

The Relative Noise Levels of Parallel Axis Gear Sets with Various Contact Ratios and Gear Tooth Forms

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[The statements and opinions contained herein are those of the author and should not be construed as an official action or opinion of the American Gear Manufacturers Association.]

ABSTRACT:

The real noise reduction benefits which may be obtained through the use of one gear tooth form as compared to another is an important design parameter for any geared system, especially for helicopters in which both weight and reliability are very important factors. This paper describes the design and testing of nine sets of gears which are as identical as possible except for their basic tooth geometry. Noise measurements were made at various combinations of load and speed for each gear set so that direct comparisons could be made. The resultant data was analyzed so that valid conclusions could be drawn and interpreted for design use.

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INTRODUCTION

The problem of gear noise in helicopter transmissions is ever present. The main exciting forces which produce this noise are the meshing forces of the gear teeth in the transmission. While this is certainly an oversimplification, since many factors influence transmission noise aside from the gear mesh forces, the simple fact remains that if the basic exciting forces are reduced and no amplifying factors are present, the overall noise level of the system will be reduced.

Among the several ways in which the gear tooth meshing forces may be reduced, two of the most directly applicable to helicopter transmissions are the form of the teeth and the overall contact ratio. Both approaches are quite attractive for an aerospace application since, unlike other "treatment" methods, which are applied with penalties to either system weight or performance, these approaches have the potential for reducing noise without causing any increase in overall system weight or reducing performance. In fact, both approaches also offer the possibility of actually providing improved gear performance in terms of longer life, higher load capacity, improved reliability, and reduced weight while simultaneously reducing noise levels.

The objective of this program was to define, by controlled testing and actual noise measurements, the effect of changes in the profile, face, and

modified contact ratios and the gear tooth form, separately and in combination, for spur and helical gears, on the noise levels produced by otherwise identical spur and helical gears. In order to accomplish this objective, a program was defined to design appropriate gears (Table I), fabricate a sufficient number of test specimens, and conduct the testing required.

While a wide range of specimens is shown, they were all configured as nearly alike as practical, within the limitations imposed by manufacturing considerations and the test stand. Testing was conducted in a single mesh gear box under controlled conditions which were maintained as nearly identical as possible. Acoustic intensity measurements were taken with the aid of a robot to insure repeatability of measurement between gear sets and to minimize human technique influence.

TEST GEAR DESIGN

Eight (8) sets of gears, four (4) spur and four (4) helical as listed in Table I, compatible with the NASA Lewis gear noise test rig, were designed. Of the four sets of spur gears, two sets have an involute tooth form and two utilize a noninvolute, constant radius of curvature tooth form. All gears were designed in accordance with normal Boeing Helicopters practice so that, except for size, they are representative of typical helicopter gears.

Table I Gear Noise Test Matrix

Configuration	Tooth Form	Type	Contact Ratios		
			Profile	Face	Modified
1. Conventional Spur Baseline	Involute	Spur	1.25	0.00	1.25
2. HCR-INV	Involute	Spur	2.15	0.00	2.15
3. Conventional Single Helical Baseline	Involute	Helical	1.25	1.25	1.77
4. Double Helical	Involute	Helical	1.25	1.25	1.77
5. HCR-INV	Involute	Helical	1.25	1.75	2.15
6. HCR-INV	Involute	Helical	2.15	2.25	3.11
7. NIF Baseline	NonInvolute	Spur	1.25	0.0	1.25
8. NIF-HCR	NonInvolute	Spur	2.15	0.0	2.15

