

Bearing Surface Requirements (Waviness) for Driveline Shafts

2011-01-0228

Published
04/12/2011

Anthony George Konstantino and Mark A. Levine
Chrysler

Copyright © 2011 SAE International

doi:10.4271/2011-01-0228

ABSTRACT

This paper summarizes the Fast Fourier Transform (FFT) methodology, special equipment, set-up and testing that is recommended to properly characterize the surface of bearing journals that will not result in objectionable noise or vibration. Traditional surface profiles and finish callouts do not capture some of the key characteristics for addressing what is often the customer's greatest complaint, noise. Noise can vary based on the sensitivity of the vehicle but understanding how to accurately describe (design, test, and measure) a surface for a given vehicle can result in an optimized design and reduce process time during manufacturing. Furthermore, this paper will recommend techniques for determining the proper limits of the FFT callouts.

INTRODUCTION

Axle systems contain components that can be a source of noise if not defined properly. The focus of this paper deals with “direct on roller bearing” applications within a semi-float axle design; however, many of the principles discussed in this paper can be applied to similar applications that involve direct on roller bearings as a means to support rotating shafts. Below is an isometric view of a semi-float axle system that can be used as a point of reference in reviewing this paper ([Figure 1](#)). A cross sectional view is also included to help the reader relate to similar applications in which the information in this paper may be applied.

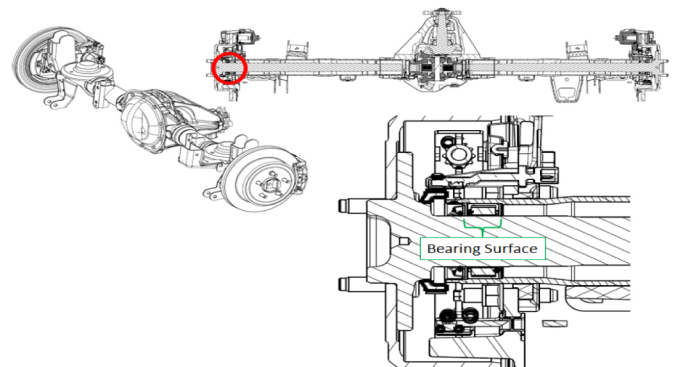


Figure 1. Semi-float axle assembly isometric, cross section & bearing interface exploded view

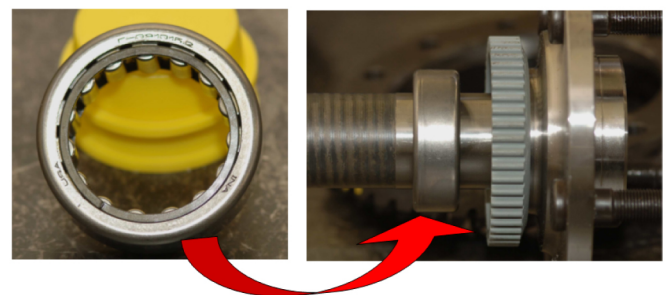


Figure 2. Left-side - direct on roller bearing; Right-side - bearing positioned onto axle shaft

For the purposes of this paper it is important to have an understanding of how a direct on roller bearing system functions. [Figure 2](#) shows a stand-alone bearing and its on-shaft position. The bearing is supported not only by the shaft but also by the axle tube in which the bearing is pressed. Since the axle shaft bearing surface is in direct contact with the rollers of the bearings, the bearing raceway irregularities

on this surface may cause an unacceptable level of noise that can ultimately be transmitted into the vehicle.

There are many potential transfer paths into the vehicle stemming from axle shaft bearing surface imperfections. Mainly, noise generated from the interaction of the rollers on the surface irregularities can manifest through the axle tube and into the vehicle via the suspension attachment points between the axle and the vehicle. This paper will describe the steps necessary to establish a bearing journal measurement method on semi-float beam axle designs as well as a technique for developing those limits. Following this process will provide an alternative to visual inspection as a method of determining if chatter on a journal surface is sufficient or not, which may be thought of as a component level sort criteria. In addition, the use of this technique will eliminate the need for a subjective attribute gage and provide a more discrete and objective measurement system.

