Acoustic Challenges of Roller Bearings in Combustion Engines

Peter Genender[1], Klaus Wolff[1], Christoph Steffens[1]

[1] FEV Motorentechnik GmbH, 52074 Aachen, Deutschland, Email: genender@fev.de

Abstract

In addition to the efficiency of gas exchange and combustion, fuel consumption is influenced to a large extent by engine friction. The distribution of mechanical losses shows that with one third, the main and con rod bearings have the largest share in engine friction apart from the piston subassembly. When substituting the plain bearing by a roller bearing, a considerable potential for friction improvement can be realized which leads to a significant reduction of CO_2. From a given 1,6l 4-cylinder naturally aspirated gasoline plain bearing engine changed to roller bearings a proved 5,4% (NEDC) improvement of the fuel consumption resulted from reduced friction. The challenges resulting from the use of roller bearings in internal combustion engines are related to the disciplines acoustics, durability, and fabrication. For balancing shafts roller bearings have lately been introduced into serial production [1].

Within this article the main influencing factors on NVH will be identified by means of simulation and experimental investigations. It will be shown in which way the critical engine NVH as a matter of principle can be improved with the help of design modifications. Based on this knowledge, an advanced test engine was set up.

Vehicle measurements, which have examined the development stages of the rolling bearing engine, verify the significant NVH improvements. Finally, interior noise level as well as psycho-acoustic parameters are on the same level as in the series production engine with plain bearings.

Roller bearing engine generation 1

For demonstration of the fuel consumption reduction potential the plain bearings were replaced by roller bearings at the main and con rod bearings and the oil pump was modified to lower volumetric flow needed by roller bearings without any other design changes at the crank train. This design approved a 5,4% improvement of the fuel consumption in NEDC. But durability and acoustic issues were discovered as well. Vehicle interior noise is not acceptable with high roughness carried in the frequency range from 200 to 2000 Hz, see Figure 4 to Figure 7, coming close to diesel engine noise impression at coasting condition. As a side effect this experiment shows the strong dependency of engine roughness issues to the crank train dynamics.

Roller bearing engine generation 2

In order to improve the acoustics of roller bearing engines combined MBS, FEM and BEM calculations are carried out with focus on the main sensitivity parameters bearing clearance, bearing stiffness, crankshaft stiffness, crankshaft balance weights and bottom end structure, see Figure 1.

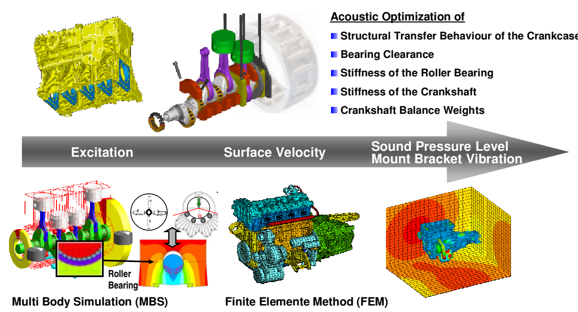

Figure 1: CAE-supported development and optimization procedure of a roller bearing engine by MBS, FEM and BEM calculation

For this task a special subroutine was developed in the model to describe the dynamics of crankshaft and bearing via the rollers correctly.

Figure 2: Crank train design of roller bearing engine generation 2.

Following design features were decided for the roller bearing engine generation 2 to optimize acoustics and durability, see Figure 2:

- 50% reduction of radial bearing clearance as the major acoustic influence factor
- 8 counterweights instead of 4 for fully cylinder wise balancing the crank train and reducing the mass force reaction crankshaft bending and bearing forces for improved acoustics and durability.
- Crankshaft material changed from cast iron to stiffer, case-hardened steel to reduce crankshaft bending and increase surface hardness for improved acoustics and durability
- Omission of outer bearing cage in con rod and direct rolling on con rod surface with higher roller diameters to increase durability

The conventional bottom end design optimization to improve the structural transfer behaviour shows minor improvement potential.

This redesign improved the acoustic behaviour, see Figure 4 to Figure 7.

