The Gear Whine Noise: the influence of manufacturing process on vibro-acoustic emission of gear-box

Niola V., Quaremba G.

Department of Mechanical and Energetics
University of Naples "Federico II"
Via Claudio 21, 80125, Napoli, ITALY
vincenzo.niola@unina.it http://niola.dime.unina.it/

Abstract – Continuing advances in the automotive industry in recent years, leading manufacturers of automobiles to develop more and more advanced products from technical and quality point of view and. In addition, consumer needs, now aligned with the high standards achieved, prevent manufacturers to make vehicles of poor quality.
The user of the vehicle, in fact, seems to be particularly attentive to the vibro-acoustic emissions.
For that reason the major car manufacturers devote significant resources to the NVH sector, which deals with noise and vibration of the vehicle to the vehicle driving comfort.
This present work was aimed to analyze two gearboxes, made by the same manufacturer, for the objective assessment of its vibro-acoustic emissions due to the phenomenon of gear whine.

Key-Words: - vibro-acoustic emission, gearbox, gear whine noise.

1 Introduction

The significant progress of the automotive sector in the last ten years, allowed car manufacturers to develop products more and more advanced in terms of quality. The customer needs, aligned with the highest standard achieved in that market, preclude the manufacturers to make vehicles of poor quality. The customer need, in fact, seems to be particularly aware to the vibro-acoustic emission of the vehicle [1]; this is the reason the major car manufacturers devote significant resources to the NVH which deals with noise and car vibration also the driving comfort.
This paper reports the results of several tests, performed in optical Gear Whine Noise, for evaluating the difference of the vibro-acoustic emission of two gearboxes of the same type. In particular, one of them has a micro geometrical error on the flank of the tooth, characterized by lack of material at the base of the tooth and showing a slight drift due to the working process. The tests were carried out in fourth gear.

2 The gear whine noise

The Gear Whine Noise (GWN), as well as the gear rattle noise, is one of the main vibro-acoustic phenomena of gearbox [2,3].
The GWN is an acoustic problem, which can be quite fastidious in the car, because of the values of frequency and sound pressure relatively high, characterizing it.
Usually, that noise occurs at meshing frequency and shows, near the gearbox, sound and pressure values ranging between 50 and 90 dB (A).
Unlike the acoustic phenomena due to the power system [4], the acoustic pressure due to GWN is not necessarily proportional to the speed of the engine and therefore it could be high in any engine running condition, manifesting itself in the car as unexpected noise and therefore particularly undesirable. These characteristics make the Gear Whine an important problem to solve or to reduce or to "manage" at least in an appropriate way [5].
Several studies on the GWN phenomenon helped to define the main factors influencing the vibro-acoustic emissions.
Mainly they are:

- Transmission error
- Variation of meshing stiffness
- Dynamical forces of meshing
- Friction forces

Detention of air and lubricant between the teeth.

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3 Gearbox specifications

The gearbox used for performing the vibro-acoustic comparison is designed for medium-powered car and allows the transmission of a maximum torque of 350 Nm.

The configuration of the model has three axles and 6 speed. As already mentioned, the gearboxes tested are of the same type, that is they were made following the same manufacturing process. One of two tested gearbox belongs to a lot which showed abnormal micro geometrical parameters due to the drift of the production process. In particular, a lot of gear showed excessive lack of material localized at the basis of tooth.

In this case the lack of material, because it affects an area of tooth not interested during the contact of the teeth, does not involve any meshing problem [6,7,8]. This area, in fact, detected by means of a micrometer at the base of the tooth is localized below the meshing profile.

4 Preparation of the test room

The running conditions of the gearbox were reproduced by means of an innovative test-bed, which allows to perform the test without the use of the engine. Thus the study of the gearbox could be performed in optical Noise, Vibration and Harshness (NVH) without the occurrence of noise and of engine vibration transmission. This potentiality, unlike a vehicle or a test cell engine, allows to separate the noise due to the gearbox from the one emitted by the engine, allowing, therefore, a detailed study of the phenomenon and the analysis of the frequency range responsible of unpleasant perceptions to the occupants of the car.

This means that we can simulate on the primary of gearbox, besides the average speed of the engine, even the periodic components due to the forces of combustion and inertia.

The main shaft of the gearbox is put into rotation by an electric motor connected in series through a flexible coupling to a torsional hydraulic pulsator; two semiaxes are braked by means of two additional electric brakes.

The test bed is installed in a semi-anechoic room, in which electric motors are acoustically shielded and the floor is covered with soundproofing material; thus, the tested gearboxes being the only noise source, in fact the background noise and reflections of room are minimized, help the detection of specific sources due to the noise transmission and their processing.

For the acquisition of signals the following sensors were used:

- 1 ferromagnetic pickup, used for the acquisition of the instantaneous rotation speed of the flywheel. It was screwed into a threaded hole drilled in the bell of the gearbox at the flywheel;
- 1 thermocouple, used to monitor the temperature inside the gearbox; it was positioned directly in contact with lubricating oil;
- 1 single-axis accelerometer used for vibration measurement; it was positioned at the bottom of the gearbox;
- 3 microphones were used for the acoustic detection. They were arranged in a semicircle near the gearbox far away one meter from it.

