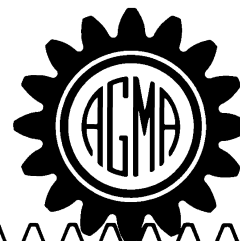


Isotropic Superfinishing of S-76C+ Main Transmission Gears

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American Gear Manufacturers Association



TECHNICAL PAPER

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Bruce Hansen, Sikorsky Aircraft Corporation, Mike Salerno and Lane Winkelmann, REM Chemicals, Inc.

[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

Isotropic Superfinishing is a chemically accelerated vibratory finishing process that is capable of generating surface finishes with an Arithmetic Mean Roughness (R_a) $< 3 \mu\text{in}$. This process was applied to the third stage spur bull gear and mating pinions along with the second stage bevel gears of a Sikorsky S-76C+ main gearbox. The gearbox completed the standard Acceptance Test Procedure (ATP) and a 200-hour endurance test. During these tests noise, vibration, and operating temperatures were shown to be significantly reduced due to the lower friction. This technology has since been flight certified and integrated into the S-76C+ with several aircraft in commercial service. A description of the tests, performance data and a general description of the process will be presented.

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Introduction

Noise and vibration control is a primary concern for the transmission design engineer, and particularly so in the design of a helicopter main transmission. Excessive vibrations generated by transmissions typically result in undesirable noise levels in helicopter cockpits and/or cabins, which cause operator and/or passenger aural discomfort and/or damage to sensitive on-board instrumentation. Cabin and/or cockpit noise/vibration abatement is of particular concern in helicopters wherein the final stage of reduction gearing of the main transmission comprises one or more bull pinions interacting with a central bull gear.

For example, Sikorsky helicopters of the S-76 series, e.g., S-76A, S-76B, S-76C, have a main transmission that includes three stages of reduction gearing: a first stage for each engine output consisting of helical gearing, an intermediate stage consisting of spiral bevel gearing, and a final reduction stage comprising a central bull gear that intermeshes with right and left hand bull pinions (to combine the inputs of the two engines that provide the motive power for the helicopter). Research has shown that the cockpit and/or cabin noise levels of S-76 helicopters are primarily the result of vibrations originating in the main transmission.

Narrow band Fast Fourier Transform (FFT) analyses, A-weighted octave levels, and overall DBA levels recorded in the cockpits and/or cabins of S-76A, S-76B, and S-76C helicopters indicate that interior noise levels are predominately the result of vibrations occurring at the bull gearing meshing frequency of 778 Hz, as illustrated in Figure 1. The vibrations produced by the first and second reduction stages of S-76 main transmission gearboxes, i.e., the noise levels generated by the helical and spiral

bevel gearing as illustrated in Figure 1, occur at higher frequencies and typically are not significant relative to the dominant noise levels produced by the fundamental and first few harmonics of the bull gearing meshing vibrations.

The gearbox vibrations resulting from bull gear meshing are transmitted to the helicopter airframe via the transmission housing. The resultant airframe vibrations generate noise in the helicopter cockpit and/or cabin. Abatement of such noise by acoustic treatment of the cockpit and/or cabin interior is generally inefficient, and therefore, effective noise control solutions must be implemented at the noise source, i.e., the main transmission.

To effectively abate such noise, it is necessary to identify the primary causal factor(s) of bull gearing vibrations. The vibrations generated by the helicopter main transmission may be aggravated by meshing between misaligned bull gearing, i.e., the central bull gear and bull pinion(s). Previous efforts to reduce the noise levels generated by intermeshing between misaligned bull pinions and the central bull gear included modifications to provide effective bull gear tip relief. While such modifications resulted in a modest reduction in bull gearing vibrations, the resultant reduced interior noise levels of S-76 helicopters were judged to still present an unacceptable level of aural discomfort.^[1]

As a result, several avenues were explored to more fully identify the design and operating parameters that cause noise induced by the intermeshing gears of a drive train. One such avenue was the investigation of Superfinishing using Chemically Accelerated Vibratory Finishing. This process generates a very smooth surface on the flanks of gears and has proven its ability to reduce the coefficient of friction^[2], and in laboratory testing, the frictional component of noise known as Vibro-Acoustic Noise.^[3]

