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EXPERT COLUMN

Friction in tooth flanks and its impact on various operating conditions in cylindrical gears - an Overview Part -3

PROCESS

How DLC Thin-Film Coatings Are Transforming High-Performance Gear Applications

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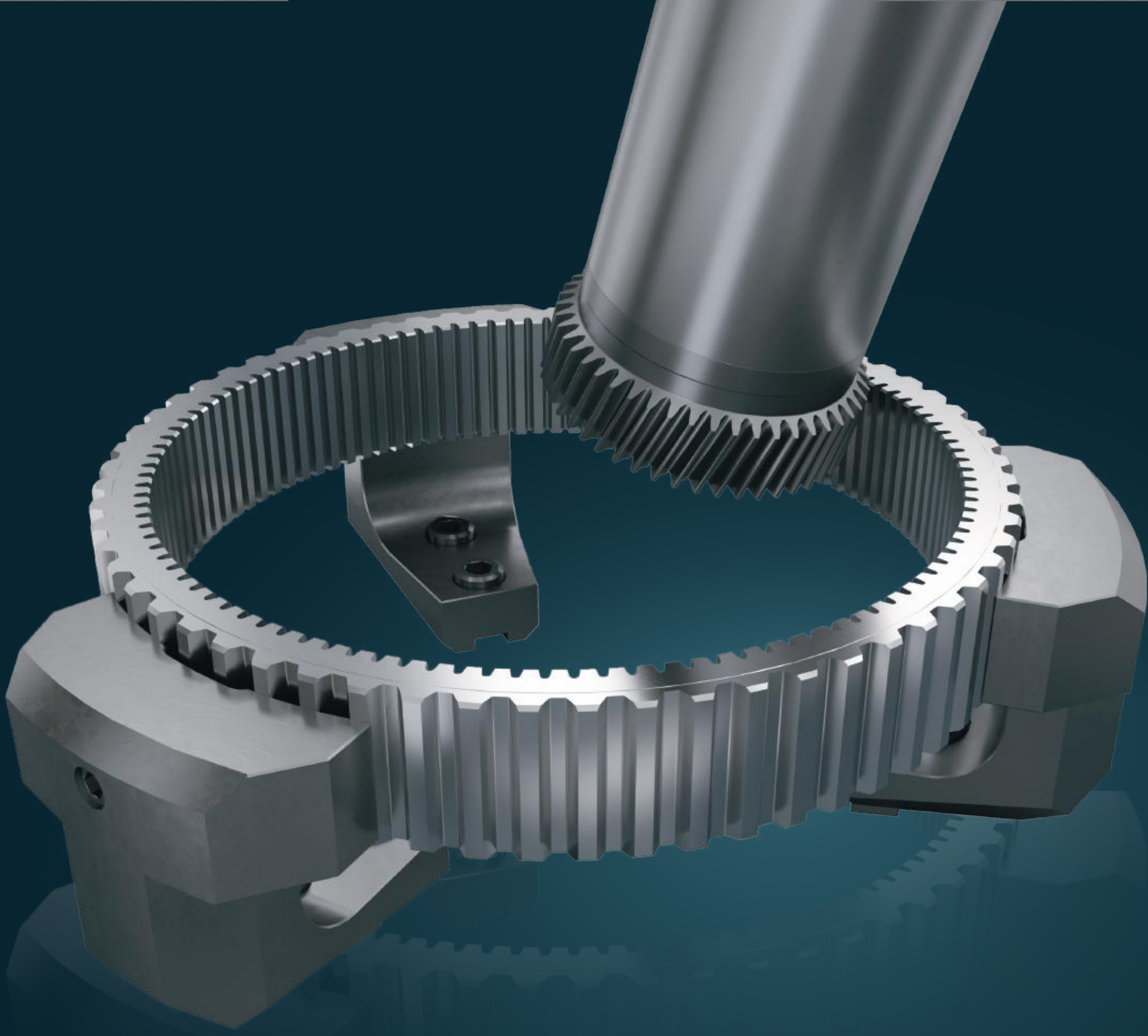

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Anitha Raghunath
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Dear Readers,

Welcome to Volume 3, Issue 4 of Gear Technology India.

This edition comes at a time when the gear industry is experiencing a profound transformation. From breakthroughs in surface engineering and predictive diagnostics to the rapid adoption of smart automation and cybersecurity protocols, the gears that once quietly powered machines are now at the forefront of global industrial change.

The theme of this issue—**Gear Industry Outlook**—is both timely and essential. As technology redefines how we design, produce, and maintain gear systems, the industry must look beyond traditional boundaries. This issue dives deep into the forces shaping the future: the rise of electric vehicles, the integration of DLC coatings, the evolution of lubrication strategies for BLDC motors, and the strategic implications of global acquisitions and innovation-led consolidation.

What makes this issue particularly exciting is the breadth of insight it offers. Whether you're a manufacturer, OEM, supplier, researcher, or policymaker, you'll find thought-provoking perspectives, technical depth, and practical direction. The articles don't just highlight where the gear industry stands but also map out where it needs to go.

We hope this edition sparks new ideas, informs strategic thinking, and supports your efforts to innovate and lead in an increasingly complex and connected world. Thank you for continuing to be part of the Gear Technology India community.

Together, let's keep driving the future of motion!

Warm regards,

gear TECHNOLOGY INDIA

Gear Technology India is a quarterly publication created in collaboration between the American Gear Manufacturers Association (AGMA) and Virgo Communications & Exhibitions. It serves as the premier platform in the industry, offering latest innovations, information, interviews and technical articles related to gears.

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Michael Goldstein founded Gear Technology in 1984 and served as Publisher and Editor-in-Chief from 1984 through 2019.
Thanks to his efforts, the Michael Goldstein Gear Technology Library, the largest collection of gear knowledge available anywhere will remain a free and open resources for the gear industry.
More than 38 years' worth of technical articles can be found online at geartechnology.com. Michael continues working with the magazine in a consulting role and can be reached via e-mail at michael@geartechnology.com.

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Shifting Gears: Mapping the Future of the Gear Industry

By Sushmita Das

As the gear industry enters a new phase of technological evolution, the future is no longer a distant concept, it's taking shape in real time. The gears of change are in motion, driven by trends such as; electrification, digitalisation, sustainability, and the evolving demands of end-user industries. Volume 3, Issue 4 of Gear Technology India explores this transformation through the lens of innovative research, process innovations, automation breakthroughs, and strategic insights, offering a detailed snapshot of where the gear industry is headed and how Indian manufacturers must prepare.

From frictional analysis at the micro level to cybersecurity at the macro scale, the technical articles in this issue converge on one idea: the gear industry is no longer operating in isolation, it is at the intersection of multiple fast-evolving domains.

Understanding the Fundamentals: Friction in Focus

In our Expert Column, we continue with Part 3 of an in-depth exploration into frictional forces at the tooth flanks of cylindrical gears. As gear systems are pushed to deliver greater performance under diverse load and lubrication conditions, understanding how friction behaves across the contact surface is no longer a theoretical pursuit, it is a design imperative.

This write-up draws attention to the way friction interacts with material properties, surface roughness, speed, and temperature, and how it can be managed to reduce power losses, improve wear resistance, and enhance overall efficiency. It lays the groundwork for practical applications, particularly in high-performance and precision-critical environments.

Surface Engineering Takes the Lead: DLC Coatings in Action

Another powerful transformation is taking place in surface engineering. In our Process feature, we dive into the revolutionary use of Diamond-Like Carbon (DLC) thin-film coatings for gears that must operate under extreme stress, temperature, and wear conditions. These ultra-hard, low-friction coatings are already proving their mettle in aerospace, motorsports, and next-gen automotive transmissions.

By reducing wear and friction, DLC coatings extend the service life of components and reduce the need for frequent lubrication, aligning well with sustainability goals. The article explores the various deposition techniques, performance benchmarks, and future possibilities of DLC in gear manufacturing—a vital development for gear makers seeking a competitive edge in premium applications.

A Lubrication Paradigm Shift: The BLDC Motor Challenge

As electric motors, especially BLDC (Brushless DC) motors—replace traditional powertrains across EVs, robotics, HVAC, and other industries, they bring with them new lubrication challenges. Our Lubrication feature takes a fresh look at how gear lubrication must evolve in this context.

Unlike internal combustion engine-driven systems, BLDC motors operate at higher RPMs and often in sealed or semi-sealed environments. This demands lubricants that resist oxidation, minimise drag, and operate effectively in compact, thermally dynamic settings. The article discusses innovative lubricant chemistries and application methods that gear designers must consider, especially when targeting the growing EV market.

Digital Risk in a Mechanical World: Cybersecurity for Gear Makers

While the gear industry has traditionally been rooted in mechanical precision, the integration of digital controls, IoT sensors, and cloud-based production monitoring systems has made cybersecurity a critical concern. In our Tech Innovation section, we examine how gear manufacturers, especially in India, can no longer treat digital security as an afterthought.

From protecting intellectual property (IP) and machine codes to ensuring uptime across interconnected networks, the article outlines practical steps for building cyber-resilient factories. As Indian gear producers grow into global supply chain partners, they will increasingly be judged on how well they safeguard data, automation assets, and customer privacy.

Automation and EVs: A Quiet Yet Powerful Revolution

The future of transportation in India is electric, and so is the future of its gearing systems. Our Automation article unfolds the evolution of high-tech gearing for electric vehicles, especially in the context of compactness, noise reduction, and torque optimisation.

Unlike traditional internal combustion engines, EVs generate near-instant torque and operate more quietly. This places new demands on gear systems: they must be lighter, stronger, and quieter. Automated manufacturing and inspection systems are making this possible by ensuring micron-level consistency, faster prototyping, and higher reliability. India's EV suppliers must now catch up to global expectations—or risk being left behind.

From Shop Floor to Show Floor: Sunnen's New Electric Hone

In Product News, we bring readers the latest innovation from Sunnen, which introduces its HTA all-electric tube hone. With increasing pressure to reduce energy consumption and improve repeatability, this solution offers enhanced control, flexibility, and efficiency, attributes that are especially valuable in precision gear applications.

Sunnen's technology highlights a broader trend toward electrification in manufacturing systems, not just in products. This signals a shift toward more intelligent, sustainable production solutions that fit into a smarter, greener industrial landscape.

Strategic Consolidation: Gleason Acquires Intra Group

In this issue's Tech News, we report on Gleason Corporation's acquisition of the Intra Group of Companies, a move that signals deeper integration between global leaders and specialised regional players. The acquisition strengthens Gleason's presence in India and enhances its ability to offer end-to-end gear production solutions. This deal is emblematic of the larger industry trend: multinational players are recognising India not just as a market, but as a manufacturing hub and innovation partner.

Learning from the Best: Semiconductor Lessons for Gear Makers

What can the gear industry learn from the semiconductor sector? In our Industry Outlook feature, we draw compelling parallels between these two seemingly dissimilar domains. Both rely on tight tolerances, massive capital investments, and globalised supply chains. The article urges Indian gear makers to adopt the semiconductor mindset: embrace automation, invest in R&D, and standardise quality benchmarks to scale globally.

A Ubiquitous Niche: The Gear Industry's Identity Crisis

Is the gear industry a niche market or a foundational one? This article feature tackles this philosophical, and strategic question head-on. Gears are everywhere: in vehicles, wind turbines, medical devices, robotics, aerospace systems, and factory automation. Yet the sector often struggles for recognition and investment.
The article argues for a rebranding of the industry's image, one that communicates its centrality in the modern industrial economy and attracts the next generation of engineers, designers, and entrepreneurs.

End-User Demands: The New Drivers of Gear Innovation

In another Industry Outlook piece, we explore how changing needs from the automotive, aerospace, defence, and renewable energy sectors are reshaping the future of gear manufacturing. Customers today demand lighter components, lower noise, higher power density, and faster delivery cycles.

This has led to major changes in material science, surface finishing, additive manufacturing, and mechatronic integration. Gear makers that align closely with end-user needs—not just at the procurement level but at the design and co-development stage, will be the ones to thrive in this new landscape.

Inspection Meets Intelligence: Introducing PRED-D

On the Inspection front, we present PRED-D: a novel approach to predictive diagnostics based on first-principles physics. Unlike traditional machine learning models that rely on historical data alone, PRED-D systems interpret real-time data through the lens of mechanical laws, offering deeper, context-aware insights into system health.

This approach marks a shift from reactive or even predictive maintenance toward diagnostic intelligence, where machines understand the "why" behind anomalies, not just the "when."

Innovation on Display: Products at EMO

Finally, our Press Release section summarises the groundbreaking technologies showcased at EMO, where global players presented tools and services aimed at transforming the gear industry. From hybrid machining centres to advanced cutting tools and AI-powered inspection solutions, the exhibition aspires to prove that modernisation is no longer optional, it's the basis for survival.

Conclusion: Gearing Up for the Future

The message across all these articles is clear: the Indian gear industry must shift gears. How? The answer is; strategically, technologically, and structurally. Whether it's through deeper research in tribology, smarter automation, global strategic partnerships, or reimagining lubrication and inspection, the time to act is now.

