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NVH INVESTIGATION OF VEHICLE HYDRAULICS PUMP

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Abstract: *This work presents a method to analyze the noise and vibration problem caused by hydraulic pumps of power steering systems and body control system of vehicle. This methodology is based on experimental research and coherent analysis of observed system.*
Experimental investigations are conducted to get data in order to determine dominant excitation of hydraulic system. Measurements were performed in different working conditions: pump number of revolution was constant and pump number of revolution was variable. Pressure of oil in hydraulics system is varied too.

A new method for assessment and determination of dominant NVH pump excitation is presented. Experimental results are used as input and output data for partial and ordinary coherent analysis. Results of analysis showed that measurement points and measured signals can be reduced especially in high frequency domain. Obtained results can be used for experiment planning.

Keywords: vehicle, steering system, multi input multi output, partial coherent analysis

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 (VPF).

The noise generated by pumps of power steering systems and body control system are an example of this kind of problem. Vane pumps are used in the majority of steering systems in automotive applications and radial piston pumps are used in body control systems. 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 [4].

The noise and vibration problems in hydraulic pumps of hydraulic power systems, as well as steering system, body control 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, [4].

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 of the moan whine. 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 [rpm]. 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 VPF. An important characteristic of these two types of noise is that the harmonics doesn't appear to have the same contribution to the annoyance sensation inside the vehicle cabin. NVH problems of hydraulic pump in vehicle determine experimental conditions.

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

EXPERIMENTAL WORK

Experimental research was conducted in laboratory condition. Performed research was conducted in order to get input data for further 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.

Measurement rig used in this research is given in Figure 1. It is consisted of: electric motor drives pump by belt transmission, thermal control unit, system for control pressure and oil reservoir. Hydraulic pumps, is driven by electric motor *SEW Eurodrive*, type DV132S4TF/IG1. At engine and pump accelerations are measured by three axial transducers *PCB* 356A16. Outlet pump pressure is measured by pressure sensor *Shaevitz*, Type P1221-0002-03 M0. Pump volume flow is measured by *Kracht* flow meter, Type VC3F1DS. Sound pressure level was measured by microphone *Microtech Gefell* Type: MK 250. Velocity of pump in radial direction was measured by digital vibrometer *Polytec*, Type PDV100. Pump number of revolution is measured by optical sensor *Baumer* Type: FZAM 181155 V152. Measuring signals are acquired and stored by *Pak Mueller* system for data acquisition and HVH analysis.

Measurements are performed in order to get proper data for further NVH investigation. Radial piston pump and vane pump are used. Radial piston pump is commonly used in control body system and vane pump is used at power steering system. Measuring protocol is defined in order to obtain necessary data for analysis of dominant factors which have influence on sound pressure level of pump. Characteristic of acceleration transducers could not give completely analysis in human hearing frequency domain. Digital vibrometer is used to get data about pump behavior in high frequency domain,[5] as well as pressure transducer and volume flow transducer. Details can be seen in Figure 2.

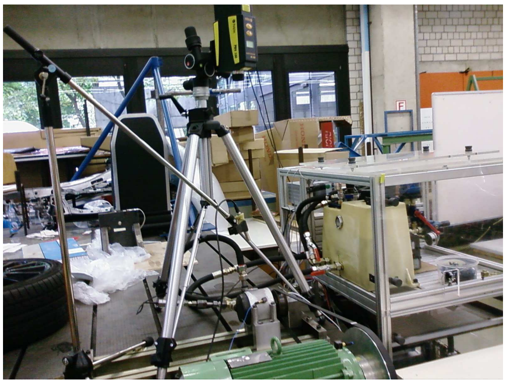


Figure 1 . Measurement rig

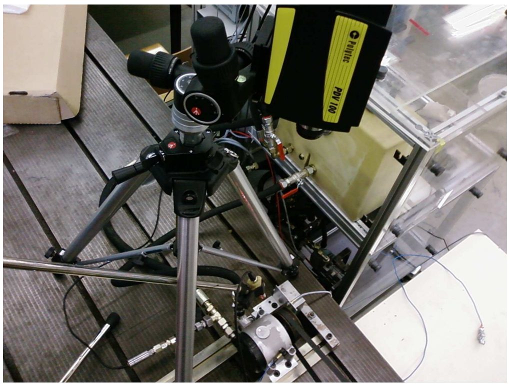


Figure 2 Measuring pump detail

Measurements are preformed under different pressure of 30, 50, 60, 70 and 80 [bar]. Pump number of revolution was constant: 1000, 2000, 3000 and 4000 [min^{-1}] and variable 500-4000 [min^{-1}].

