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# Gearbox Noise and Vibration Prediction and Control

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This paper will review practical techniques and procedures employed to quiet gearboxes and transmission units. The author prefers solving the gear noise problem at the very source to introduce an enclosure as a means to reduce radiated noise, which seems to be easy but its effect on the sound pressure level is small. The gearbox noise problem solution is focused on the improvement of gear design, on the verification of its effect on the radiated noise and the determination of the gears' contribution to the truck's or car's overall noise levels and on the analytical and/or numerical computer-based tools needed to perform the signal processing and diagnostics of geared axis systems. All of the analytical methods are based on the time and frequency domain approach. Special care is addressed to the smoothness of the drive resulting from the transmission error variation during a mesh cycle. This paper will review the progress in technique of the gear angular vibration analysis and its effect on gear noise due to the self excited vibration. This presentation will include some examples of the use of such approaches in practical engineering problems.

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## 1. INTRODUCTION

The major functions of a gearbox are to transform speed and torque in a given ratio and to change the axis of rotation. The main parts of the gearbox are the gears, shafts, bearings, housing, and the outside of the gearbox clutches and couplings. The gears are machine elements that transmit motion by means of successively engaging teeth. The transformation of speed is without slip and loss of synchronization. Thus, the relationship between the angular velocities of the driving gear to the driven gear, or the velocity ratio, of a pair of mating teeth results from the number of teeth of the driving and driven gear. A gear train consists of two or more gears (a pinion and wheel), which serve to transmit motion from one axis to another. The gear train operational condition depends on the drive systems. Some gearboxes work with the steady-state rotational speed while the rotational speed of the others varies in a certain range. Independently on the rotational speed, the transmitted power can be constant or variable.

The gearbox is a source of vibration and, consequently, noise. Except for bearing fatal defects or extreme structure-resonance amplification, gears are the main sources of high frequency vibration and noise, even in newly built units. The gearbox's overall sound pressure level (SPL), compared to the SPL associated with the meshing gears, is only by some 5 dB higher at maximum. There are two possible solutions for keeping a transmission unit quiet. Introducing an enclosure to prevent noise radiation — with the consequences of low efficiency and difficult maintenance — is the easiest one. The more sophisticated and much more efficient solution is based on solving the noise problem at the very source. It means to introduce improvement aimed at the gear design and manufacturing, which results in the greatest reduction of the SPL.

## 2. HISTORICAL NOTES

The author of this paper was a member of the team for gearbox noise reduction at TATRA, a Czech company that pro-

duces off-road and on-road trucks. TATRA trucks are used to carry goods and have a maximum authorized total mass exceeding 12 tonnes. In the past, TATRA truck gearboxes were noted for a very robust design. Their only disadvantage was that they were "a little noisy." The introduction of the 80 dB limit for the peak pass-by noise level of on-road trucks in Europe in 1994 created a challenge to start research works on gearbox noise reduction. It should be noted that the pass-by noise measurements shall be made using the time F-weighting and the frequency A-weighting on the dB scale at a distance of 7.5 m from the centre of the test track. In the USA, the SPL is measured at the distance of 50 feet (doubled in comparison to the European test method), therefore 6 dB has to be added to the USA limit to make it correspond to the European level. The truck's operational condition during pass-by noise measurements is based on the full accel-cranion test specified in the International Standard, ISO R362-1982 (E) "Acoustic Measurement of Noise Emitted by Accelerating Road Vehicles—Engineering Methods" or SAE J366 Surface Vehicle standard — (R) "Exterior Sound Level for Heavy Trucks and Buses (Issued 1969-07, Reaffirmed 1987-02)." The test requires the vehicle to be driven through a test track at full acceleration.

The noise level of road vehicles was decreased in intervals as it was possible to fulfil the requirements given by the vehicle noise legislation. The peak SPL of the mentioned category of trucks was set to 84 dB before 1994. The 84 dB trucks were easy to produce but the last decrease of the SPL by 4 dB required fundamental improvements. The truck engine is the noisiest unit. Engine noise reduction for TATRA trucks of the T 815-2 type, introduced in production in 1989, was reached by using covers and shields that fit over the engine compartment and, also, by reducing the rate of the rise in cylinder pressure, the reduction of the SPL to reach the last 4 dB was not easy. To solve the gearbox noise problem it was necessary to decide if the special enclosure should be extended over the gearbox or not. As mentioned before, the designers decided to

