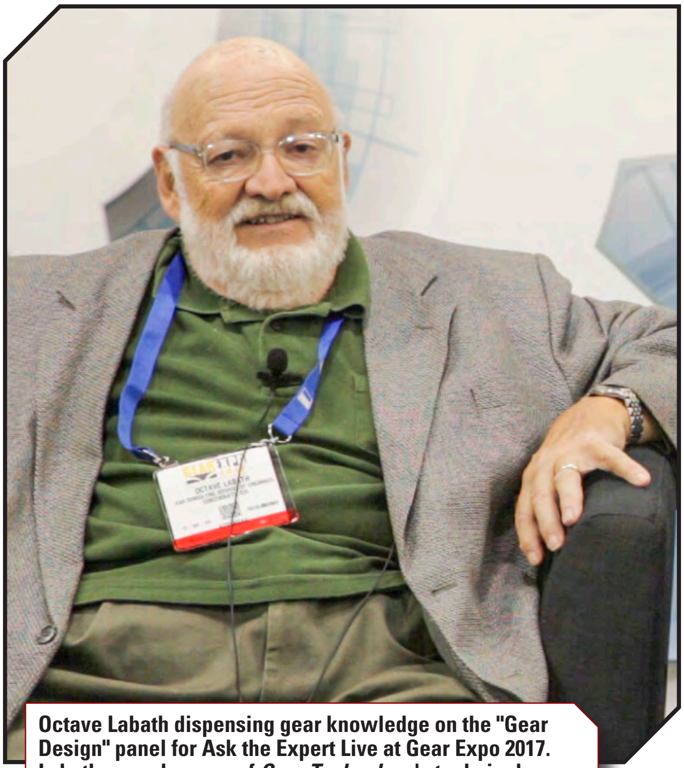
"Octave was one of the rare individuals in the gear industry who always took the time to recognize new committee members and their contributions to standards development," said Frank Uherek, principal engineer, Rexnord Gear Group. "He explained the background of the myriad of "rules of thumb" that gear engineers use to produce their designs.

LaBath was not only an important member of the AGMA technical committees but he really stood out as a leader amongst his peers, including those he worked with.

"Octave was a true gear engineer with an exceptional personality," said Tom Miller, chief engineer, Cincinnati Gearing Systems Inc. "He loved gears and gearboxes and even in retirement was always eager to teach or learn more about gears. There will never be another Octave; he will be greatly missed."

LaBath attended the University of Cincinnati in the College of Engineering. After his freshman year in 1960, he started a co-op job with the Cincinnati Gear Company. His first work section was in the shop as a machinist assistant setting up and producing pump gear blanks on an Acme Gridley four-bar feed machine. He learned to use micrometers to measure the outside diameters and face widths, depth mics to measure the hub lengths, and bore gages to measure the size in the bore.

His next job was assisting in setting up and manufacturing bevel gear blanks on a Cleveland automatic screw machine. Here, they made the blanks from a single bar stock fed automatically into the screw machine. He learned how to measure the face and back angles on the blanks.



Octave Labath dispensing gear knowledge on the "Gear Design" panel for Ask the Expert Live at Gear Expo 2017. Labath served as one of *Gear Technology*'s technical editors for more than a decade. He will be sorely missed.

LaBath worked in various shop departments — cut off saws; turning; hobbing; shaping; shaving; burring; shaft grinding; bore grinding; milling machine; and inspection.

Two years into his job at Cincinnati Gearing Systems, LaBath went into the office as an assistant to the vice president of engineering. He calculated the set-up for the gear inspection machines using a Friden mechanical calculator. He used mathematic tables in an Illinois Tool small booklet for the trigonometric and involute functions.

During his final year of co-op work, LaBath designed a gearbox that reduced the speed of a hydraulic motor that used pump gears in the motor. This included designing the housing, selecting the bearings and seals, and testing the assembly. The unit was a vertical design with splash lubrication.