Sampling frequency was 48000 [Hz], maximal frequency was 18750 [Hz], number of sampling was N=25601 [/], frequency resolution was Δf=0.732 [Hz], duration of signal was T=1.38 [s], signal overlapping 50%, Hanning filter was applied, sampling frequency was 2.56 times maximal frequency and variable linear averaging was applied, [1].

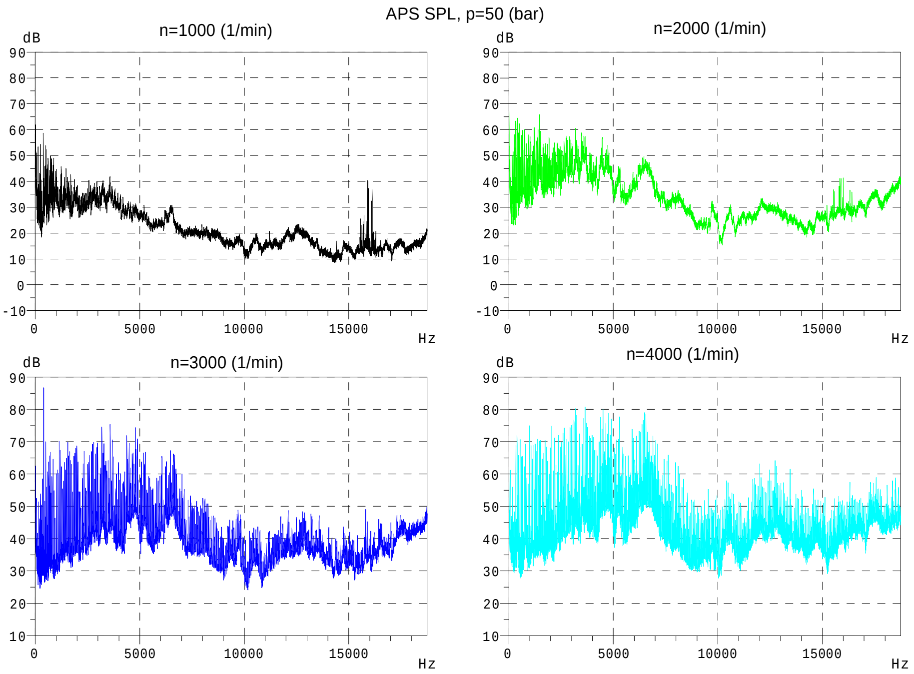


Figure 3 Auto power spectrum of sound pressure level at constant pump revolution number and fixed pump pressure *p*=50 [bar] a) n_p=1000 [min^{-1}], b) n_p=2000 [min^{-1}], c) n_p=3000 [min^{-1}], d) n_p=4000 [min^{-1}]

