Implementing More Powerful Electric Motors with PA46

Strong Ball Bearing, Smaller Motors

Ball bearings in electric cars have to meet higher requirements than in vehicles with combustion engines. The trend towards smaller electric motors with higher speeds is further reinforcing this. A material alternative to the usual PA66 and PEEK is available for implementation.

SKF hybrid ball bearings with ceramic balls: Hybrid bearings with ceramic rolling elements are the most reliable and efficient variants for preventing electrical erosion caused by stray currents. © SKF

As the automotive industry continues to evolve, latest generation of vehicle design is driven by electrification, connectivity and autonomy trends resulting in new demands from vehicle performance, efficiency and safety perspective. The electrification trend has resulted in a steady replacement of traditional combustion engine powered vehicles with hybrid vehicles and fully electric cars (BEVs). This switch to hybrid cars and BEV's has enabled more efficiently operating vehicles from an exhaust gas emissions perspective while improving the driving experience in terms of vehicle dynamics and passenger comfort.

Vehicle efficiency is one of the most important performance indicators of modern vehicles. A reduction of fuel consumption and increase of driving range by minimizing parasitic frictional losses has been one of important design focus areas at many car manufacturers, since one of the main power loss sources are indeed the parasitic frictional losses inherent to the mechanically moving parts found in different vehicle systems including combustions engines, transmissions, differentials, wheel assemblies and many others.

In case of BEVs the number of moving parts has reduced compared with hybrid cars and the conventional internal combustion engine (ICE) powered vehicles by about of a factor 100. The ICE being the primary power source in traditional and many hybrid vehicles has made place for compact but powerful

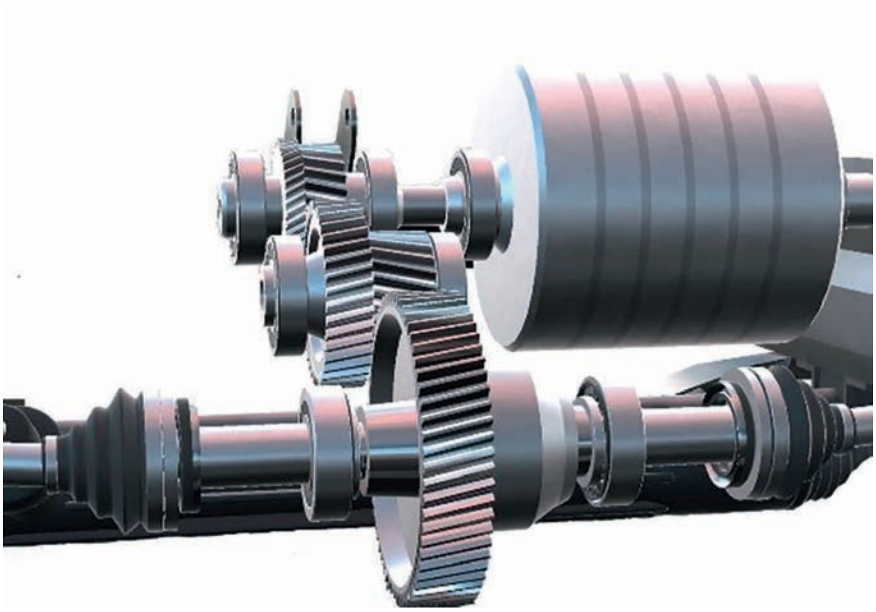

Fig. 1. E-axle combining the e-motor and reducer in one unit: Manufacturers of electric vehicles are trying to save weight at this point. © Envalior

electric motors consisting of fewer rotating components resulting into a significantly simplified powertrain.

E-Cars: Fewer Bearings, Higher Requirements

Regardless of the vehicle type and the powertrain design, rolling bearings are components that remain key for any type of power transmission and motion, especially when this is to be achieved at low as possible frictional losses. Conventional ICE powered vehicles rely heavily on bearings for proper functioning of various vehicle systems and components including ICE, transmissions, differentials, steering systems, braking systems, wheel assemblies and other vehicle components. In full electric cars bearings perform a similar function as in conventional ICE powered vehicles although the simplification of BEV powertrains has resulted in fewer number of bearings required in the electric motor, the reducer and the differential assembly. These three sub-systems are usually combined into one single unit which is commonly referred to as e-axle (**Fig. 1**).

