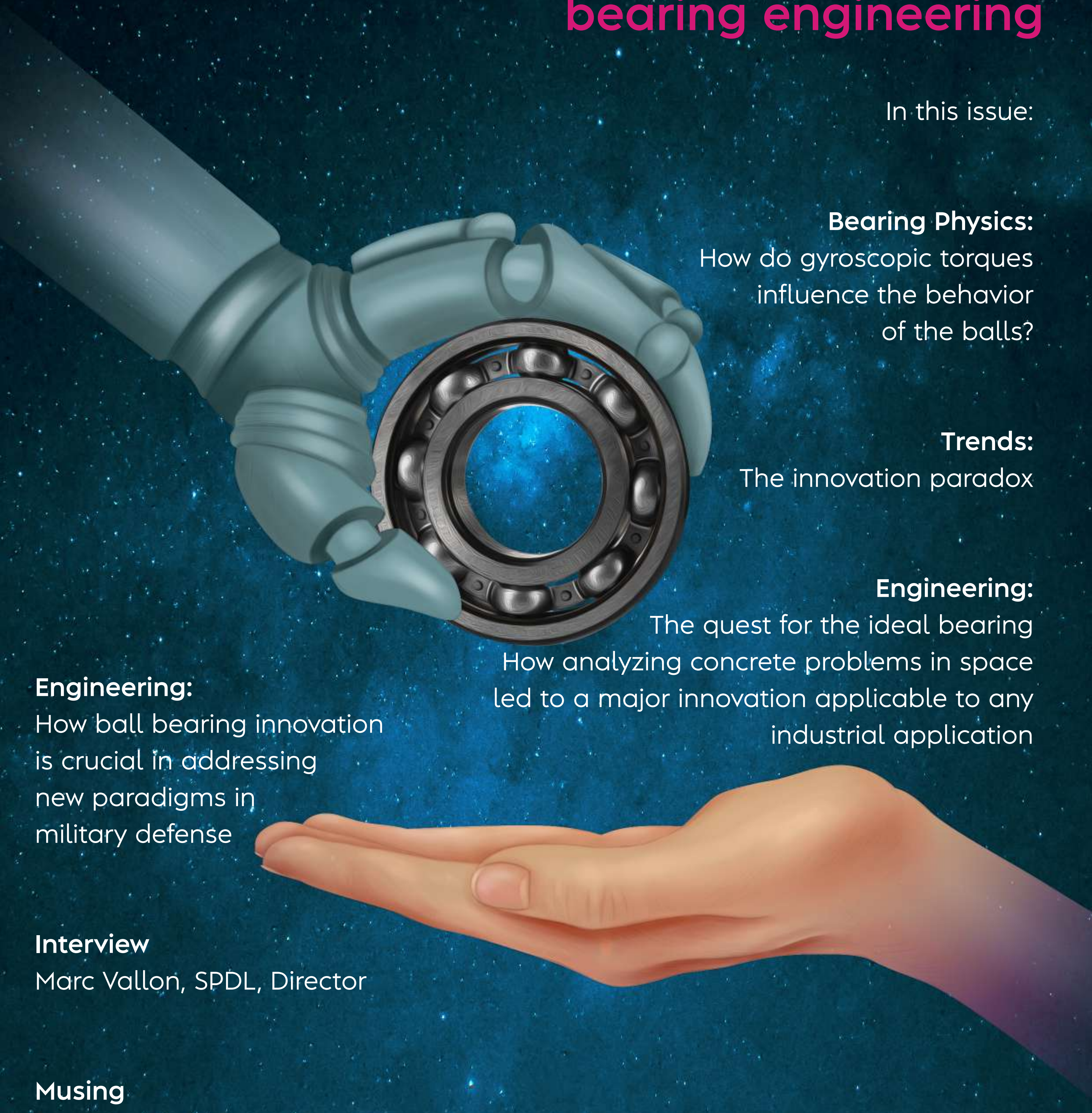
APO-GEE TALK

Innovative thinking for ball bearing engineering



In this issue:

APO-GEE
BALL BEARING ENGINEERING

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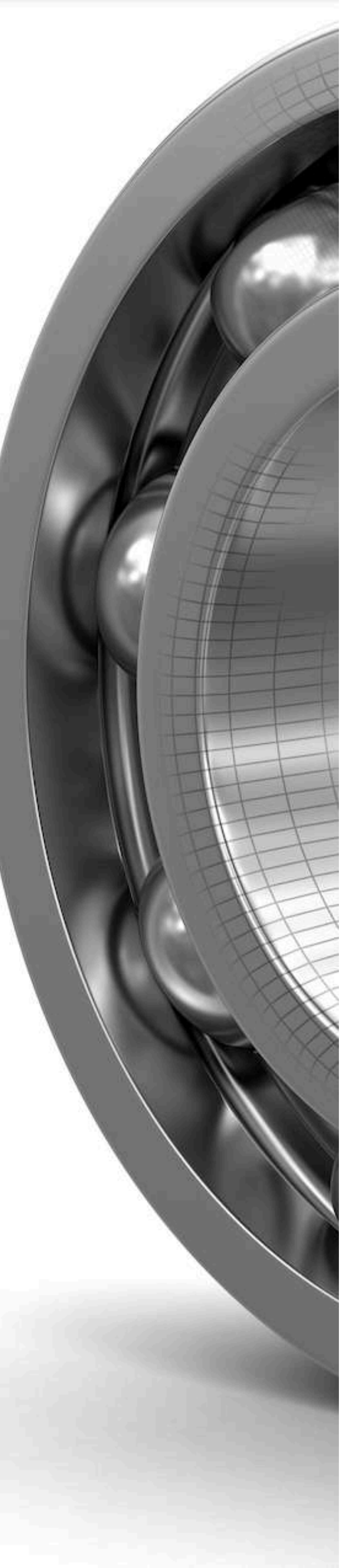


Table of content

Editorial

Dear Readers,

Welcome to the fourth edition of APO-GEE TALK!

In this issue, we enter into the transformative power of disruptive innovation in ball bearing engineering and its impact on many industrial applications.

Leading off, our popular "Bearing Physics" section revisits gyroscopic torques, exploring their influence on ball bearing behavior and the intricate dynamics at play in high-speed operations.

In "Engineering", we highlight the journey to creating the COBWEB Bearing, a solution born from addressing challenges in space engineering, now set to redefine performance standards, especially for high-speed high-precision applications. Additionally, we explore how ball bearing innovation is crucial in addressing new paradigms in military defense, emphasizing its role in enhancing operational superiority in a complex geopolitical context.

The "Trends" section discusses the innovation paradox and the significance of the Butterfly cage in solving long-standing stability issues.

Our interview with Marc Vallon, Director of SPDL, offers insights into advancements in spindle engineering, providing a glimpse into future trends and innovations in the field.

Finally, in "Musing", we draw parallels between ancient wisdom and modern engineering, emphasizing the importance of detail in achieving breakthroughs.

Thank you for your continued support. We look forward to your feedback and continuing this journey together.

