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BENEFITS AND LIMITATIONS OF ACOUSTIC METHODS IN THE VEHICLE TRANSMISSION DIAGNOSTICS – A CASE STUDY

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Abstract: In general, for the diagnostics of a faulty machine several diagnostic methods can be considered. In this paper, the benefits and limitations of the acoustic diagnostic methods are shown, based on a noise problem of a real car with a 6-speed manual transmission. The possible diagnostic methods will be pointed out, and an analysis will be performed with noise and vibration measurements on the car. Based on the analysis conclusions regarding the benefits and limits of the used diagnostic method will be drawn.

Keywords: *transmission, diagnostics, noise, vibration*

1. INTRODUCTION

The sale of passenger vehicles word wide is steadily increasing nowadays. Every car containing a powertrain, incl. a gearbox (also electric cars can have a gearbox), which is one of the most important and expensive components of the car. Its repair in case of a failure can be very expensive, regardless of the type of the gearbox. Nevertheless, the repair costs of automatic gearboxes (planetary, DCT, CVT) can explode. In case of an older vehicle a necessary repair could even mean a financial total loss. The detection of a failure in the gearbox in early phase could also mean cost saving.

The only problem for this intention is that a diagnostic method must be applied, which is able to indicate the failure's characteristics and location. The method should be simple to use and low budget. Next chapter shows some of the most promising methods for that purpose.

2. POSSIBLE DIAGNOSTICS METHODS

Practically, the vehicle diagnostics is the whole bulk of measurements and evaluations performed with diagnostics methods for vehicle condition inspection. This kind of monitoring process can be accomplished for various reasons, e.g., maintenance, repair, official technical inspection, service–operation, detection of defects, failure prevention, end-of-line test, assessment of operational safety or vehicle value, judicial technical investigation etc. In engineering practice, the diagnostics is performed through the observation of physical parameters such as temperature, rotation speed, pressure, flowrate, pressing force, torque, impedance, magnetic flux, noise/vibration values etc. that characterize the condition of engineering systems. In case of offboard diagnostics the required hardware and software do not integrated in the vehicle's mechatronic system, while the onboard diagnostics is the own function of the vehicle.

One of the tasks of motor vehicle diagnostics is to determine the wear and tear of system components i.e., which lifetime stage they are. Mechanical systems usually contain several frictional surfaces. For example, the piston-cylinder-piston ring assembly group, the valve control-system and bearings of internal combustion engines (ICE). Due to the friction the clearances between the elements are increasing, which can lead to troubles: excessive oil consumption, combustion problems, hard idle, decreased power, strange noises, leakage, etc. *Figure 1*. shows the lifetime diagram of before – mentioned assembly group in function of amount of escaped crankcase gas, but the oil consumption or compression pressure could be the indicator of the same issue.

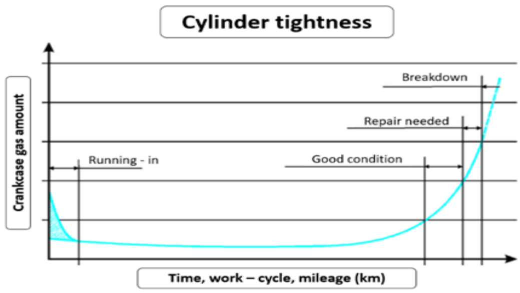

Figure 1

Characteristic diagram of machine elements due to wear [1]

Because of growing abrasion, the function loss is worsening at first in a small compass and then exponentially, as in case of tire tread. The function loss results from wearing affects disadvantageously other parts as well, e.g., the wrecking of damper's damping ability influences the function of ABS and ESP systems negatively. Apart from cylinder tightness measurement wide range of offboard diagnostic procedures are existing for ICEs; not exhaustive list: torque and mechanical power loss measurement on test bench; emission/temperature/exhaust noise/compression pressure/ battery voltage measurement on brake pad; etc. [1].

In our days modern cars are mounted up with lot of electrical devices and sensors to stabilize driving and monitor the behaviour of vehicle units. Onboard diagnostics (OBD) invented for continuous or periodical self-diagnose of degrading components and vehicle's emission system. When a problem occurs the malfunction indicator lamp (MIL) flashes on dashboard and the system stores a diagnostic trouble code (DTC) in engine control unit (ECU). A diagnostic scan tool (Generic Scan Tool) or code reader can communicate with microprocessor that allows for the service technician to retrieve information regarding the fault. As cars become more complex, it is required to extend the functionality of OBD over remaining parts of vehicle and not only emission control system. Recently, the data result from OBD system used not exclusively in maintenance services but utilized in vehicle development as well [2].

