ESTIMATION ELASTIC JUNCTION INFLUENCE ON PARTS AND JOINTS USING MECHANICAL IMPEDANCE METHOD

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Abstract. This paper investigates the application of the mechanical impedance method in determining the amplitude-frequency characteristics of parts and assemblies of internal combustion engines. The developed procedures can be applied to reduce vibrations and vibro-acoustic intensity. Analytical and experimental studies are presented to assess the significance of oil contact surfaces on the complex mechanical resistance. The influence of elastic properties of contact link elements in the mechanical system on transient transfer functions are determined by the mechanical impedance method for “piston-rod” and “rod-crankshaft” assemblies. In the range of resonance frequencies, the transient impedance module could increase by 6-8 dB from the effect of oil layers at the inter-element junctions.

Keywords: mechanical impedance method, amplitude-frequency characteristics, elastic influence at junctions.

Introduction

Vibrations of agricultural and other machinery could be reduced by using vibro-isolating inserts at the junction of individual parts. Satisfactory results can be obtained by properly choosing elastic and mass components of the machine elements. Oscillations of the mechanical system are characterized by the frequency spectrum of force F and the quality criterion of the technical system. By controling the contact layer of the moving parts qualitative criterion $F(\vec{q})$, reliability of a link (or a joint) can be ensured [1-3].

Direct and indirect contacts between moving and immobile elements exist in mechanical systems (inter–elements, i.e., gaskets, oil layers). There are also elements without mass ($j\omega m \Rightarrow 0$) but having elastic or damping features. Interaction of these elements has an effect on the output amplitude frequency characteristics of the vibro-acoustic signal [1; 2; 4].

The aim of this research was to apply the method of mechanical impedance for investigation of the amplitude frequency characteristics of oil layers at the connection of the crankpin and insert.

Theoretical study

Complex frequency response function $H(\omega)$ of two element partial mechanical system [1]:

$$H(\omega) = \frac{K_1}{K_{K-2}} \left| \frac{\dfrac{K_{K-2}}{M_2} - \omega^2}{\dfrac{K_1}{M_S} - \omega^2} \right| \tag{1}$$

where M_S – the element mass of the primary dynamic system;
ω – angular frequency, rad·sec^{-1};
K_K – the elastic element;
$K_{K\text{-}2}$ – the total elastic value of K_K and K_2.

At the contact of two elements, the equation can be written as follows

$$\begin{bmatrix} F_1 \\ V_1 \end{bmatrix} = \begin{bmatrix} 1 & j\omega(M_1 + M_2) \\ 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ -j\omega / K_{KNT} & 1 \end{bmatrix} \begin{bmatrix} 1 & j\omega M_r \\ 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ -j\omega / K_K & 1 \end{bmatrix} \begin{bmatrix} F_2 \\ V_2 \end{bmatrix} \tag{2}$$

where F_1, V_1 and F_2, V_2 – amplitudes of the system mechanical dynamic force (F_i) and velocity (V_i), respectively at the input point (F_1, V_1) and output point (F_2, V_2);
M_1 and M_2 – concentrated masses;
$Z_K(\omega) = K_K / j\omega$ – mechanical impedance of the oil layer.

The transfer function $H(\omega)$ has been investigated by various authors [1-6]. This function depends on the roughness of the interacting surfaces, material plastic characteristics, plastic deformation at the contact surface (S_K) during the impact of force (F_2), which influences the rigidity at the beginning of the force action and quality of the geometric characteristic of the surface, material elasticity modulus, Poison's ratio, the area of the contact surface and the pressure force.

For investigation of vibro-isolation characteristics of the mechanical link junction (gaskets) on vibro-acoustic signal propagation, the method of mechanical impedance can be used [1; 4; 9]. From electromechanical analogies for such connecting elements of machine parts, the oil layers of the kinematic pairs can be attached.

On the basis of the machine hydro-dynamic theory [4; 9], the slide bearing pressure depends on the crankshaft revolutions, value of the gap at the bearings, oil viscosity and geometry (diameter) of the crankshaft neck of the engine.

$$p_{layer}^{\max} = \frac{15.78\mu_{ol}\omega r^2\delta_{0l}}{\delta_{ol}^3} \quad (3)$$

where $\delta_{0l} = (\delta_{ol} - h_{0l})$;
h_{0l} – thickness of lubrication layer at the point where pressure is maximum;
$\delta_{0l}/\delta^3_{ol}$ – parameter defining the thickness of the lubrication layer at the point where oil pressure is maximum;
μ – oil viscosity;
r – diameter of the crankshaft neck.