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Performance-Based Gear Metrology William D. Mark, 2012-11-09 A mathematically rigorous explanation of how manufacturing deviations and damage on the working surfaces of gear teeth cause transmission error contributions to vibration excitations Some gear tooth working surface manufacturing deviations of significant amplitude cause negligible vibration excitation and noise yet others of minuscule amplitude are a source of significant vibration excitation and noise Presently available computer numerically controlled dedicated gear metrology equipment can measure such error patterns on a gear in a few hours in sufficient detail to enable accurate computation and diagnosis of the resultant transmission error vibration excitation How to efficiently measure such working surface deviations compute from these measurements the resultant transmission error vibration excitation and diagnose the manufacturing source of the deviations is the subject of this book Use of the technology in this book will allow quality spot checks to be made on gears being manufactured in a production run to avoid undesirable vibration or noise excitation by the manufactured gears Furthermore those working in academia and industry needing a full mathematical understanding of the relationships between tooth working surface deviations and the vibration excitations caused by these deviations will find the book indispensable for applications pertaining to both gear quality and gear health monitoring Key features Provides a very efficient method for measuring parallel axis helical or spur gears in sufficient detail to enable accurate computation of transmission error contributions from working surface deviations and algorithms required to carry out these computations including examples Provides algorithms for computing the working surface deviations causing any user identified tone such as ghost tones or sidebands of the tooth meshing harmonics enabling diagnosis of their manufacturing causes including examples Provides explanations of all harmonics observed in gear caused vibration and noise spectra Enables generation of three dimensional displays and detailed numerical descriptions of all measured and computed working surface deviations including examples

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## **Table of Contents Gearbox Noise And Vibration Prediction And Control**

1. Understanding the eBook Gearbox Noise And Vibration Prediction And Control
  - The Rise of Digital Reading Gearbox Noise And Vibration Prediction And Control
  - Advantages of eBooks Over Traditional Books
2. Identifying Gearbox Noise And Vibration Prediction And Control
  - Exploring Different Genres
  - Considering Fiction vs. Non-Fiction
  - Determining Your Reading Goals
3. Choosing the Right eBook Platform
  - Popular eBook Platforms
  - Features to Look for in an Gearbox Noise And Vibration Prediction And Control
  - User-Friendly Interface
4. Exploring eBook Recommendations from Gearbox Noise And Vibration Prediction And Control

- Personalized Recommendations
  - Gearbox Noise And Vibration Prediction And Control User Reviews and Ratings
  - Gearbox Noise And Vibration Prediction And Control and Bestseller Lists
5. Accessing Gearbox Noise And Vibration Prediction And Control Free and Paid eBooks
    - Gearbox Noise And Vibration Prediction And Control Public Domain eBooks
    - Gearbox Noise And Vibration Prediction And Control eBook Subscription Services
    - Gearbox Noise And Vibration Prediction And Control Budget-Friendly Options
  6. Navigating Gearbox Noise And Vibration Prediction And Control eBook Formats
    - ePub, PDF, MOBI, and More
    - Gearbox Noise And Vibration Prediction And Control Compatibility with Devices
    - Gearbox Noise And Vibration Prediction And Control Enhanced eBook Features
  7. Enhancing Your Reading Experience
    - Adjustable Fonts and Text Sizes of Gearbox Noise And Vibration Prediction And Control
    - Highlighting and Note-Taking Gearbox Noise And Vibration Prediction And Control
    - Interactive Elements Gearbox Noise And Vibration Prediction And Control
  8. Staying Engaged with Gearbox Noise And Vibration Prediction And Control
    - Joining Online Reading Communities
    - Participating in Virtual Book Clubs
    - Following Authors and Publishers Gearbox Noise And Vibration Prediction And Control
  9. Balancing eBooks and Physical Books Gearbox Noise And Vibration Prediction And Control
    - Benefits of a Digital Library
    - Creating a Diverse Reading Collection Gearbox Noise And Vibration Prediction And Control
  10. Overcoming Reading Challenges
    - Dealing with Digital Eye Strain
    - Minimizing Distractions
    - Managing Screen Time
  11. Cultivating a Reading Routine Gearbox Noise And Vibration Prediction And Control
    - Setting Reading Goals Gearbox Noise And Vibration Prediction And Control
    - Carving Out Dedicated Reading Time
  12. Sourcing Reliable Information of Gearbox Noise And Vibration Prediction And Control

- Fact-Checking eBook Content of Gearbox Noise And Vibration Prediction And Control
  - Distinguishing Credible Sources
13. Promoting Lifelong Learning
- Utilizing eBooks for Skill Development
  - Exploring Educational eBooks
14. Embracing eBook Trends
- Integration of Multimedia Elements
  - Interactive and Gamified eBooks

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