APPLICATION OF THE OPERATIONAL MODAL ANALYSIS IN TRANSMISSION GEARBOX TECHNICAL STATE IDENTIFICATION

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Summary

The chosen results of the technical conditions identification investigations of the car transmission gearbox which was situated in the investigative laboratory of Department of Vehicles and Diagnostics in UTP Bydgoszcz by operational modal analysis methods were introduced in this paper. Conducted investigations of transmission gearbox depended on delimitations of vibroacoustics measures for chosen gear sets and accomplishment the assessment of received results influence on transmission gearbox state by operational modal analysis methods.

Keywords: operational modal analysis, diagnostic inference

ZASTOSOWANIE EKSPLOATACYJNEJ ANALIZY MODALNEJ
W BADANIACH STANU TECHNICZNEGO SKRZYNKI PRZEKŁADNIOWEJ

Streszczenie

W pracy przedstawiono wybrane wyniki badań identyfikacji stanów technicznych skrzynki przekładniowej, która znajduje się na stanowisku badawczym laboratorium Zakładu Pojazdów i Diagnostyki UTP w Bydgoszczy metodą eksploatacyjnej analizy modalnej. Przeprowadzone badania skrzynki przekładniowej polegały na pomiarze sygnałów drganiowych dla założonych stanów zdatności oraz badanie wpływu jej rozregulowań na zmianę sygnałów wibroakustycznych z wykorzystaniem metody eksploatacyjnej analizy modalnej.

Słowa kluczowe*:* eksploatacyjna analiza modalna, wnioskowanie diagnostyczne.

1. INTRODUCTION

The necessity of the technical state estimation is conditioned the possibility of making decisions connected with object exploitation and the procedure of next advance with object. The present development of automation and computer science in range of technical equipment and software creates new possibilities of realization of diagnosing systems and monitoring technical condition of more folded mechanical constructions.

These new possibilities are connected with the new constructions of intelligent sensors, module software and the modules of transport and data exchange [1, 2, 6].

The vibrodiagnostics is one of the machine condition description methods - understood as the organized set of methods and means to the technical state estimation (his causes, evolution and consequence) of technical systems, with utilization of vibration processes or the noise signal [4].

Looking synthetically in generally possible uses of the vibration diagnostics in the next phase of the object existence, it should distinguish the need of the acquaintance of knowledge about the object, about the signals, the syndromes and symptoms and the theory elements of decision in range of the diagnostic inference, indispensable to the correct estimation of the technical object state. The investigations of vibroacoustics processes in many cases are very complicated, in peculiarity when vibration processes step out in real physical arrangements.

Modal analysis is the process of determining the modal parameters of a structure for all modes in the frequency range of interest. The ultimate aim is to use these parameters to construct a modal model of the response. Following the changes of modal model parameters as a result of engine maladjustment, waste, damages or its failure is the main idea of operational modal analysis. Modes of vibration which lie within the frequency range of the operational dynamic forces always represent potential problems [2, 3, 5, 7].

2. TRANSMISSION GEARBOX MODAL PARAMETERS ESTIMATION

For mechanical object analysis several types of function could be used – time or frequency signals: autopower spectrum, crosspower spectrum, coherence and others. Modal test could be divided into three phases. First phase of modal test is measurement set-up (system calibration, force and response tranducers attachment).

The second step of modal test is measurement of frequency response data – measured in time domain signal is transformed into the frequency domain functions.

The last step of test is modal parameters estimation where measured frequency functions are used for modal model estimation. As a result we received the stabilization diagram with natural frequencies and damping factors, the modal participation factors and estimated mode shapes.

Basis on these three steps of modal testing the investigations of transmission gearbox were conducted in the investigative laboratory in UTP Bydgoszcz. LMS SCADAS recorder with LMS Test.Lab software with Modal Analysis Lite module was used for modal analysis.

Figure no 1 presents LMS SCADAS recorder used for data acquisition during investigations.

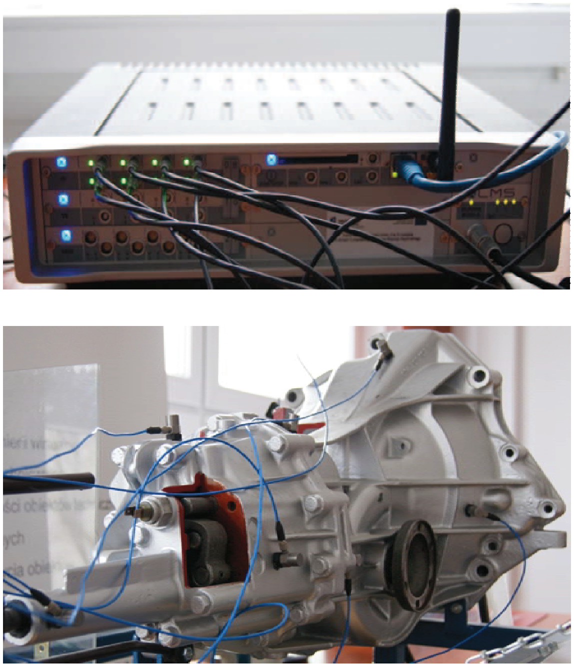

Fig. 1. The LMS SCADAS recorder used for data acquisition and object of investigations – car gearbox transmission