Electrification is not only affecting a vehicle's powertrain from a design simplification perspective but has also significant consequences for design requirements of various powertrain systems and components. To help increase a vehicle's overall power efficiency and the drive range of BEVs and also many plug-in hybrid vehicles (PHEV's), one of the strategies automotive OEMs deploy is weight reduction by using both lightweight materials and also downsizing of various systems and components. Compared to internal combustion engines, e-motors usually produce a higher power output per unit motor weight (kW/kg), which is beneficial considering the inherently higher weight of electric cars due to the relatively large battery mass. Nevertheless, in order to further reduce vehicle weight, e-axles and e-motors are often seen as areas for further improvement from a weight perspective.

Weight Reduction Drives up Requirements

The bearings used in hybrid and fully electric powertrains are required to withstand significantly higher rotational speeds and temperatures than bearings used in conventional ICE-powered vehicles and the ongoing weight reduction trend with electric vehicles only further increases these requirements for the bearings used in e-motors and e-axles. In addition to high speed and high temperature requirements, these high-speed bearings are also required to operate at low friction and low noise levels and with various grease and/or oil lubricants commonly used in bearings. »

Fig. 2. SKF deep groove ball bearings using a polymer cage: The plastic bearing cage holds the rolling elements in the correct position. It must be resistant to mechanical and chemical stresses and ensure low friction. © SKF

Fig. 3. Cage deformations (left) and cage failures (right) are caused by high rotational speeds and centrifugal loads, among other things. © Envalior

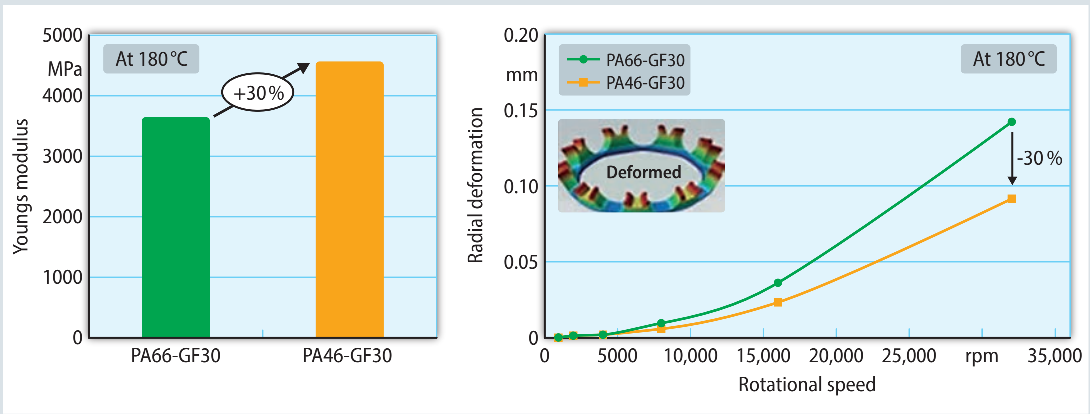

Fig. 4. The higher material stiffness of the PA46 reduced the cage deformations. Source: Envalior; graphic: © Hanser

Furthermore, electric powertrains using higher bus voltage and silicon carbide or gallium nitride based inverters are leading the system for better efficiency but with the counterpart of a higher risk of bearing (and gears) damages due to current passage through the rolling elements. In order to overcome the electrical erosion issues due to stray currents, bearing manufacturers have come up with various solutions. Different insulating solutions are currently investigated or tested, where, up to today, the most reliably and best performing solution is hybrid bearings, containing ceramic rolling elements (**Title figure**), securing the needed electric insulating function and provide lowest possible frictional losses.

Which Materials Can Be Used?