Warm Regards,

Sébastien Assouad
CEO APO-GEE

How do gyroscopic torques influence the behavior of the balls?

For most of us, rolling motion is intuitive. Roughly speaking, we imagine it as a body rotating on itself while moving over another with apparent ease. For example, anyone who has ever thrown a bowling ball has experienced this: the ball leaves the hand and heads straight toward the pins. If the player is an amateur, he will not impart any specific rotation to the ball. The friction between the ball and the lane will eventually impose a pure rolling motion, a motion in which the ball's axis of rotation is parallel to the ground, preventing any sliding motion. This description applies equally to a ball rolling across a playground as it does to a ball moving within the raceway of a bearing, which represents the elementary case of a bearing subjected to a purely radial load (Fig. 1).

Unfortunately, the behavior of precision bearings does not conform to this simplistic description. Many of these bearings are preloaded and subjected to loads combining axial and radial components, which displace the balls out of the groove of the raceways. Such a change means that the axis of rotation of the balls is no longer parallel to the bearing axis. A pivoting component, similar to that of a spinning top, appears in addition to the rolling motion.

Moreover, the kinematics of the balls changes further when the bearing operates at high rotational speeds. Indeed, new forces come into play: a centrifugal force, which tends to press the balls against the outer ring, and a gyroscopic couple, resulting from the principle of angular momentum

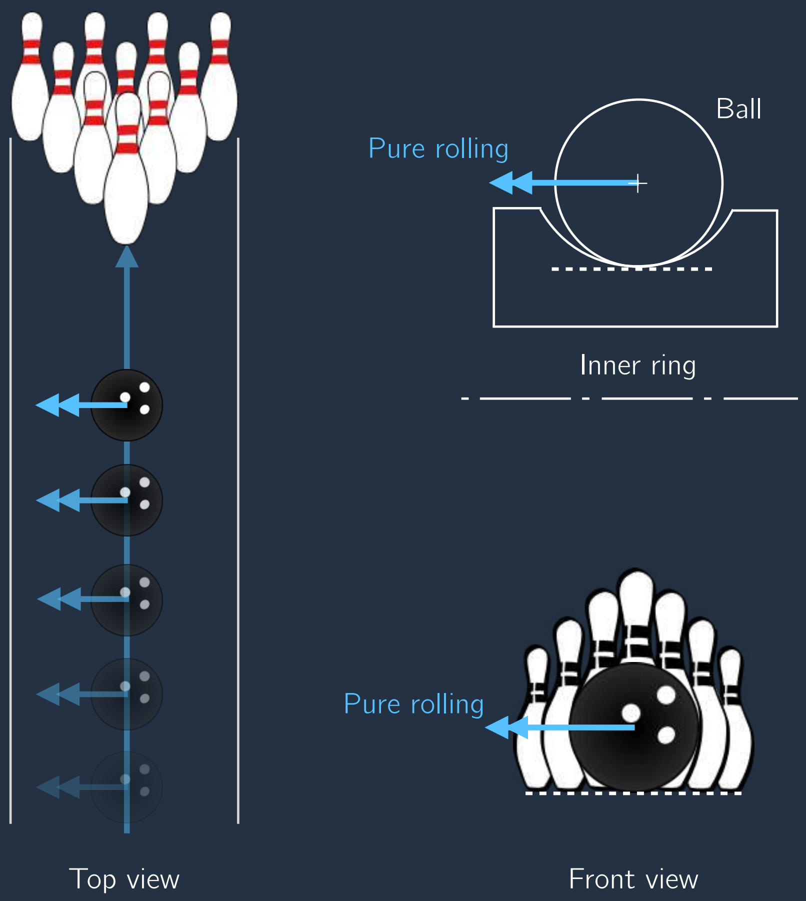


Fig. 1 – Comparison between an amateur's bowling ball and a ball of a radially loaded bearing

conservation. This gyroscopic couple is responsible for the emergence of a new rotational component: a transverse rotation of the balls, perpendicular to both the rolling and pivoting components.

Understanding the implications of this complex three-dimensional motion of a bearing ball requires taking it to the next level, elevating the amateur player to the rank of a professional.

From split to strike

The league bowler knows that a direct trajectory straight toward the pins will only rarely result in a strike. Worse, a perfectly centered straight throw will leave an abominable split, an almost unplayable shot! In other words, if he wants to improve his average score, he must apply an additional mechanical action to the bowling ball to change its angle of incidence upon hitting the pins. This maneuver is achieved by imparting a transverse rotation to the ball so that a friction force perpendicular to the lane axis (shown in red in Fig. 2) positively influences its trajectory. Clearly, such a force will impose a corresponding transverse movement. Among top players, this trajectory change can be sharp and spectacular.

