Gearbox Improvement Aimed at Noise Reduction

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Abstract:

When transferring the force, the sides of the teeth should roll on each other and not slip except at a minimum extent, so that the wear and friction losses and noise emitted by them are minimized. Moreover, the circumferential velocity of the step circuit of both gears must be equal during one cycle (The fundamental law of gear-tooth action). In this report we reviewed the research in workshop on noise reduction using different processes to establish the Structure of the gearbox and its dynamic properties and to discover the points of the dynamic weakness on its parts.

Key words >> Gears are used to change the transmission ratios, torque and to reverse the direction of rotation.

INTRODUCTION:

The gears transmit torque between two shafts of a small central dimension in a direct positive way. Gears are used to change the transmission ratios and to reverse the direction of rotation. Also, there is important point, when we look to the structure of the gear box, we can recognize that the effect of improvements of the gear box are very restricted by given the structure of the gear box on Overall sound pressure level (SPL) of the newly bult units Varies and different in Correlation with the error of the gear geometry. The most efficient improvement can be reached when the noise problem is solved at its very source, which is the tooth contact of meshing gears.

Tooth shapes

Through the tooth shapes conditions can be achieved to a large extent by shaping the sides of the teeth according to the roulette curve -The involute curve, or a cycloid curve -. The involute curve is chosen for the vast majority of applications in mechanical engineering; this curve is created by a single thread stretched from the circumference of a circle, the tooth side represents a small portion of the involute curve, the involute teeth are not sensitive to slight changes in the center divergence; they are easy to produce and reasonable. Where it can be operated with straight, cutting tools and the roots of the teeth are strong.

The cycloid curve is created by rolling a circle on the circumference of a basic circle, Cycloid teeth are highly accurate at work; however, they are more sensitive to changing the central spacing and are often used in watchmaking. The equipment that used in producing this type of tooth has curved cutting edges. When the pitch diameter of one of the two involute gears is infinitely large bypass teeth, the step circle of that gear becomes a straight line. As a result, rack and pinion with straight-sided teeth is created, which makes the angle (a) with the patch line. "This angle is called Contact angle, and the amount of the supporting side of the involute teeth α=20 according to the standard specifications DIN 867. This angle is named after the tooth pieces.

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Generating the teeth sides

If we imagine the Rack and pinion as a scraping tool, the cutting edges in it generate the shape of the involute curve of the edges of the teeth in the wheel or the gear blank in successive steps when both the rack and the gear blank move with the same magnitude to the left after each stroke) The drawing shows the generation of Both sides of the left tooth in successive steps). If the number of teeth of the involute gear is less than the number of the minimum teeth extent, the width of the roots of the teeth is less than the width of the patch circle. The undermining of this "cautious lower cut" can be avoided in the sides of the teeth by shifting the patch line to the sides of the rack within a distance (v) from the center of the severed gear. Thus, the central dimension increases by the amount (v) and so-called v teething or corrector teething arises.

1- Gear box Housing rigidity.

The gear box housing types of properties were specified using the Shapes of defluxion and empirical modal analysis. We Can notice that the effect of the load and vibration response of the gear box of each gear in the time domain by using the synchronous averaging with the frequency of the rotations was established and analyzed. The 'mechanical power' Can Spate through the gear box in different ways according to the use of the gear. The shafts housing of the gear box, gears are not perfectly Rigid Structure. The acquiescent gear box Structure is misshaped under the use of load. The tooth mesh of the R-gear pair depends on the gear pairing.

