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Faculty of Mechanical Engineering
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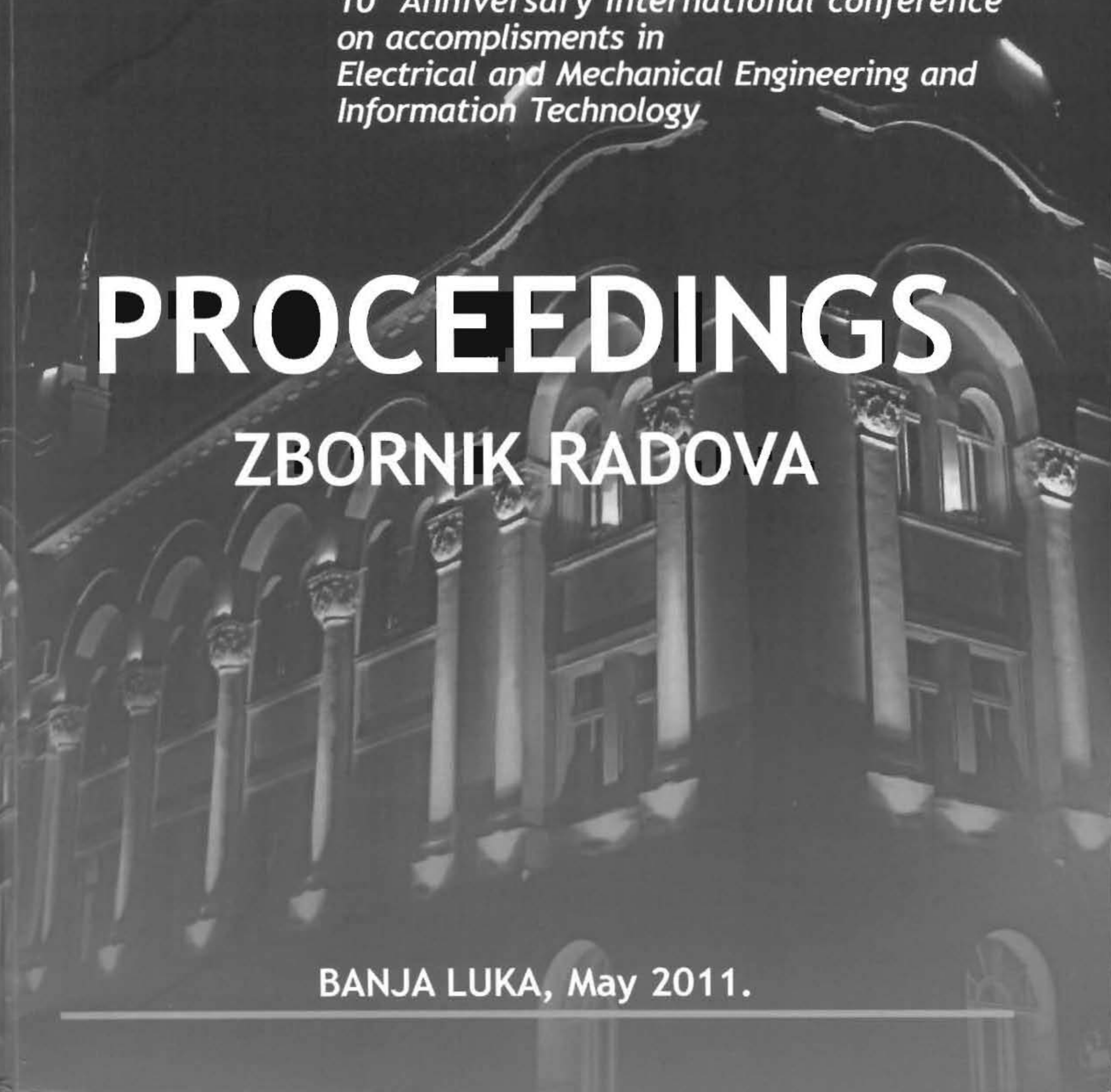
PROCEEDINGS

ZBORNIK RADOVA



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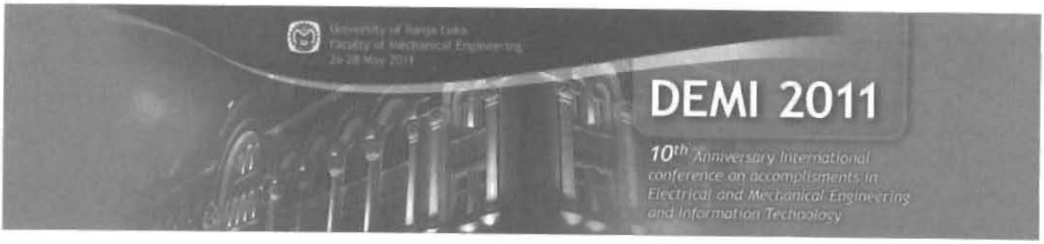

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BANJA LUKA, May 2011.