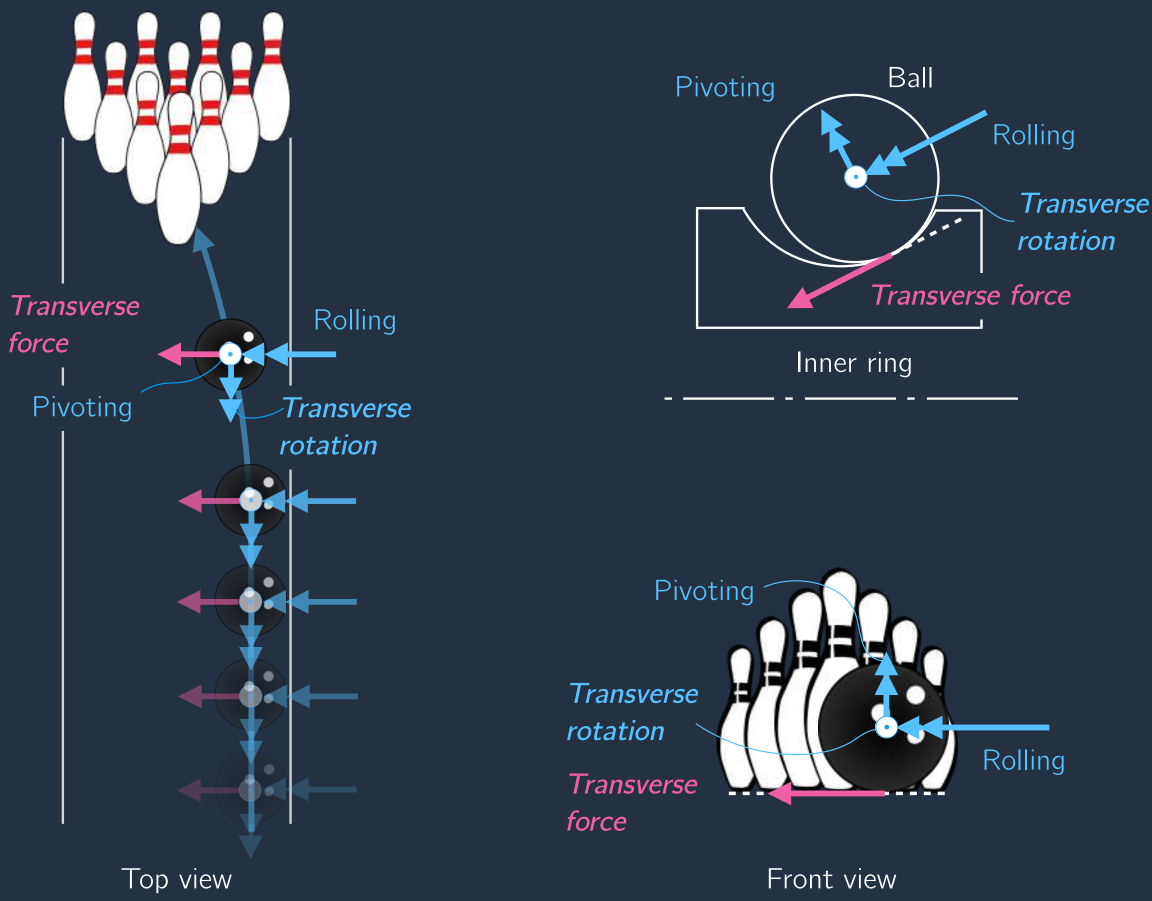


Fig. 2 – Comparison between a professional player's bowling ball and a bearing ball operating at high speeds, subjected to a combined load

The friction force resulting from transverse rotation remains very small compared to the weight of the bowling ball, regardless of the player's skill. In fact, a bowling lane is oiled over two-thirds of its length, and this oil spreads as games progress. Under such conditions, the coefficient of friction between the ball and the lane can, at best, generate only a tiny fraction of the ball's weight. And yet, it is nearly impossible to achieve a strike without these transverse friction forces, however weak they may be.

The same applies to bearings: the friction forces imposed by gyroscopic couples are small compared to other forces at play. However, at very high rotational speeds, these forces can become excessive. When this happens, the ball/race friction is no longer sufficient, and the transverse rotational component grows exponentially. This phenomenon, known as skidding, leads to an overall slipping of the balls. At that point, the bearing's heat buildup spirals out of control, with consequences that are easy to imagine.

But it is not necessary to reach such extremes for transverse friction forces to produce harmful effects. Even before reaching the skidding threshold, these forces influence the overall movement of the balls within the bearing, much like a bowling ball on its lane.

Beyond introducing a new transverse rotational component, this modification is particularly noticeable in the contact angles (Fig. 3). The gyroscopic couple tends to reduce the outer contact angle while increasing the inner one, thereby amplifying the detrimental effects associated with high rotational speeds.

However, the bearing user seeks smooth operation, free of vibrations. Therefore, anything that could disturb the trajectory of the balls, such as a gyroscopic couple, must be minimized.

This is even more true for bearings subjected to combined loading (axial preload, radial force, misalignment, etc.), as the configuration of each ball varies depending on its position on the bearing circumference. This scenario thus leads to the establishment of a vicious circle. Indeed, since the gyroscopic couple results from any variation in the rotational speed of a body, any asymmetry in the ball kinematics leads to an increase in the gyroscopic couple, which itself varies from ball to ball. Now, an asymmetric increase in the gyroscopic couple also leads to an asymmetric modification of the ball rotation...

In short, it becomes clear that the efforts of precision bearing designers must focus on reducing any symmetry defects within the mechanical component.

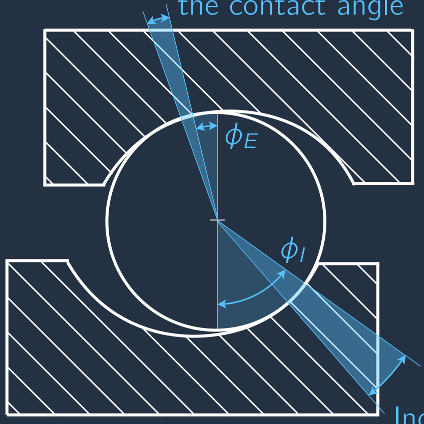


Fig. 3 – Evolution of contact angles with the presence of a gyroscopic couple

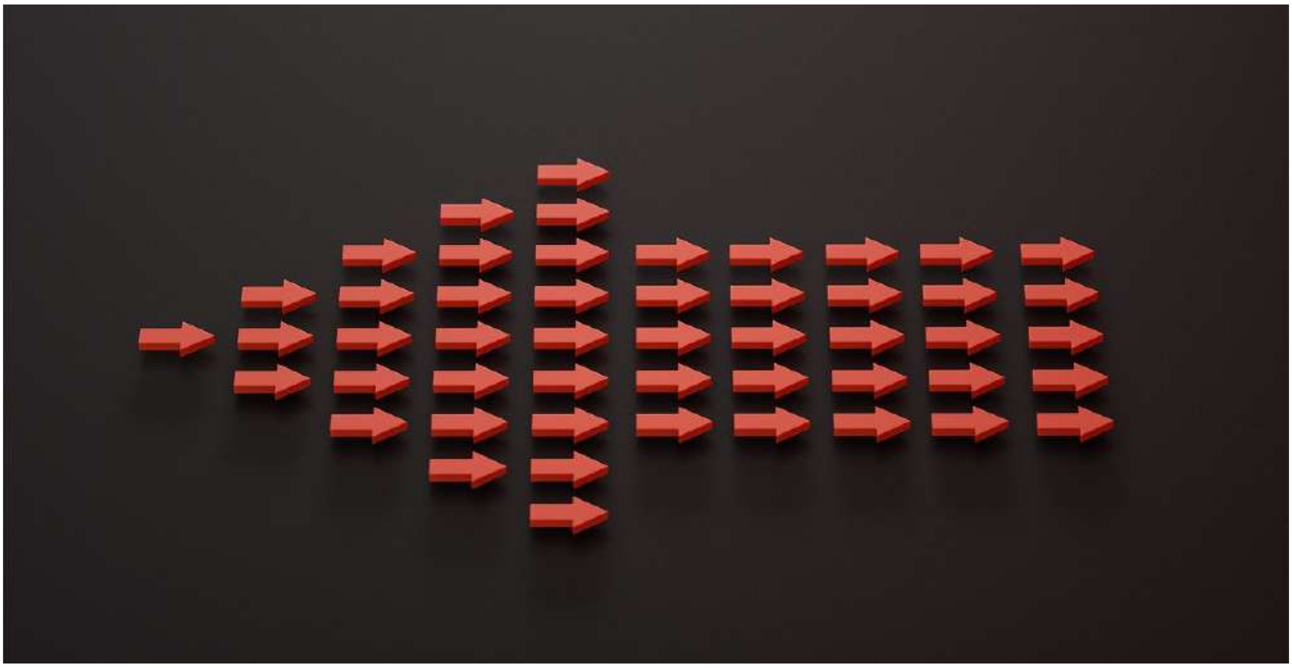
APO-GEE strikes back

APO-GEE has invented a new ball bearing geometry, the COBWEB bearing, capable of correcting performance issues related to combined loading and high rotational speeds. To achieve this, APO-GEE has highlighted the fundamental physical principles at the core of the challenges encountered. The result is an innovative technological solution that effectively reduces unwanted ball movements, particularly under difficult operating conditions.