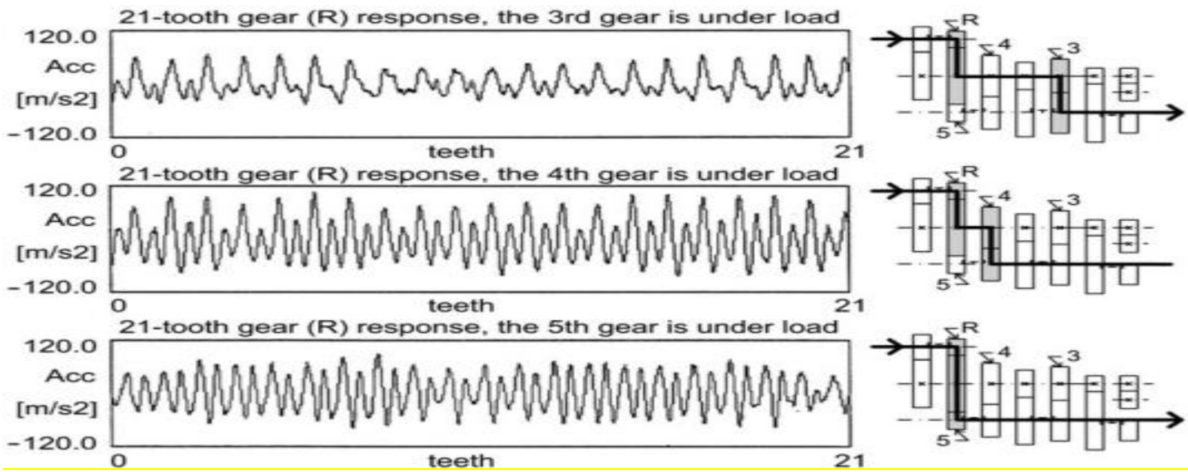

Figure 1- Synchronously averaged vibration response of the 21-tooth gear under load.

Under the load between the output Shaft and the Secondary gear the response of the averaged Vibration Of the 21-tooth gear, the pertinence between R-gear trains. For the 3rd, 4th and 5th gear under the load can established in Figure 1.

The Responses are different due to the deformation of the gear box.

To prevent the ambiguous of the tooth Contact, the housing of the gearbox was solidifying by using Ribs. When we look to the structure of the housing, we can notice that ribs were perpendicularly to the shaft while two major ribs at the surface of the housing were parallel to the shafts. The additional ribs guarantee that the bearing close to the 21-Tooth gear is tightened enough and the response of the vibration were not different [1].

2- Gears Geometric Design.

The Contact-ratio Sensitive Describe the average of the tooth mesh vibration (simply It is not accurate enough to say that the contact ratio, is the average number of teeth which in contact during the mesh cycling) is one of the most important parameters defining the gear tooth excitation and, thus, determining the noise level of the gear box. The effect of the tooth design on the average tooth mesh which is calculated from the acceleration signal is shown in Figure 3. Measurement concerns the helical gears under the load whose design differs in profile.

Contact ratio ($\varepsilon\alpha$). The overlap contact ratio ($\varepsilon\beta$ face contact ratio) is approximately equal to 1.0. The summation of overlap ratio and the profile contact ratio is designed as the total contact ratio. ($\varepsilon\gamma$). The acceleration signal was measured on the input shaft bearing a direction perpendicular.

To the gear axis. The gear train marked by 'N' connects two parallel shafts, namely the input shaft and countershaft of the truck gearbox. The engagement of the gear train N or R splits the gear ratios 1 through 5 and doubles the number of the gear ratios to ten.

The average tooth mesh of the gear train marked by N for the 3rd, 4th, and 5th gear train under load, which is shown in Figure 2, demonstrates that the path of the mechanical power flow does not affect the response of this gear train.

