

The Development of a Variable Center Distance Gear Noise Test Facility

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American Gear Manufacturers Association



TECHNICAL PAPER

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ABSTRACT:

This paper is concerned primarily with the development of a gear noise test facility which is currently being used to study the fundamental sources of gear noise excitation through the testing of carefully controlled pairs of gears. The system was designed around a special variable center distance gearbox that is capable of running a pair parallel axis spur or helical gears under conditions similar to those encountered in an automobile transmission. The test facility allows the parametric study of various gear design parameters, mounting conditions, and operating environments on the dynamic performance of a gear pair. A discussion of various physical parameters which may be experimentally measured in an effort to evaluate the dynamic performance of a gear pair is given. Three methods of computing dynamic transmission error from torsional acceleration measurements are also presented.

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DEVELOPMENT OF A GEAR NOISE TEST FACILITY

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INTRODUCTION

Gear noise has been a problem associated with mechanical equipment for decades with interests in this area steadily increasing in recent years, especially in the automotive and aerospace industries. In response to this increased interest in the reduction of gear noise, there has been a corresponding increase in the technical literature published on this subject [Houser 1987]. Much of this literature deals with analytical and computer models for the prediction of noise generated by a gearbox and the optimization of gear tooth profiles which will result in the reduction of gear noise excitation. There has also been considerable experimental research in the area of gear noise. The majority of this research has dealt directly with the analysis of specific problems involving gear noise generated by existing mechanical equipment. Experimental results which attempt to correlate levels of gear noise excitation with the physical design parameters of a gear pair running under various operating conditions is rather scarce. This information is essential in aiding the gear designer striving to reduce noise and to verify the vast amounts of analytical research that have already been performed.

In this study, a gear noise test facility was constructed which is currently being used to perform parametric studies on the effects of various gear design parameters, mounting conditions, and operating environments on the dynamic performance of a gear pair. The facility is oriented towards

the testing of automotive type gears. This paper is concerned primarily with the development of the test facility and the measurement of several physical parameters which may be used to evaluate the dynamic performance of a gear pair. However, only limited experimental data is presented. Detailed parametric studies and the refinement of the various measurement techniques described here will be presented at a later date.

BACKGROUND

A review of the technical literature reveals that there have been many different types of gear testing machines developed in the past and that these may be divided into 15 classes [Lema 1981]. Two basic types of gear testing machines which have been widely used to study the dynamic performance of a gear pair include power absorption and power recirculation types. Examples of test rigs used for dynamic studies based upon the power recirculation principle may be found in the literature [Remmers 1971], [Lema 1981]. Basically, a test gearbox is connected to a slave gearbox of the same ratio in a four-square arrangement as shown schematically in Figure 1. The gears may be preloaded by a variety of different mechanisms [Shipley 1958] such as an adjustable torsion bar. The system may be driven by a relatively small motor since the only power dissipated is due to the frictional losses in the bearings and gear meshes. Usually the test gearbox is isolated from the slave gearbox through long slender shafts in order to reduce

torsional excitation input to the test gear mesh from the slave gear mesh.

An example of a gear noise test stand based upon the power absorption principle is presented by Hayashi[1981]. Basically, the input of the test gearbox is driven by a driving dynamometer and the output of the gearbox is connected to a power absorbing dynamometer as shown schematically in Figure 2. The test stand developed in this study was based upon the power absorption principle. This was mainly due to the intended generality of the system which is used to test gears of many different sizes and ratios.

DESIGN SPECIFICATIONS

The design specifications of the test facility were based upon a review of current gear noise test stands of similar nature and upon the practical experience of several gear design engineers. The test gearbox has the capability to accurately vary the center distance between gear shafts over a range from approximately one to seven inches. The test gearbox also has the capability of providing intentional shaft misalignment in directions both parallel and perpendicular to the plane containing the ideal center lines of both test gear shafts. This allows the effects of mounting errors on the performance of a gear pair to be studied. Test gear face widths may range up to 1-1/2 inches.

