

NVH Development of Aluminum Axles

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ABSTRACT

This paper discusses approaches to properly design aluminum axles for optimized NVH characteristics. By effectively using well established and validated FEA and other CAE tools, key factors that are particularly associated with aluminum axles are analyzed and discussed. These key factors include carrier geometry optimization, bearing optimization, gear design and development, and driveline system dynamics design and integration. Examples are provided to illustrate the level of contribution from each main factor as well as their design space and limitations. Results show that an aluminum axle can be properly engineered to achieve robust NVH performances in terms of operating temperature and axle loads.

CITATION: Sun, Z., Steyer, G., Chung, C., and Kopp, G., "NVH Development of Aluminum Axles," *SAE Int. J. Passeng. Cars - Mech. Syst.* 8(2):2015, doi:10.4271/2015-01-2188.

INTRODUCTION

With today's high competitiveness in the automotive industry and the pressure of CAFE regulation, the trend of using lightweight and mass optimized structures becomes one of the key factors for future success of an auto company. Utilizing alternative metals such as aluminum to replace traditional cast iron or steel have become more common. For automotive drive axles, the weight savings using aluminum housing to replace traditional cast iron can be extremely significant. However drive axles with aluminum carriers pose new challenges to engineers, in particular for their NVH performances. This is largely due to the significantly higher thermal expansion rate and lower elastic modulus of aluminum compared with cast iron and steel.

The major NVH risks aluminum axles pose can be categorized as:

- Lower mass - with the same vibration source level, this generally means higher vibration responses.
- Lower elastic modulus - with the same geometry, aluminum part has lower stiffness; which means design optimization is required, typically with mass added back, to achieve needed stiffness.
- Thermal expansion effect on bearing preloads. For taper roller bearings that are typically used in axles, maintaining the bearing preload is critical for needed bearing stiffness. There's a tendency of losing bearing preload as the aluminum housing grows faster than the bearings with rising temperature. Consequently bearing stiffness can be quickly lost at temperature if not properly designed.

The loss of bearing stiffness due to thermal expansion has significant impact on driveline system dynamics in that:

- It shifts driveline system dynamics, causing elevated system modal coupling and therefore high vibration and noise
- It causes NVH performance variations of driveline system, which makes implementation of modal mapping strategies difficult if not impossible.

Another important impact it has is on the gear contact position - if not properly designed, the thermal expansion could create elevated gear mesh transmission error and variations due to shift of gear contact patterns. Under extreme situations, edge contact or interference may happen, causing severe NVH or even durability issues.

Figure 1 shows the performance of an aluminum axle at early design stage. The axle was tested in a dynamometer focusing the product robustness in NVH performance. It is clearly illustrated that the thermal sensitivity has extremely high similarities to the axle pinion preload sensitivity. This is due to the fact that the resulting effect from thermal expansion is the loss of axle pinion preload. FEA predicted axle gear mesh responses at different levels of pinion bearing stiffness also agreed well with test data. Results suggested that maintaining the axle pinion preload under high operating temperature is the key to the success for aluminum axles.

Through over a decade engineering practices on aluminum axle products, we have developed an engineering approach that has successfully helped the company to launch numerous aluminum axle products. The approach combines applying engineering best practices

and design procedures, as well as intensive upfront CAE analysis and design optimization activities. It also involves a well-defined CAE engineering process across multiple engineering organizations.

The major factors for a successful aluminum axle product include:

- Axle carrier design
- Bearing architecture and bearing selection
- Gear design and optimization
- Optimization of driveline system dynamics
- Vehicle integration

These factors will be discussed in detail in this paper with illustrations.