Knock down the pins, not the balls! ◆

Christophe Servais
CTO APO-GEE

The innovation paradox



As the co-founder of a deep-tech startup, I was frequently asked what has been the most challenging aspect.

- Is it researching and innovating? No.
- Turning research into a tangible product that delivers significant value? No.
- Securing the first contracts? No.
- Finding funding? Not that either.

The hardest part is undoubtedly overcoming the **Innovation Paradox**.

What do I mean by that?

We hear it all the time, loud and clear: we must innovate! Innovation is one of the main drivers of growth. It's essential, vital. For our economy and our companies. And rightly so.

As many are already aware, when considering product innovation, two primary categories emerge:

I. **Incremental Innovation:** This involves gradual, often small-scale improvements. It optimizes performance, quality, or efficiency without radically changing the nature of the product. It's less risky because it relies on existing technologies and is often guided by user feedback or market changes. It has a measurable impact in the short to medium term and allows companies to stay competitive by meeting evolving customer needs without revolutionizing the product or the market.

II. **Disruptive Innovation:** This type of innovation disrupts an existing market or creates a new one by introducing entirely new products. It often replaces established technologies or business models, leading to major transformations. By nature, it is highly risky but carries the potential for high returns. Disruptive innovation is often initiated by startups looking to break into a market dominated by established players. Its impact is longer-term, as it redefines market rules and can render existing technologies or practices obsolete.

This is especially true for disruptive innovation based on a scientific discovery. By scientific discovery, I mean a significant breakthrough in the understanding of a phenomenon, resulting from observation, theory and experimentation. It stands out because it reveals facts, laws, phenomena, or principles previously unknown, often challenging or enriching existing knowledge.

So, why do I speak of the difficulty of overcoming the innovation paradox?

Because disruptive innovation based on a scientific discovery is rare. And because it's rare, people often don't believe in it at first. It's met with doubt. Sometimes, people don't even want to acknowledge it because it could undermine years of work or substantial investments.

This is where the paradox lies. Despite the enormous potential of this type of innovation, the initial reflex is often to resist it, or worse, stifle it, even though it's at the heart of growth.

At APO-GEE we have developed a disruptive innovation: the Butterfly cage, which solves a major reliability issue in bearings used in space applications, a problem that had remained unresolved for over 50 years. This innovation is the result of more than 10 years of research and the scientific discovery of the mechanisms governing cage instability in ball bearings. This discovery is notably based on characterizing the kinematics of the balls using a novel method. The Butterfly cage now has practical applications beyond the space sector, such as in machine-tool spindles for example.

And we faced the innovation paradox head-on. That has been our greatest challenge. But we are making progress, and things are changing!

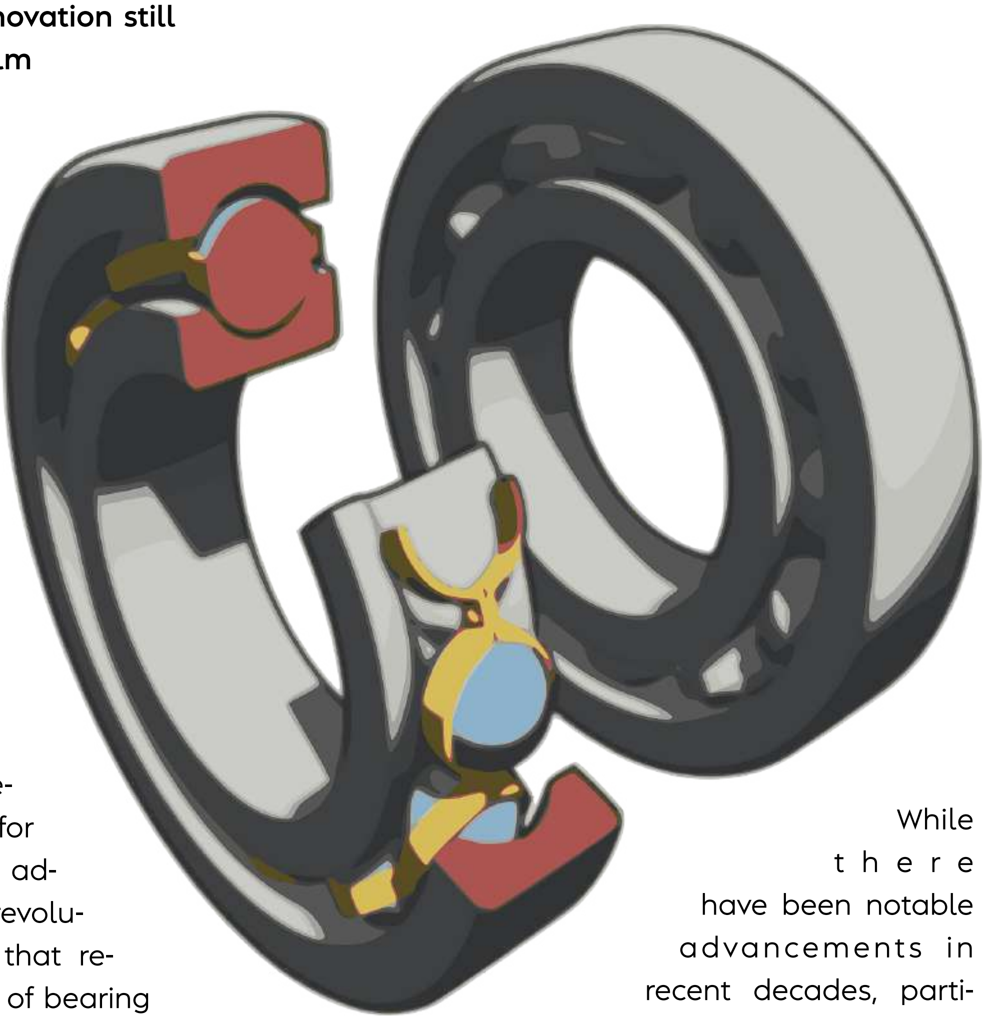
Thank you to those who believed, who continue to believe, and to those who are now changing their minds. Together, we are driving meaningful change in the ball bearing industry. ◆

SA

THE QUEST FOR THE IDEAL BEARING

How analyzing concrete problems in space led to a major innovation applicable to any industrial application

Is groundbreaking innovation still achievable in the realm of ball bearings?



Can we envision a transformative breakthrough in ball bearing technology that significantly redefines performance rather than merely making incremental improvements?

In our pursuit of substantial enhancements, we've aimed for more than just slight adjustments. We seek a revolutionary leap forward that reshapes the landscape of bearing technology. Imagine a more than significant reduction in frictional power dissipation, a notable smoothing of contact angles to minimize friction and vibration, and a remarkable decrease in the Ball Speed Variation phenomenon.

While there have been notable advancements in recent decades, particularly in materials and surface finish, the focus has largely been on refining existing designs rather than fundamentally reimagining them. However, amidst this backdrop of incremental progress, there remains space for disruptive innovation. This was exemplified by addressing a critical challenge encountered in rocket engine turbopumps – components subjected to extreme conditions such as high speeds, combined loads, extreme temperatures, challenging lubricating conditions, and cryogenic fluids.