The rolling bearings make use of rolling elements which facilitate the primary function of the bearing: transmission of power and motion with as low as possible friction. To contain the rolling elements (balls or cylindrically shaped rollers) in the correct positions within the bearing unit, bearing cages are used (**Fig. 2**). Bearing cages can be made either of metals or plastics. Commonly used metals in bearing cages are steel and brass and the metal cages are usually produced either by stamping or by machining. Plastic bearing cages are made of injection moldable engineering polymers where most often nylons and polyetheretherketone (PEEK) are used.

Polyamide 66 (PA66) and polyamide 46 (PA46) are reinforced with glass fiber and offer unique benefits for automotive electric powertrains. PA66 exhibits exceptional mechanical strength, toughness, and chemical resistance, making it ideal for durability and resilience. Its good heat resistance and dimensional stability further enhance its versatility. On the other hand, PA46 excels in high-temperature environments due to its higher thermal stability. With improved flow characteristics PA46 is favored in applications demanding superior performance. The choice between PA66 and PA46 depends on specific application needs, blending cost-effectiveness with mechanical prowess for optimal performance.

PA66 with glass fiber-reinforcement is widely used as a cost-effective solution up to approximately 120 °C operating temperature. PA46 with glass fiber-reinforcement is often used in high temperature and high-speed applications where PA66 is not able to meet requirements and as more cost-effective alternative for PEEK. For temperatures continuously above 150 °C and/or aggressive chemical environments PEEK is a good option.

Failure Modes with Plastic Bearings

During operation plastic cages are often subjected to a combination of thermal, mechanical chemical and tribological loads. Plastic bearing cages can fail when their performance limits are exceeded and the failure modes often observed are cage deformations resulting from high centrifugal loads (induced by high rotational speeds, **Fig. 3**) which in the worst case can lead to completely destroyed cages. At high rotational speeds, cages can be exposed to very high operating temperatures where peak temperature levels above 150 °C are not uncommon. The cage deformations negatively affect the bearing performance since deformations lead to unintended contact and sliding action be-

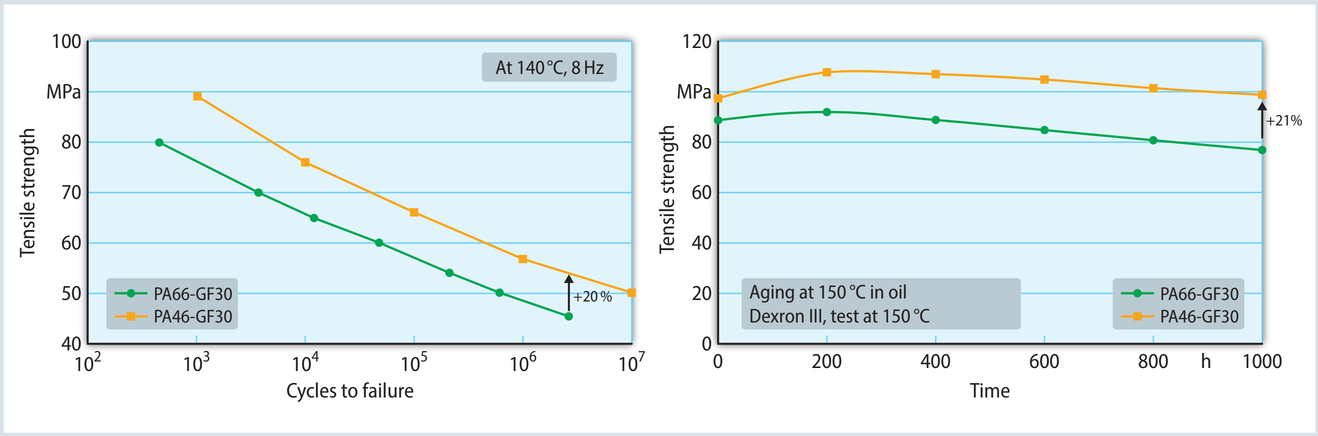

Fig. 5. Fatigue strength (left) and strength retention after exposure to 150 °C hot oil (right) for glass fiber-reinforced PA66 and PA46. PA46 performs better in both cases. Source: Envalior; graphic: © Hanser