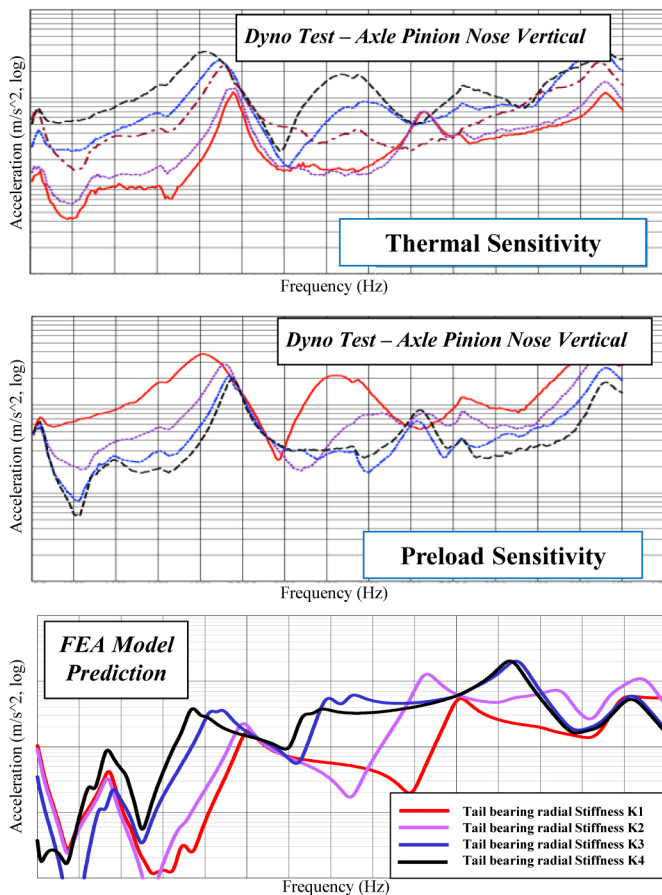


Figure 1. Example of thermal sensitivity and pinion preload sensitivity of a front independent axle, and FEA model predictions on pinion bearing stiffness sensitivity

AXLE CARRIER DESIGN

Carrier design is critical for aluminum axles in two folds:

1. The axle carrier stiffness, particularly the carrier bearing bore stiffness is a critical part of the combined effective bearing stiffness in supporting the pinion shaft.
2. The carrier geometry design is critical to proper support of bearing assembly. This requires:

- a. Minimization of the bearing bore distortion due to bearing cup press fit
- b. Proper design of oil channel location and geometry.

Figure 2 shows an example of FEA evaluation on carrier bearing bore stiffness. This type of analysis is critical to ensure the carrier contribution to the effective pinion bearing stiffness is sufficient.

The axle pinion bearings are loaded directionally by axle torque due to the hypoid gear in the axle by nature. With increase of axle torque, the uneven loading on rolling elements becomes more severe. Figure 3 shows a set of head and tail bearings in a front axle application under 450Nm gear torque load. It is expected that at certain high level of load, some rollers will eventually start to lose contact. It is critical that the lubricant flow channels are away from the primary loading zone of the bearings so that sufficient support from carrier bearing bore can be maintained.

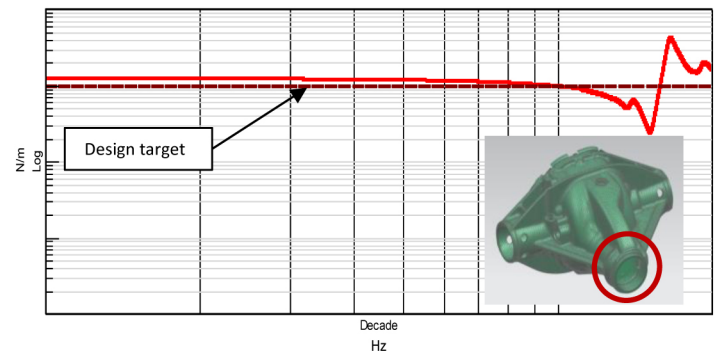


Figure 2. An example of axle pinion tail bearing bore stiffness FEA result against design target

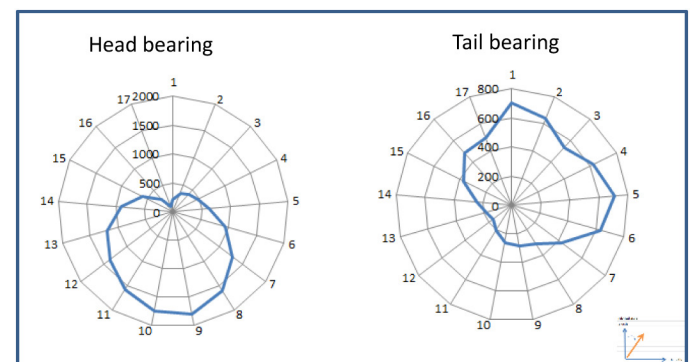


Figure 3. Axle pinion bearing load distributions on a front axle

Another factor in carrier design is the thermal growth in the bearing bore area. The structure needs to be optimized to minimize circular distortion at temperature. Well-developed CAE tools and procedures are important to make the effort successful.

BEARING SELECTION AND DESIGN

Bearing selection has two different categories: type of bearings for particularly design needs; and detail bearing size and geometry.