With the global manufacturing sector evolving at an unprecedented pace, gear makers are uniquely positioned to drive progress rather than simply adapt to it. This edition of Gear Technology India goes beyond insights, it serves as a roadmap to help navigate and shape the industry's future.

Welcome to the future of gears. It's smarter, faster, and more connected than ever before.

Sushmita Das is an accomplished technical writer. Holding a degree in Electrical Instrumentation and Control System Engineering, she brings a wealth of technical expertise to her writing.

Friction in tooth flanks and its impact on various operating conditions in cylindrical gears - an Overview Part -3

- Soundararajan KP

In Continuation of Part 2

The coefficient of friction fed into LLTCA is determined with the values selected using the Evans-Johnson method:

$$\mu = 0.87\overline{\alpha}\tau_0 + 1.74\frac{\tau_0}{\overline{p}}\ln\left[\frac{1.2}{\tau_0 h_c}\left(\frac{2k_l\eta_0}{1+9.6\zeta}\right)^{1/2}\right]$$

Eq 13

Friction parameter ζ is:

$$\zeta = \frac{4k_l}{\pi h_c/R'}\left(\frac{2\overline{p}}{E'k_s R'\rho' c'\overline{U}}\right)^{\frac{1}{2}}.$$

Eq 14

kl is the lubricant's thermal conductivity,
ks contacting tooth flanks thermal conductivity,
α is the piezo viscosity coefficient at ambient temperature
p is the mean contact pressure
he is the contact film thickness,
t0 is the limiting characteristic shear stress,
ρ is the density of the lubricant
c' is the specific heat derived from that of the lubricant film in contact with the solid contact of the tooth flank on the driver side and the tooth flank material itself, with its specific heat.

5. Friction Effect and Evaluation

When the loaded gear tooth flanks undergo higher pitch line velocities:

This method is used to ascertain the behaviour of the tooth flank surface under lubricant pressure and is often applied to estimate the heat transfer parameters. This phenomenon is taken into consideration in changes in tooth flank geometry due to thermal effects, especially on load in finish grinding.
Friction in the gear exists over the engaging tooth surface as relative sliding exists thereon, except at pitch points.

The following equation can describe the work of friction as an integral of the distribution of the friction factor.

qF = µ .parva
µ is the friction factor
Par is contact pressure
Va is the sliding velocity
qf is the particular amount of heat generated

As the oil film formed between tooth surfaces is supposed to carry away the heat generated by sliding velocity, it follows as yet this value may not be bigger at times, based on the operating conditions, mostly the rotational speed. This results in the heat getting conducted to the tooth flanks.

Besides, the lubricant mineral oil flows into the control volume at the end of the teeth, along the face width and causes losses due to windage.

The heat transfer coefficient between the lubricant medium and tooth flanks depends on the type of flow and relevant non-dimensional numbers - Reynolds, Prandtl, and Nusselt- based on the threshold value for flow.

The heat energy absorbed into the pinion and wheel need not be the same, and based on the dimensions, pitch line velocity, and diameter/length for conducting the temperatures gained by them would be unequal. It takes time for the momentary heat flux at the Hertzian contact width along the contact line of action.

The friction loss between a pair of engaging tooth L0 can be expressed as:

$$L_0 = \frac{\mu F_n}{\cos\alpha}\left(\frac{1}{r_1}+\frac{1}{r_2}\right)\frac{l_1^2+l_2^2}{2}$$

Eq 15

l1= length of line of action of pinion
l2 = length of the line of action of gearwheel

According to Japanese researchers, the friction loss estimate follows:

$$L_M = 8.34 \times 10^{-9} \frac{\mu F_n Z n}{\cos \alpha} \left(\frac{1}{r_1} + \frac{1}{r_2} \right) (l_1^2 + l_2^2)$$

Eq 16

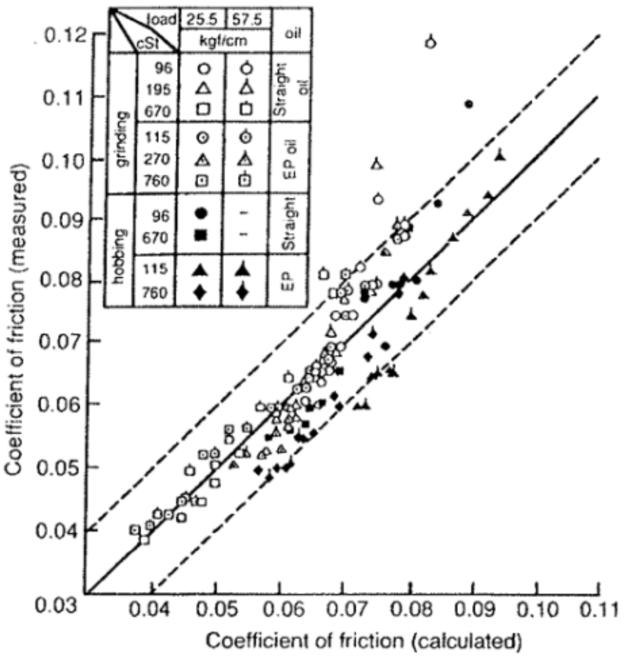

Fig 4

From equation 16, one can find that the precision on estimation of the mesh friction loss is important and the friction coefficient for the necessary pressure value.

The research on high-speed gears where V is greater than 120m/sec reveals that a relationship exists between the friction coefficient and a factor D under rolling and sliding conditions.

The friction 'D' value is the total maximum tooth surface roughness/ minimum oil film thickness.

The measured and calculated value of friction reveals that the force values are within a maximum error of 10%.

This follows that when D is less than 1, the friction coefficient is 0.01.

When D is between 1 and 10, the friction coefficient is

$$\mu = 0.01(5 \log D + 1)$$

Eq 17

When D is greater than 10

$$\mu = 0.01(2.5 \log D + 3.5)$$

Eq 18

This estimate has been reported to give reliable values of the lubricated and loaded tooth flank behaviour under load and higher operating speeds

6. The method of approach for gears operating at larger rotational speeds and correspondingly higher power in evaluating the friction bears significance on account of the loss of mesh friction. The outlook of reduction or industrial drives there is a simplified method.

The measurement of friction losses in such drives consider the summation of tangential velocities of pinion and gear, sliding component of velocity, dynamic viscosity, of the lubricant which operates in EHL/mixed lubrication regime and finally reduced radius of curvature of contact flanks the sliding velocity is equal to the difference between tangential velocities of pinion and gear tooth flanks points at right angle to the line of action.

So the coefficient of local friction = 0.12

al friction

$$= 0,12 \left[\frac{W_{bn} \cdot Ra}{\varphi_{red} V_{\Sigma} \eta} \right]^{0,25}$$

Eq 19

The normal load in unit length of contact Wbn, tooth flank surface roughness Ra are among the deciding factors of load transmission, with friction acting on the flanks under a lubricant film frictions. The roughness factor is the mean value of the mean flank roughness values.

7. Under the analogy of hydrostatic friction, the following can be stated for relevance:

Although the total heat being the result of frictional loss along the contact line, it is calculated from sliding and rolling power loss components.

The value of the latter is smaller than that of the former in most gear applications; therefore, the total power loss can be computed considering only the sliding term.

Total power loss =

$$Q=\int_{A}^{E} P_{VZP,s}(x)\mathrm{d}x = \int_{A}^{E} W(x)\cdot\mu(x)\cdot V_s(x)\,\mathrm{d}x$$

Eq 20

W(x) is the load distribution along the path of contact

μ(x) is the local friction coefficient.

The instantaneous sliding speed is calculated from the rolling velocities of the pinion and gear at each mesh point on the line of action.

$$V_s(x) = \left|u_1(x) - u_2(x)\right|$$

Eq 21

$$u_1(x) = \omega_1 \cdot x$$

Eq 22

$$u_2(x) = -\omega_2 \cdot (\overline{T_1 T_2} - x)$$

Eq 23

Due to the presence of sliding along the line of action, there is a difference in heat flux entering the gear tooth body. The heat partition is shown as:

$$\phi_i(x) = \frac{\rho_i \cdot cp_i \cdot \sqrt{k_i \cdot u_i(x)}}{\rho_1 \cdot cp_1 \cdot \sqrt{k_1 \cdot u_1(x)} + \rho_2 \cdot cp_2 \cdot \sqrt{k_2 \cdot u_2(x)}} = \frac{\sqrt{u_i(x)}}{\sqrt{u_1(x)} + \sqrt{u_2(x)}}$$

Eq 24

It is assumed that a partial EHL friction coefficient model for gears, where fluid friction μf is determined from the Eyring non-Newtonian equation. The reference stress is often calculated from the piezo viscosity coefficient, which avoids the characteristics of traction behaviour. The boundary friction coefficient μs is kept constant at about 0.7 for ground gears where the surface feed aligns with the axial direction.

The relationship is:

$$\mu(x) = \xi(x)\cdot\mu_s + (1 - \xi($$

Eq 25

$$\mu_f(x) = \frac{2\cdot\Lambda}{\alpha(x)\cdot p(x)}\sinh^{-1}\left(\frac{\eta(x)\cdot\alpha(x)\cdot Vs(x)}{2\cdot\Lambda\cdot\Phi_T(x)\cdot hc(x)}\right)$$

Eq 26

$$\xi(x) = 1 - \mathrm{erf}\left(\Phi_T(x)\cdot h_c(x)\cdot\sigma^{-1}\right)$$

Eq 27

ζ(x) is the complementary side of the error function of rolling rolling-oriented loss of power mesh.

This contains the heat transfer at point x, contact oil film thickness at point x. The heat loss factor through heat transfer is dependent on the entraining oil film speed at entry and is proportional to ζ(x).

The complementary term with hydrodynamic friction is responsible for the sliding loss of power in the mesh.

Λ is the limiting stress-pressure coefficient
δ is the RMS value of surface roughness of gear tooth flanks in mesh at an arbitrary point x.

Conclusion

In order to bring closer relationships between calculated and practically found values on the friction, it is important that the lubricant behaviour is taken into consideration. Assessment of various parameters of interest in design is required for evaluating reliability. The use of lubricated contact analysis is gaining importance. So the friction and the impact on assessment of losses, impact on running behaviour of gears and related operating conditions are the focus of research and interest. Failure prediction and understanding the mechanical forces rest on knowing friction performance well.

The paper addresses the area of a few friction factor assessment methods to suit the relevant applications.

The author is former Director and General Manager of Gleason Works India. He has four decades of experience in the gear industry, with special reference to machine tools and gear processes. He is also a Fellow of the Institution of Mechanical Engineers, UK, and a registered chartered engineer.

How DLC Thin-Film Coatings Are Transforming High-Performance Gear Applications

- Olivia Fey & Aaron Byrun

How DLC Thin-Film Coatings Are Transforming High-Performance Gear Applications

Diamond-like carbon (DLC) coatings are rapidly becoming essential to high-performance gear systems across EVs, aerospace, and industrial sectors. This article explores their tribological benefits, implementation strategies, and relevance to the Indian manufacturing ecosystem.

As gear systems evolve to meet higher power density and efficiency targets, especially under stricter environmental and maintenance constraints, thin-film coatings are no longer just an enhancement — they're an engineering necessity. Whether applied in electric vehicle (EV) drivetrains, aerospace actuation systems, industrial automation, or precision medical robotics, these coatings deliver precision-tuned surface properties that directly affect gear performance, reliability, and lifecycle cost.

What Are Thin-Film Coatings?

Thin-film coatings are nanostructured surface treatments, typically 1 to 5 microns thick, deposited using advanced technologies like Physical Vapor Deposition (PVD) or Plasma- Enhanced Chemical Vapor Deposition (PECVD). These coatings are designed to modify surface properties, such as hardness, friction coefficient, chemical inertness, or thermal conductivity. DLC coatings are typically applied using hybrid PVD–PECVD methods, which allow dense, adherent layers to form on metals, polymers, or ceramics — without significantly altering gear dimensions, clearances, or backlash.

In gear applications, thin films help suppress surface-originated failure modes like:

- Micropitting and rolling contact fatigue
- Scuffing or scoring in mixed/boundary lubrication regimes
- Fretting wear and galling in spline couplings or mating teeth
- Corrosion or chemical attack in offshore or hydrogen-rich systems [1][2]
- Why They Matter in Modern Gear Design
- Modern gearing requirements are pushing boundaries:
- Higher torque density with reduced gear size and weight
- Minimal lubrication in contamination-sensitive environments (e.g., cleanrooms, food-grade systems)
- Increased thermal loads in EV gearboxes and aerospace reduction stages
- Maintenance-free operation targets in industrial, defense, and wind-energy gearboxes

Thin-film coatings respond to these demands by:

- Extending service life via enhanced adhesive and abrasive wear resistance
- Reducing frictional losses, improving powertrain efficiency by up to 10–15% [5]
- Enabling dry- or near-dry lubrication regimes (via solid-lubricant or hybrid coatings)
- Mitigating white-etch cracking and fatigue initiation through tribochemical barriers [8]

DLC Coatings: The Flagship of Gear-Specific Thin Films

Among all coating technologies, Diamond-Like Carbon (DLC) stands out as the most versatile and high-performing for gear systems. DLCs are amorphous carbon films characterized by a mix of sp^2 (graphitic) and sp^3 (diamond-like) bonds. Depending on deposition parameters and dopants (e.g., hydrogen, Si, Cr, W), they can be tailored for either extreme hardness, ultra-low friction, or chemical passivity [1][2].

