Gearbox Noise

Much has been written on the factors involved in the generation of gear noise. It is only in recent years however the specific causes of noise generation in precision gears has been understood.

Three main factors are responsible for producing noise in a gear transmission; manufacturing errors, rotational speed and gear tooth load.

Accounting for these factors in a gearbox and assuming a properly designed system free of excess vibrations, the significant factors for low noise optimization are:

a. **Low gear transmission errors**

   Transmission errors are the result of gearset's operating with a combination of pitch, profile and tooth form errors. These errors will affect uniform loading and rotor runout. Gear transmission errors and the contact ratio of a gearset are very closely related when designing gears for low noise optimization.

b. **High contact ratio with helical gears**

   The total contact ratio of a gearset is the sum of the axial contact ratio plus the overlap ratio. Increasing the axial contact ratio by modification of the tooth addendum and/or adjusting the pressure angle heightens the tooth form and increases the line of action along a single tooth. A high tooth form with proper tip and root relief tempers the smooth entry of the tooth load from tooth to tooth. Increasing the overlap ratio by increasing the helix angle will permit the gear to share the load over more gear teeth thereby reducing the unit load. At the same time however increasing the contact ratio will increase the kinematic transmission error. Double helical gears for example are manufactured with higher helix angles than single helical gears thereby increasing significantly the overlap ratio. However the multiplicity of gear teeth in the mesh zone and the complexity of matching four helices instead of two complicates the balance of the load distribution. Also the engagement and disengagement of the gear teeth occur two at a time resulting in higher noise sensitivity to transmission errors. Pitch errors, derived from four helices with high overlap ratio gears are very difficult to adjust and may be noisier than a single helical gear of equal quality designed for the same service. Single helical gears provide a longer line of action on a single tooth which enhances the smooth transfer of load tooth to tooth. Therefore increasing total contact ratio in single helical gears always benefits noise reduction.

With the development of highly accurate gear producing machines, particularly gear grinding, the advantage of higher total contact ratio in double helical gearing can be beneficial with lower kinematic transmission error. Accuracies of ISO 1 (ISO 1328-1) or A1 (AGMA 2015-A01) result in very low noise gears. The ability to achieve this level of accuracy and do so consistently for multiple units is critical to assure success.

It is evident therefore variables in manufacturing should be minimized to reduce noise The selection of the contact ratio becomes one of judgment and experience. To reliably construct low noise gearboxes, **"variability"** in manufacturing must be minimized. Manufacturing consistency is an absolute necessity. The last generation of MAAG gear grinders, type SE machines have been commissioned during the last ten years. These grinders have improved the toothing accuracy's over the prior generation of grinders with marked results. In addition the improved surface variation (undulation errors) of the gear teeth have been diminished, a gear noise contributor. These undulation errors, or waviness patterns in the gear teeth can create a pulsation or beat. This is commonly more of concern with structure borne noise.

Gear grinding produced with generating grinders, afford the best option for lowest noise. With this grinding method gear toothing can be achieved topologically thereby optimizing the most desirable tooth form possible for operating conditions.

The girder table on very modern generating grinder is rotated with a hydraulic torque motor eliminating the worm gear drive for earlier topes. this secures the most beneficial approach possible to the manufacturer of low noise gears.

Critical measurement of gear rotors can be executed without disturbing the setup. Any adjustments required can be immediately carried out without major cost or interruption of manufacturing time.

c. **Uniform load distribution**

Under load, gears deflect elastically. This reaction contributes to transmission error which is compensated by tooth profile and lead corrections. In addition mechanical deflections under load of twisting and bending and distortion from heat generated during operation of the rotors themselves demands a precise correction of the tooth lead. The combined effects of these tooth deflections and distortions require a composite correction which assures precise uniform load distribution of the gear teeth. Thus, minimum lead variability diminishes gear noise.

Windage

A word about windage. This is a noise producer which is a physical condition resulting from the peripheral speed of the rotors as they churn through the self contained atmosphere of the gear unit housing. Higher speed units with large rotors are the most seriously affected by this condition. Not much can be done about it other than evacuate the atmosphere within the housing which will somewhat reduce the overall noise. MAAG has successfully accomplished this with the design and construction of the MAAG HET gears built to run in a low atmosphere environment for the purpose of reducing windage power losses. Units as high as 90 Mw have been designed and built resulting in 99.5 % unit power transmission efficiency.

Supporting Documentation

Supporting documentation which shows substantiating evidence accumulated by the US NAVY (for sub-surface ships) shows single helical gears are inherently quieter than double helical gears primarily due to a **"lower value of variability".**

Documentation based on:

"Gear Noise – The Generation of Rotational Harmonic Frequencies In Marine Propulsion Gears" by G. Nagorny of NAVSESS (US Navy) in 1981.

This material was originally a classified Naval document until est. 1989. Additional data remains classified today.

Donald Houser conducted work on noise which was presented at a past AGMA Fall Technical Meeting. He makes a very interesting observation with respect to noise related to transmission errors::

"A Procedure for Predicting the Load Distribution and Transmission Error Characteristics of Double Helical Gears" by Jacob Thomas of ACC and Donald Houser of Columbus, Ohio State University.

"When one tooth is leaving contact on one half of a double helical gear, a corresponding tooth is also leaving contact on the other half and thus the increased contact ratio of the double helical gear does not result in more gradual changes in the amount of load being carried by individual teeth. On the other hand the single helical gear has the full benefit of a more gradual change in the load being carried by it, which results in smaller mesh stiffness variation and thereby lower transmission errors. Therefore from a purely transmission error point of view, it is more advantageous to use a single helical gear with the same net face width than a double helical gear".

Expected "Sound Pressure Levels" for Turbo gears

For comparative purposes the test procedure used in accordance with a specific specification should be consistent. **API 613-5** for mechanical no load full speed test is one widely accepted test method. From this data, final values are then calculated for based on full load, full speed conditions. The measuring procedure is in accordance with **ANSI/AGMA 6025-D98** which also follows the same setup as outlined in **ISO 8579-1.** The procedure is consistent with industry practice, thus the values can be compared with those of other manufacturers. Past results from different manufacturers can then be compared.