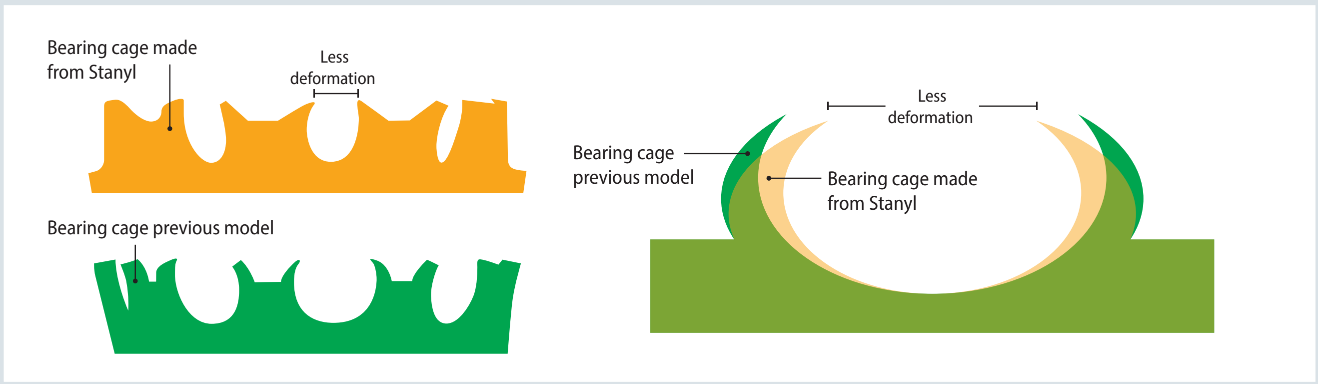

Fig. 6. The switch to Envalior's PA46 Stanyl allows lower deformation due to centrifugal forces in the SKF cages. © Envalior

tween the cage and the rolling elements, and also between the cage and the metallic bearing inner or outer rings. This unintended contact between the plastic cage and other (metallic) bearing elements results often in increased friction levels, excessive frictional heating, higher operating bearing temperature and a reduced cage service life.

High-speed bearings run lubricated with grease or oil, so also long-term chemical compatibility is required between the plastic cage components and the lubricants used. This calls for that strength performance of the plastic materials used needs to be maintained after long-term exposure to the lubricants used.

Durable and Compact Cages

Stanyl from Envalior is a PA46 with a high crystallinity of around 70 %. This high crystallinity level enables high stiffness and strength properties at elevated temperatures making the material an excellent high temperature polyamide. In addition to high stiffness and high strength it offers better fatigue resistance, creep resistance and wear resistance compared with polyamides such as PA66. The high stiffness and creep properties enable stiff bearing cages that resist cage deformation and creep at elevated temperatures at which the bearings often operate under high-speed conditions. This PA46 has about 30 % higher stiffness than PA66, enabling stiffer cages designs that resist deformation under high centrifugal loads (**Fig. 4**).

In addition to its high stiffness and high creep resistance Stanyl exhibits high weldline strength, fatigue resistance and impact resistance, a combination of strength properties that enable a strong and durable cage. Weldlines are often difficult and in some cage designs impossible to avoid and the high strength polymer properties mitigate the risks of premature cage failures enabling a longer bearing lifetime performance. The material is also resistant against most automotive oils and greases (**Fig. 5**). »

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References

You can find the list of references at
www.plasticsinsights.com/archive

Ball Bearing with 1,800,000 nDm

Cage deformation, called umbrella effect, is the main limiting factor for bearing speed capability. High stiffness and high strength properties of Stanyl enable not only higher rotational speeds but lead also to higher design freedom. Using this material, SKF has been able to optimize cage design to be robust against high accelerations/decelerations and high speed, achieving 1,800,000 nDm with the SKF High Speed Ball Bearing 1.8 (SKF HSBB1.8) – an increase of around 50 % compared to the previous generation, where nDm is a measure of the bearing rotational speed over the bearing size. The higher the nDm value, the higher the bearing speed capability is. The mass distribution of the cage has been optimized and the cage backbone thickness has been reinforced to minimize the cage umbrella effect and cage stress due to centrifugal forces (**Fig. 6**). As a consequence, the cage fatigue life is improved. Thanks to the ball bearing, electric motors can reach a higher power density.

