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THE IMPLEMENTATION OF MODAL ANALYSIS IN COMBUSTION ENGINE CAMSHAFT TECHNICAL STATE ASSESMENT

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ABSTRACT

New approach to diagnostic investigation of combustion engine technical state is vibroacoustics diagnostic methods. Combustion engines technical state diagnostic investigations with use of vibration are very difficult. The main idea of vibroacoustics investigation is following the changes of vibration estimators as a result of engine maladjustment, or its failure. The article presents questions connected with the problems of combustion engine camshaft dynamic modelling and analysis with utilization of modal analysis methods. Introduced in this paper results of investigations are only the part of investigative project results and they describe only chosen aspects of the investigative problems.

KEYWORDS virtual engineering, virtual modeling and analysis, modal analysis, diagnostic inference

INTRODUCTION

The rapid growth of combustion engine technological development increases the amount of dynamic interaction that appears on the device. These dynamic factors in common are superfluous and their excess causes the destruction of the technical environment. Prevention of these unfavourable phenomena is realized through the diagnostics tool in peculiarity by utilization of vibroacoustics methods, because vibrations draw ahead in every working machine [2].

The utilization of vibrations makes possible the description of machine dynamic condition by set of estimators from various vibration symptoms. Applied in combustion engines at present diagnostics systems concentrate on the object correct functioning through the processes diagnosing of the operating engines. Detected faultiness of the engine work usually is the result of engine arrangements dysregulations. Applied at present diagnostic methods of combustion engines in the small range concentrate on the detecting damages in the structure of the individual units of the engine. The use of the modal analysis methods could be the solution for this problem [2,3,4,6].

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 which includes the forms of vibrations, natural frequency and damping coefficients, mass and dynamic stiffness. The modal analysis methods are divided into [2,4,5]:

- theoretical modal analysis - which requires its own solution of the problem for the adopted structural model of the object,
- experimental modal analysis- controlled experiment requiring identification, during which forces the movement of an object (e.g. vibration) and measures the force and measuring the response in many measurement points distributed on the test object,
- operational modal analysis- based on operational experiment in which measurements are made only in response to the number of measurement points, while the movement of the subject is caused by the actual operating extortion.

Analysis of the camshaft dynamics is possible to perform either on the basis of the structural model (Finite Element Method) or by performing appropriate tests on a real object. For the purposes of this paper describes the use of theoretical and experimental modal analysis to identify the frequencies and mode shapes [5,6].

THE CAMSHAFT MODAL PARAMETERS ESTIMATION

For mechanical object analysis several types of function could be used – time or frequency signals: auto power spectrum, cross power 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 transducers 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 engine camshaft 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.

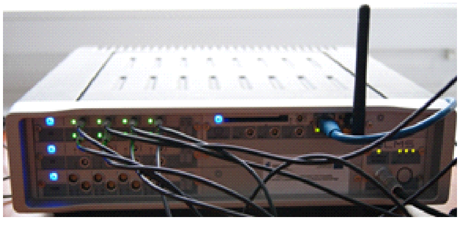

Figure 1: LMS SCADAS recorder used for data acquisition [2]

The object of investigations was a combustion engine camshaft type 7541011 SF generally used in engine number 126 A1.076/E. The theoretical modal analysis was conducted with utilization of Autodesk Inventor Professional 2014 software at UTP vibroacoustics laboratory. The numerical model created for analysis was introduced on figure 2.

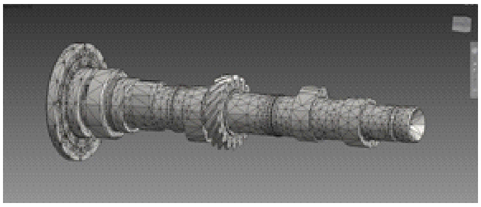

Figure 2: numerical model of analyzed camshaft with mesh created in Autodesk Inventor software. [1]

The theoretical modal analysis tool applied in Autodesk Inventor software is simplified, because the software tool creators skipped the modal damping factor which causes that results given in this tool might be different than results from real object and these results should be verified with real object. During investigations for virtual analysis were put camshaft material features that were introduced in table 1.