Three processes will be defined: a process for the inspection; a four part process that develops the undulations per revolution (UPR) limits; and a correlation process. Defining the proper limits based on vehicle sensitivity will affect the cost of the product as the limits will dictate the appropriate manufacturing processes used (hard turning, grinding, super-finishing, polishing, honing, etc.).

This paper also discusses the Waviness (Lobing and Chatter) requirements for bearing journal surfaces on driveline shafts but does not specifically cover Profile (Runout, Roundness, Diameter, Taper, Perpendicularity, etc.) and Roughness (Ra, Rz, etc.) requirements. It is also important to distinguish the filters that are used in a FFT measurement. “Chatter” is measured unfiltered and is defined as having a regular occurrence (sinusoidal / equally spaced), while “Lobing” is measured using a filter and is defined as having an irregular / random occurrence. [Figure 3](#) distinguishes the differences between lobing and chatter for a given bearing surface.

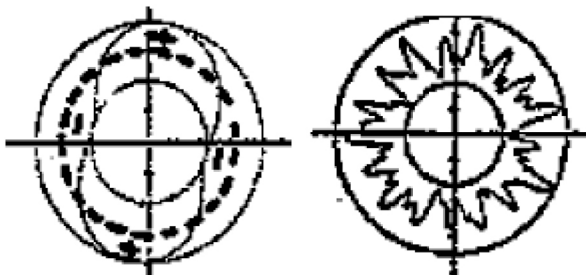


Figure 3. Distinguishing lobing (left side) versus chatter (right side) [1]

FFT AS A CHARACTERIZATION METHOD

In order to proceed with the development of properly characterizing bearing surfaces using the FFT Characterization Method, a Cylindrical Coordinate Measuring Machine (CCMM) and associated software must be capable of performing an FFT (Fast Fourier Transform) Analysis on a surface trace.

A CCMM characterizes the physical geometry of an object or surface. When measuring a bearing surface, the CCMM will take a circumferential trace which is needed for the FFT analysis. The FFT then breaks down the surface trace into different harmonics, referred to in this document as undulations per revolution (UPR). UPR's can also be thought of as the number of periodic waves found in 360 degrees. Each UPR will have distinct amplitudes which provide the harmonic orders of interest to the engineer. Details of the recommended special equipment specifications for CCMM's are provided in the Reference section of this paper. [2]

The result of an FFT is a plot of amplitude versus UPR for a given surface. An example of this is provided in [Figure 4](#).

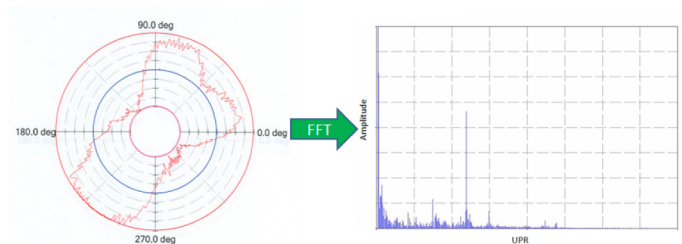


Figure 4. Surface profile trace analyzed into an FFT output

In order to properly characterize the bearing surface, a trace must be taken at three distinct locations as defined by [Figure 5](#). This is done at three equally spaced contact points from edge to edge on the bearing rolling surface. The bearing rolling surface must be defined appropriately by the customer as these points will be used during the development of the FFT limits.