While at UC, LaBath joined the student section of ASME. He ended up being a 40-year lifetime member of ASME. He graduated with a BSME degree in 1964 and joined Cincinnati Gear full-time as a project engineer. At the urging of a colleague, he decided to continue his education at night school. In fact, when he took an advanced machine design class, the teacher actually had LaBath and other students teach the section on gear design.

It was in the master's program that LaBath was introduced to computers. His work included the design, assembly, and testing of the various designs. He retired from the Cincinnati Gear Company in 2001 as — ironically enough — vice president of engineering. Learn more about Octave LaBath here: *www.geartechnology.com/blog/from-co-op-to-vice-president-octave-a-labath/*

Mahr

OPENS CUSTOMER CENTER IN WIXOM, MICHIGAN

MATTHEW JASTER, SENIOR EDITOR

Mahr Inc., a global manufacturer of precision measurement equipment and solutions, recently celebrated the grand opening of its new Midwest Regional Customer Center. Located in the Detroit area in Wixom, MI, the facility features an extensive demonstration area, fully equipped with the very latest machines, systems and precision gages from the Mahr portfolio. Furthermore, the site has been specified to provide training and conference spaces, together with office spaces for the Mahr team.

"It's been a fantastic team effort to get this off the ground," said Brett Green, CEO and president, Mahr Inc. during the ribbon-cutting ceremony. "A lot of people here and in the wider Mahr world have come together on this project and we're delighted to have everything ready and on display so our customers can bring their measurement challenges here and let Mahr help solve their problems."

"The grand opening was a great opportunity for me to come by and celebrate with our Mahr family. The state of Michigan has a very long and proud history of manufacturing. In a recent article in Global Trade Magazine, Michigan was ranked as one of the top ten states for tech-driven manufacturing. It's my great pleasure to declare Mahr's Detroit-area Customer Center in Wixom officially open," said Carl Mahr, member of the Mahr family and supervisory board.

According to Pat Nugent, vice president of product management at Mahr, Wixom was chosen as the location for Mahr's second Midwest customer center because it's in the heart of the automotive manufacturing industry and is a key area of focus for Mahr's business.

"Mahr's strategy for the Americas is to bring its expertise closer to customers, so a local presence in this automotive and manufacturing industry hotspot is important to grow the Mahr brand in Michigan and beyond. Furthermore, the location in Alpha Tech Park specifically is ideal because of its easy access off the interstate," Nugent said.

Given the prevalence of gears in automotive manufacturing, Mahr expects gear metrology to be an important area of focus at the Wixom facility.

"As surface finish on gears is becoming increasingly important, the Wixom facility currently includes a dedicated and automated gear surface finish machine. A gear can be placed on this machine and the user simply inputs its basic parameters, and the tool will automatically measure the gear's surface finish. Furthermore, there are numerous hand tools currently at our Wixom facility that are used in gear measurement."

Nugent said that the MarShaft SCOPE 600 plus 3-D, an optical and tactile shaft measuring machine for gears and camshafts, should be in Wixom soon and they expect the GMX universal gear measuring machine to be available in the future as well.

"The MarShaft SCOPE, GMX universal gear measuring machine and surface measurement machine are all made to measure a gear simply by inputting the parameters into the software, and then it automatically calculates how it has to move around to get around the gear and in between the teeth and make all the measurements — they are all very easy to operate.

We ultimately expect all products to be represented in the Wixom facility," Nugent added.

Gear inspection training and education at this facility will be a key area of focus.

"We've built a dedicated training facility adjacent to the product demo room to provide training for all products. It was designed this way so that any product can be moved into the training room very easily, at any time," Nugent said. "Additionally, we expect to offer our full suite of Mahr Academy classes at Wixom. We began conducting MarSurf and MarForm classes this year, and MarGear is coming next year. (*www.mahr.com*)

Adam Gimpert

DISCUSSES HELIOS NAME CHANGE

Helios Gear Products Business Manager **Adam Gimpert** recently discussed the name-change from Koepfer America to Helios in an industry Q&A:

Q: Helios is a new name in the gear manufacturing industry. What do you do?