TABLE 1: Material feature put for analysis [1]

Name	High-strength alloy steel	
General information	Mass density	7,84 [g/cm3]
	Yield point	275,8 [MPa]
	Tensile strength	448 [MPa]
Operating stress	Young's modulus	200 [GPa]
	Poisson's ratio	0,287 [ul]
	Coefficient of elasticity	77,7001 [GPa]

The results of theoretical modal investigations applied in Autodesk Inventor software were set of own vibrations and modal displacement of studied camshaft. The results of virtual analysis were introduced in table 2. On figure 3 were introduced sample of cam mode shapes for estimated modal own vibrations.

TABLE 2: Results of theoretical modal analysis

Estimated modal own vibration	Modal own vibrations frequency value
F1	325,76 [Hz]
F2	347,33 [Hz]
F3	1793,50 [Hz]
F4	1802,29 [Hz]
F5	3331,67 [Hz]
F6	3353,61 [Hz]
F7	4682,19 [Hz]
F8	4789,24 [Hz]

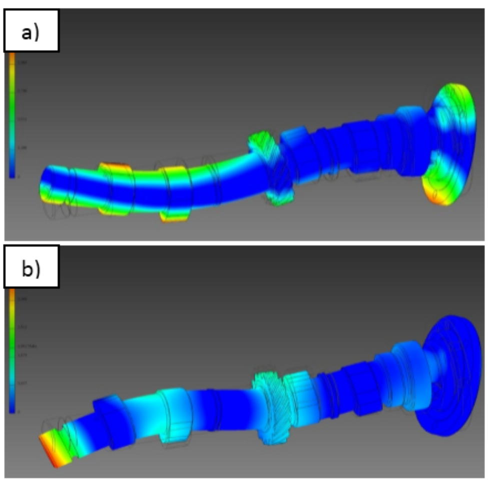

Figure 3: example of camshaft displacement for estimated own vibrations: a) own frequency value 3331,67 [Hz] for axis X, b) own frequency value 4682,19 [Hz] for axis X

The next step of investigation was implementation of experimental modal analysis for real camshaft conducted with utilization of LMS Virtual. Lab software. In this methods the first step of investigations are the geometry and measure points' setup. The analysis was conducted for ten measure points marked on the camshaft. The results of geometry model and measure points' co-ordinate were introduced on figure 4. Basis on the above mentioned geometry model the experimental modal analysis were conducted on the real object. As a results of investigations on this stage the mode shapes of acceleration, damping factors and modal hammer input force values were estimated.

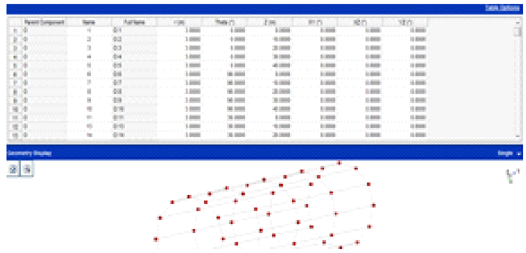

Figure 4: geometry model of camshaft with measure points co-ordinates [1]

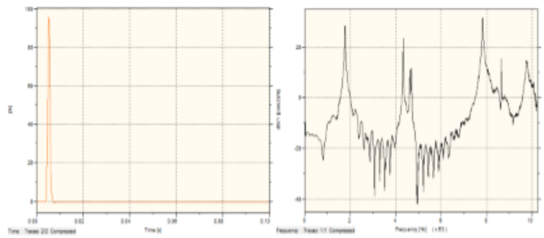

Figure 5: sample results of impact force and mode shapes of acceleration for point 4 in axis X

Basis on the results of investigations the final results of own vibrations and damping factors were estimated for studied camshaft. The sample of camshaft mode shapes for estimated modal own vibrations were introduced on figure 6. The results of investigations were introduced in table 3.