3. THE MEASUREMENT POINTS

Measurements were realized with gearbox speed 930 min-1 on the various shifts. During measurement 90 seconds time periods of the signals were recorded with the frequency range 128 Hz.

Figure no 2 presents transmission gearbox model with signal acquisition points.

Figure no 3 presents LMS Data Collection module.

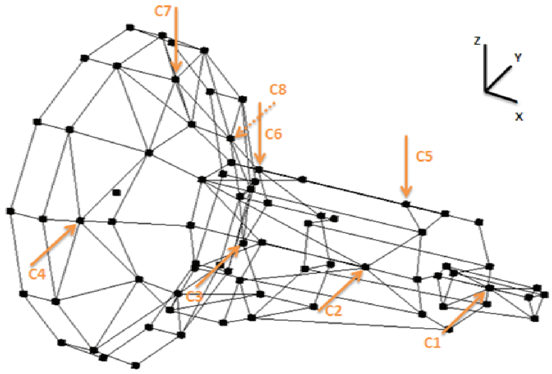

Fig. 2. Transmission gearbox model with signal acquisition points

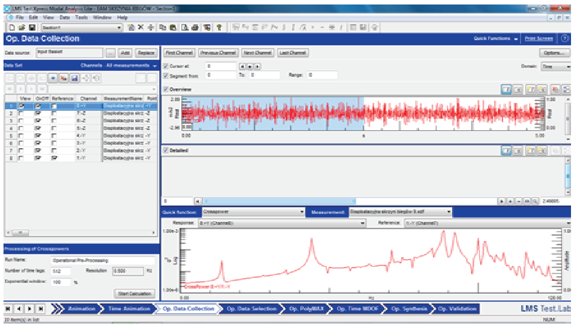

Fig. 3. The LMS Data Collection module

4. THE MODAL TEST

Basis on modal analysis theory the Time MDOF module with non-linear Least Square Frequency Domain (LSFD) method and Balanced Realisation (BR) was used for modal parameters estimation. LSFD is multiple degree of freedom method that applied for multiple inputs it generates global estimates for stabilisation diagram (system poles), modal participation factors and mode shapes.

In first step of Time MDOF method we should define the frequency range within modal test will be done. The geometrical model creation in “Geometry” module will enable the arrangement natural frequencies visualisation. Figure no 4 present “Geometry” module during investigations.

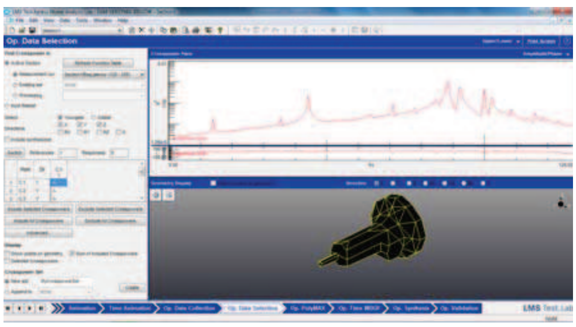

Fig.4. Data selection with “Geometry” module during investigations

In second step of Time MDOF the Balanced Realisation method was used. This is one of the "subspace" techniques which identifies natural frequency, damping and mode shapes. A subset of the response functions can be selected as references. These are used in the computation of the cross power functions from the original time domain data. This method is useful in identifying the most dominant modes occurring under operational conditions [8]. Figure no 5 presents sample of Time MDOF stabilisation diagram for investigated transmission gearbox.

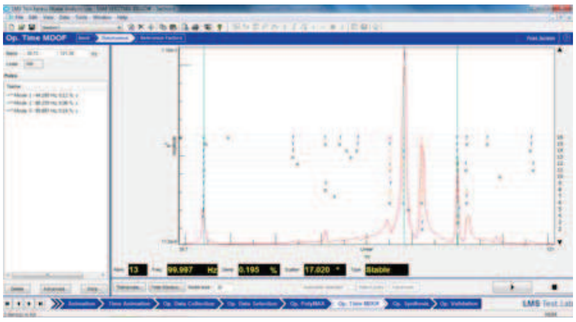

Fig. 5. Time MDOF stabilisation diagram

The result of investigations was a modal model of investigated transmission and mode shapes. The results of modal tests were introduced in table 1.