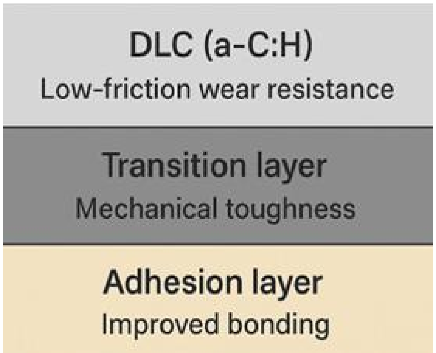

Figure 1: Schematic of DLC multilayer structure used in gear coatings.

DLC Coatings: The Flagship of Gear-Specific Thin Films

Property	Performance Benefit
Hardness (18–30 GPa)	Improves micropitting and scuffing resistance under high- contact loads
Friction Coefficient (<0.1)	Reduces sliding losses in hypoid and planetary stages, enhancing mechanical efficiency
Chemical Inertness	Resists lubricant breakdown, corrosion, and hydrogen embrittlement
Low Surface Energy	Suppresses debris adhesion and wear particle agglomeration
High Thermal Stability (300–500°C)	Suitable for high-speed gearboxes and hybrid-electric drivetrains

Figure 2: DLC-coated spur gear.

Studies show that DLC-coated gear pairs can achieve 2–3× improvement in scuffing resistance and 30% reduction in wear volume under starved lubrication conditions [6][7].

Applications in Gear Types and Industries

Electric Vehicle Transmissions (EVs)
High RPM (10,000+), compact packaging, and oil-starved zones near magnetic coils make EV gears ideal candidates for DLC. Coated pinions and bearings reduce losses, extend range, and improve thermal margins.

Ring & Pinion Gears
In automotive and truck differentials, DLC coatings on ground or lapped hypoid teeth eliminate the need for break-in, reduce lubricant degradation, and suppress NVH from transmission error. They also outperform traditional lapping for "lubed-for-life" systems [6].

Industrial Gearboxes
Industrial gearboxes operate under demanding conditions: shock loads, high contact pressures, misalignment, and long-duration duty cycles in oil, gas, mining, pulp & paper, and wind energy environments. These systems often face lubricant starvation, high operating temperatures, and cyclic loading — conditions that degrade traditional surface treatments and lead to early onset of micro-pitting or scuffing.

DLC coatings, especially those engineered with nanocomposite structures (e.g., adhesion + transition interlayers), serve as a robust tribological barrier that prevents metal-to-metal contact, even when lubrication is marginal. They also protect against hydrogen embrittlement and corrosive degradation caused by residual moisture or additives in industrial oils.

Worm Gearboxes
Worm gears are uniquely challenging due to their inherent sliding contact mechanics, which result in high frictional losses and localized heating at the tooth interface. Traditional gear materials — even when hardened — are prone to wear, galling, and efficiency loss over time. DLC coatings drastically reduce friction (coefficient of friction < 0.1) at the sliding interface, mitigating wear and improving overall mechanical efficiency. In fact, studies have shown that a 5–7% improvement in gearbox efficiency is achievable in DLC-coated bronze-steel worm pairs, with a corresponding reduction in oil temperature and extended lubricant life [5].

DLC is particularly useful in sealed, maintenance-free worm gear drives, such as those used in conveyor systems, packaging machinery, actuators, and defense platforms where re-lubrication is impractical or prohibited.

Precision Gear Sets (Medical, Aerospace)
Where lubrication must be minimal or biocompatible (e.g., prosthetics, flight actuation), DLC offers low stiction, zero particulate generation, and biocompatibility, making it suitable for both cleanroom and medical-grade gears.

Engineering and Implementation Considerations

Implementing thin-film coatings in gear production requires a close collaboration between coating engineers, gear designers, and production teams. Key considerations include:

- Substrate Compatibility & Hardness Gradient: The adhesion and performance of DLC depend on the substrate's surface energy, roughness, and microstructure. Gears made from low-alloy steels (e.g., 8620, 9310) often require a pre-treatment step such as Cr or CrN adhesion layers or surface activation via ion bombardment. For polymers, oxygen plasma or silane bonding primers may be needed.

- Post-Heat Treatment Processing: DLC-coated carburized or nitrided gears may retain residual compressive stress. Controlled finishing methods such as isotropic superfinishing are often recommended before coating to avoid asperity-driven stress concentrations that could cause delamination under load.

- Coating Thickness Control: Uniformity matters — especially on gear flanks, root fillets, and contact zones. Uneven deposition can lead to transmission error, dynamic noise, and imbalance in high-speed gear sets. PECVD methods are typically used for better step coverage on complex geometries.

- Tribological Validation: Gears with DLC coatings should undergo customized scuffing (FZG A10/16.6R), pitting (ISO 14635), or rolling/sliding wear testing. Also consider thermal cycling and oil compatibility testing, particularly for electric or hybrid vehicle gears operating at higher temperatures.

- Economic Justification: While initial coating costs vary depending on complexity, the ROI is often realized within the first maintenance interval through reduced lubricant consumption, downtime, and extended MTBF (mean time between failure).

Looking Ahead: Smart and Multifunctional Coatings

The future of gear coatings lies not just in making surfaces harder or slicker, but in making them smarter. Several developments are already reshaping how we think about gear surface engineering:

- Multilayer Nanocomposite Architectures: Next-gen coatings integrate graded hardness profiles using layers such as Cr/WC/DLC or CrN/Si-DLC stacks, optimizing both fatigue resistance and adhesion. These are especially useful in gears exposed to both sliding and impact loading (e.g., actuators, shift forks, hypoids) [2][3].

- Embedded Tribosensors: Researchers are exploring DLC-based sensing layers that change electrical resistance or capacitance under mechanical wear, enabling real-time health monitoring of gear surfaces — ideal for condition-based maintenance in defense, aerospace, or offshore energy systems [10].

- Self-Lubricating & Self-Healing Coatings: Coatings doped with solid lubricants (e.g., WS , MoS , or graphene-like additives) or tribo-chemical precursors can release protective third bodies under friction-induced stress. Some even incorporate nano-capsules that rupture to heal microcracks or replenish lubricant under overload conditions [2][8].
- • Hydrogen Barrier Films: With the growing interest in hydrogen fuel systems, coatings that block hydrogen ingress (e.g., fluorinated DLCs, barrier interlayers) are being evaluated for valves, gears, and pumps to mitigate embrittlement and fatigue cracking in hydrogen-rich environments [9].

Special Note for Indian Gear Manufacturers

DLC coatings are gaining traction among Indian manufacturers striving for longer maintenance intervals, higher efficiency, and reduced lubricant costs. Many Indian gear manufacturers in sectors such as wind, steel, and agricultural equipment are increasingly adopting DLC-coated components to extend gear life, reduce wear, and minimize unplanned maintenance, aligning with national goals for energy efficiency and reliability improvements. With increasing momentum from initiatives like Make in India and government-backed productivity enhancements, thin-film coatings present a strategic pathway to globally competitive gear production.

These advances have been discussed at recent industry events such as IPTEX/GRINDEX India, and the upcoming 2025 edition is expected to spotlight live demonstrations of smart coatings and tribosensors. Indian engineers exploring AGMA- and ISO-recognized standards will find DLC to be not only a performance upgrade but a sustainability enabler as well.

Frequently Asked Questions (FAQ)

Q: Can DLC be applied to nitrided or case-hardened gears?
A: Yes, provided surface preparation is optimized. Surface activation and stress-relieving finishes like isotropic superfinishing are recommended to promote adhesion and prevent premature delamination.

Q: Does DLC require special lubricants?
A: No, DLC is compatible with most conventional industrial and automotive lubricants. However, pairing it with ester-based or additive-enhanced oils can improve durability and friction performance.

Figure 2: DLC-coated spur gear.

Conclusion

Thin-film coatings, and DLC coatings in particular, are no longer optional enhancements for high-performance gears; they are strategic enablers of next-generation mechanical systems. From EV drivetrains to worm gearboxes and aerospace actuators, the benefits of lower friction, higher durability, and extended service life are well established. As gear designers and manufacturers face growing pressure to improve efficiency, reliability, and sustainability, thin-film surface engineering offers a proven path forward. With continued advancements in smart coating architectures and integrated condition monitoring, thin films will remain at the forefront of tribological innovation, transforming gears from passive power-transmitting elements into intelligent, high-efficiency components fit for the demands of tomorrow.

United Protective Technologies, LLC (UPT) is an industry leader in high-performance coatings. Founded in 2002, UPT has spent decades bringing solutions to the surface.

UPT's thin-film coatings support multiple industries ranging from defense to automotive and firearms. For more information, please visit UPT's website: www.upt-usa.com

References

1. C. Donnet and A. Erdemir, Tribology of Diamond-like Carbon Films: Fundamentals and Applications, New York: Springer, 2008.
2. S. Zhang and N. Ali, Nanocomposite Thin Films and Coatings: Processing, Properties and Performance, London: Imperial College Press, 2008.
3. United Protective Technologies, LLC, "United Protective Technologies," [Online]. Available: https://www.upt-usa.com/ [Accessed 21 August 2024].
4. ISO, ISO 14635-1: Gears — FZG test procedures — Part 1: FZG test method A/8.3/90 for relative scuffing load-carrying capacity of oils, Geneva: International Organization for Standardization, 2000.
5. T.T. Petry-Johnson et al., "Experimental Investigation of Spur Gear Efficiency," ASME IDETC/CIE Conference Proceedings, Las Vegas, NV, 2007.
6. L. Winkelmann, J. Holland and R. Nanning, "Superfinishing Motor Vehicle Ring and Pinion Gears," American Gear Manufacturers Association, Alexandria, VA: AGMA, 2004.
7. K. Holmberg, P. Andersson and A. Erdemir, "Global Energy Consumption Due to Friction in Passenger Cars," Tribology International, vol. 47, pp. 221–234, 2012.
8. M. Nosonovsky and B. Bhushan, "Green Tribology: Principles, Research Areas and Challenges," Philosophical Transactions of the Royal Society A, vol. 368, no. 1929, pp. 4677–4694, 2010.
9. ISO, ISO 6336-22: Calculation of load capacity of spur and helical gears – Part 22: Calculation of micropitting load capacity, Geneva: International Organization for Standardization, 2018.
10. G. Changenet and P. Velex, "A Model for the Prediction of Churning Losses in Geared Transmissions — Preliminary Results," Journal of Mechanical Design, vol. 125, no. 3, pp. 653–660, 2003.

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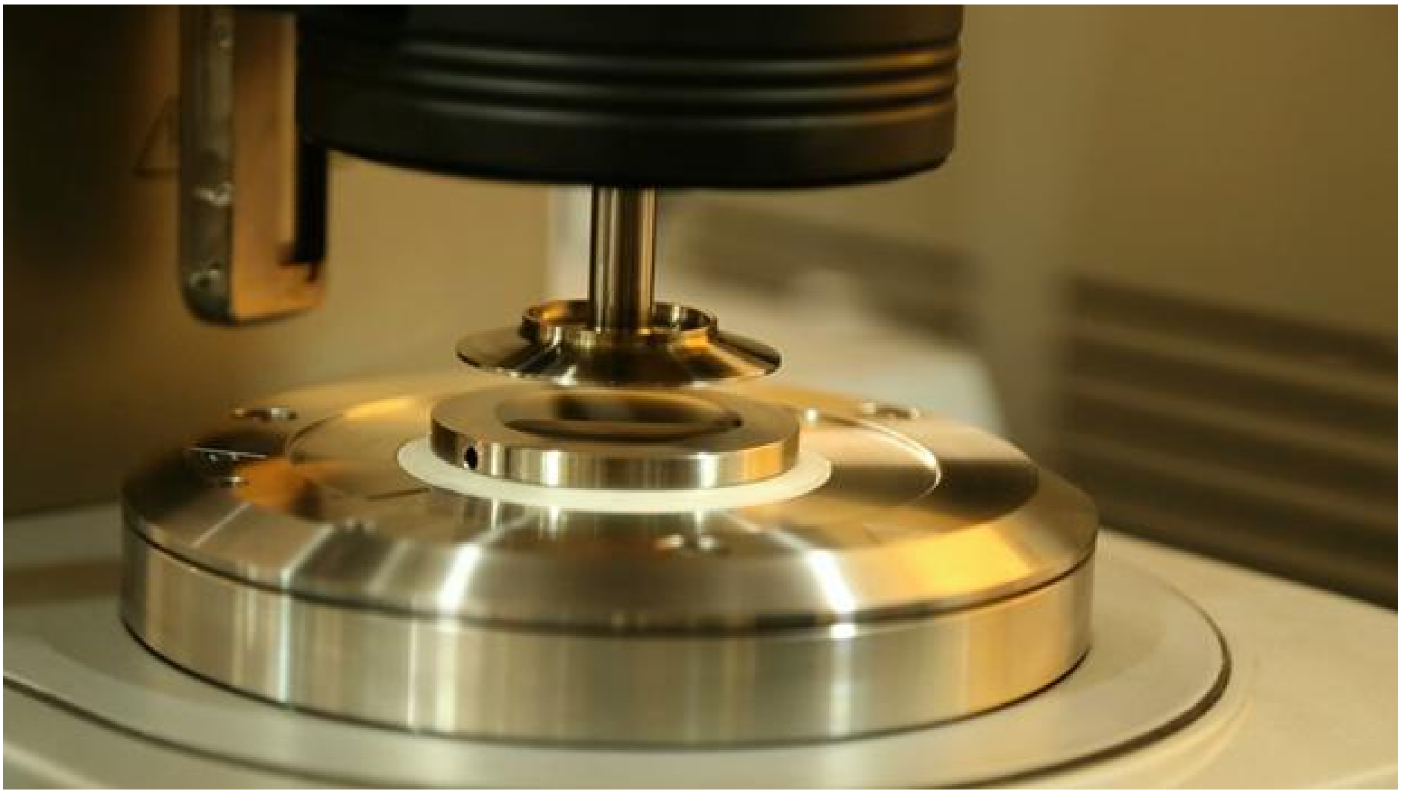
Rethinking Lubrication for Gears in BLDC Motors: Challenges, Innovations and the Way Forward

\- By Samar Mavani

Introduction & Market Landscape

Brushless DC (BLDC) motors have emerged as the powerhouse behind a new generation of energy-efficient, compact and high-performance applications. Their brushless design allows for precise speed control, quiet operation and low maintenance—attributes essential for modern consumer, industrial and mobility applications. According to some estimates, the global BLDC motor market is projected to surpass USD 21 billion by 2030, growing at over 8% CAGR. As these motors become integral to our daily lives—from electric vehicles and robotic arms to household appliances—the need for precise and long-lasting lubrication of their gear assemblies becomes crucial.