The vibration signal is sensitive to all faults, while other measurements – mentioned above – able to detect only some specific faults. It is well known that due to the malfunctions and wearing of machine elements during operation the emitted noise and vibration values change compared to the intended operating conditions. Therefore, the noise and vibration analysis technically can be an efficient tool for faulty condition detection. In this cited work [3], fault diagnostics of gear transmission system via vibration signal analysis is performed. In order to examine the vibration condition of a gearbox a test rig was created. With the help of time and frequency domain analysis gear defect was revealed and categorized successfully. Puchalsk [4] presented a diagnostics method of valve system of a spark ignition (SI) engine based on vibration acceleration signals. The technique based on mathematical processes, namely the lower triangular orthogonal (LQ) factorization and the singular value decomposition (SVD). The method uses vibration time series data after angular resampling without transformation in the frequency domain. With this method the status changes of valves are investigated. The method was verified by experimental tests of the engine valve systems. An automated diagnostics system [5] was established based on Artificial Neural Network (ANN) to determine various malfunctions in internal combustion (IC) engines such as misfiring, piston slap and bearing knock. It was exhibited that the network fed with simulated data can properly reveal the location and severity of faults. Regarding mechanical failures the data for the network training came from envelope analysis of vibration signals and in case of combustion faults it came from torsional vibration of crankshaft and angular acceleration of engine block.

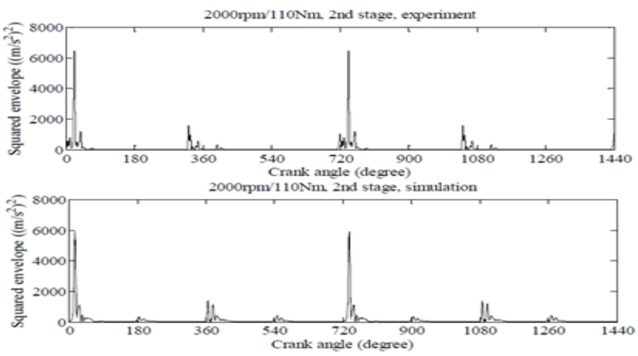

Figure 2

Simulated and experimental envelope signals with 2nd stage piston slap fault [5]

Currently, number of techniques are available for engineers to predict malfunctions and specify the reason of failures. With the appears of control systems the diagnostics transferred from outside to inside the vehicle and became continuous. Moreover, diagnostics procedures based upon vibration and noise analysis increasingly utilized in engineering practice.

3. PROBLEM DESCRIPTION AND TESTS

A relatively new passenger car (year of manufacture: 2019) is given with a turbo charged direct injection 1.5 Litre petrol engine, front wheel drive with a 6-speed manual transmission. After about 6 months of using the car, the owner complaining about a certain noise during gear shift up from gear 1 to gear 2, resp. from gear 2 to gear 3. We assume, that the noise is also existent at the other gear shifts (3-4, 4-5, and 5-6), but in these cases due to the higher speed the rolling noise masks the failure noise originated from the gearbox.

The characteristics of the noise can be described as impact or hit noise; in terms of frequency content, it can be characterized subjectively as a sharp noise. The noise can be clearly heard inside and outside of the car during shifting and it is very disturbing for certain persons sitting in the car. The analysis is problematic, since some of the passengers may not find the noise to be very disturbing, some of them do not even notice it. Nevertheless, the problem was immediately reported to the dealer after discovering, who replaced several components, e.g., the clutch, the axle-shafts, and the gearbox one after the other. This repair tries failed; the noise still can be a heard. The dealer refuses any further repairs or other measures, he claims the car is ok. despite of the still existing noise.

Our task is therefore to analyse the problem without disassembling the gearbox, in order not to lose the guarantee. First a pass-by noise measurement was performed in order to identify the noise characteristic, and to make sure the noise is really existent. For outer noise measurement of a passenger car there is a standardized measurement (ISO 362: Measurement of noise emitted by accelerating road vehicles — Engineering method — Part 1: M and N categories). In our case due to the characteristic of the noise it was not constructive to perform the standardized measurement, since this has to be performed during the accelerated ride in a certain gear speed (e.g., in 2. or 3.). However, the disturbing noise is generated only by gears shifts. Thus, we used an approx. 30 m long light slopy road with one lane and the car was started from the stillstand in gear speed 1 and was driven uphill. After a few meters of driving the gear speed 2 was shifted through the driver. At the start of the car until the stop the raw time signal of the sound pressure was recorded *(Figure 3)*. The microphone was positioned 4 m from the middle of the road. The overall measurement length was 10 s from start to stop of vehicle. The measurement was performed with a single channel analyser. The measurement was repeated several times, and the noise phenomena could be reproduced in every tests.