PROCEEDINGS OF THE 10th ANNIVERSARY INTERNATIONAL CONFERENCE ON ACCOMPLISMENTS IN ELECTRICAL AND MECHANICAL ENGINEERING AND INFORMATION TECHNOLOGY

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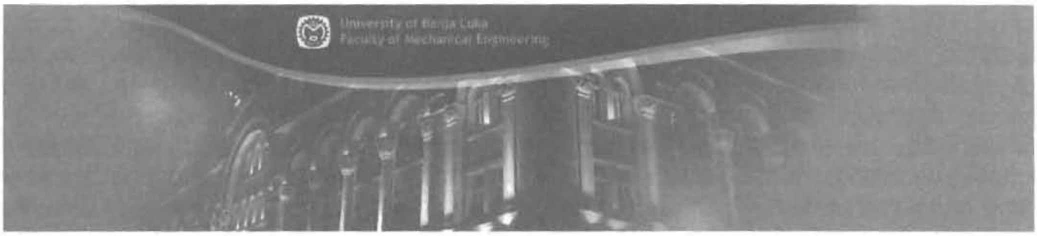

NVH INVESTIGATION OF POWER STEERING SYSTEM HYDRAULIC PUMP

Jovanka Lukić[1], Radivoje Pešić[2], Dragan Taranović[3]

Summary: *Paper presents a method for analyzing the noise and vibration problem caused by hydraulic pump of a vehicle power steering system. The method is based on experimental research and coherent analysis of observed system. Measurements are performed order to determine dominant excitation of hydraulic system in different operating conditions. Pump number of revolution was constant and was varie. Pressure of oil in hydraulic system is varied too. A method of assessment and determination of dominant NVH pump excitation is presented. Experimental results are input and output data in coherent analysis. Results showed that number of measuring channels can be reduced, especially in high frequency domain. Obtained results can be used in experiment design.*

Key words: *vehicle, steering system, hydraulic pump, NVH, noise, vibration, coherent analysis*

1. INTRODUCTION

Contemporary vehicles are faced with undesirable fluid borne, structure borne and airborne noise. Fluid borne noise is typically generated in the fluid reservoir or in the hydraulic lines and could propagate through the mounting brackets. Structure borne noise transmitted to the driver via body structure through the pump mount, engine mounts, lines and system mounting brackets. Moan is the structure borne noise. Moan frequency is driven by natural frequency and harmonics of the pump rotational Vane Passing Frequencies or Blade Pass Frequency, depending on type of the pump [2, 4, 9,10].

The noise generated by pump of power steering systems is an example of this kind of problem. Vane pumps are used in the majority of steering systems in automotive applications. These pumps generate noise due the vane passing frequency. Basically, the hydraulic pump noise can be classified as moan or whine, regarding the operating condition [2, 4, 5, 6].

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The noise and vibration problems in hydraulic pumps of hydraulic power systems, as well as steering system, mainly moan and whine noise, have similar generation mechanisms. For a diagnostic procedure, it is necessary to find the frequencies and amplitudes for which these noises become annoying for the passengers. In most cases, the moan and whine noise are related with different running conditions of the power steering system and the diagnostics must be done for each one apart. However, the moan and whine problems are directly related with the engine rotation and the frequencies of noise and vibration can be pointed knowing the construction and operation characteristics of the hydraulic pumps, [15].

The moan problem can be noted as a noise and/or a vibration. This kind of problem occurs when the vehicle engine is in idle condition and when the wheels are being steered. In this case, the system needs hydraulic assistance and the pump is charged.

The whine noise has the same generation characteristics as well moan noise. However, the whine noise arises for engine rotations out of the idle condition. In most cases, this category of noise becomes annoying for the vehicle passengers when the engine is accelerated around 2000 min^{-1}. Above this frequency, the engine noise masks the whine noise and the analysis become more difficult. In the same way as well as moan noise, the whine noise is also noted at the harmonics of the vane passing frequency. An important characteristic of these two types of noise is that the harmonics does not appear to have the same contribution to the annoyance sensation inside the vehicle cabin. NVH problems of hydraulic pump in vehicle determine experimental conditions, [2-7,10].

Aim of this work is to determine dominant hydraulics system parameter on pump noise. Experimental investigation is conducted in order to get a input data for suitable NVH modeling of hydraulic system.

2. EXPERIMENTAL WORK

Experimental research was conducted in laboratory condition. Performed research was conducted in order to get input data for coherent analysis and to determine dominant excitation of hydraulics systems. Measurement set up is designed to investigate the level of influence of hydraulic system parts.