- Robotics and Industrial Automation: Precision gearboxes in robotic arms and actuators require greases that minimize stick-slip, support high torque and survive repeated start-stop cycles.
- Consumer Appliances: From washing machines to mixer-grinders, gear trains are expected to function for years without relubrication while maintaining silence and torque consistency.
- HVAC and Air Handling Units: High-speed fans and louvers driven by BLDC motors demand thermally stable and vibration-dampening lubricants.



Key Application Sectors

BLDC motors serve as the backbone for a wide array of critical gear-driven systems across industries:

- Electric Vehicles (EVs): E-scooters, power-assisted steering, HVAC blowers and drivetrain actuators - demand silent, thermally stable lubrication that lasts the vehicle's lifetime.
- Medical Devices: Compact gear motors in diagnostic and therapeutic equipment require chemically inert and noise-free greases.

Application Parameters

Lubricants used in BLDC motor gear applications are expected to perform under stringent operational parameters:

- Operating Temperature: -30°C to +120°C, with some EV-specific motors going up to 150°C.
- Speed: Gear systems driven by BLDC motors often exceed 10,000–20,000 RPM.
- Torque: Typically low to medium, but high peak loads occur during start-up or directional change.
- Environmental Exposure: Most applications involve enclosed systems, often co-existing with sensitive plastic or composite components.
- Noise, Vibration & Harshness (NVH): Particularly crucial in EV and appliance markets where quiet operation defines user experience.
- Lifecycle Expectations: "Lubricated-for-life" systems, often exceeding 20,000 operating hours without re-lubrication.

Current Lubrication Practices

Despite the sophisticated nature of BLDC motors, many OEMs still rely on standard bearing greases or general-purpose lithium soaps for gear lubrication. This mismatch between lubricant performance and application needs often results from legacy supplier agreements or insufficient tribological testing. These traditional greases may be optimized for rolling contact but lack the film-forming behavior or shear stability required for high-speed gear interactions. Furthermore, the incompatibility with plastics, poor thermal aging behavior or excessive oil bleeding continues to be overlooked in cost-sensitive segments.

Challenges with Current Practices

The inadequacies of conventional lubrication manifest in several ways:

- Centrifugal grease separation at high RPM leading to gearbox contamination.
- Polymer gear failures due to additive incompatibility.
- Stick-slip phenomena causing erratic gear movement.
- Thermal caking, especially in enclosed housings with poor ventilation.
- Accelerated wear due to lack of EP or AW additives tailored for gear tooth contacts.

User Expectations

Modern equipment designers and maintenance engineers expect high-performance greases that:

- Support low-torque startup, even in sub-zero temperatures.
- Are acoustically optimized to reduce NVH signature.
- Exhibit stable consistency and oxidation resistance over extended thermal cycles.
- Are inert to plastics like POM, PA, ABS and elastomers used in seals.
- Comply with environmental and regulatory norms (REACH, RoHS, Biodegradability).
- Offer 'fit-and-forget' lubrication across multi-year service lifespans.

Validation Approaches

The validation of greases in BLDC gear systems typically follows a staged approach:

- Short-Term: Bench tests for oil separation (ASTM D6184), drop point (ASTM D2265) and basic compatibility with substrates.
- Mid-Term: Gearbox run-in for 500–1000 hours, often under simulated loads and monitored via thermography and dB sensors.
- Long-Term: Chamber-based accelerated life testing under thermal cycles, vibration and torque variation; rheological profiling using cone-plate viscometers or FTIR.

Some OEMs also deploy custom jigs replicating exact motor-gear dynamics to benchmark candidate greases.

Quick Onsite Tests

Engineers and quality assurance teams can conduct fast-track checks including:

- Grease migration tests: Tilted panel evaluation or centrifuge method.
- Torque consistency observation: Motor current draw under cold and warm conditions.
- Acoustic signature: Recording and comparing dB levels during motor operation.
- Visual inspections: Signs of grease leakage or discoloration.

- Material softening test: Immersion of polymer components in grease at 100°C for 168 hrs.

Recommended Grease Chemistries

Several high-performance grease architectures have emerged as industry-preferred for BLDC gears:

- PAO + Polyurea: Offers excellent thermal resistance, noise suppression and polymer compatibility.
- Synthetic Ester + Polyurea: Eco-friendly option with superior cold start and biodegradability.
- PFPE: Highly inert, suitable for cleanroom or chemically sensitive devices.
- Silicone Greases: Work well with plastic gears but must be stabilized to prevent separation.
- PAO + Lithium Complex: Economical, good balance of shear stability and anti-wear protection.

Grease selection should consider not just the thickener and base oil, but also additive load tailored to gear contact mechanics.

Addressing Performance Gaps

These formulations specifically address known pain points:

- High RPM resistance: Prevents centrifugal oil throw and consistency degradation.
- Low noise: Damped acoustic response under varying torque.
- Thermal stability: Maintains viscosity and prevents dry-out under cyclic heating.
- Compatibility: Zero cracking or swelling in contact with PA or rubber materials.
- Regulatory alignment: Helps manufacturers meet ESG and compliance targets.

Red Flags in Grease Selection

Engineers and procurement teams must be cautious of:

- Greases with no validation for plastics or elastomers.
- Use of greases with high volatility oils leading to odor or vapor emissions.
- Thickener dropout or excessive softening after prolonged mechanical working.
- Grease lacking corrosion inhibitors or AW additives where condensation is expected.
- Grease sourced without consistent batch traceability or QA documentation.

Grease Selection Best Practices

To ensure effective lubricant performance, teams should:

- Specify NLGI grade and base oil viscosity in line with design torque.
- Verify compatibility with all housing and gear materials.
- Use lab and field testing data to validate consistency and wear resistance.
- Prioritize formulations with prior field success in similar motor profiles.
- Evaluate performance not just by specs but total lifecycle behavior.

The Road Ahead: Future of BLDC Motor Lubrication

As the integration of BLDC motors intensifies in both consumer and industrial ecosystems, the lubrication paradigm is shifting:

- Smart Greases: Under development with embedded condition indicators.
- Biodegradable Greases: Expected to dominate personal mobility and appliance segments.
- AI-driven Tribology: Simulation tools predicting grease life and reapplication schedules.
- Grease-Free Designs: Emerging in ultra-compact sealed motors, yet challenges persist for loaded gear trains.

Strategic lubrication will define how quietly, reliably and sustainably our BLDC-driven future operates.

Samar Mavani,

Director at Mosil Lubricants Private Limited

Strengthening the Future: Cybersecurity Necessities for Indian Gear Manufacturers

- By Nishant Kashyap

India's gear-making industry has been one of the stalwarts of its industrial growth for years, driving industries from automotive and aviation to renewable energy and railways. The industry has undergone a dramatic transformation over the last ten years, adopting high-tech CNC machines, CAD/CAM software, IoT-connected devices, and smart manufacturing concepts. This move is largely towards digital manufacturing, which has incredibly driven productivity, accuracy, and international competitiveness.

Yet, amid this tide of modernisation, there is a usually unsuspected battlefield: cybersecurity. As businesses spend a lot of attention on physical manufacturing, quality checks, and supply chain optimisations, too many overlook the digital exposures that hide behind networked systems and smart devices.

Cybersecurity is not merely an IT issue any more - it's a strategic necessity to preserve business continuity, defend intellectual property, and preserve customer confidence in a world where a single cyberattack can bring down an entire shop floor.

The Increasing Threat Environment: Why Gear Makers Are Targets

For gear makers, the increasing use of digital technologies introduces new efficiencies but also opportunities for advanced cyber threats. New gear-making environments are built on a network of interlinked machines, sensors, remote troubleshooting, and software-driven production planning. While this digital foundation gives operations greater agility, it also expands the attack surface for attackers.

Ransomware attacks are perhaps the most prevalent and destructive threat manufacturers encounter in the present day. Through the encryption of critical files, such as design databases and production plans, ransomware can halt operations in their entirety until outrageous ransoms are relinquished, often with no promise of total restoration. Also troubling are threats such as tool path file corruption.

Attackers who get control of CNC machine controllers can tamper with machining commands, resulting in faulty gears that may be passed through initial inspections but fail in the field and create safety risks and economic losses.

Data breaches add another threat. Trade-secret blueprints for proprietary equipment, secret process know-how, and customer data are all top priorities for industrial spying. A breach can sabotage years of R&D efforts, harm customer relationships, and erode competitiveness.

For export-oriented gear makers, their stakes are higher. Most Indian gear makers deal with international Tier-1 suppliers, aerospace integrators, or defence contractors - sectors where any compromise could become a matter of national security and result in heightened compliance auditing or contract cancellations. With a more protectionist world, being able to show strong cybersecurity is not only best practice, but necessary in order to maintain global collaborations.

Challenges Faced by Indian SMEs in Cybersecurity Adoption

Although major gear manufacturers might have begun incorporating cybersecurity frameworks into their processes, small and medium-sized enterprises (SMEs)—the majority of India's gear manufacturing market - lag behind. The issues are numerous and tend to be systemic in nature.

In the first place, most gear manufacturing SMEs lack even fundamental cybersecurity infrastructure. Antiquated firewalls, legacy software systems no longer supported, and unsegmented networks provide attackers with an easy route into critical operations. Daily routines are also a common contributor to these weaknesses.

For example, certain businesses skip normal software updates for fear of disrupting operations, unknowingly leaving the environment vulnerable to known vulnerabilities. Vendor data, such as machine maintenance records or remote diagnostics, is often sent without proper encryption or safe transfer mechanisms in most situations.

Password security is still one of the weakest areas. Shared logins among various shop floor machines, easy default passwords for CNC controllers, and the absence of two-factor authentication are common complaints. These factors open doors for attackers and only require a single weak entry point to cause havoc.

The shortage of resources is yet another significant impediment. In contrast to big conglomerates, SMEs usually do not have IT security teams. Most have general system administrators who handle routine IT upkeep with minimal exposure to developing cyber threats. When there is an attack, these firms hardly ever possess an incident response plan, resulting in a delayed recovery, prolonged downtime, and increased financial losses.

Adding to these issues is a mindset issue. For most traditional producers, cybersecurity is still not regarded as an IT expense, but an integral component of business strategy. Investments in new equipment or process automation are more commonly prioritised over effective network security and cyber awareness training, making digital foundations weak despite physical capability extension.

Building a Resilient Defence: Key Cybersecurity Measures

The truth is that no gear maker—large or small—is in a position to make cybersecurity optional. Creating a strong defence takes a multi-layered approach with strong technology, sound policies, and ongoing education.

Network Protection is the initial defence. Firewalls should be used to demilitarise office networks from production networks, segregating mission-critical CAM systems and CNC controllers. This restricts the propagation of any intrusion and denies attackers the ability to hop from system to system.

Data Security must be maintained throughout the entire manufacturing value chain. Secure file transfer protocols and cryptography must be the norm for sending design files between CAD workstations, simulation tools, and manufacturing devices. Secure backups need to be produced on a routine basis and offline stored, so recovery can be made in case of ransomware attacks.

Access control policies are just as vital. Manufacturers must enforce stringent user authentication for the use of common drives, vaults, and machine controllers. Role-based access provides assurance that only qualified staff may alter sensitive tool path instructions or change machine parameters.