5 Operational set-up of test

In order to take over the noise in optical GWN it is fundamental to maintain a constant temperature of the lubricant in order to ensure the repeatability of test.

The experimental protocol stated for the analysis of GWN on both gearboxes was as follows:

- Slow acceleration in fourth gear from 1000 rpm to 4000 rpm in 60 s with a constant torque applied to the primary ranging from 30 to 300 Nm, with the increasing of 30 Nm for each ramp

Steady speed in fourth gear at 1000, 2000, 3000, 4000 rpm with torque applied to the primary ranging from 30 to 300 Nm.

5 Results

Following the acquisition of acoustic signals by the microphone and the accelerometer and tachometer signals, the data-base was processed to extract the “order” of main interest for evaluating the Gear Whine phenomenon and in particular for extracting, for each gear, the meshing order.
For a complete visualization of the meshing order diagrams for each torque value applied a detailed ColorMap was made.

Such a diagram shows on the abscissa the speed of engine (rpm) and on the ordinates the torque applied to the main shaft (Nm). On the third axis, the colour scale represents the values of sound pressure detected (dB(A)).
By observing the colour changing we can understand which are the areas where the noise shows the highest value; in particular the areas in red show the highest values while the lowest noise levels are pointed out in blue.

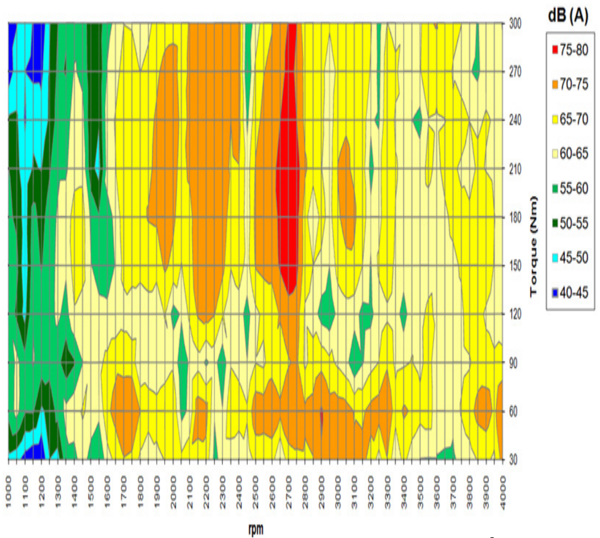

Fig. 1 - Gearbox without errors - 4th gear, Acoustic pressure dB(A) - Order of meshing

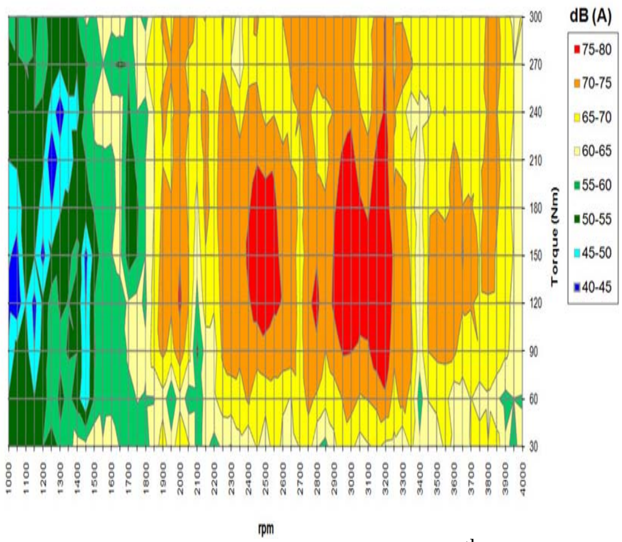

Fig. 2 - Gearbox with errors - 4th gear, Acoustic pressure dB(A) - Order of meshing

The Fig.1 shows the response of test performed on the gearbox without geometrical error.
By the comparison of these two diagrams it is possible to evaluate the noise level of the two gearboxes as function of the speed and torque applied to the primary.
The Fig.2 illustrates the response of the gearbox influenced by geometrical errors.

6 Analysis on the engine speed

6.1 – Low-range (1000÷2000 rpm)

For low values of speed, both gearboxes are relatively aligned and the acoustic emission follows an increasing trend that is directly proportional to the speed reaching for both gearboxes tested the maximum values of 70 dB(A), close to 2000 rpm.

6.2 – Low-range (1000÷2000 rpm)

This operating range highlights most relevant critical issues for both gearboxes tested. In particular the gearbox with geometrical errors is more noisy. In fact it has two critical areas, 2400÷2600 rpm and 2900÷3200 rpm. The gearbox without geometrical errors reaches critical level of noise only in one narrower range 2600÷2750 rpm. For both gearboxes, in these areas the sound pressure level reaches values close to 80 dB(A).