In diesel tractors, the kinematic pair "journal-bearing gasket" often has lateral oil leak. Thus, in some cases the pressure decreases.

$$p_{layer}^{\max} = \frac{10.5\mu_{ol}\omega r^2\delta_{0l}}{\delta_{ol}^3} \quad (4)$$

This expression can be used to characterize the area element of the oil layer by elastic parameter K_L:

$$K_L = 10.5\mu_{ol}\omega r^2\,\delta_{0l}/\delta_{ol}^3 \quad (5)$$

This expression describes the vibro-acoustic characteristics of the mechanical link junction.

Experimental investigation and discussion

Complete information on the mechanical system and amplitude frequency characteristics of the elements can be obtained experimentally by determining the active and reactive components of the mechanical impedance module $|Z|$ and the phase angle (φ) between the vector force ($\vec{F}$) and velocity ($\vec{v}$). Measurements of these parameters were performed using special instrumentation, where vibro–acoustic signals were analyzed by the Fast Fourier Transform (FFT), see Fig. 1 [7; 8].

Vibrations of the systems "piston–rod" and data analysis were obtained by PULSE software developed by Brüel&Kjær together with the PULSE data acquisition module 3580, impact hammer 8206 for imposing known or controlled excitation and type 4370 piezoelectric charge accelerometers. The mechanical system (element) is excited by the impact force and the response vibrations are measured by an accelerometer. For this purpose the impedance hammer was used. The force measurement was obtained by using the impulse response generated by the impact hammer and the impact force was measured by the sensor located at the hammer tip. The accelerometer and impact force locations are shown in Fig. 1 a. Using a calibrated measurement scheme shown in Fig.1 b., the measurement accuracy of ±0.1 dB was achieved [7].

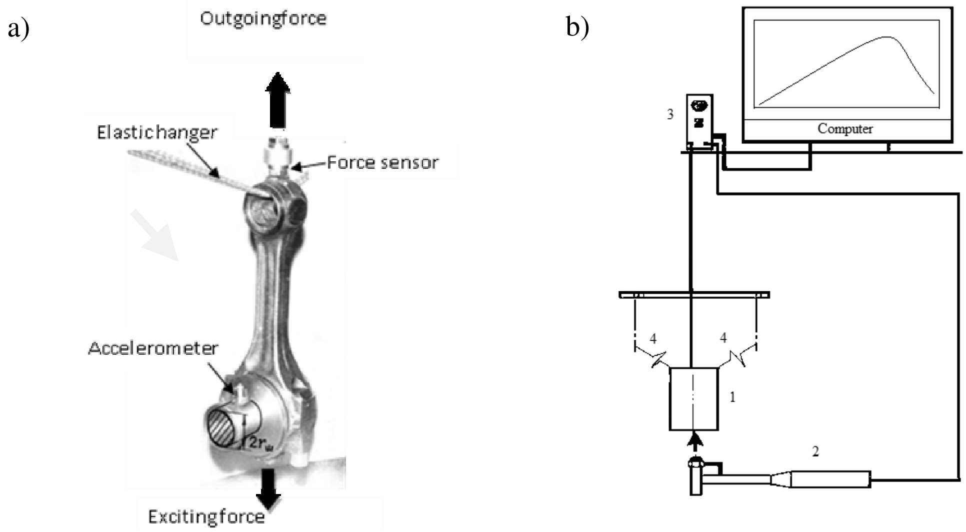

Fig. 1. **Accelerometer and impact force locations (a) and experimental set-up for measurement of mechanical impedance (b):** 1 – piston-rod; 2 – impact hammer; 3 – data acquisition; 4 – elastic construction hangers

The influence of elastic features of contact link elements of the mechanical system on the transient function was investigated by the method of mechanical impedance presented as the systems of "piston-rod" and "rod-crankshaft". Measurements of part junctions were performed for conditions without pressure and under pressure from the oil layer. Two oil types were used: 10W40 and 80W90. The results of the transient mechanical impedance are plotted as $|Z_K| = f(F)$.