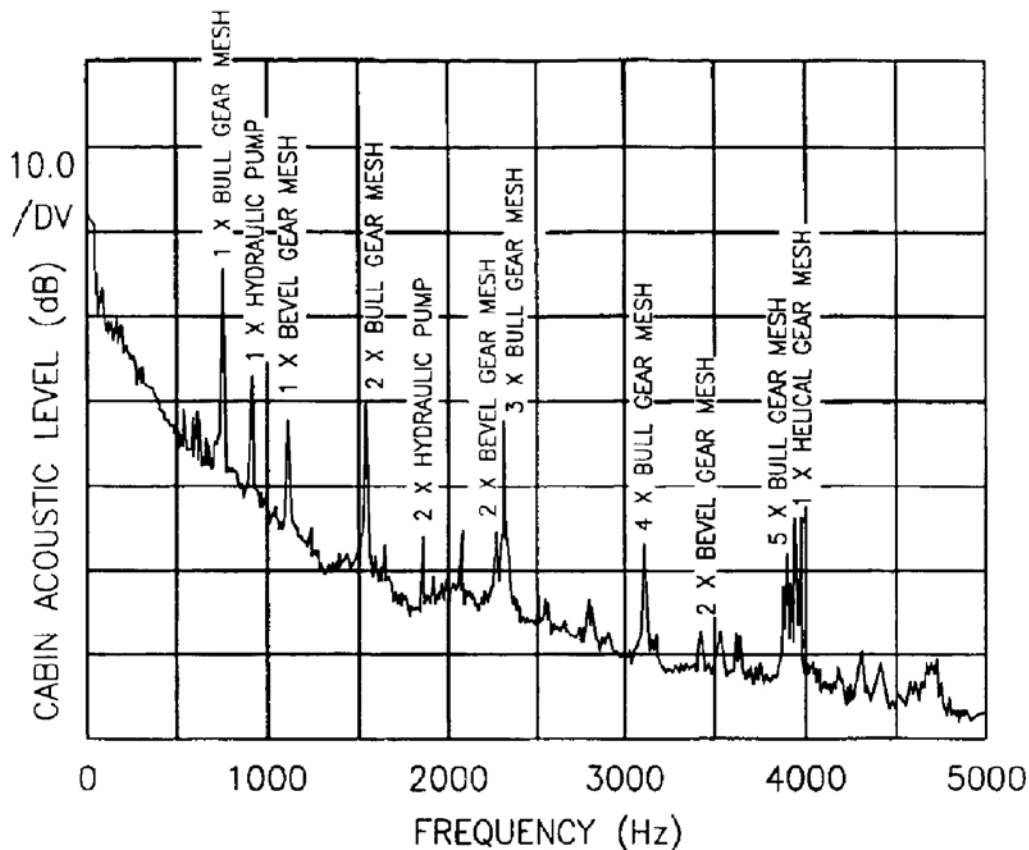


Figure 1: Chart showing that the predominant cabin noise is produced by the gearing meshing vibrations of the first few harmonics of the bull gear. Note that the highest cabin noise level is predominately the result of vibrations occurring at the first harmonic bull gearing meshing frequency of 778 Hz.

Vibro-acoustic noise

The gear meshing cycle consists of a large amount of sliding between the teeth making contact. At the pitch point, the gears experience pure rolling, however, the areas before and after the pitch point experience much more sliding motion. At this interface, the teeth experience high contact stresses which can result in low oil film thickness. When this happens, the result can be mixed or boundary lubrication conditions which lead to an increased coefficient of friction. At this point, the coefficient of friction is controlled either by the choice of lubricant or the surface finish of the teeth. This sliding and/or shearing of intermeshing teeth has been theorized as a significant contributor to the total noise signature of a gearbox and in the last few years, this theory has been proven in laboratory tests^{NO TAG}. As such, it will be appreciated that by Superfinishing, the friction coefficient on the gear teeth will be dramatically reduced, and so too, is the component

of noise produced by the sliding action of the inter-meshing gear teeth.

Superfinishing using chemically accelerated vibratory finishing

Chemically accelerated vibratory finishing incorporating high density non-abrasive ceramic media enhances the performance of components that are subjected to metal-to-metal contact or bending fatigue. The isotropic surface generated is unique when compared to even the finest honing and lapping in that it has no directionality and is capable of producing a final surface roughness of $< 4 \mu\text{in.}$ ($0.1 \mu\text{m}$) R_a . It has a texture which consists of only random scratches and shallow dents. When the resultant surface has an R_a of approximately $4.0 \mu\text{in.}$ ($0.1 \mu\text{m}$) or less and a non-directional surface pattern, it is referred to as an Isotropic Superfinish (ISF[®]), however, for this document Superfinish will be used to denote this process and surface topography. Figure 2 shows an SEM image at 1000X of a typical

