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NEW CONCEPTS OF USING VIBROACOUSTIC METHODS FOR THE NEEDS OF AUTOMOTIVE INDUSTRY

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ABSTRACT
Authors of this paper are engaged since years in various research projects, carried out in the area of machine vibroacoustics. As an effect of these projects, some new concepts of using the vibroacoustic techniques for the needs of automotive industries were formulated. In the first part of this paper a brief review of concepts concerned with automotive noise is introduced. First of all, it was proposed to develop methods of testing the quality of gearboxes by means of acoustic as well as vibration signals in the stage of manufacturing and assembling of gear transmissions. The main assumptions and a concept of objective VA method of testing gears are presented. In the last part of the paper the developed idea of using "individual vibroacoustical characteristics" for the needs of advanced maintenance of automobiles is introduced.

1 - INTRODUCTION

Acoustic effects emitted by gears belong to the important problems of designing and manufacturing transmissions for automotive industry. The noise of gears belongs to the category of mechanical noises and is concerned with such phenomena as: putting the pairs of teeth in contact, mutual slipping displacement of the tooth surfaces or effects of all kind of backlashes as well as manufacturing and assembling inaccuracies. In literature [1] the acoustic noise of gears is very often considered together with the mechanical vibrations of gear trains. Thus, the term "vibroacoustic effect" is often used in this context.
A complex structure of the noise of gears requires complicated methods of measurement and analysis [2]. Because of the periodic nature of the functioning of gear trains, various tools of spectral analysis are usually used for the needs of processing vibroacoustic signals of the gears. Basing on the relationship between the results of spectral analysis and basic design features of the gear train we can recognize the primary sources of vibroacoustic effects in the gearbox and draw conclusions about possibilities of reducing the discussed effects. Using more complex frequency characteristics, like the "waterfall" spectrum diagrams, the influence of time changes of velocities on the form of the spectra can be identified. Such a characteristic makes it possible, for instance, to distinguish between the components related to the resonant frequency and the effect of changes of velocities in time [2].
Vibroacoustic signal contains information about the individual features (behavior) of a particular item. If so, the results of measuring and analyzing the acoustic effects may be used for the purpose of testing gear boxes and their components in fixed steps of assembly lines. In particular, it should be possible to create a "vibroacoustic-based" system of gear production testing.

2 - TESTING THE QUALITY OF GEARBOXES

In industrial practice the method of audio testing is commonly used as a tool of testing gear trains. A human expert evaluates the acoustic effect of functioning gear train and subjectively decides about the quality of the tested item. In the same category, we may consider the method of investigating vibrations of a gearbox by means of "hand touch". The subjective nature of the method, introduced above, is the weakest side of it. Various experts can classify the same object as "good" or "not good". The method

is "by origin" a qualitative one. Any quantitative measures are identified so that it is practically not possible to formulate strict criteria for procedures of testing [3], [4].
The problem of developing an objective method of vibroacoustical (VA) testing of gearboxes seems to be still open. According to results of our recent research we can assume that the method of objective acoustic testing of gear boxes would be developed basing both on a direct measurement of the acoustic effects emitted by the investigated gear and on the toolbox of the diagnostic method. By use of fixed diagnostic symptoms we could identify the relationship between the VA signals and the sources of these signals in the tested box.
It has to be clearly mentioned in this point that − comparing with the needs of a "pure" diagnostic of gears − in the case of the discussed method we intend to recognize rather the "vibroacoustic behavior" of a single investigated item than to formulate general conclusions. "Classic" rules of diagnostic reasoning link symptoms with some general features belonging to a class of investigated objects. Usually we are able to fix such rules in a specific procedure called "learning investigations". It is assumed that the relationships between the measured values of features of the diagnostic signals and observed features of the members of the learning group of objects can be generalized i.e. the behavior of the every object of the same type can be diagnosed by means of fixed rules.
In the case of a single/individual unit, its behavior can be "untypical". In such a case, the previously identified diagnostic rules are not fully effective. Therefore the diagnostic solution ought to be supplied by a tool appropriate to "individual reasoning". We assume that the method of objective testing of gearboxes should contain, apart from a set of diagnostic rules, a "knowledge base". In a next step, the using of an expert system for the needs of supporting the process of formulating final conclusions about the state of an investigated gearbox ought to be taken into consideration.

3 - CONCEPTION OF THE VA SYSTEM OF OBJECTIVE TESTING OF GEAR BOXES

We will talk about the "system of objective testing of gear boxes": this term will contain two components: design of a test stand and procedures of testing [4]. The test stand will be based on an anechoic chamber. The design of such a chamber has to include − first of all − necessity of eliminating acoustic effects of the engine that moves the tested gearbox. The second important problem to be solved is the need of absorbing the power transmitted by the tested gearbox. If the number of boxes tested in a time unit should be big, the design of the stand has to assure easy and quick mounting and remounting of a tested item.
The program of tests will contain two main groups of activities:

- tests of a "continuous" functioning,
- tests of influences of fixed changes on acoustic effects.