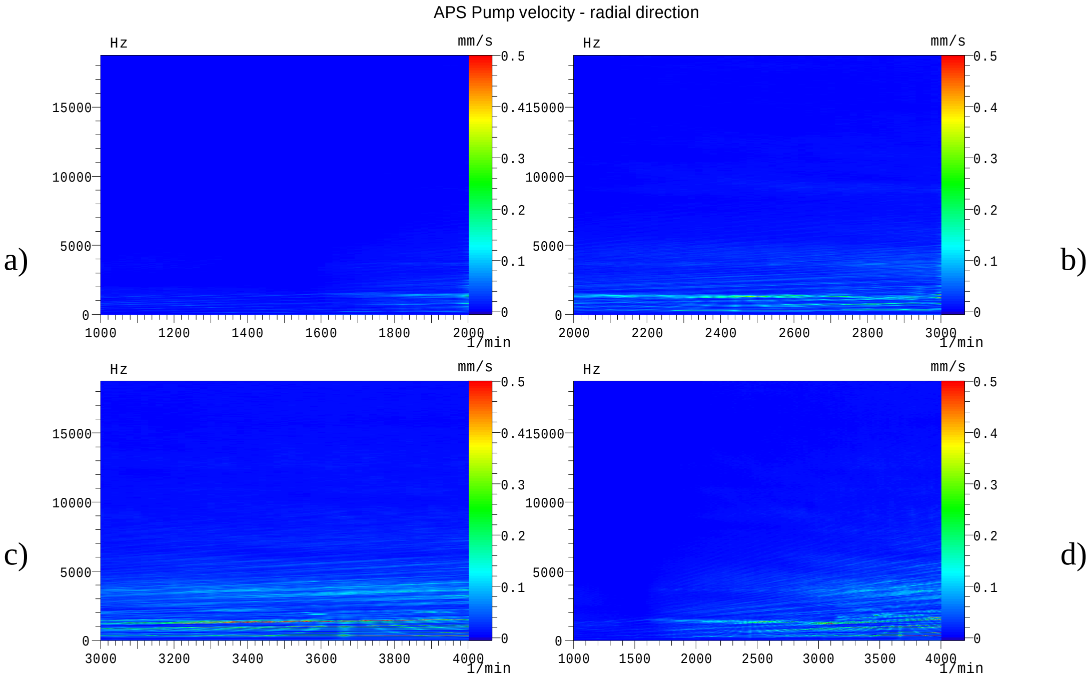


Figure 4 Auto power spectrum of pump velocity in radial direction at variable pump revolution number: a) n_p=1000÷2000 [min^{-1}], b) n_p=2000÷3000 [min^{-1}], c) n_p=3000÷4000 [min^{-1}], n_p=1000÷4000 [min^{-1}]

Experimental results are partially given in Figure 3 and Figure 4.

In figure 3 Autopower spectrum of SPL is given. Hydraulic pressure was adjusted on 50 [bar] and pump number of revolution was constant. In figure 4 waterflow diagram of autopower spectrum of pump velocity in radial direction is given.

Increase of pump number of revolution caused increase pump velocity especially in frequency till 5 [kHz].

DATA ANALYSIS

Aim of the work was to investigate the influence of different hydraulics system parameters on sound pressure level (SPL) of pump. Analysis of coherent functions is conducted according to [1].

In order to performed coherent analysis software for calculation of partial and multiple coherence functions was developed according to [1]. Measuring system can be presented as multi input one output system, (MIMO), Figure 5. According to figure 5, input data are:

- x_1 – pump acceleration in axial direction,
- x_2 – pump acceleration in tangential direction,
- x_3 – pump acceleration in radial direction,
- x_4 – pump pressure,
- x_5 – motor acceleration in axial direction,
- x_6 – motor acceleration in tangential direction,
- x_7 – motor acceleration in radial direction,
- x_8 – pump velocity in radial direction,

Output data is

- x_9 – sound pressure level

Figure 5. MIMO System in frequency domain till 4.5 [kHz]

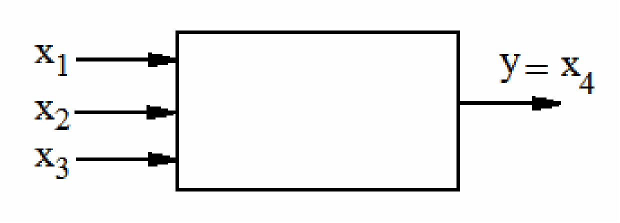


Figure 6. MIMO System in high frequency domain

Input signals x_i (i=1,…,q; q=1,2,…,8) are mutually correlated, $0<\gamma_{ij}^2<1$

Conditioned spectral density functions are:

$$S_{i\,j.r!} = S_{ij.(r-1)!} - L_{rj} S_{ir.(r-1)!},$$

where $S_{ij.(r-1)!}$ is conditional spectra of $x_i(t)$ and $x_j(t)$ when linear effects of $x_{(r-1)!}$ are removed, [1].

Frequency response function is:

$$L_{ij} = \frac{S_{ij.(i-1)!}}{S_{ii.(i-1)!}}$$

Partial coherence function:

$$\gamma^2_{iy.(i-1)!} = \frac{\left|S_{iy.(i-1)!}\right|^2}{S_{ii.(i-1)!} S_{yy.(i-1)!}}$$

Results of performed coherent analysis are partially given in Figure 7-10.

