Technical Trends Regarding Rolling Bearings Used with Balancer Shaft Systems in European Engine Applications

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In present automotive and heavy-duty engine applications, plain bearings are primarily used and, vice versa, rolling bearings, such as ball or needle bearings, are of minor relevance. However, the share of plain bearings will be decreased in automotive applications because they are gradually replaced by rolling bearings. This is, on the one hand, owed to more stringent CO_2-emission standards set by European governments and, on the other hand, to the customers' desire for a reduced fuel consumption of the car. An increased benefit value implies a reduced energy demand with simultaneously minimized friction losses which, consequently, lead to reduced engine emissions. Since the changes as for bearing technology requirements lead to an increased demand for rolling bearings in automotive engines, JTEKT has committed itself to developing special bearings for automotive engines. The development process of rolling bearings for balancer shaft systems is introduced in this journal.

Key Words*: automotive, engine, balancer shaft, rolling bearing, low friction, CO_2-emission reduction*

1. Introduction

The automotive industry is currently facing major challenges in terms of structural and technological change. One of these challenges is the new and more stringent CO_2-emission requirements set by the European governments. Increasing the power and efficiency of the engine by reducing internal frictional losses is a major target of the European automotive manufacturers.[1)] Another important issue is the continuous enhancement of the engine's level of comfort and running smoothness.[2)] One of the European car manufacturers' options to achieve these targets consists in replacing plain bearings on balancer-, cam- and crankshaft by rolling bearings. These operations lead to an increased demand for rolling bearings for engine applications, such as Needle Roller Bearings and special Ball Bearings.[3)4)] Consequently, JTEKT has developed particular bearings for automotive engines to fulfill the customer needs, such as compensating annoying vibrations and uncomfortable noise related to engine operation. Specific rolling bearing solutions for automotive balancer shafts will be presented in the next chapters.

2. Balancer shaft design concepts in European engine applications

Modern diesel and gasoline engines have been released from annoying vibrations and uncomfortable noise due to the implementation of balancer shafts and balancer shaft units (add-on). A balancer shaft system can be developed by the European automotive manufacturers themselves or in a development partnership between European automotive manufacturers and the suppliers of balancer shafts and bearings.

The balancer shaft is a mass compensation system designed to reduce and to eliminate second-order mass forces which, in a fired engine, result from engine operation. With the help of extensive FEM calculations that are based on the initial CAD draft models of all engine components, an optimal compromise between rigidity (positive effect on noise and vibration), strength and weight of the balancing system is achieved. Since the engine manufacturers aim at reducing friction losses and decreasing engine weight as well, they try to optimize the balancer shaft design as for mass saving and limitation of its deformation in operation. This results in, e.g., a partly circumferential inner race (so-called 180° shaft, covering an angle of 180°).

The balancer shaft bearings are used in different engine architectures, such as L2, L3 L4 or V6 engines, see **Fig. 1**. Depending on the engine concept, one or two shafts are included in the respective application, running at single or double engine speed.

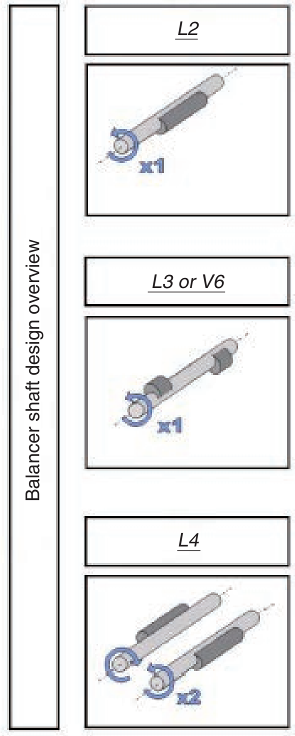


Fig. 1 Balancer shaft design architecture overview

Regarding the system architecture, there are two basic balancer shaft concepts on the market. The first concept called "tunnel assembly" means integrating a balancer shaft system in the engine block (**Fig. 2**).

The second concept is a balancer shaft module, **Fig. 3**, which is separately attached to the engine block. Depending on the balancer shaft design different bearing types can be applied.

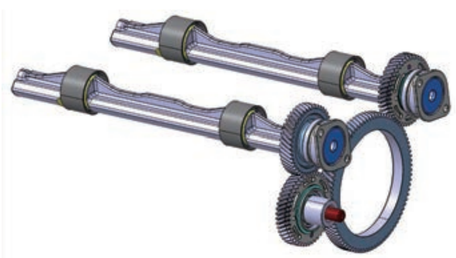


Fig. 2 Balancer shaft tunnel system

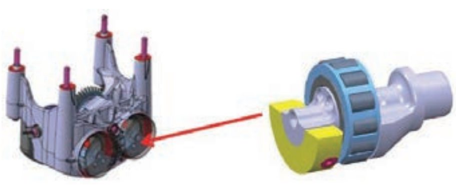


Fig. 3 Balancer shaft module

3. Rolling Bearing Design Development

The design of balancer shafts and the corresponding bearings requires a consideration of all the underlying conditions, including the balancer shaft housing and the drive system as well as the oil supply and oil system. These aspects are discussed in detail in the following sections.