The significance of these challenges cannot be overstated. Turbopump engineering and the bearings within them have been the subject of extensive development efforts by manufacturers, given the dire consequences of a defect in these components.

In response to these challenges, a breakthrough emerged – a transformative solution that promises to bring a performance boost to bearing technology. By tackling fundamental issues plaguing turbopump bearings, notably, APO-GEE has paved the way for a paradigm shift in bearing design. With the potential to significantly enhance performance across various metrics, from reducing friction to minimizing vibration, this innovation heralds a new approach in bearing technology. It's not just an evolution; it's a groundbreaking approach that pushes the boundaries of what's achievable in bearing design.

So, in answer to the question of whether groundbreaking innovation is still possible in ball bearings, the resounding answer is yes. Through ingenuity and determination.

The key steps in a decade of research

Here are the key stages of this exciting journey:

- The research was initiated within a laboratory active in space technologies, particularly focusing on liquid propellant turbopumps, such as those used in space launchers.

- The initial steps of our research involved establishing a complex mathematical model to replicate bearing cage movement. However, these early findings also showed that controlling cage movement would require a comprehensive study of the bearing. Thus, to progress and attempt to unravel the mystery of cage instability, we also needed to understand how the rolling elements between the two rings actually behave.

- We consequently continued our work by examining the contacts between the rolling elements and the rings. Specifically, we wanted to understand what happens within such contacts during bearing operation. We identified the role of micro-slippage occurring at the ball/ring interfaces in characterizing cage dynamics. Therefore, we first needed to learn how a rolling element exactly rolls between its rings.

- While specialized literature on the subject was abundant, we noticed that most research focused on other issues than ours: primarily lifespan evaluation, exploration of new materials, and quantification of effects induced by lubricants. In essence, while balls were compressed between rings, they still had to enable reliable rotational movement for a certain period. However, the way the balls rotate within the bearing, namely the kinematics, was often relegated or even neglected in scientific literature.

- However, when Jones[1] faced the challenge of addressing the kinematics of the rolling elements, essential for achieving mechanical equilibrium, he encountered an insoluble problem. He could not adequately model the rolling element movement given the knowledge and tools available at the time. How did he manage to provide a calculation method capable of holding up while being unable to predict the rolling element movement within the bearing? He simply worked as a good scientist: he made a hypothesis. In essence: "I hypothesize that the rolling elements roll to continue developing my method." However, in reality, the rolling elements do not just roll as per Jones' hypothesis. And therein lies a crucial, fundamental difference.

- The research thus continued in the quest to precisely determine how rolling elements move, with the next step being to describe accurately the temperature rise at each point of the ball/ring contacts. To achieve this, we had the unique opportunity to benefit from extended test data from a turbopump bearing of a rocket launcher. These data illustrated what happens under real conditions when a bearing is overstressed and heats excessively. We were able to qualitatively and quantitatively demonstrate that bearing problems were indeed due to locally excessive temperature rise, directly related to rolling element rotation. These results earned us the "Maurice Godet Award" at the 40th Leeds-Lyon Symposium on Tribology[2].

- We were then able to incorporate these advancements into our cage dynamics model and refine our understanding of cage dynamics. In particular, we developed a new way to account for the influence of critical parameters regarding unstable phase entries and precisely understand the mechanisms governing cage instability. These discoveries later gave rise to the BUTTERFLY Cage, an

1 Jones, A. B., 1952, “The Life of High-Speed Ball Bearings,” Trans. ASME, 74(5), pp. 695–703.

2 Servais, C., Bozet, J. L., Kreit, P., and Guingo, S., 2014, “Experimental Validation of a Thermal Model of a LOx Flooded Ball Bearing,” Tribol. Int., 80, pp. 71–75.

unconditionally stable new bearing cage for ball bearings.

- We mastered cage dynamics and had a first outline of rolling element behavior. But we lacked the Holy Grail: describing the operation of high-speed, even very high-speed ball bearings subjected to any load. In other words, we wanted to discover a wholly generic approach to achieve bearing equilibrium in all scenarios. Since Jones, many individuals have attempted to go further. Among the few who attempted to remove Jones' hypothesis, none arrived at a conclusive solution. At best, the famous hypothesis was replaced by considerable mathematical uncertainty. What was the common denominator of these unsuccessful attempts? Why did this fog persist despite the exponential evolution of modern computing power? The answer: it's not modernity that's the problem but the old: the Newtonian approach. Balancing all forces in a bearing actually resembles building a gigantic house of cards. In theory, it works; but in practice, it fails. We then directed our research toward an original method that allows constructing this house of cards solidly, by reformulating mechanical equilibrium with a new criterion: power. We demonstrated that this new method enabled removing Jones' hypothesis and replacing it with certainty. Thus, we succeeded in precisely describing rolling element kinematics, developing a new complete algorithm, and an associated software tool. This tool became at the core of Rose, the APO-GEE modeling toolkit. The magic eventually happened: we calculated balls kinematics and demonstrated that bearing mechanical equilibrium was indeed à posteriori upheld, in the sense of Newton.

- We then possessed all the knowledge and tools necessary to improve rolling element movement between rings during high-speed bearing rotation, with or without combined loading. Since we had dispelled the fog surrounding their kinematics, we precisely knew the pitfalls of bearing operation. We thus wrote a list of properties that the new ideal bearing should possess. Because we were indeed talking about an entirely new type of bearing. Therefore, our field of vision gradually narrowed until focusing on a single aspect: the bearing grooves. These have always been circular. Always! And comparing the previously inventoried ideal properties, or this sort of "wish list" of ideal bearing attributes, the

conclusion appeared very special to us: conventional grooves do not have the required qualities! We then managed to define a groove profile perfectly meeting our list's desires: the COBWEB Bearing was born.

THE COBWEB Bearing: dramatically improving high-speed bearing performance

The COBWEB Bearing features a specific ring profile. It is more precisely a family of profiles associated with a software tool allowing parameter variation to adapt to any conditions or performance objectives – which provides the possibility to create and manage a range of COBWEB Bearings. We can truly talk about a new type of bearing, direct consequence of over 10 years of continuous R&D efforts leading to the perfect modeling of rolling element kinematics!

Three legitimate questions may arise at this stage:

I. **"Is it too good to be true?"**
   No! The COBWEB was developed based on concrete experimental data and through pragmatic continuous step-by-step research. We can also prove that it works. The knowledge and tools used to create the COBWEB have already been tested with the BUTTERFLY cage, which addressed the cage instability problem, and experimentally validated. We can precisely calculate the COBWEB's contribution and verify it once produced.

II. **"How does the COBWEB compare to the state of the art?"**
   We conducted a thorough state-of-the-art analysis, also in collaboration with top IP firms. It revealed that many attempts have been made to improve ring

profiles. This confirms the innovation's interest because the application areas are numerous (machine tools, space applications, dental handpieces, automotive, etc.). The analysis also shows that these attempts fail to ensure optimal bearing operation in all cases, adapt to specific conditions, and also demonstrate a lack of control over parameters. The COBWEB, for its part, results from a perfect mastery of the parameters.