6.3 – High-range (3000÷4000 rpm)

From 3000 to 4000 rpm the gearbox with geometrical errors shows higher values if compared to the gearbox without error, close to 70 dB(A).

7 Analysis of the applied torque

Below are charts showing the performance of vibro-acoustic emission as a function of torque applied to the primary. In order to allow quick identification of the torque values that ensure optimal operation of the transmission, with respect to vibro-acoustic emissions, in the figures are highlighted in green the minimum points of the diagrams.

As already mentioned because of the direct correlation between tooth bending, transmission error and vibro-acoustic emissions, it is possible to optimize the noise levels in a very narrow range of applied torques.

Data analysis indicated that, both in terms of noise and vibration, minimal emissions of the gear without errors are obtained for a value of about 120 Nm of applied torque at all engine speeds.

The gear with errors, however, has low emissions in the range 30 to 60 Nm. In particular, there is a shift of the optimal running to lower values of torque. It is clear also that the trends of the emission values are quite similar, this means that the diagrams of emissions do not vary in terms of shape, but to the position referred to the applied torque and, in part, to the number of *rpm*.

The figures below explain what we observed.

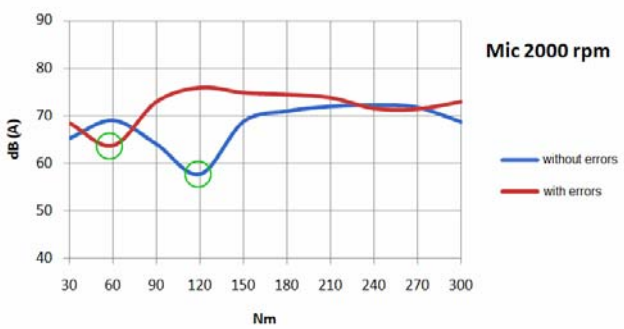

Fig. 3 – Acoustic response at 2000rpm

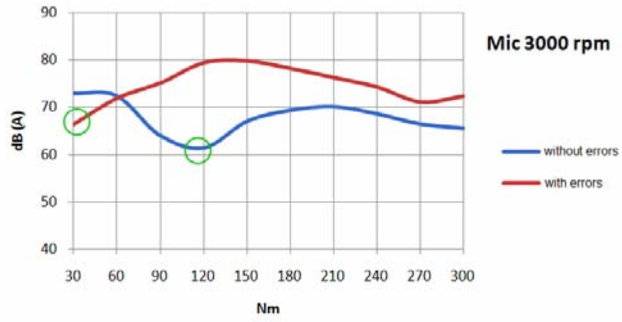

Fig. 4 - Acoustic response at 3000rpm

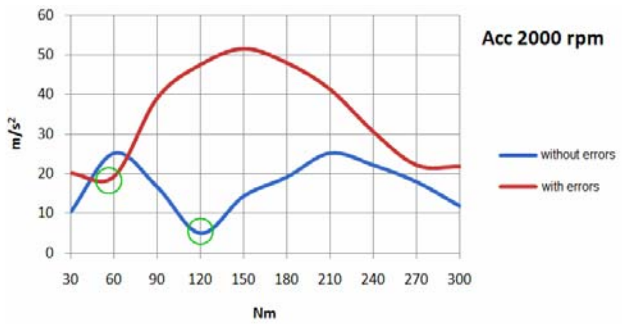

Fig. 5 – Vibrational response at 2000rpm

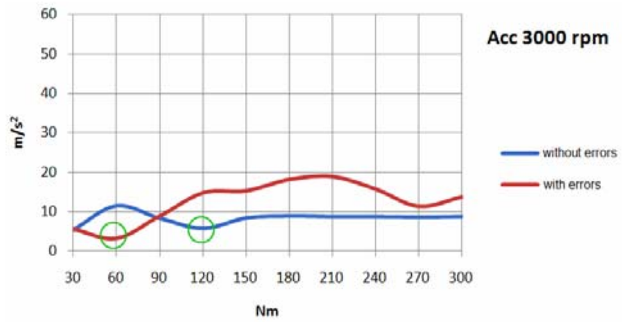

Fig. 6 - Vibrational response at 3000rpm

8 Conclusions

In conclusion, regarding to the number of revolutions of the primary shaft, the gearboxes tested show a very different acoustic behaviour. It highlights in particular that the gearbox with geometrical errors is characterized by higher noise in almost all engine speed [9].

The colormaps of data acquired at the test-bed provide a complete map of all possible operating points of the gearbox tested, regardless of application.

In the car, however, the operating points are limited by the type of engine coupled to the gearbox and by the dynamic parameters of the vehicle. That kind of study is in progress.

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In fact, the car used for testing the gearbox, is another variable to take into account to define the actual running areas of engine. Using as reference the equation of the road vehicle, we can define, for the gear speed tested, the range of normal engine running.

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