3. 1 Operating conditions considered in the calculation

During the process of calculating and developing (**Fig. 4**) the optimal bearings for the investigated balancer shaft, loads and speeds occurring in engine operation need to be considered – these characteristics effect misalignment (shaft deformation & tolerance sensitivity) on each bearing position. As well, the expected bearing lifetime is affected by temperature and lubrication (Oil grade, quantity, contamination…).

Identified risks and design parameters

- The main goal is an adequate bearing having sufficient dynamic capacity: bearing dimensions and life target are to be balanced.
- In order to provide robust bearing operation for all application conditions, stress resistance related to both, inner and outer race, is specified: material & heat treatment definition, specific race & rolling element profile for stress balancing, also shaft design improvement as for limiting deformation.
- High speed bearing capability => definition of optimized cage design type; e.g. cage guidance by outer race or by rolling element and rolling element size.
- Bearing mounting in housing (Retention, stress in housing) => housing material, interference and minimum outer race thickness, housing design are optimised as for enduring all application conditions.
- Clearance management => system geometry, sorting & selective assembly.
- NVH level => system assembly, raceway geometry and surface finish, clearance management are investigated.

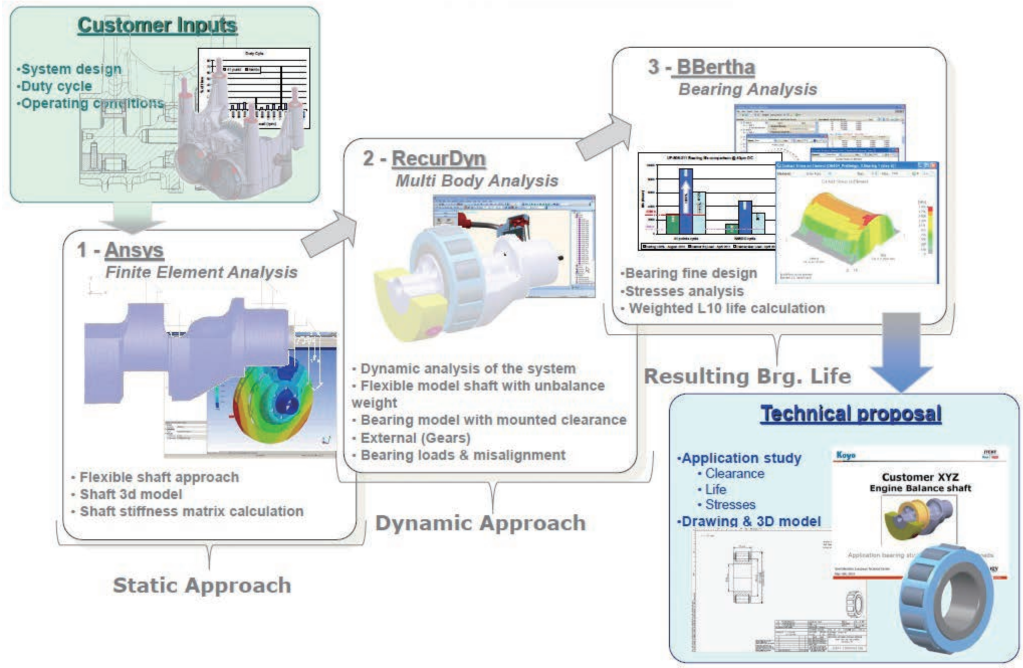
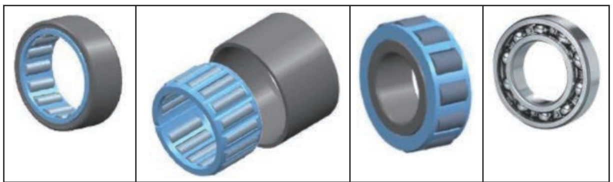


Fig. 4 Balance shaft analytical development process - e.g. balancer shaft module

4. Balancer Shaft Bearing – design overview

As shown in **Fig. 5**, bearing design is characterised by a balance of the bearing capacity on the one hand and load conditions and durability target on the other. As well considered are assembly conditions, the operating clearance management, friction and NVH requirements and other customer needs.