One of the ways to reduce weight of e-motors and e-axles is by reducing the motor size, however this approach in itself can negatively affect motor's output torque and also vehicle (acceleration) performance. To compensate for any power losses the rotational speed of the motor can be increased, resulting in a similar power output at a lower motor weight and thus in a higher power density unit (**Fig. 7**). In addition to reducing weight, the more compact motor also saves space while still being capable of producing the output power required. Another advantage of more compact motors is that their design often requires a lower amount of expensive rear earth materials which opens also cost saving potential.

Electric Motors with 20,000 rpm

Powerful and compact electric motors often rotate at high speeds. The rotational speed levels achieved in such high-power density units can easily reach or exceed 20,000 rpm. A motor operating at such high speeds is not only required to operate reliably but also efficiently with as low as possible frictional power losses. The Stanyl cage used in SKF HSBB1.8 enables the realization of such high speeds and thus the design of electric motors with higher power density.

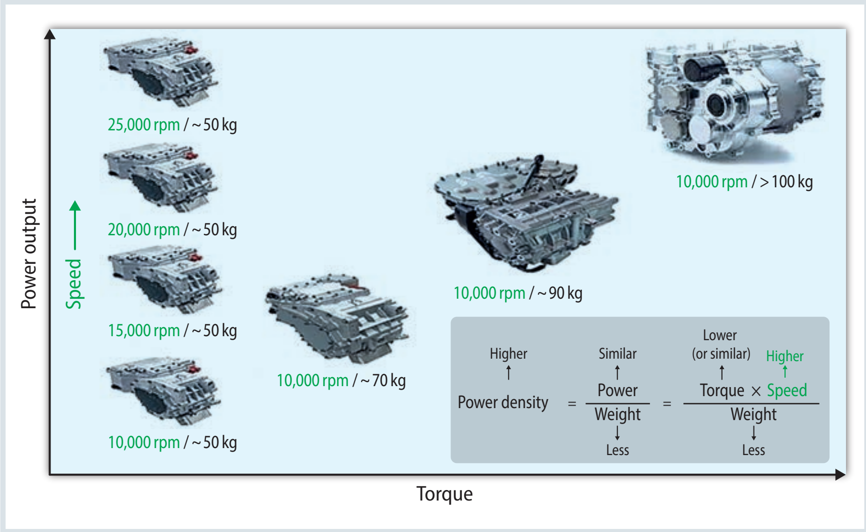

Fig. 7. Higher motor speeds increase the power output and power density of electric motors. © Envalior

In addition to bearing cages used in rolling bearings, this PA46 is also widely used in sliding bearings and bushings (also called plain bearings). Rather than relying on the rolling motion like the case is with the rolling bearings, sliding bearings and bushings rely on sliding motion which makes this type of bearing often very demanding from a tribological perspective. The high temperature, low friction and low wear properties of PA46 make Stanyl highly suitable for sliding bearings and bushings. The material has successfully been used in sliding bearings over the last 30 years. Applications examples include bushings and friction pads used in belt tensioners within the Front End Accessory Drives (FEAD) (**Fig. 8**), but also various other general purpose bushing and thrust-washer components found in transmissions and other applications.

To further enhance the tribological material properties, a number of material grades from Envalior make use of W&F-additives which are either polytetrafluoroethylene (PTFE)-based or PTFE-free. The PTFE-free grades are available that can be used for potential replacement of PTFE-containing alternative polymers including POM, PA66, PPS and PPA. ■

Fig. 8. The PA46 Stanyl from Envalior is already being used for various bearing bushings and friction pads. © Envalior