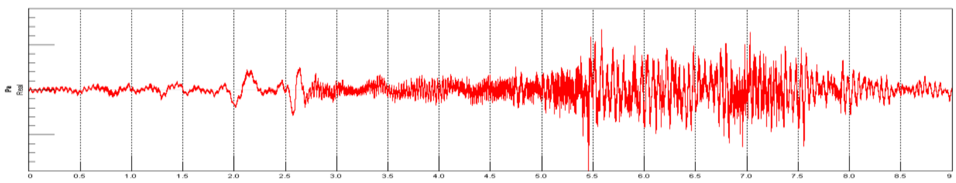

Figure 3

Pass-by noise time signal

In order to get closer to the failure a static state measurement of the car was also performed. In our case we put the car on the lifting platform, and we disassembled the lower engine protection panel. In that way the engine-gearbox unit could easily reached and could be moved back and forth by hand against the pendulum support. At this rhythmic movement of the unit a sharp impact/hit noise could be heard, as something might be loose in the gearbox, and this part is hitting another one. The noise was very similar to that which was recorded at the pass-by noise measurement. Subjectively the source of the noise could be in the gearbox. For the more exact localization a near field microphone was applied close to the gearbox surface. In addition, accelerometers were mounted to the gearbox housing in order to measure the vibration *(Figure 4)*.

Figure 4

Accelerometer locations (red circles) on the gearbox housing (left: point 1; right: point 2)

The raw time signals of sound pressure and vibrational acceleration were measured approx. 8 s long, with the sampling frequency of 48 kHz with a single channel analyser, thus the noise and the acceleration in the 3 measurement positions were recorded sequentially. The raw time signals can be seen in *Figure 5*.

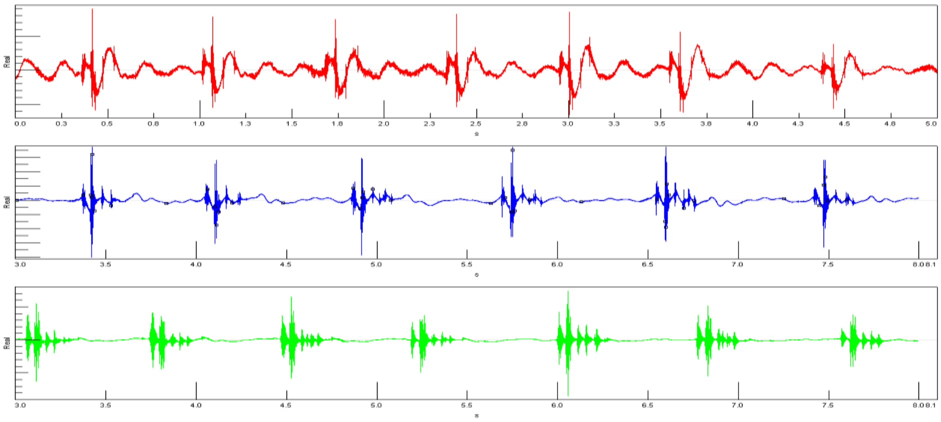

Figure 5

Time signals at the standstill measurements (top: sound pressure; middle: acceleration point 1; bottom: acceleration point 2)

4. THE ANALYSIS

Based on the raw time signals from the pass-by and standstill measurements, in the post processing of the time signal the spectrograms and averaged spectrums were created by the Fast Fourier Transformation. The goal was to find frequency contents, which may refer to a failure of a certain component of the gearbox.

Figure 6 shows the frequency content of the time signal of the pass-by noise. The frequency range of the noise approx. 4000 Hz wide and there are only a few frequency peaks that might refer to a certain component of the gearbox. Unfortunately, the peaks in this frequency spectrum cannot refer to a specific component.

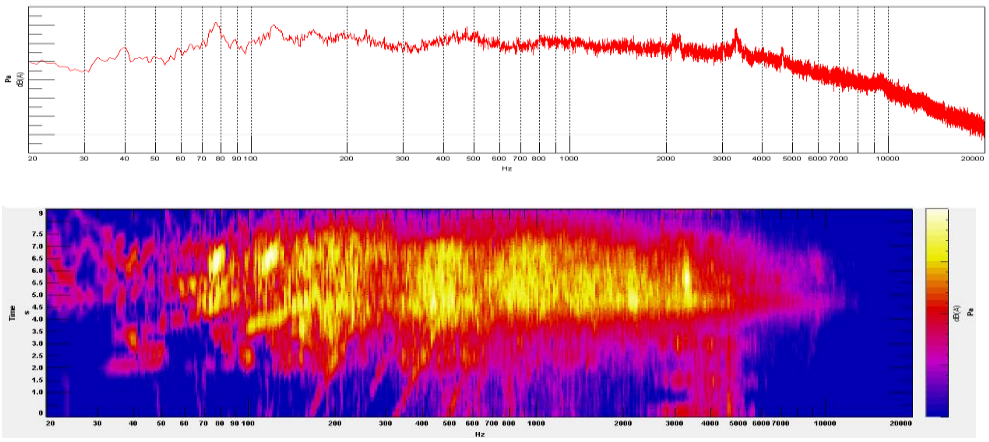

Figure 6

Averaged spectrum (top) and colormap (bottom) of the pass-by noise

The next analysis is based on the time signals in *Figure 5* (standstill measurements), the average FFT spectrums of the vibration signals were created. The curves are representing the almost the same curve progression, except in the frequency range of 400–1500 Hz. This difference is the result of the different impedance of the two measurement points. Point 1 (red curve) is located on a stiff part of the gearbox housing, point 2 (green curve) is located on softer part with lower impedance (on the side cover) of the gearbox housing.