The first group of test should contain, among others, the test of an influence of power load on acoustic effects. In the second group, the following tests have to be included:

- changes of gears,
- maneuverability ("switching ability"),
- others (if needed).

It is assumed, that some elements of more complicated test should be automatically controlled (according to fixed programs). Fig. 1 shows a simplified scheme of the measuring stand which is designed in order to be used for the needs of testing gear transmissions.
The stand contains the anechoic chamber supplied with a signal analyzer, based on a PC class computer. Testing procedure should be simplified to a high degree. It is necessary to limit the number of operations of mounting the tested box on the stand and switching the routine on. Changes of speeds as well as switching between the gears will be carried out automatically. The automatic control will enable us also to analyze automatically the maneuverability of the tested gearbox. In such an option the stand ought to be additionally supplied with the possibility of measuring the load necessary to switch on the needed gear in the function of time or, for instance, the passed distance.
For this test stand two basic routines of vibroacoustic tests may be proposed. The first one is based on the measurements of the acoustic pressure in the free-field room with sensors located on a half-spherical surface. The second variant of the testing routine is based on an individual measurement program. In the first step of this program, the direction of maximal noise emission is found. Next, the noise level is measured when the microphone is moved along the line of maximal emission. For both the proposed

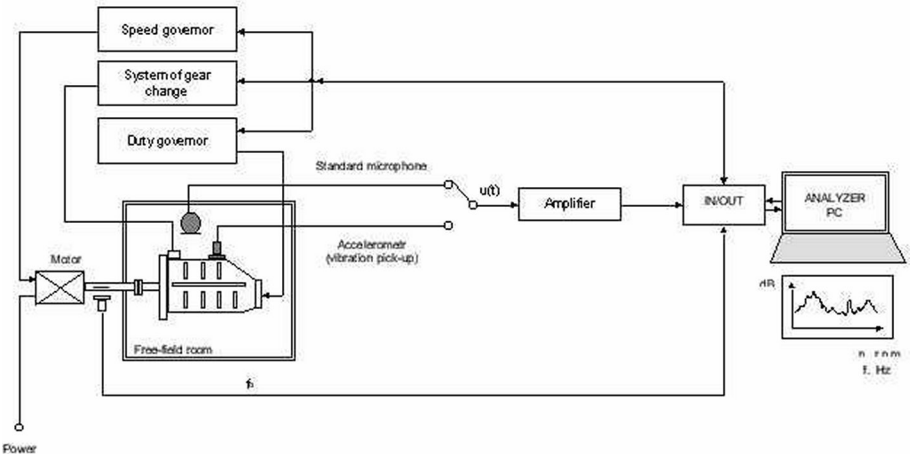

Figure 1: Scheme of the measuring stand designed for the needs of testing gear transmissions by means of acoustic signals.

routines, measurements of noise level are repeated for every considered gear in the tested transmission with the previously fixed range of rotational speeds. It should permit us to simulate conditions, which appear during the normal exploitation of the gearbox. In order to evaluate the quality of manufacturing and assembling the gearbox, an appropriate set of criteria has to be fixed. Such criteria should be based on the results of appropriate "teaching" research, carried on separately for every type of tested gears.
The criterion introduced in Fig. 2 can be used as a base of the "first approximation" of the evaluation of the gear quality: we are able to say that the tested product is "good" or "bad". Anyway, such estimation can not satisfy the producer of gearboxes. For instance, apart from the classification result he may be interested in more detailed information about the reasons of inappropriate functioning of the tested gearbox. The behavior of the tested items in unstable conditions can be also of significant importance in complex testing. Thus, the test stand ought to be supplied with advanced software (knowledge base, expert system) which will enable the user to formulate proper conclusions about the state of the tested items basing on a set of cases and rules of reasoning.

4 - INDIVIDUAL VA CHARACTERISTICS OF AUTOMOTIVE GEARS

As a result of the above-described testing routine, we are able to record for every tested item a specific set of data. This set of data will represent in the space of VA signals the individual "vibroacoustical behavior" of the tested gear. It offers very interesting possibilities for further live of the gear. If we treated the data from measurement, carried out during the manufacturing/assembling tests as an initial one, it would be possible to compare such a data with results of measurements after a fixed operational time. Results of such a comparison will give us information about changes of the state of the investigated object.
The individual VA characteristics of gear transmissions [4] as well as of other "noisy" elements of the car could be treated as a significant element of the car "equipment". Because contemporary vehicles are more and more often equipped by a "deck" computer, the VA characteristics can be stored in the disposable memory and used during maintenance activities. The important research problem is how to synthesize VA characteristics of various assemblies and sub-assemblies of the vehicle in a form of a unique characteristic of the whole vehicle.

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