Proactive Steps are crucial in getting ahead of changing threats. Periodic cybersecurity audits ensure that system vulnerabilities, outdated software, and insecure practices are identified and addressed before they can be targeted. Bi-annual staff training sessions are key to developing a security-centric mindset on the shop floor. Employees must be trained to identify phishing emails, suspicious file downloads, and the use of strong, unique passwords.

Lastly, there must be a strategic reorientation in the way cybersecurity is thought of. It has to be viewed not only as technical insurance but as an integral aspect of quality and compliance. In the same way manufacturers follow ISO standards for manufacturing quality, they ought to strive to fall in line with global cybersecurity standards like ISO/IEC 27001, which spells out standards for information security systems management.

Cybersecurity as a Competitive Advantage and Compliance Mandate

Robust cybersecurity routines do not simply safeguard operations—they also open doors and foster trust. For export market growth, gear manufacturers who comply with international cybersecurity standards are rapidly making this a non-negotiable expectation. Aerospace and defence original equipment manufacturers, for instance, commonly expect demonstrations of rigorous cyber cleanliness before the approval of suppliers, since cyber weakness in their supply chain may have extensive national security consequences.

Furthermore, companies that prove themselves committed to digital protection can ensure the protection of their brand reputation and have long-term relationships with customers. In the world of gears, which is high-precision, one bad batch traced back to cyber sabotage could lead to expensive recalls, warranty claims, or loss of business to competitors.

Investing in cybersecurity also entails future-proofing operations. As digital twins, remote monitoring, and predictive maintenance become more prevalent, the amount of valuable operational data will continue to increase. Securing this intellectual property guarantees that gear makers will remain at the forefront of innovation without the worry of having their designs or process know-how stolen and made available to the wrong individuals.

Most importantly, strong cybersecurity is more and more regarded as an ethical imperative. Since companies accumulate customer information, they are obligated to maintain its protection. Failure to provide such protection can result in legal liabilities, regulatory penalties, and irreparable loss of brand value.

Conclusion: Prioritising Digital Fortification for Sustainable Growth

The Indian gear-making industry is poised on the threshold of historic opportunity. With increasing emphasis on exports, Industry 4.0 adoption, and an increasing role in strategic areas such as renewable energy and electric vehicles, Indian gear manufacturers have every reason to reach high. But that aspiration needs to be grounded in resilience.

Cybersecurity is not an afterthought or a luxury—it is an unavoidable cornerstone of sustainable development. By reinforcing digital assets, manufacturers safeguard not only their own business operations but also create the trust essential for success in global supply chains. For SMEs especially, acknowledging cybersecurity as a strategic business investment, not a technical headache, is the beginning of a secure and competitive future.

As the manufacturing environment continues to change, those that incorporate strong cybersecurity practices into their business strategy will be well-prepared to evolve, innovate, and thrive in the years to come. The time is now. In the digital age, strengthening your shop floor is strengthening your future.

PRED-D: Predictive Diagnostics by Design, Not by Chance

- By Anureet Das

Reimagining Maintenance Intelligence Through Physics-Based AI Systems

In an age where industrial safety and reliability are paramount, predictive maintenance technologies are evolving beyond static thresholds and retrospective machine learning. A groundbreaking concept—PRED-D—proposes a future where machines not only detect faults but understand them from first principles.

Modern industrial systems, whether in manufacturing, maritime, or energy, are becoming increasingly complex and interconnected. Yet, the health of these systems is often monitored by maintenance protocols that are either reactive or narrowly trained to detect known patterns. This limitation can have catastrophic consequences when faced with rare or evolving faults.

Enter PRED-D, a novel approach to predictive maintenance that combines engineering theory with empirical intelligence to anticipate failures, not merely recognise them.

Understanding the Genesis

PRED-D began with a simple experiment: monitoring vibration data across different RPMs (48, 92, 148) on a lathe machine. At first glance, nothing seemed amiss. But deeper analysis revealed subtle shifts in the vibration patterns—signals too faint for conventional systems to detect. These shifts hinted at the possibility of training AI systems to detect anomalies based on deviation from baseline behaviour, long before any visible symptom emerges.

To enable this, the lathe was reverse-engineered into a multi-model system. Modal analysis identified its natural vibration frequencies, while material properties and structural dynamics were mapped to replicate the machine's response under stress. This formed the foundation of the PRED-D twin-engine diagnostic

framework.

The Dual Core of PRED-D

PRED-D's power lies in its twofold intelligence:

1. Empirical Core

A data-driven model built on historical fault logs, maintenance records, and operational parameters. This core statistically maps the probability of component failure under varying conditions and usage scenarios.

2. Physics-Based Core

A simulation engine based on mechanical modelling—spring-mass-damper systems, fatigue theory, and resonance behaviour. This core predicts how physical systems should behave when subjected to known forces and conditions.

Together, these cores form a living library of fault signatures, not only from observed incidents but also from theoretical mechanical behaviour. PRED-D doesn't need thousands of labelled fault datasets; instead, it learns from what should happen when deviations occur.
Simulating Anomalies for Early Detection

To test this approach, PRED-D was subjected to RSST (Random Shock Signal Testing) on the lathe system. The resulting vibration signals were analysed to build predictive spike models—templates for detecting subtle deviations in real-world systems.

Unlike traditional AI that relies on pre-labelled fault events, PRED-D constantly monitors baseline behaviour, identifying even minute divergences. With each new data point, it refines its knowledge base, improving its sensitivity to early-stage anomalies before they escalate into failures.

A Hypothetical Scenario: Revisiting the Bhopal Gas Tragedy

To illustrate PRED-D's real-world potential, consider a tragic historical case: the 1984 Bhopal gas disaster.

Imagine PRED-D deployed in that scenario:

- T-minus 3 hours: A slight vibration anomaly is detected at 90 Hz on a valve housing. The system logs it as an early-stage deviation.
- T-minus 2 hours: MIC gas begins to leak subtly. PRED-D correlates changes in local temperature and chemical signatures with the earlier vibration data, triggering a medium-priority alert.
- T-minus 90 minutes: Hazardous gas concentrations begin to rise. Multiple PRED-D nodes independently confirm secondary anomalies.
- T-minus 60 minutes: A high-confidence alert is issued. Evacuation and system shutdown protocols are triggered.

In this alternate reality, with PRED-D's proactive and integrated approach, the outcome could have been drastically different. Rather than 16,000 fatalities, timely detection and automated response may have enabled containment and control.

PRED-D: Mathematical Framework for Predictive Diagnostics

This document outlines the mathematical foundations that underpin the PRED-D system (Predictive Diagnostics by Design, Not by Chance). It is intended to complement the article for technical and academic audiences by formalising the theoretical and data-driven models used.

1. Vibration Signal Modelling

To extract frequency components from raw vibration data, we use the Fourier Transform:
$X(f) = \int x(t) \cdot e^{(-j2\pi ft)} dt$
Where:
$x(t)$: Vibration signal over time
$X(f)$: Frequency-domain representation

2. Anomaly Detection Using Statistical Deviation

$Z = (X - \mu) / \sigma$
Where:
X: Current signal value
μ: Mean of baseline signal
σ: Standard deviation

3. Failure Probability Modelling (Empirical Core)

$F(t) = 1 - e^{(-(t/\lambda)^k)}$
Where:
$F(t)$: Cumulative probability of failure at time t
λ: Characteristic life (scale parameter)
k: Shape parameter (failure mode)

4. Spike Deviation Detection (RSST)

$A(t) = |x(t) - x (t)|$
Where:
$x(t)$: Observed signal
$x (t)$: Predicted baseline signal

5. Mechanical Simulation Model (Physics-Based Core)

m·x (t) + c· (t) + k·x(t) = F(t)
Where:
m: Mass
c: Damping coefficient
k: Stiffness
F(t): Applied force

6. Bayesian Fault Inference (Optional)

P(Fi | D) = (P(D | Fi) · P(Fi)) / P(D)
Where:
Fi: Fault type
D: Observed data

Toward a Smarter, Safer Future

PRED-D is not just an upgrade to existing maintenance strategies; it is a paradigm shift. By fusing empirical data with physics-based modelling, it transforms diagnostic capabilities from reactive responses to proactive prevention. This hybrid intelligence enables early detection of unseen anomalies, reduces reliance on historical fault libraries, and empowers industries to act before failures occur. Whether it's safeguarding critical infrastructure or preventing large-scale disasters, PRED-D exemplifies how predictive diagnostics can evolve from statistical guessing to scientific certainty. As industries embrace the demands of smarter, more autonomous systems, the PRED-D framework stands as a blueprint for intelligent, anticipatory maintenance—designed not by chance, but by intent.

Anureet Das

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The Quiet Revolution: High-Tech Gearing Solutions for India's EV Industry

- By Sudhanshu Nayak

India's automotive sector stands at the threshold of a significant revolution, one that is quiet but intense. Electric vehicles (EVs) are no longer an elusive dream; they are increasingly becoming an integral component of India's sustainable mobility blueprint. Thanks to positive government policies, a widening charging infrastructure, and increasing acceptance among consumers, EVs are gradually making their presence felt in the country's domestic market. From two-wheelers darting through urban roads to electric buses transporting commuters between cities, the pace is unmistakable.

However, even as batteries, motors, and charging stations take centre stage, one vital element largely goes unheralded - the gears that facilitate this quiet revolution. While ICE cars employ intricate multi-speed transmissions to manage changing torque and speed demands, EVs generally utilise simpler single-speed reduction gear sets. But the simplicity conceals the complexity required in contemporary gear design and production. In an EV, gears have to accommodate high torque loads, provide optimal power transmission efficiency, and be low-noise to retain the soundless magic characterising electric mobility. In many ways, advanced gearing solutions are the quiet heroes powering India's EV ambitions.

Understanding the Role of Gears in Electric Vehicles

To grasp why sophisticated gearing is so crucial in EVs, consider how the drivetrain works differently from conventional ICE vehicles. Standard cars make do with engines that only put out useful torque within a particular RPM range. That requires a multi-speed transmission to balance engine output with different driving situations. The gear system continuously changes to have the engine in its sweet spot for efficiency and power.

Conversely, electric motors provide peak torque virtually instantly, from zero RPM. This trait enables most EVs, particularly passenger vehicles and two-wheelers, to be efficiently powered using a single-speed gearbox. In these cases, a reduction gear set is used to mate the high-revving electric motor with the wheels, reducing motor speed to wheel speed and increasing torque.

Although the design is less complicated, the requirements for the gear system are greater. The gears need to transmit high torque reliably and efficiently on a daily basis. They have to do that quietly as well; in ICE vehicles where engine sound drowns out gear whine, there is nothing to hide gear deficiency in an EV's transmission since passengers can immediately sense it. For this reason, gear accuracy and noise, vibration, and harshness (NVH) features become essential performance drivers.

New Requirements: What Sets EV Gearing Apart

The change to electric drivelines has profoundly reshaped the requirements for gear design and manufacture. Perhaps foremost among the most significant factors is the much greater torque of electric motors at low speeds. The gears in EVs have to take these intense loads without suffering undue wear, which requires stronger materials, optimised tooth geometry, and precision manufacture.

Another high priority is noise reduction. In ICE cars, the engine drowns out gear noise, yet EVs are virtually silent by design. Whine or vibration from the gearbox can spoil the peaceful cabin ambience, something that has led manufacturers to emphasise gear geometries that reduce meshing noise and vibration. Helical gears, for example, are extensively employed in EV transmissions due to their angled teeth, which engage more slowly, lowering impact forces and operating more quietly than straight-cut spur gears.

Weight is also another consideration. With range anxiety still prevalent among many EV purchasers, every kilogram of weight reduction matters. Lighter gear designs and the incorporation of stronger, less dense materials contribute to overall vehicle efficiency. Thermal management is also critical. Gears under high torque and speed conditions produce heat, and in an electric drivetrain where efficiency is the key, reducing thermal losses is critical to maximising component life and optimising performance.

All these demands imply that gearing solutions for EVs need to be designed with unparalleled accuracy. This has initiated a quiet but important revolution in the design, testing, and production of gears.

Innovations in Advanced Gearing Solutions

To meet the high requirements of EV drivetrains, gear makers have been compelled to implement cutting-edge technologies and processes. Increasing implementation of advanced manufacturing methods such as power skiving, grinding, and honing is among the most notable trends. Power skiving, for instance, is becoming popular due to its ability to machine complex internal gears efficiently with excellent surface finish and close tolerances, which are essential to NVH performance.

Materials development is another pillar. High fatigue strength, advanced alloys, and wear resistance improve the ability of gears to endure high torque transmission while maintaining weight. The most widely used are nitriding and shot peening surface treatments that increase durability and minimise friction loss.

Gear design is also changing. Helical and planetary gear systems are used extensively in EVs because they can better distribute loads, leading to less noisy and smoother operation. Planetary gear sets, especially, provide high torque density with a compact design, which makes them suitable for electric powertrains where space is a constraint.