III. **"Is there a challenge in industrialization?"**
Yes, there is of course a manufacturing challenge. Producing a non-circular profile is indeed more complex than a circular one, but it is by no means insurmountable. Thus, the COBWEB is primarily intended for cutting-edge or highly demanding applications (such as for turbopumps in space, for example), but we could quickly reach volume if we consider applications such as machine tool spindles or turbochargers, for example.

Yes, we can talk about disruptive innovation

The COBWEB can, therefore, be considered a groundbreaking innovation in the realm of ball bearings. For decades, engineers grappling with demanding operating conditions have had to make do with suboptimal solutions, leading to issues such as noise, vibrations, heat dissipation, and bearing malfunction. But today, with the advent of the COBWEB Bearing, those compromises are a thing of the past.

What sets the COBWEB Bearing apart is its ability to facilitate smoother ball movement. This translates to enhanced operational efficiency and extended lifespan, making it the ultimate choice for high demanding high-speed high-precision applications.

One of the key advantages of the COBWEB Bearing is its adaptability across a wide range of speeds. Unlike conventional bearings that require choosing an optimal operating point, the COBWEB Bearing excels at supporting high speeds while maintaining optimum performance across all intermediate speeds. It also boasts perfect preservation, by reducing drastically the Ball Speed Variation phenomenon, even under extreme conditions. ◆

SA

How ball bearing innovation is crucial in addressing new paradigms in military defense

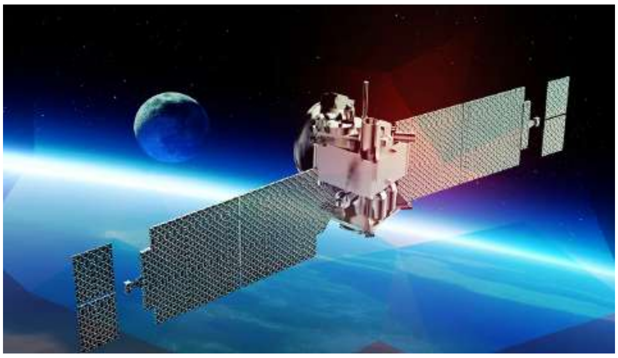
Engineering for supremacy

In the ever-evolving defense industry, where performance, durability, and reliability are non-negotiable, ball bearing technology plays a crucial yet often overlooked role. From high-precision aerospace components to advanced missile guidance systems, innovation in bearing design is essential to meeting the extreme demands of modern warfare.

As global tensions and shifting geopolitical landscapes drive nations to modernize their defense capabilities, cutting-edge engineering solutions are becoming critical to ensuring operational superiority. This article explores the latest breakthroughs in ball bearing technology and their impact on defense applications.

Space: a new potential arena for confrontation

Over the last few decades, numerous space missions have faced significant disruptions, and some even had to be aborted due to ball bearing performance problems. This issue is evident not only in commercial and institutional missions but also in defense missions.



The problems are particularly located at the level of reaction wheels and gyroscopes of satellites, which are key equipment for maneuvering satellites in orbits. Those problems with reaction wheels and gyroscopes are by no means marginal. In an openly accessible report published by NASA in 2014[1], for instance, NASA reported that since 2001, over a billion dollars worth of NASA spacecraft have been rendered non-functional or placed in jeopardy due to reaction wheel failures. Since the launch of commercial activities of APO-GEE in late 2022 and the feedback received from the market, it can be asserted that ball bearings continue to pose significant problems even today.

Moreover, it is all the more important as space is evolving into a potential arena for confrontation, necessitating the development of active military defense capabilities

[1] https://ntrs.nasa.gov/api/citations/20140013265/downloads/20140013265.pdf

in space. Satellites are the main tools of military powers for observation, reconnaissance, surveillance, communication, and espionage. The control and potential neutralization of military satellites have thus become major concerns. That's why new technologies are key to enabling satellites to maneuver, intercept, or change orbits, even leading to the resurgence of ideas such as space torpedoes or kamikaze satellites. Addressing these challenges is undoubtedly crucial for states to strengthen their defense capabilities.

That being said, if we now look more closely at the cause of the bearing failures in the guidance systems, we can assert that a lot of these failures are due to what is known as the cage instability problem in bearings. The bearing cage is the mechanical component that keeps the balls equidistant between the two rings. The issue results in a sudden increase in the energy of the cage, causing it to take on a hula hoop-like movement, leading to vibrations and even bearing failure.

This problem has remained unresolved for over 50 years. No one has been able to completely solve the problem for all operational contexts. Based on over 10 years of research, APO-GEE has done it with the Butterfly cage, to address a concrete problem posed by the space community. This technology is a game-changer as it ensures reliability, performance, and the elimination of the risk of failure in guidance and navigation systems.

Reducing noise and vibrations

Ball bearings also play a critical role in various land-based military applications, where vibration reduction is essential for the performance, reliability, and stealth of equipment. For instance, in missile guidance systems, minimizing vibrations enhances stability and precision, reducing trajectory deviations. Targeting systems

equipped with electro-optical sensors also rely on low-friction bearings with minimal vibration to ensure accuracy and operational efficiency.

Another key example is the use of bearings in submarines, where precision and vibration attenuation remain of prime importance.

In these applications, the bearing cage, an often-overlooked component, is crucial, as it is the only part of the mechanism free from direct mechanical constraints. Its design directly influences the level of vibrations generated. The Butterfly cage, in particular, has demonstrated its ability to significantly reduce noise and vibrations across all types of bearings, offering a tangible advantage in high-performance military applications.

High-speed high-precision military applications

Solving the cage Instability problem was just the beginning of our innovation journey. Building on the unique ability to model and compute the kinematics of the balls, we have also engineered the COBWEB Bearing. The COBWEB bearing represents an innovation that offers the most precise functioning in the world thus far, particularly for high-speed or very high-speed applications.

Once again, this innovation stems from a specific problem we addressed. In this instance, it involved resolving an overheating issue with one of the bearings in a turbopump rocket. The bearings of turbopumps rotate at exceptionally high speeds and are subjected to intense stresses.

By solving this problem, we have opened doors to optimizing the operation of numerous military applications, ranging from missile guidance and propulsion to aircraft maneuvering systems.

A new era for military bearings

As defense technologies evolve to meet the demands of modern warfare, innovation in ball bearing design has become more critical than ever. From space-based defense systems to missile guidance, submarines, and high-speed propulsion, bearings play a pivotal role in ensuring precision, reliability, and stealth.

With groundbreaking solutions like the Butterfly cage and the COBWEB bearing, APOGEE has not only addressed long-standing challenges but has also redefined performance standards for defense and aerospace applications. By eliminating failure risks and enhancing operational efficiency, these innovations are setting new benchmarks in defense engineering, allowing more resilient and agile military systems in an increasingly complex geopolitical landscape. ◆

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INTERVIEW

Marc Vallon

Director & Founder
SPDL SA
spdl-spindles.ch

What is your professional background and what are your responsibilities within SPDL?