ground surface with an R_a of approximately 10 $\mu\text{in.}$ (0.25 μm) ((top image) and a Superfinished surface with an $R_a < 2 \mu\text{in.}$ (0.05 μm) (bottom image) for reference. Note the directional asperities on the ground surface and the lack of directional asperities on the Superfinished surface. Only light scratches and tiny dents are visible amongst smooth, plateaued areas of the Superfinished surface. It is theorized that these tiny dents facilitate lubricant retention during operation.^[4] Such surfaces are

unique in their remarkable ability to reduce friction^[2], wear^[5], operating temperature^[6], and noise^[3], as well as contact^[7] and dynamic fatigue^[8] when compared to similar surface finishes produced by other techniques. There has been increasing interest over the years in applying this process to aerospace gears since the industry is being driven to produce higher cycle life gears at increased power densities while still allowing for large safety margins.

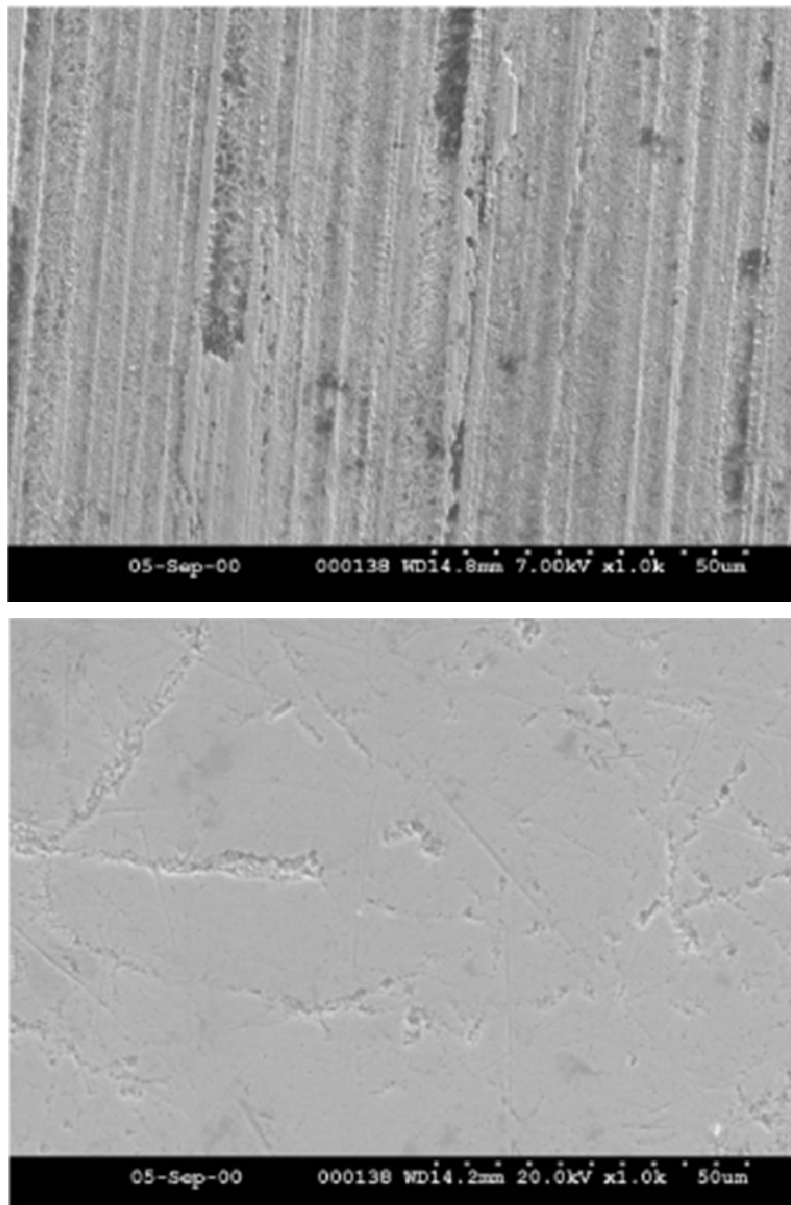


Figure 2: Scanning Electron Micrograph (SEM) at 1000X of a typical ground surface with an R_a approximately 10 $\mu\text{in.}$ (0.25 μm) (top) and a Superfinished surface with an $R_a < 2 \mu\text{in.}$ (0.05 μm) (bottom). Note the isotropic (non-directional) surface texture on the Superfinished surface versus the directional asperities on the ground surface.