Digitalisation has penetrated equally deep. Gear designers are now utilising sophisticated simulation software and digital twin technologies to simulate gear performance in actual operating conditions. The software predicts wear patterns, thermal expansion, and NVH properties, enabling engineers to refine designs well before any physical prototypes are manufactured. This not only shortens development cycles but also guarantees greater dependability in the field.

In combination, these technologies represent a profound divergence from traditional gear manufacturing. They are indicative of an industry which is assertively but quietly retooling itself to meet the distinctive needs of electric mobility.

The Indian Gear Industry's Response

India's gear-making industry has been known for its cost advantage and technical acumen in catering to traditional automobile markets. The shift to EVs, however, forced most players to rethink their capabilities and investments.

Major gear makers are enhancing their machining facilities to accommodate the tighter tolerances and surface finish needs imposed by EV use. Some have installed advanced gear grinding and honing equipment and sophisticated metrology systems for QA. Heat treatment facilities are being upgraded to produce consistent, distortion-free gears.

Cooperation is equally crucial. Gear manufacturers are collaborating with original equipment manufacturers and new EV startups to jointly develop solutions for various vehicle segments, ranging from electric three-wheelers and two-wheelers to passenger vehicles and commercial vehicles. This tight integration guarantees that gear designs fit specific motor features, torque needs, and packaging considerations.

For example, certain Indian suppliers have started shipping precision planetary gear systems for e-scooters and tiny electric vehicles, assisting local brands in competing with foreign players. Others are looking to exploit export opportunities with the potential to establish themselves as go-to partners for international EV programs. These steps indicate that India's gear-making industry is not just converting but also emerging as an innovation hub for EV transmission solutions.

Challenges Ahead

Though the development is encouraging, the future path is not without hurdles. Perhaps the largest hurdle is the skills gap. Producing precision gears for EVs requires higher technical competence, from simulation-savvy design engineers to shop-floor personnel with experience in high-precision CNC machines. Developing this talent pipeline will call for continued investments in training and skilling initiatives.

Upgrades in infrastructure are another challenge, particularly for SMEs that are the backbone of India's gear industry. Most SMEs have to modernise their workshops, embrace Industry 4.0 concepts, and incorporate strict quality control systems to be compatible with global EV markets. This involves extensive capital outlay, which proves intimidating in a very cost-sensitive market.

Cost is a balancing act. While value-adding advanced gearing solutions exist, so does the cost. Gear manufacturers need to innovate to achieve high performance without charging more than the competition so as not to be priced out of the market, particularly with OEMs remaining committed to affordable EVs for value-conscious Indian buyers.

Future Outlook: Gearing Up for India's EV Growth

Despite the obstacles, the future for advanced gearing solutions within India's EV market is irrefutably bright. With the government's ambitious goals to electrify a substantial percentage of the vehicle parts and increasing demand for environmentally friendly mobility, the market for efficient, quiet, and reliable transmissions will only continue to grow.

Industry players feel that India can become a global hub for precision EV gears, just as it has become for parts in the conventional auto industry. Support from strategic policies, technology collaborations, and an emphasis on quality can enable Indian manufacturing to access domestic as well as international markets.

Aside from automobiles and scooters, the next ten years potentially hold promise in electric commercial trucks, electric farm tractors, and even specialised uses such as electric flight and drone technology - all of which will need specialised gear sets.

Conclusion: Powering Silent, Sustainable Mobility

As India wheels its way towards a quieter, greener tomorrow, sophisticated gears are quietly but revolutionising everything. They are the invisible key enablers that not only make electric vehicles efficient and dependable but also actually silent, providing the smooth, soundless ride that consumers increasingly want from new mobility.

The silent revolution happening in the gear sector is a reflection of the industry's strength and resilience. By adopting state-of-the-art manufacturing technologies, pumping money into R&D, and forging intimate relationships with automobile manufacturers, India's gear manufacturers are at the vanguard of this change.

In India's big story of electric vehicles, the gear may never hog the spotlight the way batteries or motors do. But without them, the promise of clean, quiet, and green mobility would be unrealised. For gear manufacturers willing to transform and innovate, this revolution is not merely a chance - it is their moment to drive India's electric fantasy, one finely cut tooth at a time.

Sudhanshu Nayak, a dynamic mechanical engineer, is driven by a fervor for cutting-edge technologies like 3D printing, cloud manufacturing, & Industry 4.0. He has gained invaluable firsthand experience with 3D printing during his tenure at innovative startups. His youthful energy fuels a deep expertise in social media marketing, technical content creation, & market research.

Sunnen Highlights All-Electric HTA Tube Hone for Enhanced Precision and Efficiency

- By Gear Technology India

Transforming Industrial Processes with Innovative Technology and Enhanced Operational Capabilities for Improved Tube Honing Performance

ST. LOUIS, MO - Sunnen Products Company, a global leader in high-precision bore finishing and measurement, highlights its innovative entry-level HTA Tube Hone machine, setting a new standard in bore finishing for various industries. With over 375 sold to date, the HTA Tube Hone represents a significant advancement in honing technology, offering a range of features that deliver superior performance, efficiency, and precision, perfect for hydraulic cylinder repair.

Its all-electric design ensures quieter operation, eliminates oil leaks, and provides better control and greater accuracy during bore reversals. This lean design also boasts a smaller footprint compared to traditional horizontal tube honing systems, saving valuable floor space and capital.

At the heart of the HTA Tube Hone is an electromagnetic Siemens Servo Stroker Motor with Belt Drive, providing quiet and precise operation. The 3 HP (2.24 kW) spindle unit, combined with a servo stroker capable of speeds from 5-90 ft/min (1.5-27.4 m/min), delivers ample power for resurfacing and repairing applications at spindle speeds of 20 to 300 RPM.

The HTA Tube Hone features a programmable auto tool feed system, increasing efficiency and consistency in the honing process. A 55-gallon paper media coolant filtration unit with quick disconnects, casters, sight glass, and manual paper bed filter maintains clean coolant, improving honing performance and extending abrasive life.

Ergonomics and safety are prioritised in the HTA Tube Hone's design, reducing the risk of injury by eliminating manual work with repetitive motions.

Operators will appreciate the Siemens PLC with a colour touch screen, which controls all machine functions such as stroke reversal, speeds, and a cross-hatch calculation. The stroker joystick allows for precise positioning of the honing tool and stroke length adjustment during setup, while stroke control override enables short-stroking in any part of the bore for clean-up in tight spaces.

The HTA Tube Hone offers flexibility with its swivelling operator station. Multiple language options and metric/inch conversion are selectable from the touch screen, enhancing ease of use across global markets.

Additional features include a load meter for quickly identifying tight spots in the bore, a universal V-block work holding system for flexible and quick fixturing of various workpieces, and an integral work tray that combines with the enclosure and operator console for a clean and efficient workspace.

The HTA Tube Hone is compatible with ANR-275 tooling, allowing shops already using ANR-style tooling to utilise existing stone supports, master holders, and abrasives, thereby reducing tooling costs.

About Sunnen Products Company

Sunnen Products Company, a global leader in precision manufacturing for over a century, has established itself as a premier provider in the creation, sizing, and finishing of machined surfaces. Headquartered in St. Louis, Missouri, Sunnen is a "total solutions provider," manufacturing everything from machinery and abrasives to precision bore gages and customized coolants. This comprehensive approach enables Sunnen to deliver turnkey honing solutions that encompass cutting-edge equipment, tooling, consumables, and coolants. The company's expertise spans a diverse range of industries, including aerospace, automotive, energy, hydraulics, medical, firearms & defense, and tool & die, showcasing its versatility and commitment to innovation. Sunnen's dedication to quality is evident in its products, which exemplify the company's focus on high efficiency, precision, and advanced technology. With a worldwide presence and a track record of building thousands of honing machines, Sunnen continues to drive innovation in bore sizing and finishing, providing tailored solutions to meet the exacting demands of modern manufacturing across diverse sectors.

Gleason Corporation Acquires Intra Group of Companies

- By Gear Technology India

Recently, Gleason Corporation announced it has acquired 100% of the shares of the Intra Group of Companies with its headquarters in Westland, Michigan. Intra is a global industry leader offering a broad range of custom measurement technology, including single-flank gear testing equipment and is a supplier of high-precision gears and components to many of the world's leading aerospace and defence companies.

The acquisition includes the entities of Intra Corporation and Intra Technical Services, LLC in Westland, Michigan; Intra Limited in Hitchin, United Kingdom; Intra Aerospace LLC in Rancho Cucamonga, California as well as its affiliated sales and service companies.

John J. Perrotti, Gleason Chairman and Chief Executive Officer, stated, "Intra's established range of metrology solutions for propulsion systems, including for NVH analysis, complements Gleason's existing gear metrology products and will bring exciting opportunities for future joint developments and further market expansion. In addition, we see opportunities across many other aspects of our respective businesses, ranging from precision machining, workholding, automation and more."

Mr. Perrotti further stated, "This strategic addition to our portfolio fits nicely with our mission of Total Gear Solutions and the Design-Manufacture-Measure ecosystem fundamental to that mission, while at the same time expanding our presence in market segments which promise future growth."

John Battista Jr., Chief Executive Officer of the Intra Companies commented, "We have been a family business for 48 years and we see Gleason in terms of its similar culture and values along with its well-known global brand and range of technology to be the ideal successor to take the Intra Group to the next level of performance."

John Battista III, President of the Intra Companies, said "I am excited to join the Gleason leadership team and work collaboratively to realize the full potential of our combined companies for the benefit of our customers, employees and other partners. We will continue forward with the same operating organisation and are diligently working together to achieve a seamless integration. Any changes regarding company names, banking and other administrative details will be provided in separate communications to those respective partners."

What Can Gear Makers Learn from the Semiconductor Industry?

- By Vivek Singh

Part 1: Precision, Process Control, and Predictive Intelligence

Parallel Worlds of Precision

Few manufacturing industries run upon dimensional perfection as much as semiconductors, where deviations can have disastrous consequences and tolerances are measured in nanometres. It's interesting to note that, despite its historical mechanical and macro scale nature, the gear industry is currently pushing closer to comparable levels of precision, and that's because of the continuously changing needs in industries such as robotics, aerospace, electric vehicles, and high-speed microtransmissions.

With a heavy focus on process repeatability, thermal stability, and geometric control, both sectors operate near the limits of physical capabilities. However, many gear manufacturers continue to use traditional techniques that limit productivity and consistency, even though semiconductor factories have long enabled system-wide integration of data-driven processes, closed-loop control, and ultraclean environments.

The takeaway is straightforward: developing a precise culture at scale is more crucial in manufacturing semiconductors than merely producing chips. Gear makers can no longer afford to ignore the blueprint supplied by this high-tech industry, which covers everything from advanced metrology and environmental control to simulation-driven production and yield management.

Despite their obvious incompatibility, the concepts of semiconductor manufacturing have the potential to transform the gear sector.

From Nanometres to Microns - Learning Tolerance Discipline

In semiconductors, variations larger than a few nanometres could make entire plates worthless. Predictive correction systems, environment-controlled machining, and real-time metrology are all used in the manufacturing process in order to reinforce this culture of excessive tolerance.

On the other hand, similar pressure is currently being applied to gear manufacturing, particularly for high-precision applications such as planetary motors, surgical tools, and EVs. Pitch, run out, lead, and gear profile must now be controlled down to the micron level. Surface waviness, tooth-to-tooth variances, and non-uniform stock removal are all emerging as major failure concerns in high-speed or noise-sensitive systems.

Gear manufacturers have to look like semiconductors in order to close this gap.

- In-process metrology can detect deviations before they expand by using scanning heads, touch probes, or optical encoders.
- Machine-integrated feedback loops, such as heat sensors and tool wear monitoring, enable adaptive machining, which changes cutter paths, speeds, and depths dynamically to maintain dimensional accuracy.
- Corrective measures can be made in real time rather than after the fact due to tight closed-loop control between CAD/CAM, machine controls, and inspection systems.

Semiconductor fabs engineer out variance at every node rather than simply inspecting. The same approach must drive investment in sub-micron positioning, process-integrated inspection, and clever compensation procedures for gear makers seeking zero-defect output.

Dust, Debris, and Defects - A Common Enemy

The semiconductor industry has adopted ISO Class 1 cleanroom settings that include HEPA filtration, laminar airflow systems, and molecular-level contamination control since even a single micron-sized particle can cause circuit failure during semiconductor production. Even though the gear business does not operate at the nanometre scale, the notion of particle-induced failure is applicable, particularly in high-precision industries such as robotics, aircraft, defence, and electric car transmissions.

In end-use applications, residual chips, fine metal dust, and coolant-borne contaminants may harm surface finishes, accelerate tool wear, and introduce micro-defects that appear as noise, vibration, or early gear failure.

Creating digital copies of the entire gear-cutting technique allows manufacturers to include:

- Simulating heat zones and thermal gradients formed during dry or high-speed gear milling allows you to predict their impact on distortion.
- Estimate the rate of tool wear, especially in applications involving multi-axis dry cutting or microgearing, and adjust compensation settings or tool change intervals accordingly.
- Simulating stress distributions across gear teeth under dynamic loads can help improve cutting techniques and tooth geometry design.