The test gearbox is driven by a 150 horsepower dynamometer and is capable of operating at speeds ranging from 50 to 3500 RPM. The controlled variables include the physical design parameters of the test gears, the center distance and alignment of the test gear shafts, the nominal operating speed and torque, and the temperature and application of the gear mesh lubrication.

Table I Design Specifications of the Test Facility

Test Gearbox	
Face Width:	up to 1.50 inches
Center Distance:	1.125 to 6.500 +/- 0.001 in.
Gear Outside Diameter:	1.00 inch min. 7.00 inches max.
Helix Angle:	0 to 30 degrees
Number of Teeth:	20 min. 60 max.
Ratios:	1:1 to 1:4 Reduction
Operating Ranges	
Speed:	3500 RPM max
Torque:	4200 in-lb _f max.

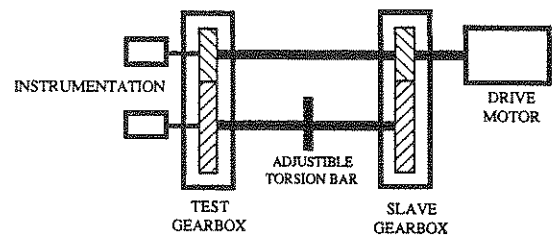


Figure 1 Power Recirculation Gear Test Rig.

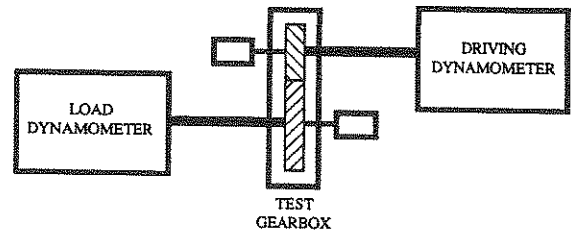


Figure 2 Power Absorption Gear Test Rig.

System Layout

The basic layout of the test stand is shown schematically in Figure 3. Some compromises were made to the ideal design of Figure 2 in order to obtain a system that was both practical and economical. The driving dynamometer is coupled to an input drive shaft which in turn is connected to a relatively compliant elastomer flywheel coupling. This coupling isolates the test gearbox from vibratory excitations due to input shaft misalignment and rotating unbalances. A torque sensor mounted in-line between the flywheel and input test gear shaft monitors speed and torque. The torque sensor is coupled to the input test gear shaft through a low inertia coupling which is torsionally rigid, but relatively compliant in the axial and transverse directions. This coupling serves to uncouple the test gearbox from axial and transverse vibrations of the input shaft while minimizing distortion of the dynamic torque measurements. The test gearbox is intended to be operated as a speed reducer drive. The output of the test gearbox is connected to an output drive shaft via a low inertia flexible coupling which is relatively compliant in all directions. The opposite end of the output drive shaft is coupled to a speed increaser gear drive by a torsionally stiff flexible coupling which can tolerate substantial misalignment between the two shafts. The purpose of the speed increaser drive is to bring the rotational speed of the system into the favorable operating range of the power absorbing dynamometer, a water cooled eddy current brake.

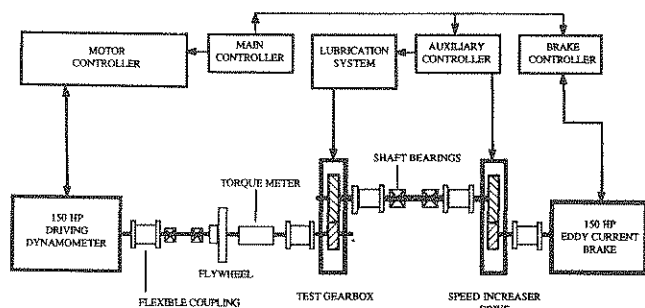


Figure 3 Block Diagram of Gear Noise Test Facility

Test Gear Box

The main housing of the test gearbox was designed to be very rigid. The approximate overall dimensions of the gearbox are 22" wide by 32" tall by 6" deep. The walls of the housing are constructed of steel approximately 1" thick. The top cover of the gearbox is constructed of thick plexiglass to allow visual observation of the test gears. The test gears are straddle mounted on standard arbors between constant preload duplex back-to-back angular contact bearings. These bearings are capable of supporting axial loads so that helical gears rotating in either direction may be accommodated. Transverse vibrations of the test gears are minimal due to relatively stubby gear shafts and double row bearings supporting either end. System torque is applied to opposite sides of the gear mesh. Instrumentation devices such as optical encoders or angular accelerometers are connected to the free ends of the test gear shafts.