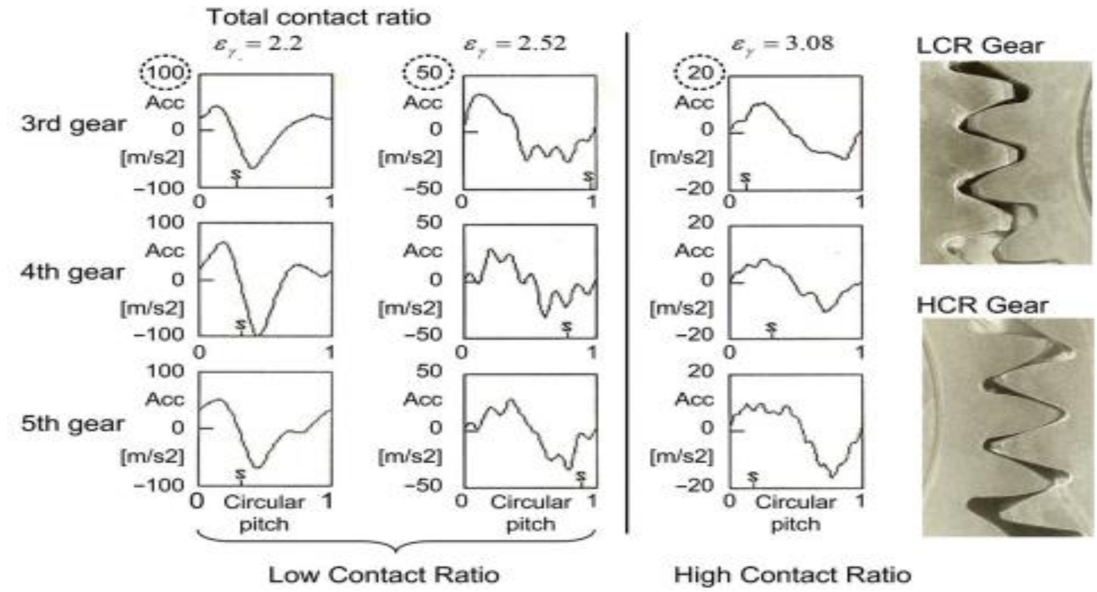

Figure 2- Effect of the total contact ratio on the average tooth mesh acceleration signal of the N gear train for the 3rd, 4th, and 5th gear train under load.

The average tooth mesh of the mentioned gear train can be simply shown in Figure3 the low contact ratio (LCR) gearing can be defined the value of the profile contact ratio which is usually less than 2.0. While the gearing in mesh this parameter equaled to 2.0 or more is specified as high contact ratio (HCR). We can get the integrated value of the profile contact ratio and overlap.

Ratio outcome in enormous reduction of the gear box noise and vibration it can be evaluated that introduction the HCR tooth leads to reducing the level of the noise of the gear box.

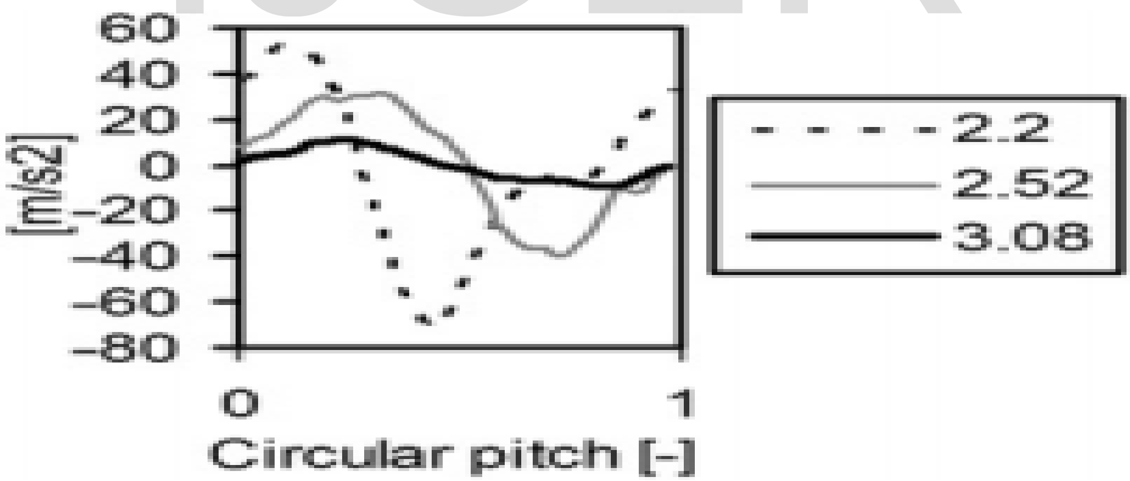

Figure 3- Average tooth meshes vs. circular pitch for various total contact ratios.

With LCR tooth will be border to 6dB as was already mentioned. [2]

When the contact ratio from 4.0 to 5.0 increases, the transmission sound pressure decreases by about 10 db. There is an effective method to detect any regular error in tooth profile geometry, to verify contact ratio, and to improve gearing by modifying the lead and tooth profile; this method is to use the averaged tooth mesh signal; while during a complete revolution, the envelope of acceleration signal is just necessary for controlling quality. Figure (4) shows the impact of the design of tooth on the level of gearbox level. The figure shows the probability plot of normal distribution and it contains three groups of data. The first group represents a reference measurement of the noise of gearbox with the LCR gears ($\varepsilon\gamma = 3.08$) that were produced before the year 1994; it is originated from the gearbox's tests with geometric deviations within limits. The rest data groups correspond to the gearbox with the HCR gears ($\varepsilon\gamma$ = 3.08) that was first produced by TATRA in 1994; it was the same year as the Germany example.