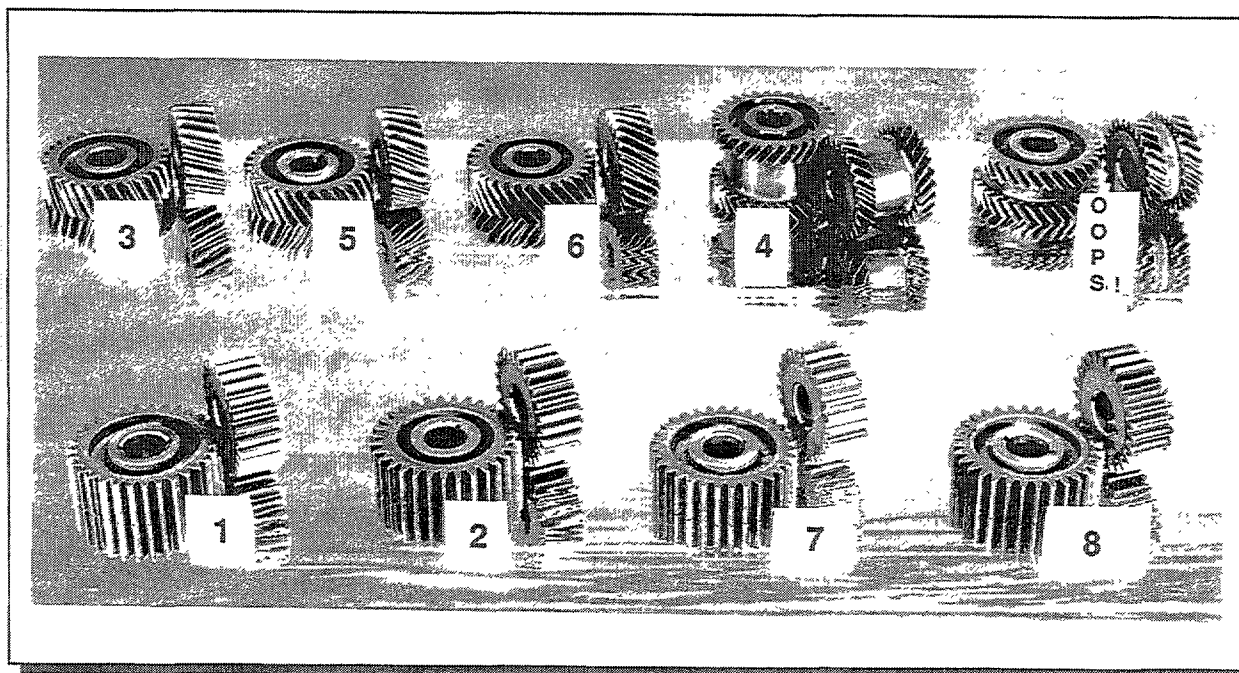


Figure 1 - Test Gears

Table II - Basic Test Gear Configuration

	Pinion	Gear
Number of Teeth	25	31
Diametral Pitch, Transverse	8.	
Center Distance	3.50	
Pressure Angle, Transverse	25 (Std Profile Contact Ratio)	
	20 (High Profile Contact Ratio)	
Face Width (Spur & Single Helical)	1.25	
Face Width (Double Helicals)	Double Helicals 0.625 ea Helix	

Since these gears were tested in the NASA test rig, it was also necessary to maintain compatibility with the test rig. The standard NASA test gears incorporated a loose fit between the gear bore and the shaft outside diameter. In order to be sure that the noise test results, especially for the helical gears, were not affected by this loose fit, it was changed to a press fit which would be more typical of that used in a helicopter application. While this change caused some difficulty in changing from one configuration to another, it was important from a test validity point of view. Previous¹ NASA testing of Boeing Helicopters designed small gears using the high profile contact ratio noninvolute tooth form (HCR-NIF) indicated that their surface load capacity was substantially higher than that of conventional involute gears and that their bending load capacity (at torque loads) was at least equal to and actually slightly greater than the standard involute gears. The scoring resistance of the HCR-NIF gears, in the NASA tests, appeared to be lower than that of equivalent standard gears. The lower scoring load capacity performance may have been due to inadequate profile modification on the small test gears therefore the HCR-NIF gears for this testing incorporated improved profile modifications.

The test gear configurations were selected to be representative of those which are either actually in use or have near term potential of being used in helicopter transmissions. While lower noise levels are generally associated with helical gears as compared to spurs, there was no definitive data, for accurate, ground tooth gears, which defines the noise advantage which may be obtained. Similarly, anecdotal information indicates that higher contact ratios, both face and profile, also tend to reduce noise levels but, again, hard data was not readily available.

While helical gears provide some noise reduction, their use also generates a thrust load which must be dealt with in the design of the overall system, especially the support bearings, gear blank design, and housing structure. Double helical gears provide some relief from the net thrust problems, however, the thrust loads from each helix must still be cancelled within the gear blank and the overall effect of this on the noise level of the gear has not been studied at all.