My initial education was Mechanical Engineer (ETS, bachelor level) in machine tools design. After few years in different fields (packaging, watch industry), I started my career in the machine tool sector in 2005. My first experience in this field was VOUMARD MACHINES CO, a well-known Grinding machine manufacturer. Since then, machine tools and especially spindles follow my professional way.

I am the founder of SPDL SA: Spindles services for machine tools. The company is small. It means I have to handle different roles from sales to customer support, through customization spindle design and so on….

What is SPDL story and what specific knowledge or design features SPDL brings to the spindle industry?

We found the company in 2022 with the hard conviction that the industry needs strong actors in spindle services. For us, "services" means: Spindle Repair, Spindle optimization, Spindle diagnostic and advices, Spindles and related accessories sales.

At SPDL, we have comprehensive knowledge in spindles, machine tools and manufacturing processes. This allows us to provide extensive services for machine tools users in different industrial fields.

The DNA of SPDL is to serve our customers best in their daily issues, which are the performance of the spindles and their reliability (owner costs).

Following this target and because we are in contact to customers issues in a daily base, we innovate in terms of services and technologies. Spindle monitoring is typically one sector where we have identified opportunities to serve better our customers.

Comparing to common actors like machine tool manufacturers and spindle manufacturers, SPDL is an independent spindle service company, which is probably more in contact with the users of machine tools than manufacturers.

What sets SPDL apart from traditional spindle service companies?

First of all, in Switzerland, there are a lot of spindle and machine tool manufacturers and relatively few independent repairs spindle companies in comparison with other European countries.

SPDL services are very similar to existing spindle repair companies. Our commitment is to provide the best service we can and extend the field of research to all components which are in contact with the spindles.

Sometimes, we heard that some spindle types are poor spindles. In our point of view, there is no poor spindles but poor way of using it. It's a big difference. SPDL is able to adapt the existing spindle to real needs or to determine what is the best combination. That's the reason why we consider we are a good addition to the existing actors, because manufacturers of machine tools and spindles manufacturers have quite different targets.

How has SPDL incorporated innovative mechanical engineering solutions to optimize spindle performance and reliability?

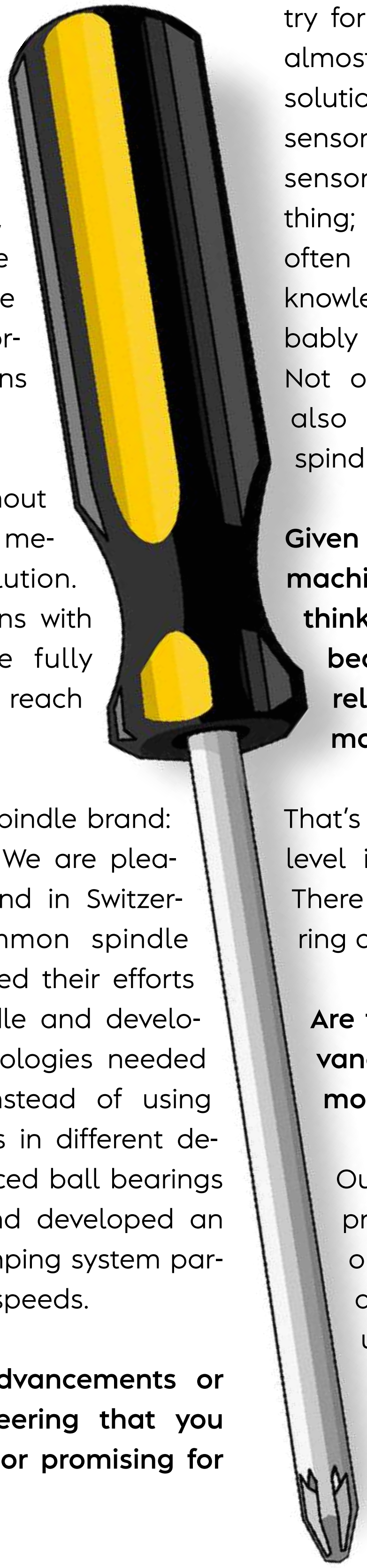
We are always open-minded to optimize the spindle performances. We have to admit that there hasn't been much real innovative mechanical engineering for spindles for the

recent years. The way of integration existing updated technologies is more our way of thinking. We try to be smart and pragmatic. A spindle in a machine tool is not like a formula 1, we don't try to have the absolute best performance but more a reliable performance more like a Le Mans racing car.

Then APO GEE has without doubt a real innovative mechanical engineering solution. We have huge expectations with this technology and are fully convinced it will help to reach our goals!

We must also mention a spindle brand: LEVICRON from Germany. We are pleased to represent this brand in Switzerland. Compared to common spindle manufacturers, they focused their efforts on design the ideal spindle and developed new innovative technologies needed to reach their targets instead of using usual spindle components in different designs. Typically, they replaced ball bearings by aerostatic bearings and developed an innovative spring less clamping system particularly adapted for high speeds.

Can you discuss any advancements or trends in spindle engineering that you find particularly exciting or promising for the future?



We have been talking a lot about 4.0 Industry for some years. The spindle actors are almost all oriented to develop monitoring solutions for their spindles. Through a lot of sensor solutions, there is a wide range of sensors and solutions. Measures is one thing; analysis is more complicated… and often seems like black boxes. The deep knowledge of spindle behavior will be probably one hight spot trend in the future. Not only for predictive maintenance but also for improving and simplifying the spindle designs.

Given the demanding nature of precision machining, what advancements do you think are necessary in the field of ball bearings and to further improve the reliability and efficiency of spindle for machine-tools?

That's pretty clear for us that the vibration level is critical and has to be improved. There are some ways for it, from ball bearing design, lubrication optimization, …

Are there any unique innovations or advancements that SPDL has made in its modular spindle?

Our target on this product line is to provide a spindle which is modular not only for the spindle manufacturer but also for the machine tool builders or users. The market needs differentiation at good price then modularity is key. Everything changes quickly then it is not rare that the needs change during the daily life of a machine/spindle. Opportunity to change the configuration/performance in an easy way will be a huge competitive advantage in our opinion. Furthermore, the ownership costs of the spindle line is optimized.

What were the key technical challenges encountered in developing SPDL modular spindle, and how did SPDL address them?

Basically, there are few technological challenges to design a modular spindle. The most difficult is to take the right choices according decomposition and function in order to serve 80% of the market.

New technologies could complete the package to increase the value and performances. A huge challenge to sale such products is to achieve to well communicate about what is the modularity and advantages!

In terms of future innovation, what do you envision as the key areas of focus SPDL?

Because we are a service provider, I guess that our organisation/process is a key of success in order to permit us to be efficient and fast. There are a lot of similarities between the different types of spindles. But it is not so easy to well use and deploy our skills for each spindle repair work. We are working hard to build our process and information storage!

What advice would you give to aspiring mechanical engineers who are interested in a career in the mechanical and spindle industries?