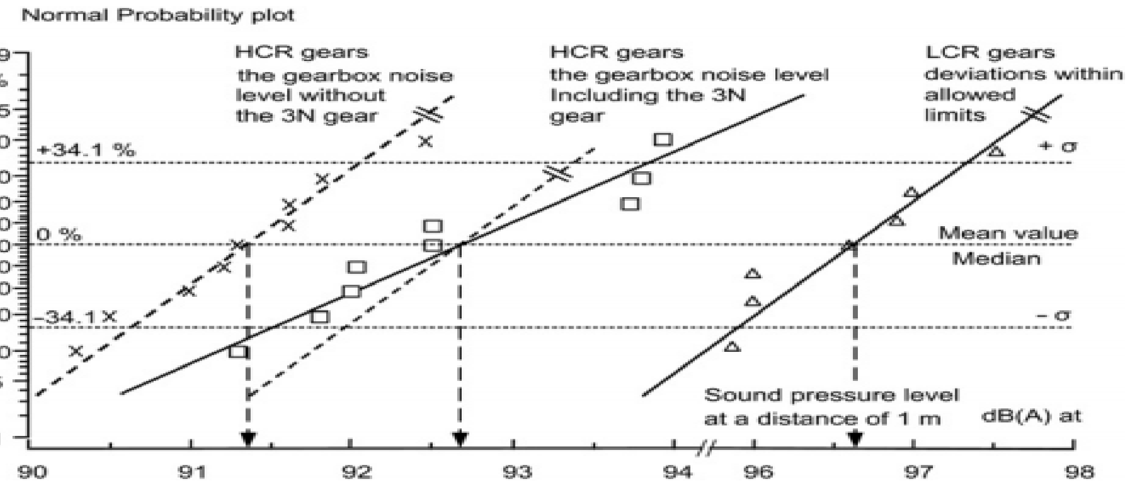

Figure 4- Effect of LCR and HCR gears on experimental distribution functions of SPL.

(Eco split 3 type, ZF Friedrichshafen AG). The functions of the empirical distribution of these two measurements are computed; this included the measurement when the 3N gear is used and without the use of this measurement. When the distribution function intersects with the horizontal line of 50 %, the gearbox SPL mean value, which is the median for the data distributed normally, results; this is shown on the horizontal scale. On the other hand, the double standard deviation is given, while the intersections with lines 50 ± 34.1 %. It is noted that the noise level was reduced by 4 db. and then after solution of the problem with the gear ratio of 3N even by 5 db. The introduction of the tooth surface modification decreased the mean value of SPL below 90 dB as is shown in Figure 5.

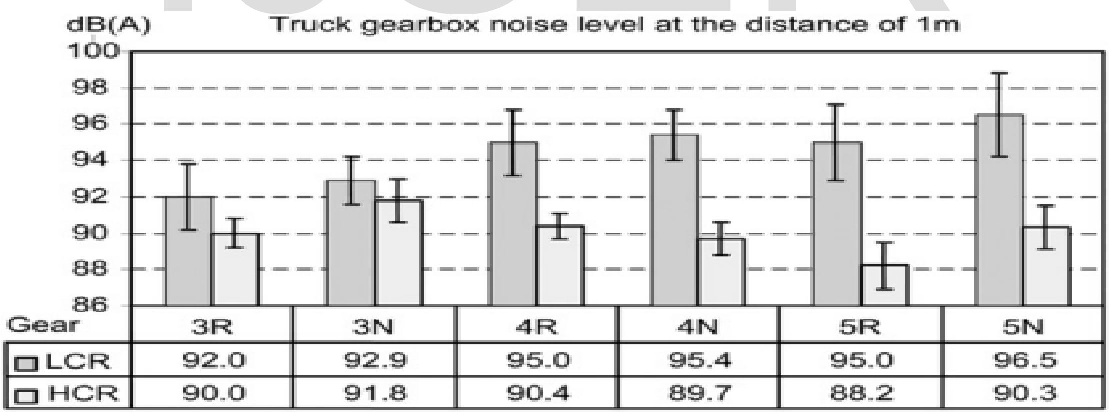

Figure 5- The gearbox overall noise level of the HCR gears in comparison with the LCR gears for six engaged gears important for the pass-by noise level measurement.