A: The name is relatively new, but our company has supplied machines and tools to the industry for over 30 years as Koepfer America. As of January 1, 2019, our name changed to Helios Gear Products.

Q: What spurred the name change?

A: The confluence of three forces convinced us it was the right time for a name-change.

Firstly, our company has grown to offer manufacturers several solutions for machines and tools. We directly represent several OEMs (original equipment manufacturers), including ourselves, and many consumable tool OEMs. A neutral brand like "Helios" allows us to more equally represent all our partner OEMs.

Secondly, in 2018, our key OEM partner announced a new hobbing solution well suited for the direct and Tier 1 automotive sectors. We have structured our company to serve job shops and similar small manufacturing operations, so the alignment between our group and this new hobbing machine required an evolution of our organization.

Lastly and thirdly, YG Tech, OEM of the Hera line of gear hobbing equipment, needed new representatives in North America. After visiting the YG Tech factory and vetting their machine tool solutions, we knew that working together would bring a great hobbing solution to market. With the Hera line, we can now offer gear manufacturers three empowering forces: affordability, quality, and from-stock delivery—all with our proven, reliable technical assistance.

Q: Does this mean that Koepfer is gone?

A: "Koepfer" is owned by the EMAG Group, and here in the United States, Helios Gear Products will continue to be the technical service provider for legacy Koepfer equipment, which includes models such as 300, 200, 160, 180, 173, 153, and others. We proudly continue to serve our existing Koepfer customers with our proven technical support and new affordable technologies.

Q: For technical assistance on Koepfer equipment, should customers contact Helios?

A: Absolutely! We are EMAG Koepfer GmbH's technical service partner for all "K-type" machinery. In simple terms, if the machine is a Koepfer Model 300, 200, 160, 180, 173, 153, or similar, Helios is the go-to company for technical assistance and domestically stocked parts.

Q: Why is Helios and YG Tech such a great combination?

A: The Hera machines from YG Tech offer world class technology, such as Fanuc CNC, direct-drive torque motors, hardened and ground linear rails, and unified automation systems that our existing customers will expect and find familiar. YG Tech is a multi-generational family-owned business echoed by today's leadership at Helios, and YG Tech has built gear machines since 1963 and other machine tools since the early 20th century. With Helios's expertise and reputation in the North American gear manufacturing industry, the Helios Hera line offers manufacturers a new, affordable, high-quality, high-technology, reliable option for gear hobbing in the 21st century.

Q: What does "Helios" mean?

A: For our team, Helios means equipping manufacturers with machines and tools to make profitable gears. For others, Helios is the god of the sun in Greek mythology. We liked the sun symbolism, and "Helios" is not tied to any one brand that we represent. We strive to "shed light" on the path to profitable production for gear manufacturers, so they can compete in the global arena.

Q: What are Helios's main product offerings?

A: Machines and tools for gear manufacturers: We supply hobbing equipment for gears up to about 30 inches in diameter, and on the other end, we have hobbing equipment that comfortably handles gears smaller than a baby's little finger. Our deburring and chamfering machines are a growing segment of our products, and we also supply abrasive tools for generating grinding, form grinding, bevel gear grinding, and more. Cutting tools, of course, are an important part of our offerings: carbide and HSS hobs, milling cutters, and shaper cutters. Lastly, manufacturers also rely on us for hob sharpening and contract inspection work.

Depending on the hobbing solution required, our hobbing machines are built by ourselves, Monnier+Zahner, or YG Tech, and our deburring and chamfering machines are built by Tecnomacchine.

Q: Will Helios continue to offer used equipment?