When simulation is used correctly, defects are detected before production rather than after. Gear manufacturers must now use this technology, which the semiconductor industry has developed, to reduce iteration cycles and ensure first-pass yield in difficult geometries.

Simulate Before You Cut - Lesson from IC Fabrication

Digital twins, or virtual models of equipment, materials, and process variables, are critical tools in semiconductors that simulate models at every critical stage of the manufacturing process before a single wafer is touched. Engineers can use these models to properly forecast tool-induced strains, wafer warpage, thermal expansion, and inconsistent deposition. By anticipating failure situations, these models provide insights that help optimise tool paths, make real-time process modifications, and greatly minimise yield loss.

Adopting digital twin technology is no longer simply desirable but also required in the gear manufacturing industry, which has traditionally relied on physical trials and post-process repairs. The ability to model the entire gear-cutting process becomes a tactical advantage as tolerances grow and cycle durations drop.

Manufacturers can predict the temperature zones and gradients produced during high-speed or dry milling by digitally simulating the cutting process. This is critical for minimising gear distortion and residual stress. It is possible to calculate tool wear over time, particularly in multi-axis cutting and microgearing operations, allowing for proactive adjusting and tool change methods. In addition, gear designers can improve performance and durability by fine-tuning geometry and machining methods by simulating stress distributions across gear teeth under real-world loads.

When digital twins enter the gear production lifecycle, the paradigm moves from reactive correction to predictive control. It empowers manufacturers to reduce expensive iteration cycles, achieve first-pass yield in difficult geometries, and better align with the process maturity displayed by semiconductor fabs for many years. This level of simulation-led production is quickly becoming a competitive requirement, rather than simply a goal.

Conclusion: Intelligence, not reaction, in manufacturing.

These four insights, process modelling, real-time adaptation, contamination control, and tolerance discipline, could help gear manufacturers see accuracy as a dynamic, responsive system rather than a static goal. This way of thinking was not adopted by the semiconductor industry overnight; rather, it evolved by viewing each manufacturing stage as a predictable, controllable, and adaptive process.

Gear producers must adopt the same notions of precision integration, simulation-before-execution, and a zero-defect purpose rather than copying clean rooms or lithography. These are survival techniques for the next generation of gear manufacturing, not trends.

Coming Up in Part 2 in the next issue :

The next part will look into the ways in which the gear sector might profit from:

- Advanced yield management strategies drawn from wafer defect mapping
- Material engineering and surface science inspired by chip-layering technologies
- Fully automated and closed-loop control systems
- With semiconductor fab efficiencies

These findings will allow gear makers to rethink their operations in terms of system-level intelligence rather than merely mechanics.

Is the Gear Industry Really a Niche Industry? Exploring the Specialised Yet Ubiquitous World of Gears

- By Sushmita Das

Navigating the Facts

Gears are everywhere. They drive your car, power wind turbines, keep industrial robots moving, and enable precise motion in medical devices and defence systems. Yet, despite their omnipresence, the gear industry is often labelled as "niche." This label, while partly true, is also misleading. It reflects a perception shaped by the industry's technical complexity, invisibility to the public, and its highly specialised nature. So, is the gear industry truly niche, or is it a foundational pillar of the mechanical world hiding in plain sight? Let's explore this multifaceted question.

What Is a Niche Industry?

A niche industry typically serves a highly specialised segment of a broader market. It focuses on:

- Specialised products or services requiring deep technical know-how
- A targeted customer base, usually in B2B markets
- High barriers to entry due to investment, skills, or regulatory demands
- Low public visibility, as products are often components rather than consumer-facing items
- Lower production volumes, but high unit value due to customisation and precision

By these characteristics, the gear industry does resemble a niche, yet that classification doesn't tell the full story.

Why the Gear Industry Is a Niche Industry

1. Specialised Manufacturing Processes and Equipment

Producing high-precision gears is a complex undertaking. It requires:

- Advanced machining operations like hobbing, shaping, grinding, and lapping
- Heat treatments, such as carburising or nitriding, to enhance durability
- High-end CNC machines, metrology systems like CMMs, and skilled operators

Example: A standard metalworking shop cannot begin producing aerospace-quality gears without significant capital investment and technical capability.

2. Extremely High Precision and Performance Requirements

Gears are central to power transmission. Failure due to misalignment, poor surface finish, or incorrect tooth geometry can cause catastrophic breakdowns in machinery.

Example: In aerospace, gear systems must endure extreme environments with micron-level tolerances. Similarly, robotic actuators demand zero-backlash, high-accuracy gears to function correctly.

3. Diverse and Application-Specific Design Requirements

Although gears are found in almost every mechanical system, their designs, materials, and tolerances differ greatly by application:

- Automotive: Requires cost-effective, quiet, and fuel-efficient gears for transmissions.
- Wind turbines: Large, high-torque gears must endure constant stress and environmental exposure.
- Medical devices: Miniature gears used in surgical robots demand silent, precise, and sterilizable components.
- Defence: Lightweight, high-strength gears from exotic alloys are crucial for reliability and weight reduction.

This diversity has led many gear manufacturers to specialise in serving particular industries, further segmenting the market.

4. B2B Nature and Lack of Consumer Visibility

Most people never buy a gear in their lifetime, yet almost everything they use contains one. This makes the gear industry:

- Essential, but hidden
- Critical to end-use products, but far removed from public awareness

Example: A consumer choosing a washing machine cares about the brand and features, not the planetary gear set inside that drives its motion.

5. Relatively Small Market Size Compared to End-Use Industries

While gears are indispensable, their market value is modest compared to the giant industries they support:

- The global gear motor market was worth ~$24 billion in 2023
- In contrast, the global automotive market is valued in the trillions
- In India, the precision gear segment was valued at just USD 20.92 million in 2024, projected to reach USD 36.07 million by 2033

This economic disparity reinforces the perception of gears as a sub-sector rather than a core driver.

6. Challenges and Expertise in Emerging Markets

In India, the gear industry's niche nature is further highlighted by:

- Shortage of skilled talent in gear design and metrology
- Inconsistent access to high-precision machinery
- Need for dedicated gear manufacturing programs in education and training

Example: Unlike general mechanical engineering, gear manufacturing demands niche knowledge in areas like tooth geometry optimisation, thermal distortion control, and material fatigue analysis.

Why the Gear Industry Is Not Merely a Niche

While the gear industry meets many criteria of a niche sector, dismissing it as small or insignificant would be a grave mistake. Here's why:

1. Ubiquity Across All Sectors

Gears are used in:

- Transportation (automobiles, aviation, rail)
- Energy (wind, hydro, thermal)
- Manufacturing (robots, CNC machines, conveyors)
- Healthcare (surgical instruments, prosthetics)
- Consumer electronics, defence, and more

Their application breadth is far-reaching, often making them a silent enabler of global industrial productivity.

2. Global Economic Relevance

Though niche in appearance, the gear industry is a strategic enabler:

- Critical for electrification and EV adoption
- Key to renewable energy infrastructure
- Essential in aerospace and defence manufacturing capabilities
- Enables precision automation in Industry 4.0 contexts

3. Technological Innovation and Transformation

The gear industry is undergoing significant change:

- Smart hobbing and grinding machines now use AI and IoT
- Digital twin simulations optimise performance before manufacturing

- Additive manufacturing is emerging for prototyping specialised gears
- Eco-friendly lubricants and energy-efficient gearboxes are driving sustainability

These developments elevate the gear industry from traditional manufacturing into the realm of high-tech innovation.

Final Word:

A Niche Industry with Non-Niche Importance

So, is the gear industry a niche?

Yes, in the sense of its technical specialisation, B2B orientation, and hidden role in product ecosystems. But also, because of its massive cross-sector influence, enabling technologies, and indispensable role in the global economy.

Rather than calling it niche or mainstream, perhaps the gear industry is best described as a "mission-critical enabler"—specialised in skill but universal in impact. It may not always be visible, but without it, the world would grind to a halt—quite literally.

In a world increasingly driven by automation, electrification, and precision, the gear industry may be quietly specialised—but it is anything but small.

Sushmita Das is an accomplished technical writer. Holding a degree in Electrical Instrumentation and Control System Engineering, she brings a wealth of technical expertise to her writing.

Shifting Gears: How End-User Industry Demands Are Redefining the Future of Gear Manufacturing

- By Sushmita Das

As we all know, the gear manufacturing industry is undergoing a period of rapid evolution and transformation, driven by evolving demands from diverse end-user industries. From the electrification of automobiles to the surge in renewable energy and precision-driven expectations in robotics, gear producers are recalibrating strategies, technologies, and capabilities.

In this article, I have tried to explain how five key sectors, namely automotive, aerospace/defence/marine, industrial machinery, renewable energy, and the digital revolution of Industry 4.0, are shaping the future of gear design, production, and performance.

1. Automotive Industry: Driving Change through Electrification and E-Mobility

The automotive sector has long been the bedrock of gear demand. However, the ongoing transition to electric vehicles (EVs), hybrid powertrains, and advanced driver-assistance systems (ADAS) is revolutionising the traditional gear landscape.

EVs require fewer mechanical components than internal combustion engine (ICE) vehicles, but the gears they do use—such as those in e-axles, reduction gearboxes, and electric drivetrains—must meet more stringent standards for durability, noise reduction, and efficiency. These gears operate at higher RPMs and must endure intense torque loads while minimising NVH (noise, vibration, and harshness). As a result, gear manufacturers are investing in new materials, improved heat treatment processes, and high-precision grinding technologies.

Also, with the emergence of autonomous vehicles, gear systems are being integrated into smart mobility platforms, demanding tighter tolerances, digital traceability, and real-time diagnostics.

2. Aerospace, Defence, and Marine: Precision Under Pressure

Aerospace, defence, and marine sectors continue to demand the highest level of precision, performance, and safety from gear systems. Aerospace gearing applications—such as actuators, landing gear mechanisms, and engine gearboxes—must withstand extreme temperatures, variable pressures, and rigorous vibration profiles.

Lightweight yet strong materials like titanium and advanced composites are increasingly used in aerospace gears to reduce weight and improve fuel efficiency. Meanwhile, the defence sector's focus on reliability and stealth has pushed gear design toward quieter operation and enhanced thermal management.

In the marine industry, the rise in naval modernisation programs and commercial shipping advancements has amplified the need for corrosion-resistant, high-load gearboxes that can function efficiently over long periods and under challenging conditions. Digital monitoring systems are also being integrated into naval vessels to allow for condition-based maintenance.

3. Industrial Applications: Meeting the Demands of Heavy-Duty Workhorses

Gearing solutions are integral to the performance of heavy machinery used in construction, mining, agriculture, and increasingly, industrial robotics. These applications require robust gears capable of delivering high torque in dusty, wet, or chemically aggressive environments.

In construction and mining, gears power hydraulic systems, drilling rigs, and conveyor belts, all of which face constant mechanical stress. Recent trends show a growing demand for compact gear units with high load capacities and long service life.
Agriculture, driven by the need for productivity and automation, is witnessing increased adoption of precision farming equipment. Gear manufacturers must cater to a dual requirement: producing rugged components for traditional tractors and harvesters while also supplying compact, high-efficiency gears for GPS-enabled autonomous machines.

On the other hand, the robotics sector, particularly in manufacturing and warehousing, demands ultra-precise, backlash-free gear solutions. Harmonic and planetary gears are increasingly used in collaborative robots (cobots), where safety, repeatability, and space optimisation are critical.

4. Wind and Renewable Energy: Scaling Up for a Sustainable Future

The global push toward renewable energy, particularly wind power, has opened new frontiers for gear manufacturers. Wind turbine gearboxes are among the most complex and largest mechanical transmissions in use today. They must operate reliably for decades, often in remote or offshore locations with limited access for maintenance.

The shift toward higher capacity turbines—now commonly exceeding 10 MW—has driven innovation in gear design, metallurgy, and predictive maintenance. There is also a growing emphasis on reducing lifecycle costs and improving energy efficiency through gear designs that minimise friction and heat generation.

Besides wind, the solar and hydro sectors are also beginning to incorporate advanced gear systems in tracking mechanisms and micro-hydropower solutions, further broadening the spectrum of demand.

5. Industry 4.0: The Precision Gear Revolution

Digitalisation and Industry 4.0 technologies are not just changing how products are made—they are transforming what is expected from the products themselves. In gear manufacturing, smart factories now leverage data analytics, digital twin simulations, AI-based quality control, and predictive maintenance to optimise gear performance and reduce downtime.

For end-users, this translates to gears that are not only high-performing but also digitally connected. Smart gearboxes embedded with sensors can now monitor torque, temperature, and vibration in real-time, enabling condition-based maintenance strategies and reducing unexpected failures.

This intelligent connectivity is especially valuable in sectors like robotics, aerospace, and high-volume manufacturing, where precision and uptime are non-negotiable. The demand is shifting from components to systems—complete, connected gear solutions that deliver performance insights and operational intelligence.