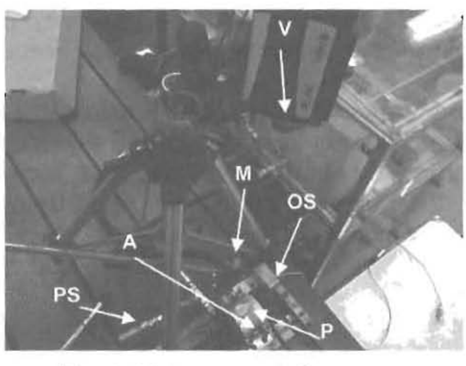

Fig. 1 *Mesurement rig*

Measurement rig used in this research is given in Figure 1 and is consisted of: electric engine which drives pump by belt transmission, thermal control unit, system for control pressure and oil reservoir. Hydraulic pumps (*P*), is driven by electric engine SEW Eurodrive, type DV132S4TF/IG1. At engine and pump accelerations are measured by three axial transducers PCB 356A16, (*A*). Outlet pump pressure is measured by pressure sensor Shaevitz, Type P1221-0002-03 M0, (*PS*). Pump volume flow is measured by Kracht flow meter, type VC3F1DS, (*F*). Sound Pressure Level (*SPL*) is measured by microphone Microtech Gefel,l type MK 250, (*F*). Pump velocity in radial direction is measured by digital vibrometer *Polytec,* type PDV100, (*V*). Pump number of revolution is measured by optical sensor *Baumer,* type: FZAM 181155 V152, (*OS*). NVH Measuring signals are acquired and stored by *Pak Mueller* system for data acquisition and HVH analysis, [8]. Measurements are performed in order to get proper data for further NVH investigation. Measuring protocol is defined in order to obtain necessary data for analysis of dominant factors which have influence on SPL of pump. Characteristic of acceleration transducers could not give completely analysis in human hearing frequency domain. Acceleration transducers have flat characteristics in frequency domain till 4.5 kHz. The human ear can nominally hear sounds in the range 20 Hz to 20 kHz. The upper range tends to decrease with age, most adults being unable to hear above 16 kHz. Region 2 kHz to 5 kHz is very important for understanding of speech, [7,9]. Digital vibrometer is used to get data about pump behavior in high frequency domain, as well as pressure transducer and volume flow transducer.

Measurements are preformed under different pressure condition: 30, 50, 60, 70 and 80 bar. Pump number of revolution was constant: 1000, 2000, 3000 and 4000 min-1 and variable from 500 to 4000 min-1.

Sampling frequency was 48000 Hz, maximal frequency was 18750 Hz, number of sampling was N=65536 -, frequency resolution was Δf=0.732 Hz, duration of signal was T=1.38 s, and Hanning filter was applied. Sampling frequency was 2.56 times maximal frequency, [8]. Overlapping of 50% of measured signal, averaging procedure was applied.

Experimental results are partially given in Figure 2. In Figure 2, the auto power spectrum of SPL is given. Under constant pressure (50 bar), overall SPL increases with respect to increase of pump number of revolution. At higher pump number of revolution, the auto power spectrum of SPL has more signal variations. At constant pump number of revolution, the auto power spectrum of SPL decreases with increase of pump pressure, Figure 2. Signal oscillations are firmly marked in frequency region till 10 kHz and are less as well as pressure increase. Low pump pressure indices more pulsation in the Auto power spectrum of SPL. The resonant frequency is around 6.5 kHz. This peak is more pronounces under high pressure, Figure 2. More results can be seen in [6].

3. DATA ANALYSIS

Aim of the work was to investigate the influence of different hydraulics system parameters on SPL of pump. Analysis of coherent functions is conducted according to computational algorithms given in chapter 10. 3, pages 249-263, [1].