A: We certainly will continue to offer cost-conscious solutions. Manufacturers looking for budget-friendly machines should consider our used and re-controlled ("K-Repowered") options, which we offer with warranties and backed by our Helios technical support. Our stock is always changing, so manufacturers should give us a call or visit our website for the latest.

Q: Is there anything else you'd like to add about the future of Helios?

A: We continue to work on being a leading supplier of gear manufacturing solutions. Part of that effort is our sales partnership with Kapp Technologies of Boulder, CO. Combined, our engineers and sales teams offer manufacturers are trusted, high-quality resource for hobbing, grinding, deburring, and inspection solutions. Manufacturers know that working with either Helios or Kapp will open doors for productive and profitable gearing for the future. (*www.heliosgearproducts.com*)

October 16–23—K 2019 Düsseldorf Exhibition Center, Düsseldorf, Germany. Over 3,000 exhibitors from 60 nations will be on-hand at this trade fair for plastics and rubber. Four topics have been chosen for K 2019 by the academics and experts from the K 2019 Innovation Group: Plastics for Sustainable Development & Circular Economy, Digitization and the Plastics Industry 4.0, System Integration: Functionality through Material, Process and Design, and Young Talents in the Industry. K 2019 is the performance barometer for the entire industry and its global marketplace for innovations. For eight days, the "Who's Who" of the entire plastics and rubber world will meet here to demonstrate the industry's capabilities, discuss current trends and set the course for the future. For more information, visit *www.k-online.com*.

October 22–24—SouthTec 2019 TD Convention Center, Greenville, S.C. South-Tec draws manufacturing suppliers, distributors and equipment builders from across North America and around the world—bringing them together in Greenville, South Carolina. With hundreds of exhibiting companies, attendees can find all the latest technologies and services—plus the experts who build them—ready to demonstrate solutions that can help them grow their business. Visitors can make side-by-side comparisons, discover integrated equipment, hear about industry trends and forecasts, and leverage their purchasing power. For more information, visit *www.southteconline.com*.

October 30–31 —Advanced Engineering 2019 Birmingham, United Kingdom. Advanced Engineering continues to build even further upon its position as the UK's largest annual gathering of OEMs and engineering supply chain professionals. Advanced Engineering provides a platform for knowledge transfer and business discussions across: R & D, design, test, measurement & inspection, raw materials & processing, manufacturing, production and automation. The 2019 edition features co-located shows such as Aero Engineering, Composites Engineering, Automotive Engineering, Performance Metals, Connected Manufacturing and Medical Device Engineering. Lab Innovations is the UK's only show dedicated to the entire laboratory industry. 150+ exhibitors will showcase laboratory equipment, laboratory technology, analytical equipment, life science supplies and much more to thousands of laboratory managers, laboratory technicians and procurement managers. For more information, visit *https://www.easyfairs.com/advanced-engineering-2019/advanced-engineering-2019/*.

November 6–8—AGMA Gear Failure Analysis (Fall) St. Louis, Missouri. Explore gear failure analysis in this hands-on seminar where students not only see slides of failed gears but can hold and examine those same field samples close up. Experience the use of a microscope and take your own contact pattern from field samples. Gear engineers, users, researchers, maintenance technicians, lubricant experts, and managers should consider attending. Instructors include Rod Budny (RBB Engineering) and Andy Milburn (Milburn Engineering, Inc.). For more information, visit *www.agma.org*.

November 19–21—Power-Gen International 2019 New Orleans, Louisiana. Power-Gen International provides comprehensive coverage of the trends, technologies and issues facing the generation sector. Displaying a wide variety of products and services, Power-Gen International represents a horizontal look at the industry with key emphasis on new solutions and innovations for the future. Topics include plant performance, cyber security, energy storage, flexible generation and more. Learn more at *www.power-gen.com*.