New tooth forms of various noninvolute types have been investigated for possible use in helicopter transmissions in recent years but these investigations have centered almost universally on the load capacity

aspect of the forms and not their noise behavior. One of these has demonstrated some potential for improved load capacity in previous testing.

Considering all of these factors, the range of gear configurations defined in Table I and shown in Figure 1 was selected to provide some basic answers to their respective noise behaviors. The basic gear tooth data for the test gears is provided in Table II.

TEST FACILITY

The NASA Lewis Research Center gear noise rig, Figure 2, was used for these tests. This rig features a single-mesh gearbox powered by a 150 kW (200 hp) variable speed electric motor. A poly-V belt drive was used as a speed increaser between the motor and input shaft. An eddy-current dynamometer loads the output shaft at speeds up to 6000 rpm. The rig was built to carry out fundamental studies of gear noise and the dynamic behavior of gear systems. It is designed to allow testing of various configurations of gears, bearings, dampers and supports.

To reduce unwanted reflection of noise, acoustical absorbing foam baffles cover test cell walls, floor, and other surfaces. The material attenuates reflected sound by 40 dB for frequencies of 500 Hz and above.

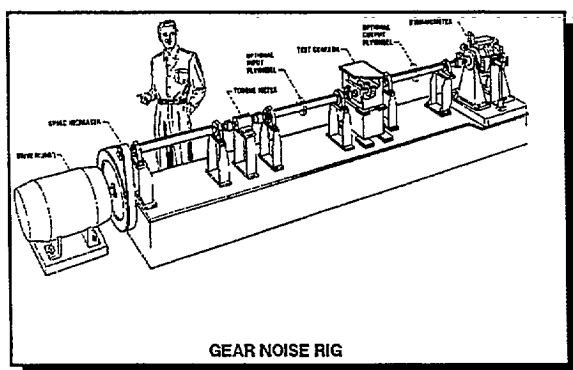


Figure 2 - Nasa Gear Test Rig

A 20 node measurement grid was drawn on the top cover of the gear box and used to insure repeatability of the noise measurements and to aid in avoiding operator induced errors. The grid covers an area 228 x 304 mm (9 x 12 in) centered on the 286 x 362 mm (11.25 x 14.25 in) top. A cutaway section of the test gear box is shown in Figure 3. All data was collected

using the computer controlled robot arm coordinated with the reference grid so that no matter what gear set was running, the readings were identically taken.

INSTRUMENTATION

An experimental modal test was performed to determine the modes of vibration and natural frequencies of the gearbox top. An 800 line, 2-channel dynamic signal analyzer collected frequency-domain data. Commercial modal software running on a personal computer was used for the analysis. The tests were performed with the gearbox heated to operating temperature. The structure was excited sequentially at each of the 63 nodes using a load cell equipped modal hammer to measure excitation forces. The response was measured with a small piezoelectric accelerometer mounted at a reference location near the center of the gearbox top.

The gear box modal test was not accomplished as part of this program. The modal testing was performed as part of a previous program². Modal test results were used to assure that gear mesh frequencies did not coincide with important modes of the gear box.

NOISE MEASUREMENTS

Acoustic intensity measurements were performed, under stable, steady-state operating conditions, with the aid of a computer-controlled robot designated RAIMS^{3,4}, (Robotic Acoustic Intensity Measurement System). The RAIMS software commanded the robot, Figure 4, to move an intensity probe over a prescribed measurement grid; recorded acoustic intensity spectra in the analyzer for each node of the grid; and transmitted the spectra to the computer for storage on disk.

The acoustic intensity probe consists of a pair of phase-matched 6 mm microphones mounted face-to-face with a 6 mm spacer. The probe has a frequency range (± 1 dB) of 300-10,000 Hz. Measurements were made at a distance of 60 mm between the acoustic center of the microphones and the gearbox top.

The 20 intensity spectra collected at each operating condition were averaged, then multiplied by the radiation area to compute an 800 line sound power spectrum. The radiation area was assumed to be the area of the grid plus one additional row and column of elements or 0.0910 m². The actual area of the top is 0.1034 m². The measurement grid did not extend