Roller bearing engine generation 3

A further "design to concept" instead of "design to fit" approach implemented following design changes, see Figure 3:

- One piece con rods instead of cracked and bolted con rods reduce rotating masses by 30%
- One piece main bearings
- Rollers directly running in one piece con rod or main bearing surface, no split in surface
- Reduced tolerances in the system by above measures enable reduced clearances
- Screwed counterweights

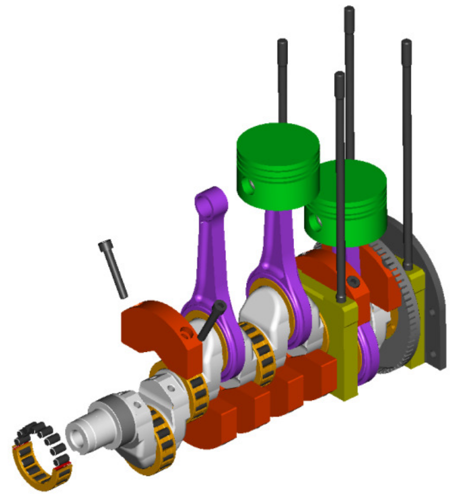

Figure 3: Crank train design of roller bearing engine generation 3.

This generation 3 design leads to even further improved durability and acoustic behaviour, see Figure 4 to Figure 7. Interior noise level and psycho-acoustic parameters similar to series production engine with plain bearings.

Measurement Results

The measurement results show interior noise measurements for the different roller bearing engine generations in comparison to the plain bearing engine

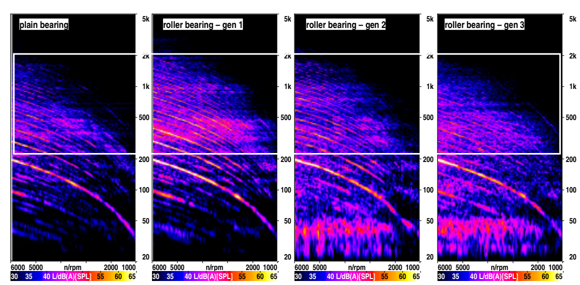

Figure 4: A-weighted campbell diagram, artificial head at passenger seat, coasting, 2nd gear

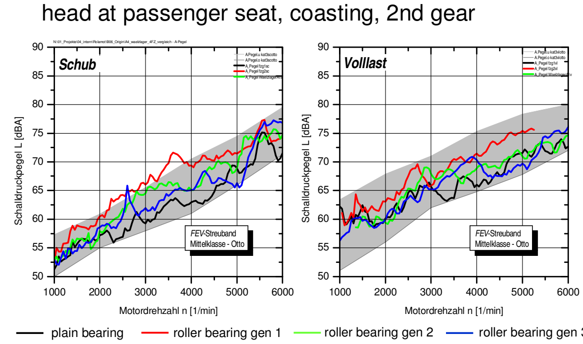

Figure 5: A-weighted level, artificial head at passenger seat, coasting (left) and full load (right), 2nd gear.

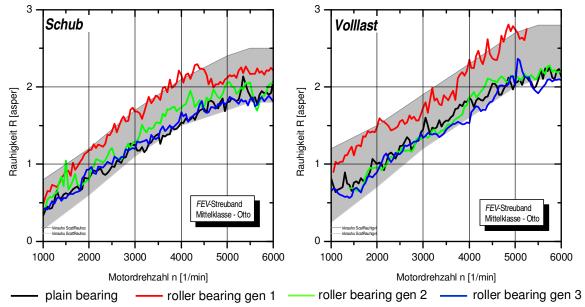

Figure 6: Roughness, artificial head at passenger seat, coasting (left) and full load (right), 2nd gear.

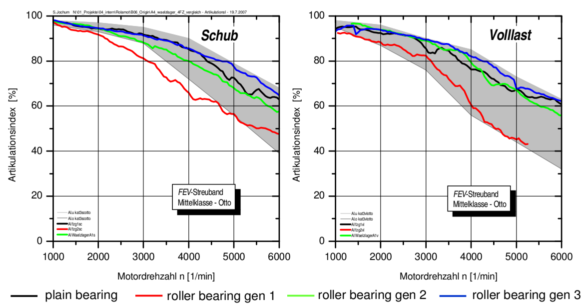

Figure 7: Articulation index, artificial head at passenger seat, coasting (left) and full load (right), 2nd gear

References

[1] Integriertes Ausgleichswellensystem des neuen Vierzylinder-Dieselmotors von BMW, MTZ 69 (06/2008)