The time history of the impulse force and the acceleration time response to the impact force input were measured. The frequency response function for all cases of investigation is shown in Fig. 2-4.

The experimental results of the transient mechanical impedance are given in Fig. 3. In the frequency spectrum of the oil layer (see Fig. 5 curves 1, 2, 3), the change of the transient mechanical impedance is estimated over the range of resonance frequencies. In this range, the active mechanical resistance part $R(\omega)$ of the part joint has a significant influence. The transient mechanical impedance is increased by 6-8 dB in the joint by the oil layer. This increase depends on the oil viscosity and oil layer thickness. In case of machine failure, a direct contact of the kinematic pair is possible. In the mechanical links, this contact is generated by the vibro-impulse. The amplitude of the vibro-impulse depends on oil between the components and the size of the lubricant connecting pair.

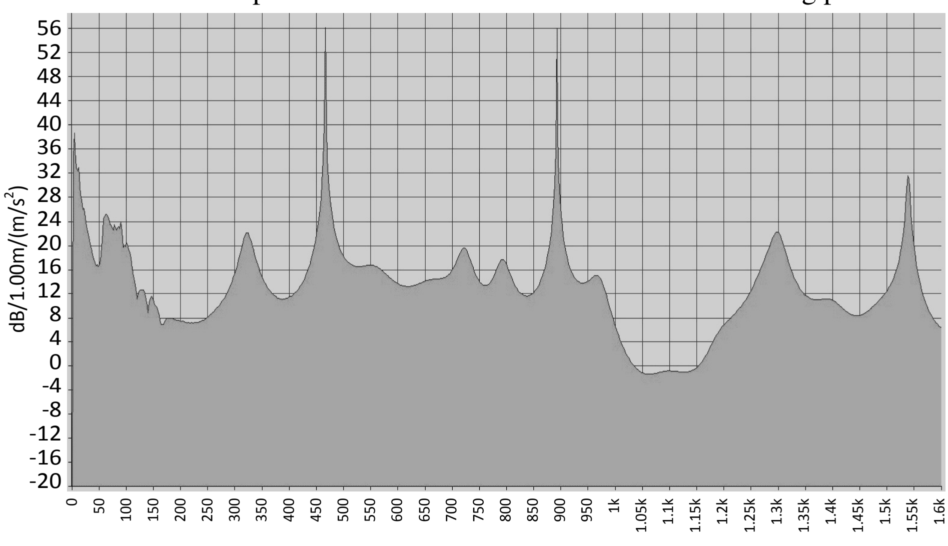

Fig. 2. **Frequency response function (FFT), excitation without oil**