3- Effect of Gear Quality on the Gearbox SPL

The gear tooth quality is given by the permissible maximum values of individual variations. Individual variations are those variations from their nominal values, which are exhibited by the various parameters of the gear teeth, such as pitch, profile shape, base diameters, pressure angle, tooth traces and helix angle. It is known that a gear could be perfect when referring to these variations, and yet be very noisy in the conditions of meshing. We can find in the tolerance data a few microns and have many times more deformations due to the loading.

In reverse some low noisy gears are imperfect. An example of the effect of the gear tooth quality on the emitted noise in SPL is shown in Figure 6.

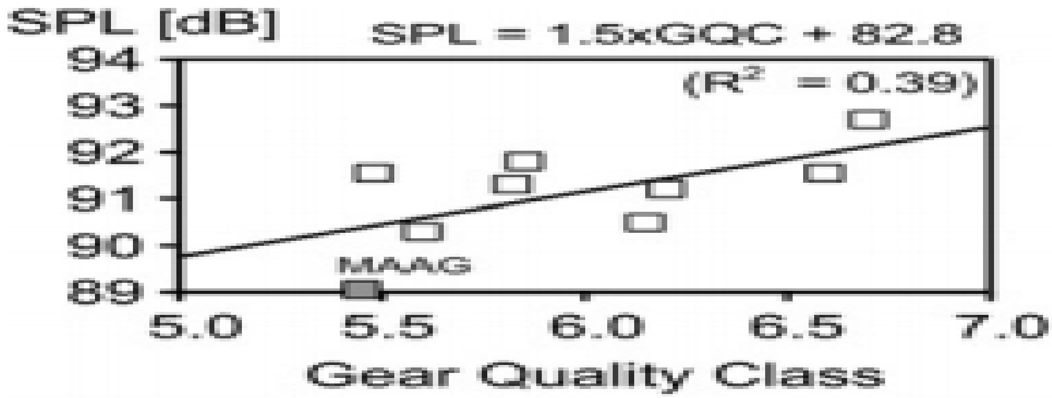

Figure 6- Effect of mean gear quality class on noise level in dB at 1 m.

Machine that employs the continuous shift grinding method (Reischauer) are corresponded to by the others. Nevertheless, it can be estimated that the improvement done by class 1 pf DIN 3961 quality leads to the SPL reduction by about 1.5 db. The Gear Quality Class (GQC) is defined as a quantity which is mostly affected by the tooth profile variations) the form of tooth trace or the angle of tooth alignment) and weakly in the radial run-out. This quantity is the weighted sum of the form of the tooth trace and the angle of tooth alignment (the weighing coefficient for both deviations equals 0.4) and the radial run out (3). The level of the gearbox noise corresponds to the deviations of the gear geometry if the structure of gearbox is stiff enough. Professor Morava (4, 5, 3 6) designed the computation of GQC as a real number; he studied the impact of individual deviations on gearbox noise. Individual deviations are defined as the deviations with values that are expressed by several parameters of the gear teeth, including base diameters, circular pitch, helix angle, profile shape, tooth traces, and pressure angle. The GQC calculating formula includes a select set of the types of deviation.

4- Operation Conditions Impacts on the Gearbox Vibration:

In the case the torque at the shaft of gearbox input increases, this leads to misalignment because of the deformation of gearbox case, and the shafts system including bearing. These deformations can lead to shifts in the distribution of load across and along the surface of the tooth of a gear pair that leads to variation of the stiffness of tooth contact as a basic source of the vibration's parametric excitation. Vibration's measurement and using the technique of the special filtration may assist in analyzing the dynamic force that acts between the teeth in mesh. Figure (7) shows an example of the gearbox load impact on the RMS value of the signal of acceleration on the gearbox bearing. A supplier of grinders prepared the models of the gears with and without modifying shape for testing. The gearbox design input torque equals 1200 Nm. The teeth profile and lead are modified by tapering the lead and crowning across the face, to prevent the vibration increase, and accordingly, to prevent the increase of the noise level resulting from the deformation of teeth and gearbox structure (7). When the modified tooth is compared to the unmodified tooth, it appears that the pair of gears with modified surface meshes in a smoother way than the unmodified gears. This improvement of design can lead to decreasing SPL by 3 dB during the tests on the test stand.