Based on, obtained results of partial coherent analysis of system with eight input and one output dominant parameters could be observed and system can be reduced with less input data especially in high frequency region. Previously mentioned coherent analysis is performed in frequency region till 4.5 [kHz], because of transducers characteristics.

Coherence functions between pump pressure and sound pressure level are middle level in region around 250 [Hz], while partial coherence functions are as well as level of ordinary function.

Partial coherence functions are low when linear effects of pump accelerations are removed, Figures 7 and 8.

Ordinary coherence function between pump velocity and sound pressure level is high, and partial coherence functions are lower than ordinary coherence function. Partial coherence function between pump velocity and sound pressure level when pump accelerations in axial and tangential directions are removed is lower than when pump acceleration in axial direction is removed only. There are no differences in amplitude level between partial coherence functions when linear effects of pump accelerations and motor accelerations in axial and tangential direction are removed and are same level as well as one given in. It can be concluded that values of accelerations of pump in all three directions and accelerations of motor in axial and tangential directions have no influence on coherence function between pump velocity and sound pressure level. Partial coherence function $\gamma^2_{89.7!}$ when linear effects of pump acceleration, pump pressure and engine accelerations are removed is lower than previous one. It can be concluded that motor acceleration in vertical direction has influence on coherence function between pump velocity and sound pressure level.

All coherence functions levels are higher when pump pressure is increased to 80 [bar] than when it is not.

Ordinary coherence function between pump acceleration in radial direction and pump pressure is higher than partial coherence function when linear effects of pump accelerations in axial and tangential directions are removed.

Ordinary coherence function is higher than partial. Resonances of ordinary coherence function are the same as well as at ordinary partially coherence functions.

Partial coherence functions are lower than ordinary one. Significant difference can be observed between ordinary coherence function and partial coherence function when linear effect of pump acceleration in axial direction is removed.

Ordinary coherence function is lower than partial coherence functions. Partial coherence functions $\gamma^2_{89.3!}$, $\gamma^2_{89.4!}$, $\gamma^2_{89.5!}$ and $\gamma^2_{89.6!}$ have no influence on partial coherence function. Partial coherence function $\gamma^2_{89.7!}$ is significantly lower than the other partial coherence function, especially in higher frequency regions.

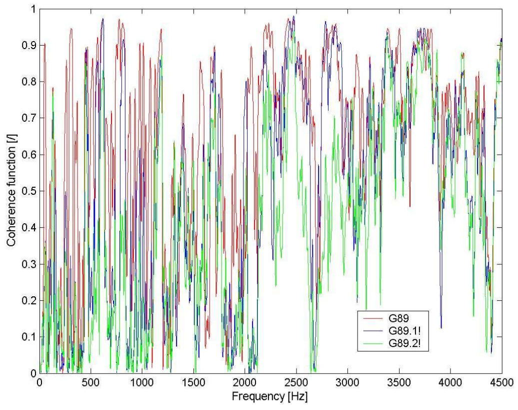


Figure 7. Coherence functions (Pump velocity / Sound pressure level) , n_p=4000 [min^{-1}]

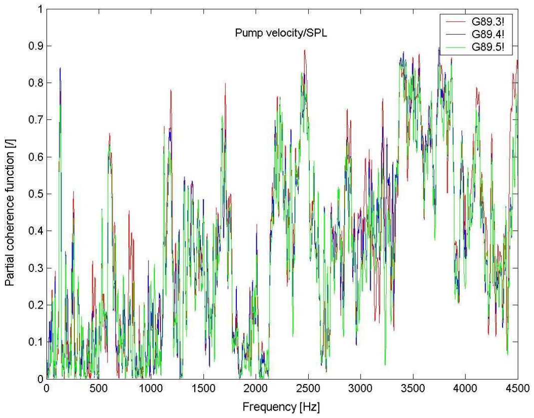


Figure 8. Coherence functions (Pump velocity / Sound pressure level), n_p=4000 [min^{-1}]