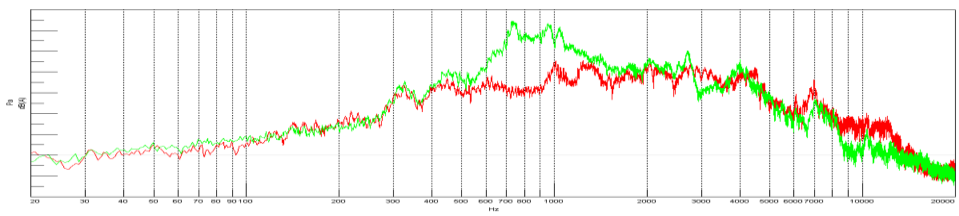

Figure 7

Averaged vibration spectrum at point 1 (red) and point 2 (green) on the gearbox housing

Figure 8 shows the comparison of noise spectrum in near field of the gearbox and vibration spectrum on the gearbox housing by the standstill measurements. In this case the curves have also almost the same progression, with some minor differences. It can be stated that the noise and vibration generated by the failure, on one hand will be transmitted through the wall of the gearbox housing, on the second hand the vibration is transferred to the housing and the housing is radiating the noise to the surrounding field. Unfortunately, also in this case the exact localisation of the failure is not possible.

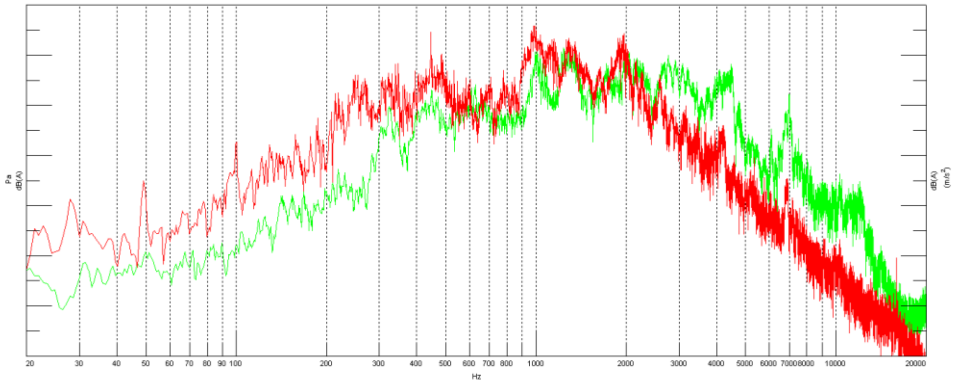

Figure 8

Averaged noise spectrum in near field (red) and averaged vibration spectrum at point 1 (red) on the gearbox housing

As shown before the noise and vibration analysis did not lead to the localization of the faulty component of the gearbox. For further analysis the study of the gearbox structure and later the disassembling of the gearbox could lead to the solution. The manual gearboxes containing a mechanism, which function is the moving certain gears into mesh position with other gears. This mechanism contains several shift rods (3 pcs. by a 6-speed manual gearbox) and shift forks. The rods are connected to the forks, and the forks are connected to the synchronizers. By the shift process triggered by the driver one of the shift rods (depending on which speed is shifted by the driver) is moving to its end position (shift position). In this shift mechanism in the gearbox a large clearance between some of the parts could be responsible for the generated impact noise. Another possible noise generation mechanism could be when the shift rod reaching its end position and an undamped impact happens.

5. Conclusions

It could be shown that acoustic methods through noise and vibration measurements, are not always capable to identify a specific problem in the car powertrain (and in general). If the generated noise and vibration of the specific failure are broadband, it is nearly impossible to make a proper failure detection. On the other hand, some of the failures generate very specific noise and vibration, with discrete frequency contents. In this case the identification could be more sufficient, since the fault frequency refer exactly to the component, e.g., the meshing frequency of a gear pairing. In case of a broad band failure noise/vibration (as in current case study) only the localisation the unit (gearbox) which containing the faulty component might be possible, but it is not possible to exactly localize the faulty part. In this case unfortunately further analysis must be done, even the disassembly of the unit must be performed.

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