The calculation of the average tooth mesh can also be used as a tool to check the effect of the surface modification of the teeth on the overall level of vibration or noise. Total vibration values in Figure 8 correspond to average tooth mesh in Figure 7. The choice of appropriate surface modifications of the teeth can be considered art, which can handle only an experienced designer. Decisive evidence that the solution is optimal can only be obtained experimentally. Mathematical modelling is problematic because such parameters as the stiffness of the bearing is uncertain [7].

Suggesting a proper modification of the gear train at the beginning of the flow of mechanical power is

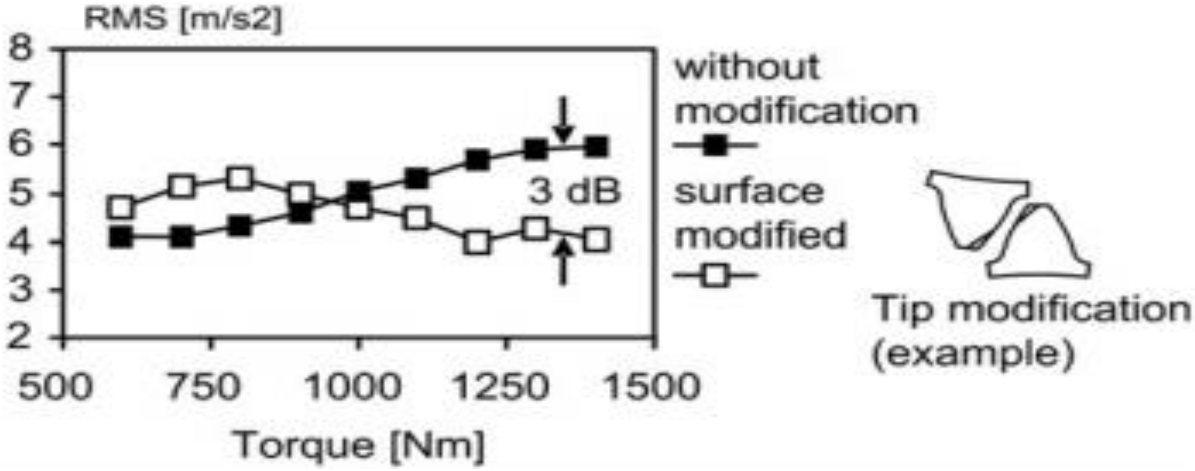

Figure 7- Effect of load and surface modification on RMS of acceleration.

Easy for a small range of torque and speed. The difficulty of this task is for the gear train at the end of the power flow through the gearbox. This gear train operates in various conditions ranging from high-speed rotation at small torque to low-speed rotation at high torque.

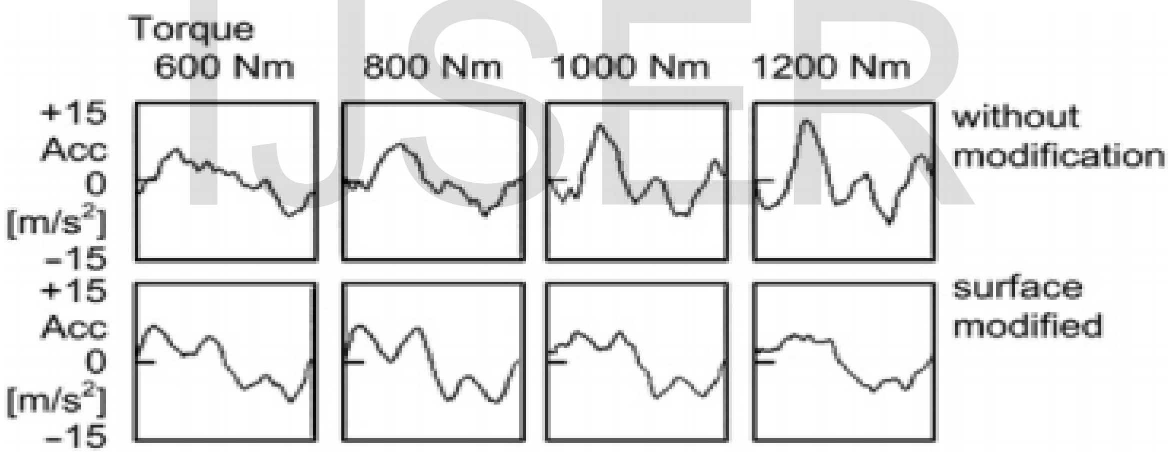

Figure 8- Effect of load and surface modification on average tooth mesh.