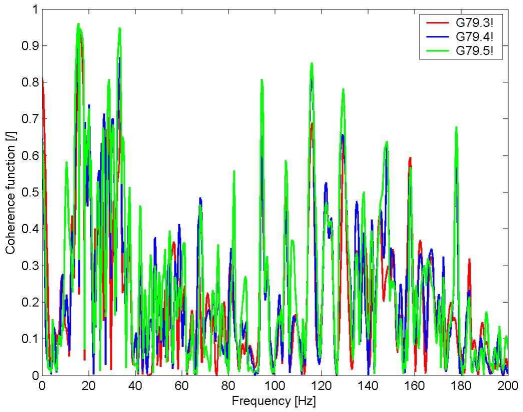


Figure 9. Coherence functions (Pump velocity / Sound pressure level) , n_p=4000 [min^{-1}], p=80 [bar]

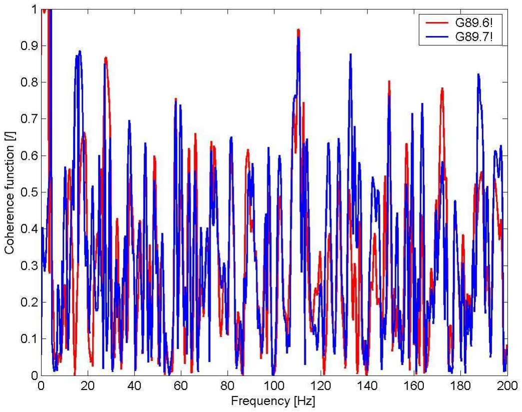
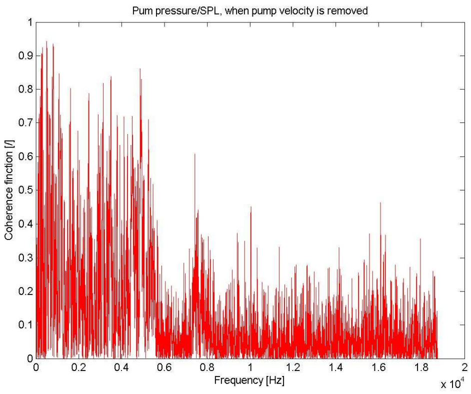


Figure 10. Coherence functions (Pump velocity / Sound pressure level), n_p=4000 [min^{-1}], p=80 [bar]

System with three input one output, Figure 6, could be used in high frequency domain with respect to characteristics of applied transducers. Input data are: x_1 – pump velocity, x_2 – pump pressure and x_3 – pump volume flow, output data is y=x_4 – sound pressure level.

Partially, given results here present one way of contribution to NVH pump modeling in order to get validated data for further model development, Figures 11 and 12.



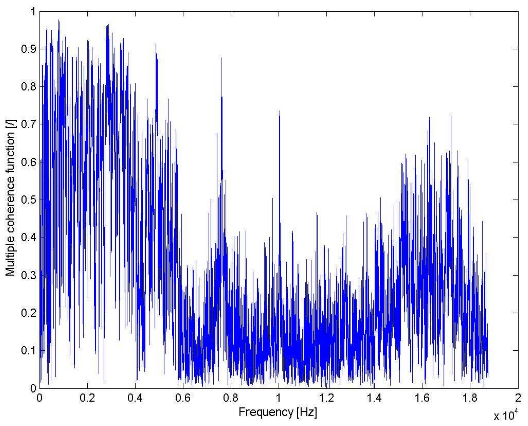


Figure 11. Coherence functions (Pump velocity / Sound pressure level) , n_p=4000 [min^{-1}], p=80 [bar]

Figure 12. Multiple Coherence functions (Pump velocity / Sound pressure level), n_p=4000 [min^{-1}], p=80 [bar]

Results showed that existing measuring rig could be updated by involving digital pump pressure control unit. Used measurement rig also can be used in developing phase of active noise control. New ideas for further research in pump NVH area are appeared. 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. Possibilities for further research collaboration and research exist and there are ideas too.

CONCLUSIONS

Obtained results showed that performed coherent analysis can be applied in order to set input data for NVH modeling.

Experimental results can be used as input data for further NVH modeling of steering system pump.

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 are higher.
- Multiple coherence function is significant in low frequency region till 4.5 [Hz].
- The same analysis method can be applied both on vane and radial piston pump.
- Coherent NVH analysis showed that reduced measuring rig can be used. Depending on volume flow characteristics in high frequency domain MIMO 2x1 can be used if the volume flow is constant.

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