Table 1. Results of transmission gearbox modal tests

	Natural Frequency [Hz]	Damping factor [%]	Modal model Order
Idle run	44,160	0,12	16
	88,235	0,06	14
	99,997	0,19	13
First gear	44,080	0,20	8
	70,976	0,13	14
	88,504	0,13	12
	99,986	0,03	16
Second gear	44,444	0,15	12
	88,890	0,22	10
Third gear	43,844	0,28	7
	70,433	0,25	12
	124,216	0,46	9
Fourth gear	42,627	0,17	8
	81,967	1,01	8
	87,734	3,04	10

The last step of Time MDOF modal parameters estimation were mode shapes estimation with LSFD method introduced in figure no 6.

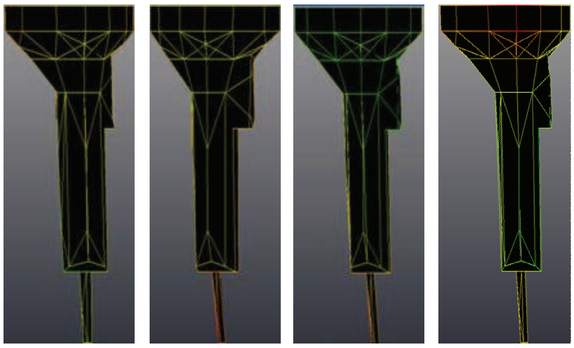

Fig. 6. Transmission gearbox sample mode shapes for frequencies: (from left) 44,16 Hz, 70,97 Hz, 88,23Hz, 99,99 Hz

5. RESULTS VALIDATION

As results validation was used LMS Synthesis module with Auto-MAC criteria estimation - introduced in figure 7, where we could calculate the error of estimation for all recognised mode shapes of object.

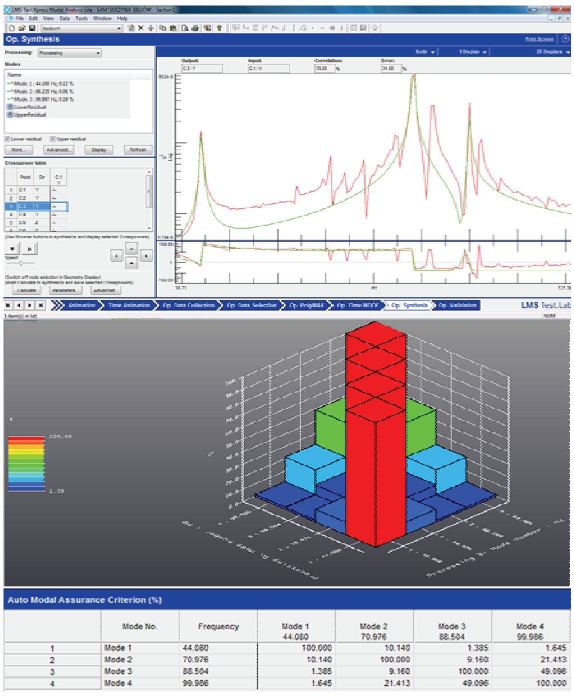

Fig. 7. LMS Synthesis module and Auto-MAC criteria estimation

6. CONCLUSION

Conducted investigations of gearbox depended on delimitations of vibroacoustics measures for chosen gear sets and accomplishment the assessment of received results influence on transmission gearbox state by operational modal analysis methods. As a results we received the stabilization diagram with natural frequencies with damping factors, the modal participation factors and estimated mode shapes. Analysing results of investigations for idle run, the first identified natural frequency (44,160 Hz) describes the movement of shaft unbalances. The figure of this own vibrations is very well visible on the animation of modal model in the geometry model analysis as determined deformations of model. Second identified figure of natural frequency (88,235 Hz) is caused the differential mass schedule on the gearbox casing and also the unbalances shaft movement - that influences on whole gearbox stiffness. Third figure of natural frequency (99,997 Hz) results from the way of studied gearbox fasten and the kind of the supports on which the whole construction of gearbox leant. Changing gears we received changes of natural frequencies for given transmissions realised by gearbox.

Presented in this paper conducted investigations and modern engineering application allows to quick process of transmission gearbox identification including their own vibration and gearbox body mode shapes visualisation. The advantage of this method is fact that the studied object can be investigated during normal process of exploitation, the investigations don't generate additional costs and we got results basis of real signals that are generated through the exploitation process of studied object.

Introduced in this paper results of investigations are only the part of realized investigative project and they do not describe wholes of the investigative question, only chosen aspects. This paper is a part of investigative project WND-POIG.01.03.01-00-212/09.

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