Drawn cup bearing with polymer cage	Split polymer cage with drawn sleeve or machined ring. Cage roller or outer diameter guided.	Cylindrical roller bearing with solid race	Ball bearing with a axial load support capability

Fig. 5 Balancer shaft bearings-design overview

4. 1 Needle Roller Bearing

A Needle Roller Bearing is designed for radial loads exclusively and has a drawn cup to form the outer raceways in most cases. A particularly thick-walled “heavy duty” drawn cup can be used to cover even extremely loaded mountings in aluminum housings/engine blocks. A broad variety of cage design according to application speed and cage material (steel or polymer) can be applied.

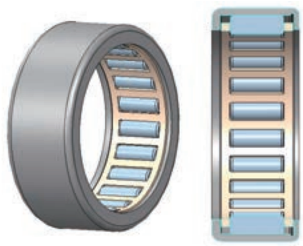


Fig. 6 Needle roller bearing

Advantages:
- Flat cross section, low diameter
- NVH convenient with polymer cage
- Low cost

Drawbacks:
- Limited capacity, no extremely loaded configuration
- Sensitive to misalignment in case of long rollers
- NVH risks due to housing geometry effects

4. 2 Cage and Roller

A Cage & Roller Assembly is a bearing designed for radial loads only. One variant suitable for balancer shafts in particular has a split polymer cage – it allows the mounting on a fully assembled shaft in a conclusive step. A solid ring could serve as an inner race, and a machined ring or drawn sleeve could constitute the outer race. For ideal operating conditions the outer and inner races need to be properly specified for a rolling contact (heat treatment and clearance management).

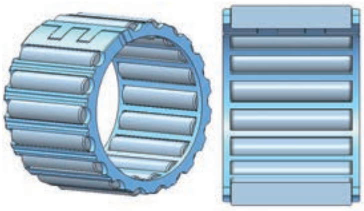


Fig. 7 Cage and roller

Advantages:
- Assembly in a conclusive process feasible (split polymer cage)
- Clearance management with machined outer ring
- NVH capabilities (polymer cage and solid race with customized surface finish)

Drawbacks:
- Sensitive to misalignment in case of long rollers
- Limited NVH capabilities in combination with drawn outer sleeves (sensitive to housing geometry)

4. 3 Cylindrical Roller Bearings

Characteristic of Cylindrical Roller Bearings is, in relation to their length, the large diameter of the rollers which generally roll on massive, thick-walled raceways. Usually they are operated in balancer shaft applications which involve high radial loads. Several configurations are possible, e.g. a steel or polymer cage type, with or without an inner ring. A thick-walled drawn cup may also be applied in combination with cylindrical rollers.

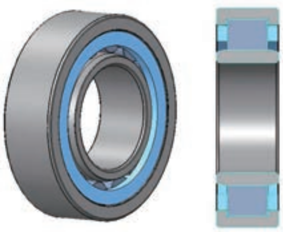


Fig. 8 Cylindrical roller bearing

Advantages:
- High capacity, high expected life in high radial load condition
- Support axial load in some cases
- Clearance management with solid races
- Friction and NVH capabilities (solid race, polymer cage)

Drawbacks:
- Larger outer diameter
- High costs for the case that drawn cups are not applicable
- Extra load at high speed (Roller mass) and slippage risks

4. 4 Ball Bearing

Commonly used in balancer shaft applications are as well single or double row ball bearings, characterized by steel cages and specially customized material and heat treatment.

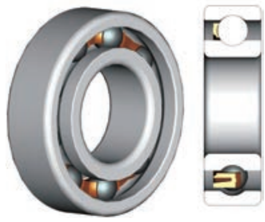


Fig. 9 Ball bearing

Advantages:
- Thrust load capacity and axial positioning
- Low sensibility to misalignment
- Low friction

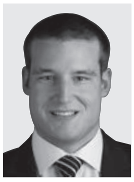
Drawbacks:
- Bearing dimensions
- Low radial capacity, compared to needle roller or cylindrical roller bearing

5. Conclusion

The development of special rolling bearings for balancer shaft systems in European engines has successfully supported the European automotive manufacturers in various ways: reducing the CO_2 emissions of their car-fleet to meet European governmental emission standards, and satisfying the customers' desire for improved fuel consumption. As for the specific rolling bearings for balancer shaft application, volume production has now been implemented in Europe. Regarding rolling bearings used in future automotive engine applications, the JTEKT European Bearing Technical Centre will fully use its expertise and advance innovative solutions and valuable technologies.

References

1) T. Koch: Paradigmenwechsel in der Automobilindustrie, MTZ worldwide, Volume 63 (2002).
2) BMW: The Balancer Shafts on the New Four-Cylinder Diesel Engine from BMW, MTZ worldwide, Volume 63 (2002).
3) Daimler: Diesel Engines for new E-Class MTZ worldwide, Volume 63 (2002).
4) K. Hoag, B. Dondlinger, Vehicular Engine Design, Powertrain (2016).



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