November 19–22—Formnext 2019 Frankfurt, Germany. Formnext is more than an exhibition and conference. It's an entire platform for companies from the world of additive manufacturing. Here, a veritable who's-who from the realms of design and product development, industrial tooling, production solutions, quality management, and measurement technology comes together with leading providers in basic materials and component construction. It will also explore clever ways in which AM can be integrated into process chains in industrial production. In addition, top international speakers and other experts will be on hand to engage conference attendees in in-depth discussions at the highest technical level. For more information, visit *https://formnext.mesago.com/events/en.html*.

December 3–5—AGMA Epicyclic Gear Systems: Application, Design and Analysis Seattle, Washington. Learn and define the concept of epicyclic gearing including some basic history and the differences among simple planetary gear systems, compound planetary gear systems and star drive gear systems. Cover concepts on the arrangement of the individual components including the carrier, sun, planet, ring and star gears and the rigid requirements for the system to perform properly. Critical factors such as load sharing among the planet or star gears, sequential loading, equal planet/star spacing, relations among the numbers of teeth on each element, calculation of the maximum and optimum number of planet/star gears for a specific system will be covered. This session provides an in-depth discussion of the methodology by which noise and vibration may be optimized for such systems and load sharing guidelines for planet load sharing. The instructor is Raymond Drago and Steve Cymbala. For more information, visit *www.agma.org*.

December 9–12—CTI Symposium Germany 2019 Berlin, Germany. CTI Symposium Germany provides the latest automotive transmission and drive engineering for passenger cars and commercial vehicles. The international industry event delivers the appropriate platform to find new partners for purchase and sales of whole systems and components. Automobile manufacturers, transmission and component companies give an overview and outlook on technical and market trends including digital manufacturing, IoT, zero-emissions, electric vehicles, hybrid transmissions and more. Speakers include representatives from Porsche, Volkswagen, StreetScooter, Continental, BorgWarner, Magna Powertrain and more. For more information, visit *https://drivetrain-symposium.world/*.

January 6–10 —SciTech 2020 Orlando, Florida. From its creation in 1963, the American Institute of Aeronautics and Astronautics (AIAA) has organized conferences to serve the aerospace profession as part of its core mission. Spanning over 70 technical discipline areas, AIAA's conferences provide scientists, engineers, and technologists the opportunity to present and disseminate their work in structured technical paper and poster sessions, learn about new technologies and advances from other presenters, further their professional development, and expand their professional networks that furthers their work. Five focus areas include science and technology, aviation, space, propulsion and energy/defense. For more information, visit *https://scitech.aiaa.org/*.

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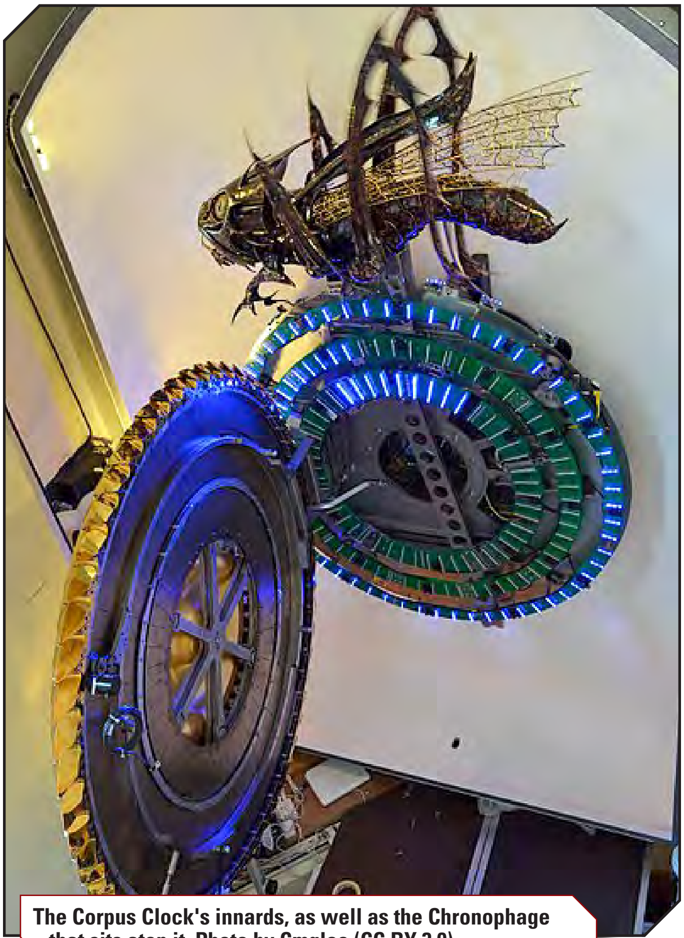
The Million Dollar Clock