Figure (9) shows a good tool for assessing the suitable modification which may be SPL of the selected gear that was measured for different gear ratios, but with a constant torque at the gearbox input.

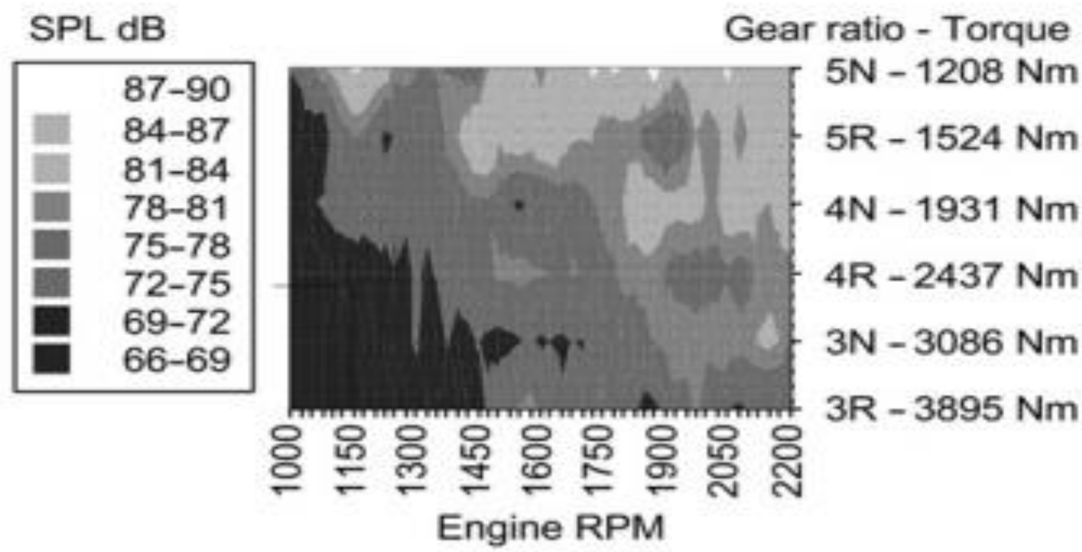

Figure 9- SPL of a gear train of the drop gearbox vs. torque at the main gearbox input

Figure (5) shows the positive impact of the introduction of the HCR gears into the TATRA gearboxes and the modification of the tooth surface on the noise level of 6 gear ratios (3R through 5N) that are necessary for the measurement of the pass-by noise. It is noted that introducing the HCR gears improved the design of the gear of the tested truck. Noise transmission itself is not reduced by only implementation of HCR gears. It is important to improve the class of quality at least by 1.5 to 2. Reducing the dynamic forces acting between teeth, not only decreases the gearbox noise, but also doubles the gearbox lifetime. Some problems were caused for the truck manufacturer by reducing the pre-mentioned gear noise when the SPL is decreased in the cab in a way that drivers could distinguish the tonal noise resulted from the other unit, for instance, by axles, especially when they used engine brakes. The subjective perception of noise sees that cab environment is necessary. It is notable here that the gear of the HCR type has a good and positive impact on the transmission's lifetime. The time interval and the dynamic forces amplitude are reduced by smooth mesh up to the fatigue fracture occurrence. The lifetime was nearly doubled.

5 - Quality Control in Manufacturing:

The quality of producing a well-designed gearbox, that achieved excellent results in the prototype testing, should be accurately controlled. Testing of gearboxes is performed during run-up / coast down. The rational speed of input shaft was slowly raised from 1000 to 2200 RPM. The first five harmonics of the frequency of tooth meshing is usually adequate to constitute the frequency range for measurements. Figure (10) shows the analysis of gear noise, the reliance of the overall SPL in dB (Total), in addition to the five tooth meshing harmonics levels of all the gear trains under load on the rational speed of the input-shaft for the 3N gears. Just three pairs of the gears involved in work, and which have the marks of N, 3, and SG (Drop Gearbox), are under load, except for the 5R gear.