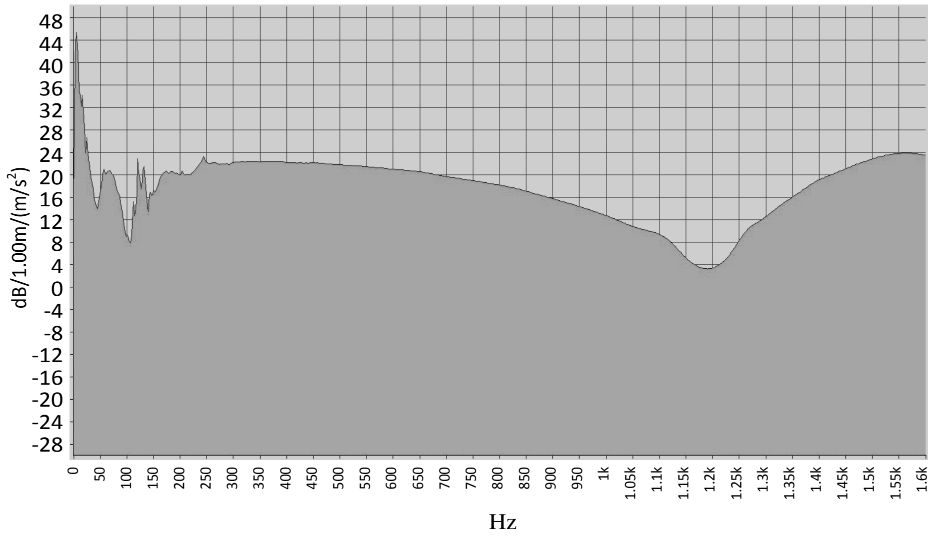

Fig. 3. **Frequency response function (FFT), with oil type 10W40**

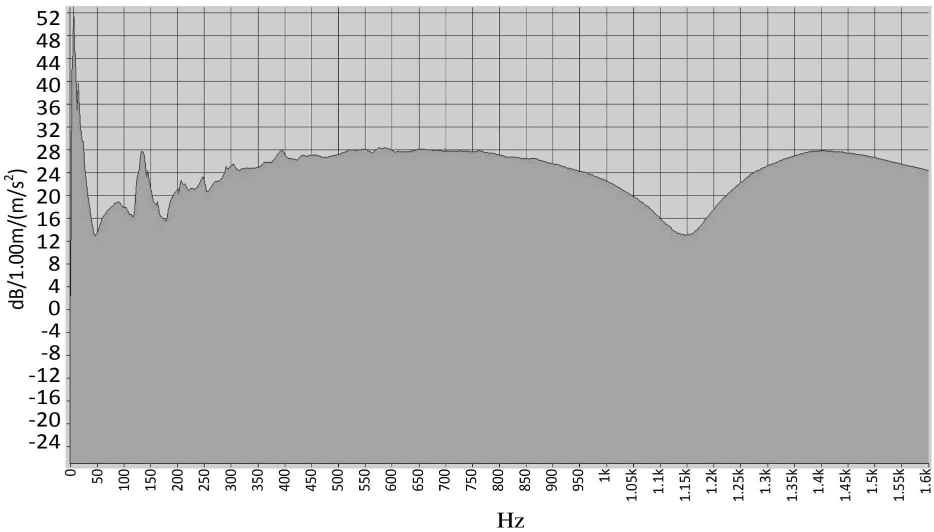

Fig. 4. **Frequency response function (FFT), with oil type 80W90**

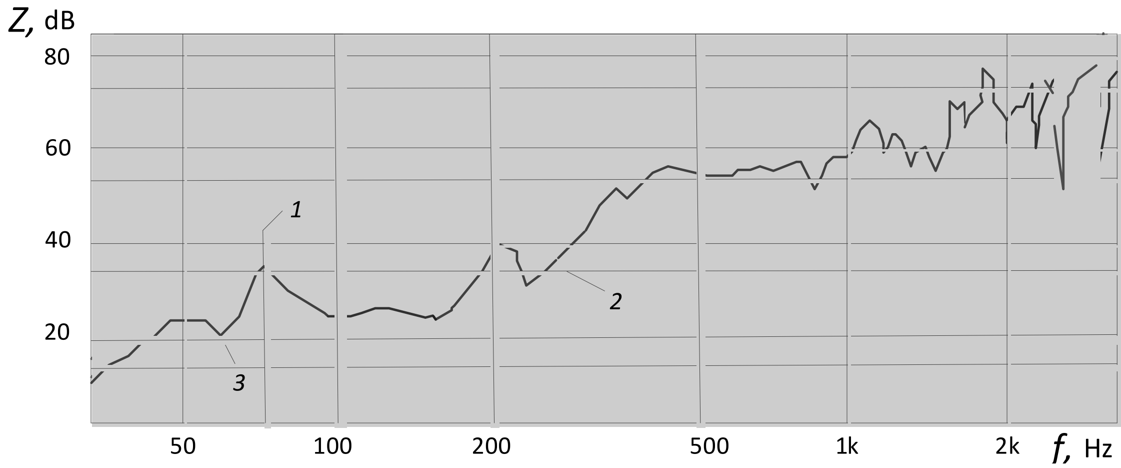

Fig. 5. **Transient mechanical impedance frequency spectrum:** 1 – without oil; 2 – with oil type 10W40; 3 – with oil type 80W90

Conclusion

1. Vibro – acoustic properties of the machine oil layer junction are defined by mechanical impedance.
2. In the inter – element junctions, the oil layers that do not depend on the machine lubrication system are characterized by an active (damping) part of the elastic elements.
3. The oil layer of the machine lubrication system is characterized by elastic elements of the mechanical system and have influence on the frequency characteristics of machine parts and junctions.
4. The transient impedance module is increased by 6-8 dB by oil layers of the inter – element junction in the range of resonance frequency.

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