The Corpus Clock has a hundred and one little interesting factoids about everything from its design to its unveiling to its message — and it's just hanging out on a street corner in Cambridge.

Alex Cannella, Associate Editor

If somebody's going to throw a million dollars and five years towards constructing a single clock, you'd figure a project of that scale might come with its own building just to house it. But bucking expectations, the Corpus Clock fits comfortably in a display case on a street corner. You could walk right past it on Corpus Christi College's campus and barely even blink, much less guess the clock's cost.

That's hardly the only way the Corpus Clock bucks convention. A grasshopper escapement clock with a literal grasshopper statue from hell carved on top, it tells time without the use of hands. Instead, the clock's gold-plated face has a number of blue LED backlights and dozens of little doors in it. As each second, minute or hour ticks by, the corresponding doors flip open to allow the backlight to shine through. Instead of watching the second hand tick by, you can watch these blue lights orbit around the clock's surface. One quirk, however, is that it doesn't tell time precisely. It's only accurate once every five minutes.



The Corpus Clock's innards, as well as the Chronophage that sits atop it. Photo by Cmglee (CC BY 3.0)

And perhaps wildest of all, this entire contraption works through almost purely mechanical means. It would have been incredibly easy to do things the other way around — to just slap those little LED lights all over the clock's surface like a carnival game and have them light up one at a time. But instead, the Corpus Clock goes the extra mile, creating the same effect with its more complicated system of opening doors and lights. And it would have been almost as easy to just have those doors run on electrical means, but only the light itself is powered by a single motor. Everything else is pure mechanical work.

And all of it is built up around one of the world's largest grasshopper escapements, which is on full display. In yet another of one of the Corpus Clock's many quirks, its guts are openly exposed — everything from the escapement to the escape wheel it interacts with are right on the face of the clock for any curious onlooker to study.

The glamour doesn't stop with the clock's lavish design, however. There was also a consequential amount of pageantry surrounding it. Professor Stephen Hawking was a guest of honor at the clock's unveiling. It's been dubbed "The Strangest Clock in the World." TIME had an even more glowing name for it: the 48th best invention of 2008.

Though perhaps not the most rigorous timekeeper, the Corpus Clock is a work of art, both in mechanical ingenuity and in aesthetic form. And like a lot of art, it has an intended message. Its designer, John Taylor, had a lot of different things to say about his creation, but he often focused on that grasshopper on top.

The Chronophage, it's called. Time Eater. Striding forward against the turning of the escape wheel, each step marking a second, and opening and closing its jaw repeatedly, devouring time itself as the seconds and minutes tick past. And beneath it, a line from the Bible: "the world passeth away, and the lust thereof." Taylor said that he intended the clock to be "terrifying," to fit the image of time as a voracious, unfriendly creature.

And such a thing is just hanging out on a street corner. A work of art, ambitious in both its engineering and its intended artistic meaning, with a hundred interesting little facts about it, just chilling on the street. To the casual observer just looking at it, most of Corpus Clock's groundbreaking facets are almost invisible despite literally being worn on the outside of its frame, but once you do a little research, it makes sense how this could be a million dollar clock.