Preparing for a Future-Ready Industry

1. Diversify Capabilities to Serve Emerging Sectors Like Robotics and Renewable Energy

Traditional gear markets like automotive and industrial machinery remain important, but the fastest-growing opportunities now lie in emerging sectors such as robotics, electric vehicles, and renewable energy. These industries often require specialised gear types, such as high-precision harmonic drives in cobots or massive torque-transmitting gearboxes in wind turbines. To remain competitive, gear manufacturers must expand their engineering and production capabilities to address these new demands. This might include:

- Developing expertise in compact, high-efficiency gears for robotic joints
- Designing corrosion-resistant, maintenance-free systems for offshore wind installations
- Creating modular gear platforms adaptable across sectors

Strategic diversification, supported by market research and customer collaboration, can open up long-term, high-growth revenue streams.

2. Invest in Precision Technologies Such as 5-Axis Machining, Hard Finishing, and Real-Time Metrology

As end-user applications become more sophisticated, so too must the manufacturing technologies behind the gears. Today's customers expect gears with:

- Tight tolerances
- Zero backlash
- Low noise emissions
- Extended service life

To meet these expectations, gear producers must invest in advanced manufacturing solutions such as:

- 5-axis machining for complex gear geometries
- Hard finishing processes like profile grinding, honing, and skiving to ensure superior surface quality
- In-process metrology and closed-loop feedback systems to ensure consistent, traceable quality at every stage

These technologies not only enhance precision but also reduce rework, scrap, and lead times—making manufacturers more agile and efficient.

3. Explore Lightweight Materials for Aerospace and EV Applications

Weight reduction is a top priority in both aerospace and electric mobility. While steel remains dominant, there's growing demand for advanced lightweight materials that don't compromise strength or durability.
Materials gaining traction include:

- Titanium alloys for aerospace components, offering a high strength-to-weight ratio and corrosion resistance
- Aluminium-based alloys in EV transmission systems
- Advanced composites and powder metallurgy products in custom, low-weight designs

To capitalise on these trends, manufacturers must understand the machinability, heat treatment needs, and fatigue behaviour of these materials. Partnerships with material science experts and investment in multi-material machining capabilities will be key differentiators.

4. Adopt Digital Twin and Predictive Maintenance Tools to Create Smarter Gear Systems

Gearing systems are no longer just mechanical components—they are evolving into cyber-physical systems that generate, communicate, and respond to real-time operational data.

By adopting Industry 4.0 technologies such as:

- Digital twins, which simulate gear behaviour under varied conditions
- IoT-enabled sensors embedded in gearboxes for data capture
- AI-driven predictive analytics to forecast maintenance needs

Gear manufacturers can offer smarter, service-oriented products. These systems help OEMs and end-users reduce unplanned downtime, optimise maintenance cycles, and extend equipment lifespan, creating value well beyond the initial sale.

Additionally, manufacturers that implement these tools in their production environments can achieve better process control, faster problem-solving, and more transparent quality assurance.

5. Collaborate Across the Value Chain to Meet Evolving End-User Specifications

Today's market is driven by co-development and system-level thinking. Gear manufacturers can no longer operate in isolation. Instead, they must collaborate with OEMs, automation integrators, software developers, and material suppliers to deliver holistic, optimised gear solutions.

Key benefits of such collaboration include:

- Early alignment with design requirements and performance benchmarks
- Integrated solutions that combine mechanical, electrical, and digital elements
- Accelerated product development cycles and quicker market entry

Examples include:

- Co-developing gearboxes tailored for a customer's next-gen e-mobility platform
- Partnering with robotics firms to design gear sets that match motion control software parameters
- Working with additive manufacturing specialists to produce complex, lightweight gear prototypes

Open innovation, knowledge sharing, and strategic alliances will increasingly define success in this interconnected gear ecosystem.

Adapting to a Multi-Dimensional Future

The evolving landscape of end-user industries is compelling gear manufacturers to rethink their product portfolios, invest in advanced technologies, and embrace greater collaboration with OEMs and system integrators. Whether it's through enhancing the torque density of EV gears, engineering corrosion-resistant marine drive systems, or integrating smart sensors into wind turbine gearboxes, the gear industry is at the heart of multiple revolutions.

As Industry 4.0, sustainability, and electrification become non-negotiable, the ability to adapt and innovate will define tomorrow's gear leaders. Manufacturers who align their offerings with end-user priorities—precision, reliability, efficiency, and intelligence—will not only survive but thrive in this dynamic era of transformation.

Products and Services on Offer at the EMO Form: the Basis for Modernizing the Industry

- By Sylke Becker

EMO Preview offers exclusive insights into the highlights of international production technology

In the run-up to the EMO 2025, interna- tional technical trade journalists from 28 countries met with selected EMO ex- hibitors in Frankfurt am Main on July 10 and 11. In short pitches, the exhibitors presented the highlights that trade visitors can expect from them at the world's leading trade fair for production technology from September 22 to 26 in Han- nover.

Under the motto of Innovate Manufacturing, the EMO stands for innovation, an international outlook, inspiration, and the future of the metalworking sector. "As a platform for dialogue between all international players in the industry – man- ufacturers and users alike – it is unique in the world, because nowhere else do visitors encounter so much international expertise as at an EMO event", says an enthusiastic Dr. Markus Heering, Executive Director of the VDW (German

Machine Tool Builders' Association), which is responsible for organizing the EMO event. Around 1,500 exhibitors from 40 countries have currently regis- tered for the EMO 2025. Two years ago, the trade fair attracted around 92,000 trade visitors from almost 140 countries.

For 50 years, EMO has been the only trade fair to present the entire value- added chain for metalworking: from machine tools, production systems, addi- tive processes, precision tools and automation through measuring technology, quality assurance, software and accessories. Our target groups are the global industrial trendsetters: mechanical engineering, automotive industry, aero- space engineering, metalworking and metal processing, medical technology, energy suppliers, but also the electronics industry and many other branches of industry.

"The products and services on offer from the EMO exhibitors form the basis for the all-round modernization of the industry. After three years of reces- sion and a major investment slowdown, at least here in Germany, the exhibi- tors are offering plenty of impetus for investment in production with new devel- opments and new solutions so that our customers can head well-equipped into the future. We are getting a first look at this at the EMO Preview here in Frank- furt," says Dr. Heering.

The EMO exhibitors are not only setting the pace in terms of technology. The trade fair also aims to provide guidance on how demand is expected to de- velop. At the EMO Economic Forum Made for Tomorrow - Discover what drives the future of manufacturing. on September 23, 2025 in Hannover, ex- perts from the top customer industries in the metalworking sector will discuss how they see future developments.

EMO focusing on global megatrends

Industry all over the world is in the middle of an extensive transformation pro- cess. Similar challenges can be seen everywhere: Competition is intensifying. Investors are taking a wait-and-see approach. Costs are rising. The demand for sustainable products is increasing. At the same time, the aging of society and the subsequent increase in the shortage of skilled workers are also mak- ing advances more difficult, while the integration of new technologies such as additive manufacturing and artificial intelligence necessitates continuous ad- vanced training.

EMO 2025 will address these challenges and focus on three topics: automa- tion, sustainability, digitalization including artificial intelligence.

Automation for greater efficiency in the metalworking industry

Against the background of high quality requirements and the shortage of skilled workers, automation is vitally important for the industry. Automation so- lutions increase efficiency and quality in the production process. They repre- sent one of the main drivers for investments and are offered in many different forms by numerous EMO exhibitors. Automation replaces manual activities and ensures more transparency in the entire production process. Automation should be easy to operate, be flexibly adaptable to the individual needs of the users and be capable of being integrated in manufacturing from series produc- tion through to economical single-piece production. Automation extends from simple solutions such as pallet changers and handling systems through to the use of robots and autonomous factories with self-driving systems. Automation also means help for machine operators, for example through assistance systems. A growing trend is the integration of ancillary processes such as cleaning, labeling or measuring.

Sustainability for greater climate protection

A large number of countries are focusing on measures for greater climate pro- tection and investments in the green transformation of their industry. In compa- nies, this is driven by legislation, which involves numerous reporting obliga- tions, and by customers who want to calculate their carbon footprint.

The focal points of sustainability in production are lower energy and material consumption, and the introduction of a circular economy. Experience shows that investments in new machines lead to energy savings of around 25 per- cent. The CO2 footprint is thereby reduced. Numerous individual measures achieve the desired objective in this context. Modern electric motors and inno- vative drive technology save a considerable amount of electricity compared with the predecessor generation.

Other determining factors include improved control technology, optimized design of compressed air and hydraulic applica- tions, or friction-minimized warehousing and guidance systems. Ancillary and follow-up processes also play an important role here, for example, tempera- ture control of cleaning baths during parts cleaning or cooling of a machine.

The Sustainability Area in hall 15 at EMO 2025 will be the ideal meeting point to experience state-of-the-art solutions for sustainable production in the future. Here, exhibitors will provide information on trends in energy efficiency, the in- tegration of renewable energies, the circular economy and life cycle concepts. These not only promote climate protection but also reduce production costs in times when energy and raw materials are scarce. “Together with other organi- zations, the VDW has also been working on a basis for calculating carbon footprints from an early stage. This has resulted in a standardized form that is in extremely high demand among customers. Of course, we will also present this in the Sustainablity Area,” says Dr. Markus Heering.

Artificial intelligence and digitalization for greater productivity

Digitalization and networking have long been important topics in production. Artificial intelligence has now been added to them. However, there are still some variables that can be adjusted in order to attain greater productivity with data and develop new business models.

Semiconductors make it possible for users to design their production processes more intelligently by harnessing technologies such as the Internet of Things (IoT) and Artificial Intelligence (AI). These create transparency about the efficiency of production processes, facili- tate real-time monitoring and control of machines and processes, and also en- able predictive maintenance.

The basic prerequisite here is the use of open, standardized data interfaces. Machine manufacturers in many countries are now familiar with the global umati initiative (universal machine technology interface) or have already joined it. umati will once again be demonstrating the benefits of standardized ma- chine networking at EMO 2025 in hall 6, and this is of great interest to users from all over the world. That's why umati also cooperates with all major inter- national initiatives such as NC Link from China and mt connect from the USA.

Digitalization and networking also promote the customization of products and adaptation to rapidly changing market requirements. With methods such as mass customization, companies can manufacture small batches of customized products without losing the efficiency of series production.

It is important to integrate data analyses and Big Data in production pro- cesses. Evaluation of large data volumes can help to optimize production pro- cesses, detect errors at an early stage, and use resources more efficiently. This increases competitiveness on the global market significantly.

At EMO 2025, the AI Hub@EMO 2025 in hall 6 will offer practical demonstra- tions of the potential of artificial intelligence in production to investors from in- dustry and the administration sector. Experts from the field of research will be on hand to provide information and answer detailed questions. "EMO exhibi- tors are invited to communicate their best practices and network with the AI Hub@EMO2025 to give visitors a complete picture of the future of production with artificial intelligence," says Dr. Heering. This is an opportunity for compa- nies to position themselves in the market.

The AI Hub will be complemented by "P.O.P. Talks", which will take place daily at 2 p.m. at the central EMO lecture forum in Hall 12. The various aspects of AI in production will be highlighted and discussed - sometimes controversially - in different formats, lectures, interviews and panel discussions. These include possible applications, data security, automation, political framework conditions for digitization and much more.

Advanced manufacturing - the future of the metalworking sector world- wide

The three focus topics are closely linked and describe the production of the fu- ture. Advanced manufacturing means automation, 24 hours a day, seven days a week, 52 weeks a year, e.g. with the use of robots. The aim is to reduce costs, increase quality and compensate for staff shortages. Digitalization, in turn, is an enabler for automation. The next step is to integrate artificial intelligence into all areas of the company, such as HR, marketing, software de- velopment and, ultimately, production. This will ensure that machines are oper- ated more efficiently and that production processes are made more sustaina- ble on the basis of the data obtained. The focus is on energy and material
efficiency as well as the circular economy. This in turn reduces costs and con- serves resources.

Highlights of the EMO supporting program

Progress in all three areas is driving industrial production forward. These ad- vances can stimulate investments and boost demand for production technol- ogy. "As EMO organizers, we are making every effort to present the crucial factors that will ensure progress at the trade fair, so that we remain at the cut- ting edge together with our exhibitors and visitors", says Dr. Heering.
This will be reflected, for example, at the Additive Manufacturing area in hall 12 where the latest applications in the area of additive manufacturing will be presented.

With an eye on the future and young talent, the Nachwuchsstiftung Maschi- nenbau foundation is playing a crucial role in developing up-and-coming skilled workers to face the challenges of tomorrow with its special education showcase. Qualified training is the basis for the success of the industry. Tar- geted support measures are helping here to ensure that the mechanical engi- neering industry will also remain innovative and competitive in the long term. The special education showcase in hall 7 will be presenting a number of inno- vative formats that show how training can best be oriented towards the current challenges in technology, digitalization and artificial intelligence in companies. The Startup Area in hall 6, where young innovative companies will present their forward-looking technologies, will also make an important contribution in this area.

The EMO motto of Innovate Manufacturing is therefore more than just a slo- gan. It is an appeal to suppliers and users to bravely exploit the possibilities of new technologies. The products and services on offer during the EMO will pro- vide suppliers and users with a great deal of inspiration and new ideas in this respect. These both represent the driving forces behind business success.


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