Each test gear shaft is constrained to rotate within a bearing assembly located on opposite side plates of the gearbox. Both side plates are free to slide apart from the main housing when unbolted along two linear bearing assemblies. This allows for the easy disassembly of the gearbox when changing gear sets. The input shaft bearing assemblies are fixed to the respective side plates in stationary locations. The output shaft bearing assemblies are attached to eccentric mechanisms located on either side plate as shown in Figure 5. Rotation of this eccentric disk allows the center distance to be adjusted. Gage bars located over the outer locating surfaces of the bearing assemblies accurately determine the center distance and restrain the eccentric mechanisms from movement.

Types of Shaft Misalignment

There are five basic types of mounting errors or misalignments which may exist between gear shafts. For purposes of illustration, assume that a pair of gears are in mesh with their ideal center lines both lying parallel in the horizontal plane. Further assume that one shaft remains in its ideal position. *Center distance offset* simply involves a constant offset between two parallel shafts whose center lines both lie in the same plane. *Parallelism misalignment* is angular misalignment between two shafts whose center lines both lie in the same plane, i.e. the horizontal distance between the two shafts varies along the length of the shafts while both have the same vertical location. Two separate parameters must be specified in order to quantitatively define

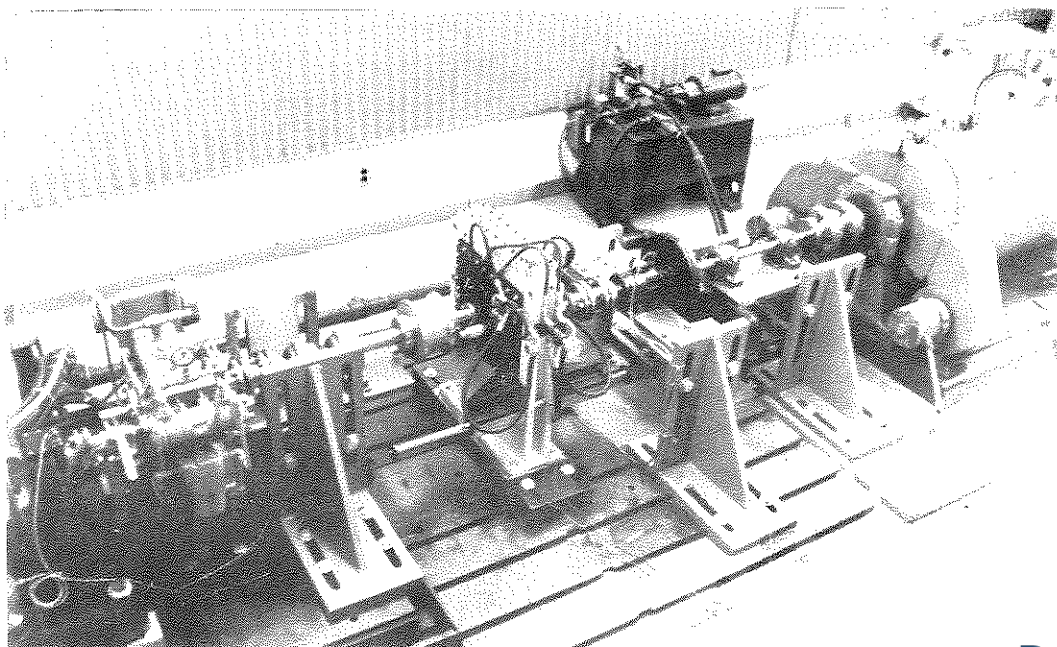


Figure 4 Photograph of Gear Noise Test Facility