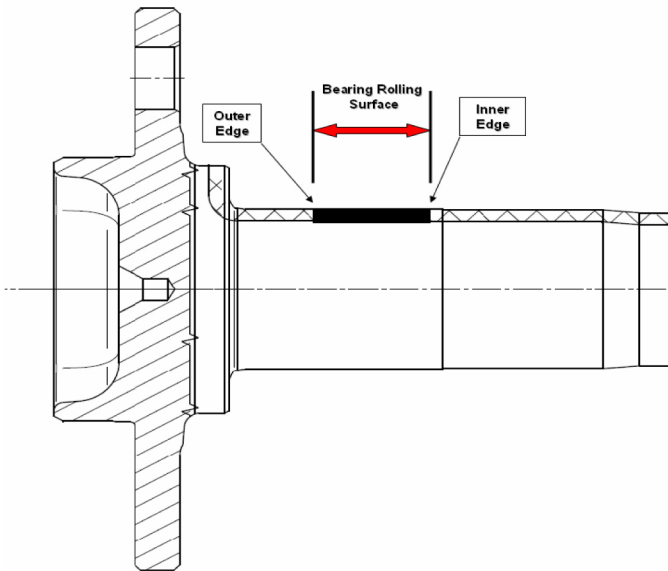


Figure 5. Example of an axle shaft bearing rolling surface

DEVELOPMENT OF THE FFT AMPLITUDE LIMITS

Once the part has been characterized using a CCMM and the Amplitude vs. UPR curves have been processed using an FFT tool, the amplitude limits need to be determined. Developing the Undulation per Revolution (UPR) Amplitude Limits is a four part process (Part A thru D described below). This four part process will ensure that the requirements set forth meet the vehicle sensitivity and functional objectives. An overview of the process is listed below:

Part A. Develop a “Regression Curve”. The Regression Curve is developed so that UPR limits are set for any low harmonic (lobing) characteristics of the part and is largely dependent on the roundness specification of the design. For the purposes of this paper, the UPR range for low harmonics is considered to be between 1 and 48 inclusive.

Part B. Develop a “Horizontal Line”. The Horizontal Line is developed so that UPR limits for amplitude are set for any high harmonic (Chatter) characteristics of the part (48 UPR and greater in this paper).

Part C. Develop a “Hybrid Curve”. The Hybrid Curve combines the Regression Curve and the Horizontal line into one curve that defines the limits for the entire UPR range.

Part D. Superimpose the “Hybrid Curve” onto the FFT graph. This is used as a way to determine if a part meets the product specification or not.

PART A: DEVELOP “REGRESSION CURVE”

The maximum amplitude for all UPR's between 1 and 48 inclusive will be developed using a regression curve (intentionally omitted due to its proprietary nature). The regression curve is valid only to a certain UPR and may differ from the 48 UPR specified above (see Part C below). In [Figure 6](#), the black line is the curve developed using the “Regression Curve Formula” over the entire UPR range.

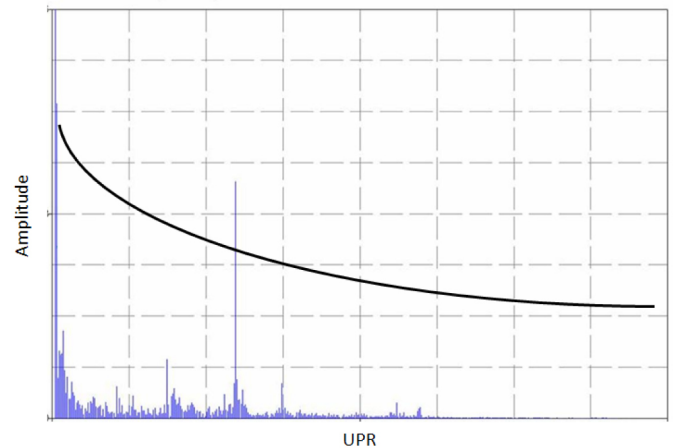


Figure 6. Regression curve

PART B: DEVELOP “HORIZONTAL LINE”

The development of the “Horizontal Line” requires a four step process within itself which is listed below. This process will develop the proper maximum amplitude limit for the “Horizontal Line”. The objective of the “Horizontal Line” is to set the maximum amplitude allowed in the high harmonic range (above 48 UPR's for the purposes of this paper).

Step 1.1. Capability

Understand the manufacturing capability of UPR's based off all lines machining the bearing surface. UPR is often a characteristic of the machining process parameters and therefore each machine may have its own UPR signature. In order to properly understand the manufacturing capability, all machining lines must be analyzed for process variability. This includes but is not limited to parameters such as C_{pk} and C_p for each machining line and process.

Step 1.2. Best of the Best (BOB) & Worst of the Worst (WOW) Sample Selection

Obtain the “highest amplitude” axle shaft for a given UPR from each machining line and process. Differences in each machine require this diligence because of influences from speeds, feeds, grinding wheel diameters, polishing paper, machine location relative to plant layout, etc. These “highest