It is a very interesting and important question! Spindles and mechanical engineering are everywhere where we consider physical businesses. And at the end, physical business is the most important one even if services, software are sexier and better paid.

But nowadays, if you consider the sustainable development and geopolitics uncertainty, I think we need absolutely more engineers and projects to ensure our future! Energy, defense, transportation, etc… the key of success will be in the hands of new generation of mechanical engineers!

How does SPDL foster a culture of innovation and entrepreneurship within the organization? Are there any unique strategies or practices that have contributed to the company's success?

We are a young and small company. That means we have to adapt every time our services and products to better fit to customer needs. It is not only a wish, it is vital. We keep our vision in mind but we hardly try to really heat what are the customer needs.

Globally we are more oriented to developing our knowledge in spindle in order to be able to change and optimize our services. We are not focused on a specific service or product. We use our skills and experiences to serve the spindle industries.

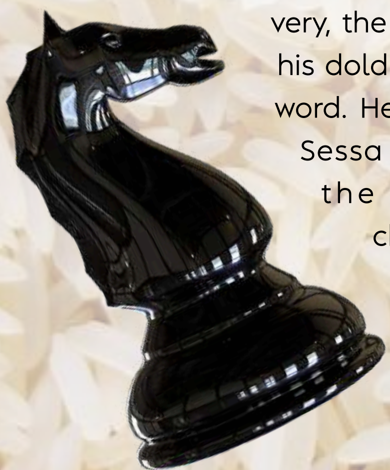
We also try to catch the much information as we can to have a better understanding of the market and customer needs to provide the best in class spindle services. ◆

Small causes, big effects

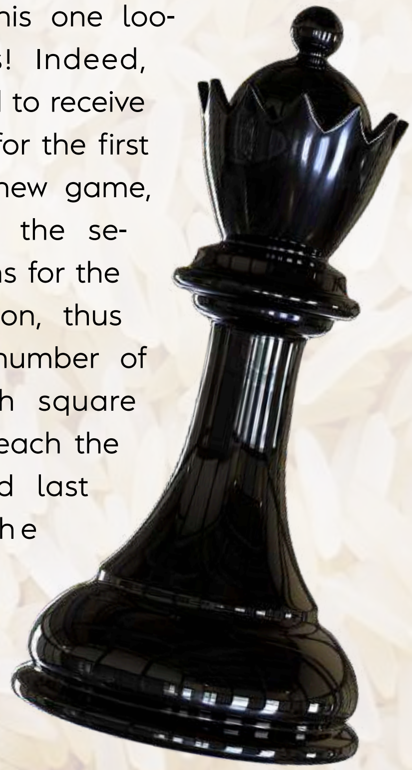
What connection is there between a brave but ruined old monarch and a ball bearing?

A well-known oriental legend is associated with the creation of chess. A long time ago, King Shiram ruled India. He was a great king. He had done well, his kingdom had grown rich and a lasting peace had settled under his rule. So much so that Shiram plunged into a great depression, due to a lack of new action to take. Driven by despair, he sent for his minister Sissa and begged him to deliver him from the misery in which he had been locked. In exchange for a solution, the king pledged to offer everything his minister had always dreamed of.

Sessa immediately got to work. Some time later, he returned to the palace and offered Shiram an entertainment of his own making. The modern chess was born.

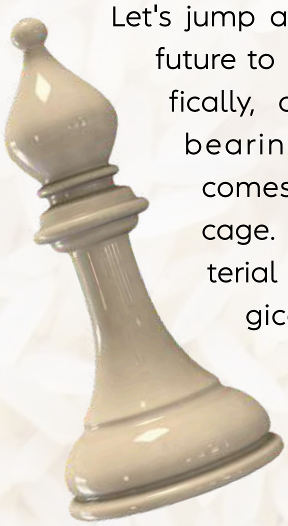


Fascinated by Sessa's discovery, the king came out of his doldrums and kept his word. He demanded from Sessa that he claims the reward of his choice, no matter its greatness. But for only answer, the minister simply asked for a certain amount of rice. Besides, this one looked ridiculous! Indeed, Sessa proposed to receive a grain of rice for the first square of his new game, two grains for the second, four grains for the third, and so on, thus doubling the number of grains at each square jump, until to reach the sixty-fourth and last square of the chessboard.



Touched by such modesty, the good king begged Sessa to choose a reward much more in accordance with the immense service he had just rendered to him. But nothing helped and the faithful minister remained on his initial idea.

Shiram ordered his accountants to assess the price due to Sessa. Amused and a little mocking, they set to work. What was their terror as they approached the last square! And for good reason: they calculated that the quantity of rice was ultimately worth much more than what the granaries of the globe contained!



Let's jump a few centuries into the future to land in our time. Specifically, do we picture a ball bearing designer when it comes time to design the cage. He chooses a light material with favorable tribological properties, selects geometric clearances of a few tenths of a millimeter and quickly assesses the impact of the rotation speed on the forces that the small separator will have to withstand. Result? The centrifugal forces are negligible, of the order of a thousandth of a newton! And, in view of the very low friction, the impacts of the cage with the balls will probably not be able to exceed this threshold.

It is true. But this also means forgetting that the engineer is on the first square of the chessboard.

Notwithstanding his long experience, our designer now finds himself trapped by his common sense and his intuition, like the good King Shiram. He does not know it, but the bearing he is about to sell will soon present a highly problematic behavior, characterized by unbearable noise and vibrations.

How is it possible? How can an almost imperceptible force lead to bearing failure?

By simply presenting a mechanism similar to the logic of Sessa, that is to say by progressing exponentially from square to square, or more precisely from impact to impact. The cage is free of any constraint within the bearing. Thus, the contacts with the rolling elements and the rings will increase. Like the evolution of the grains on the chessboard, the intensity of the impact forces of the separator will follow a geometric progression as a function of time, so much so that the initial few thousandths of a newton will quickly be multiplied by several thousand!

This exponential explosion, this doubling from square to square, has a name: cage instability. APO-GEE has identified the physical mechanisms behind this dreaded runaway. The understanding of these mechanisms naturally led to a new design: the Butterfly cage. In essence, this prevents any start of instability, any increase in force intensity, any multiplication of grains of rice, regardless of the square on which it is located.

Checkmate to cage instability! ◆

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About APO-GEE

APO-GEE is the Belgian deep-tech start-up specialized in ball bearing engineering.

APO-GEE helps space agencies, satellites launch companies, aircraft manufacturers, defense contractors and equipment manufacturers, with innovative products and dedicated high value services related to ball bearings used in harsh environments and severe conditions.

APO-GEE'S tools and methods have also proven to be highly effective for high demanding applications in other sectors and industries (medical techs, machine-tools or automotive).

APO-GEE is driven by innovation and IP development. The Butterfly Cage (unconditionally stable cage), the Cobweb Bearing (smoothest functioning high-speed bearing) and APO-GEE's unique computational tools are real breakthroughs in the bearing world.

APO-GEE is located in the Liège Science Park, Belgium, in a premium environment dedicated to deep-tech start-ups.

www.apo-gee.tech