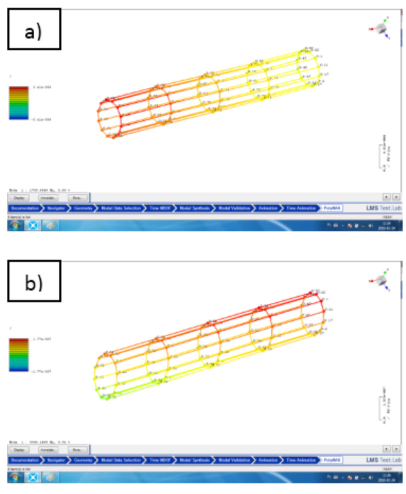

Figure 6: sample results of mode shapes for own vibrations: a) 1739,6849 [Hz], b) 3306,1485 [Hz]

TABLE 3: Results of experimental modal analysis

Estimated modal own vibration	Modal own vibrations frequency value	Dumping factor value [%]
F1	357,6383 [Hz]	7,65
F2	642,2722 [Hz]	11,05
F3	1739,6849 [Hz]	0,6

F4	2178,2163 [Hz]	0,81
F5	3306,1485 [Hz]	0,91
F6	3757,7804 [Hz]	1,09
F7	4331,1302 [Hz]	0,08
F8	4690,863 [Hz]	0,04

CASE STUDY

The study results were introduced in table 4. For these two methods the mode shapes of own vibrations are very similar but unfortunately estimated values of own vibrations frequencies are not similar. The reasons for this issue are connected with type of modal method used for estimation.

TABLE 4: Results analysis

Modal own vibrations	Theoretical modal analysis		Experimental modal analysis	
	Own freq. [Hz]	Dumping factor [%]	Own freq. [Hz]	Dumping factor [%]
F1	325,76	-	357,64	7,65
F2	347,33	-	642,27	11,05
F3	1793,50	-	1739,69	0,6
F4	1802,29	-	2178,22	0,81
F5	3331,67	-	3306,15	0,91
F6	3353,61	-	3757,78	1,09
F7	4682,19	-	4331,13	0,08
F8	4789,24	-	4690,86	0,04

The results obtained from theoretical modal analysis are done for virtual environment and do not describe the influence of external forces in real conditions. The experimental modal analysis was conducted for real object and the influences of external forces are involved. During results analysis the modal frequency F1 and F2 for both methods inform us about camshaft deflection on the entire length. The F3 frequency describes the cam deflections. Estimated frequencies F4,F5,F6,F7 describe the camshaft deflection in shape of letter "S". The last own frequency F8 describe the deflection of mounting wheel of camshaft.

CONCLUSIONS

Received in the experiment modal parameters and numerical estimators of vibroacoustics signals unambiguously show, that the camshaft technical state reflects themselves in modal parameters and vibrations factors. The application of above mentioned vibroacoustics methods for combustion engine arrangements diagnostic investigations finds its use both for the investigations of virtual object as well as for real object. This type of investigations could be realized as the supplement of other differ classical diagnostics methods. Thanks to the geometrical model we could visualize the results of investigations which enable to understood the issue phenomena and explain behavior of studied object in the conditions of real exploitation.

REFERENCES:

1. Glazik K. (2016), „Badania diagnostyczne silników spalinowych z zastosowaniem metod wibroakustycznych" Praca inżynierska., UTP Bydgoszcz.
2. Kałaczyński T., Łukasiewicz M., Liss M, Kasprowicz T. (2013), "The exploited machine engines technical state assessment with applicability of LMS Virtual.Lab" V Ukrainian-Polish Scientific Dialogues Khmelnitsky-Yaremche, Ukraine 2013.
3. Kałaczyński T., Łukasiewicz M., Wojciechowski H. (2016) „The implementation of virtual engineering to the turbocharger turbine wheel dynamic stresses analysis" Indian Journal of Research, November 2016, Volume 5, Issue 11, Pages (261-263), ISSN 2250-1991.
4. Łukasiewicz M., Kałaczyński T., Liss M, Musiał J., Matuszewski M., (2013). „Wyznaczanie częstości własnych złożonych obiektów technicznych z zastosowaniem metod analizy modalnej." Bulletin of the Kiev National University Technologies and Design No 3/2013, p. 38-42, Kiev 2013, ISSN 1813-6796.
5. Łukasiewicz M., Kałaczyński T., Liss M, Kanigowski J. (2014) "The LMS Virtual.Lab application in machines technical state analysis, Journal of Polish CIMAC Vol.9 No 3. 2014r.
6. Łukasiewicz M., Kałaczyński T., Musiał J., Shalapko J. (2014), "Diagnostics of buggy vehicle transmission gearbox technical state based on modal vibrations", Journal of Vibroengineering, September 2014. Volume 16, Issue 6, Pages (2624-3168). Numbers of Publications from 1359 to 1407, ISSN 1392-8716.