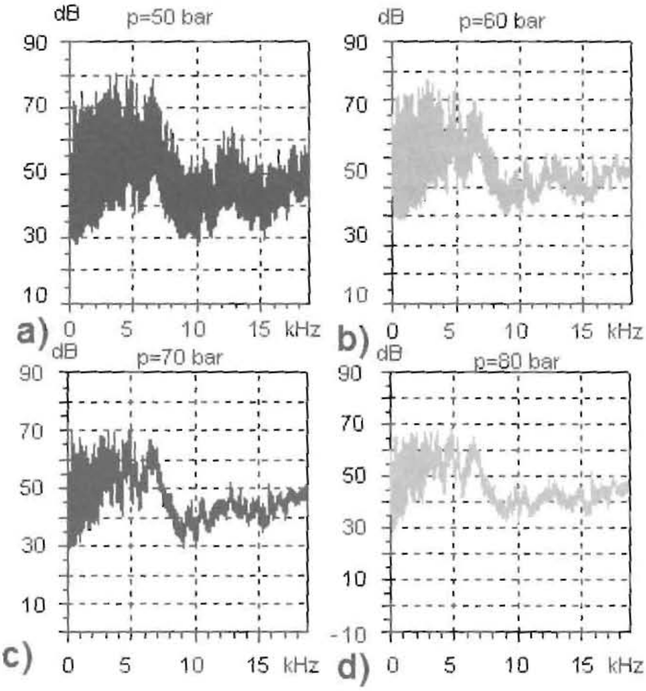

Fig. 2 *Auto power spectrum of sound pressure level at fixed pump pressure, pump number of revolution was n_p=4000 min^{-1}: a) p=50 bar, b) p=60 bar, c) p=70 bar, d) p=80 bar*

In order to perform coherent analysis, software for calculation of partial and multiple coherence functions was developed according to [1]. Measuring system, given in Figure 1, can be presented as Multi Input One Output system (MIMO), Figure 3. According to Figure 3, input data are:

- - x1 – pump acceleration in axial direction,
- - x2 – pump acceleration in tangential direction,
- - x3 – pump acceleration in radial direction,
- - x4 – pump pressure,
- - x5 – engine acceleration in axial direction,
- - x6 – engine acceleration in tangential direction,
- - x7 – engine acceleration in radial direction and
- - x8 – pump velocity in radial direction.

Output data, y, is

- - x9 – sound pressure level.

System with two input one output, Figure 4, could be used in high frequency domain with respect to characteristics of applied transducers. Input data are: x_1 – pump velocity in radial direction and x_2 – pump pressure. Output data is y=x_4 – pump SPL.

Partially, results given here, present one way of contribution to NVH pump modeling in order to get validated data for further model development, Figure 5 -

Figure 6. More results can be found in [6].

Fig. *MIMO System in frequency domain till 4.5 kHz*

Fig.4 *MIMO System in high frequency domain*

Performed coherent analysis showed that model given in Figure 6 can be substitute by model 2x1 given in figure 4. Accelerations of engine and pump can not be considered as well input data, because they have no influence on SPL. It is valid in laboratory conditions.

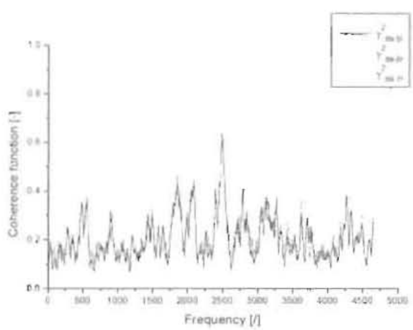

Figure 5. *Coherence functions (Pump velocity in radial direction / pump SPL), n_p=3000 min^{-1}, $\gamma^2_{89.5!}$, $\gamma^2_{89.5!}$ and $\gamma^2_{89.5!}$ are partial coherence functions when engine accelerations in axial, tangential and radial directions are removed respectively*

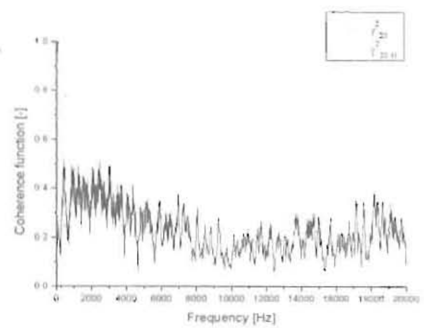

Fig. 6 *Coherence functions: $\gamma^2 23$ - ordinary coherence function between pump pressure and pump SPL, and $\gamma^2 23.1!$ – partial coherence function between pump pressure and pump SPL when pump velocity is removed, np=4000 min-1, p=80 bar*

Results showed that existing measuring rig could be updated by digital pump pressure control unit implementation. Used measurement rig also can be used in developing phase of active noise control.

For example, investigation of new duct application for pump supplying, investigation at operating conditions in vehicle and developing NVH model of pump and ducts mounting.

4. CONCLUSION

Obtained results showed that performed coherent analysis can be applied in order to get sufficient input data for NVH modeling of vehicle hydraulic system.

Results of coherent analysis showed that:

- Partial coherence functions are low when linear effects of pump accelerations are removed which means that vibration of pump can not be neglected and are dominant influence factor on pump SPL.
- Ordinary coherence function between pump velocity and sound pressure level is high, and partial coherence functions are lower than ordinary coherence function.
- When oil pump pressure is increased all values of coherence functions increase.
- The same analysis method can be applied both on vane and radial piston pump.
- Coherent NVH analysis showed that reduced measuring rig can be applied. Depending on volume flow characteristics in high frequency domain, system with two input and one output signals can be used if the volume flow is constant.
- Applied method can be very useful in initial experiment phase.

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