Load for the 3N gear vs. input-shaft rotational speed.

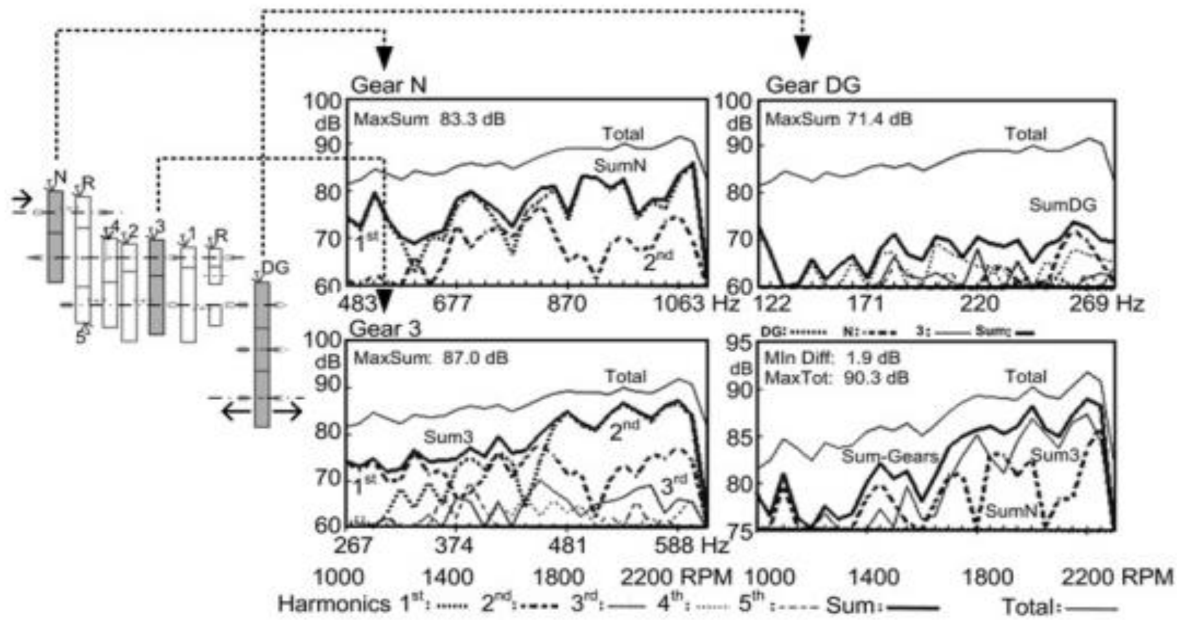

Figure 10- Overall (Total) SPL and level of five tooth meshing harmonics of all the gear trains under

In figure 10, the diagram panels titled Gear N, 3 and DG, correlate to the gear pairs already mentioned. The curve in these panels marked by "Sum", "Sum N", "Sum3" and "Sum DG" are calculated as the sum of the contributions of power of five harmonic components that result in the noise level triggered only by the adequate gear pairs. A maximum of the five tonal components SPL and the maximum of the gearbox overall SPL (Max Tot) can be selected as a criterion of gear quality, as the test of the pass-by vehicle noise depend on the maximum of the overall SPL. It is optional to evaluate the maximum for the range of the input shaft rational speed from 1000 to 2200 RPM or for an interval correlating to the rational speed of the engine throughout the pass-by tests. Because the rational speed of the secondary gearbox gear train is low, its contribution to the overall (Total) SPL trivial and negligible. In Figure (10), in the diagram, the right lower panel compares the contribution of all the gear train under load to the overall gearbox SPL. Min Diff designated the minimum of the difference between the overall SPL and the contributions of the, 3 and SG gears for the pre-mentioned RPM range. The essential sources of the gearbox noise are the under-load-gears, as it was mentioned in the introductory section. Other noise sources, like bearings, as an example, raise the SPL by 1.9 dB (Min Diff).

Conclusions:

a) Improving the performance of the gearboxes.
b) Increasing gear efficiency.
c) Extend the gear life.

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