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THE EFFECT OF HYDRAULIC ISOLATORS FOR CAB OF VIBRATORY ROLLERS ON RIDE COMFORT

Carmen Nicoleta DEBELEAC[1]

[1]"Dunarea de Jos" University of Galati, Engineering and Agronomy Faculty in Braila,

Research Center for Mechanics of Machines and Technological Equipments, carmen.debeleac@ugal.ro

Abstract: *In this paper, the author studied the characteristic of the hydraulic isolators regarding the vibration transmissibility under harmonic excitations developed in the working regime of roller. A nonlinear dynamics model of the vibratory roller under drum-terrain interaction can be established based, usually, on Matlab environment. The accelerations of the vertical driver's seat and the cab's pitch angle can be simulated with high accuracy. The research results available at technical literature indicate that the characteristics of non-linear damper of the hydraulic mounts can greatly reduce the vertical driver's seat vibration and cab comparative with the vibratory roller's cab using the traditional rubber mounts.*

Keywords: *Vibratory roller, hydraulic isolator, ride comfort, cab.*

1. Introduction

The purpose of this review consists on highlighting the isolation performances of hydraulic mounts of vibratory compactors equipments compared to solutions that have other insulation principles. As a consequence of the technical progress in the field of construction machines, over time, especially in the case of vibratory rollers, the performance requirements imposed on them (to ensure the ride comfort) have become very high according to the standard of ISO 2631-1 [1]. Knowing the characteristics of these anti-vibration systems embedded in the structure of the compactor, various models were developed to simulate the dynamic actions that occur during the working process, most of them with one degree of freedom based on the standard Kelvin-Voigt spring-damper model (with linear or nonlinear parameters) in combination with others rheological devices (Fig. 1).

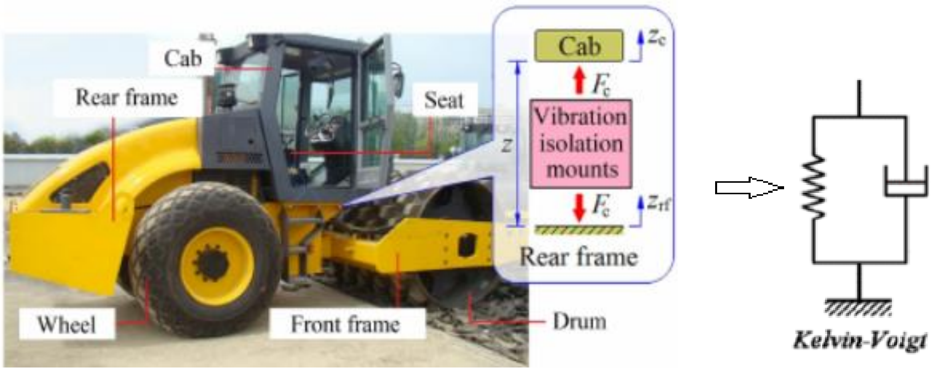

Fig. 1. Principle of isolation mounts modelling [2]

To isolate vibrations of compactor cab caused by vibratory roller excitations, low stiffness and low damping are needed because the dynamic force transmitted to the body is proportional to the stiffness and damping of the mount.

2. Modelling of the rubber and metal-rubber mounts for cab isolation

In order to isolate the vibration sources generated from the wheels and the vibratory drum of vibratory compaction machines to the operator, its seat and the cab were equipped with various isolation systems. First solutions are based of rubber elements (Fig. 2) interposed between cab-chassis and, respectively, cab floor - operator seat.

Fig. 2. Traditional rubber mounts for cab isolation

Later, metal rubber anti vibration cabin mounts (Fig. 3) are developed as industrial mounts with efficiency in vibration isolation of engines, cabs and other devices. These are available in different types of steel and rubber mesh and are use in common applications in earthmoving machinery fields, military vehicles, agricultural equipments, etc.

Fig. 3. Common rubber-metal mounts for cab isolation

The settlement of the cab of vibratory compactors on these rubber elements is illustrated in Figure 4, together with the lumped model with a degree of freedom for studying the behaviour of the analysed system.

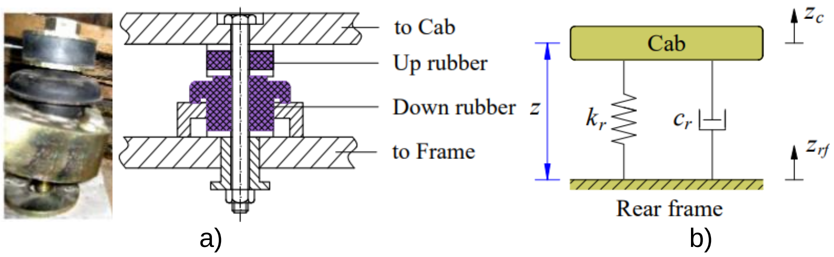

Fig. 4. Cab isolation with rubber mount:
a) Rubber mount; b) Lumped model of cab - rear frame isolation [3]

3. Modelling of the hydraulic mounts for cab isolation

Hydro mount models are more complex than rubber models. The model is designed to accurately predict the behaviour when the real design parameters like the fluid channel length and area are given [4, 5]. Figure 5 shows an example for this type of mount usually used for cab isolation.

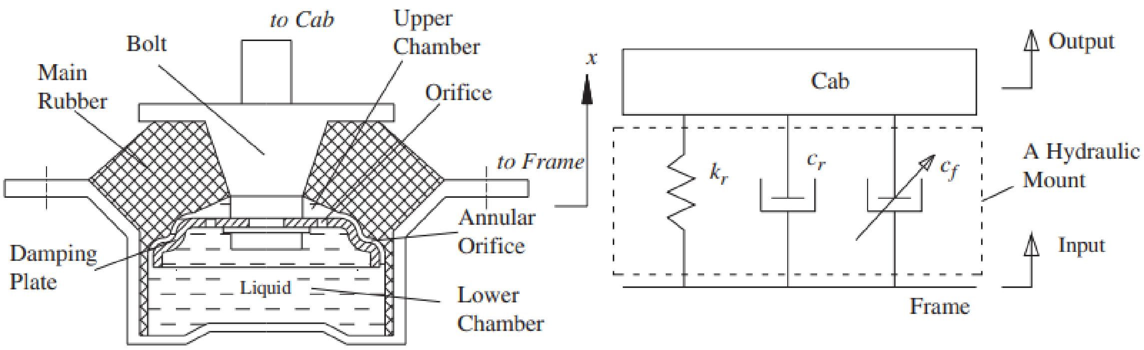

Fig. 5. Solutions for cab isolation with hydraulic mounts [6]

Hydraulically damped mounts use the tuned cab mass damping effect and additional fluid damping in order to assure high dynamic stiffness and damping around the tuned resonance frequency of vibrations generated by the vibratory roller (Fig. 6).

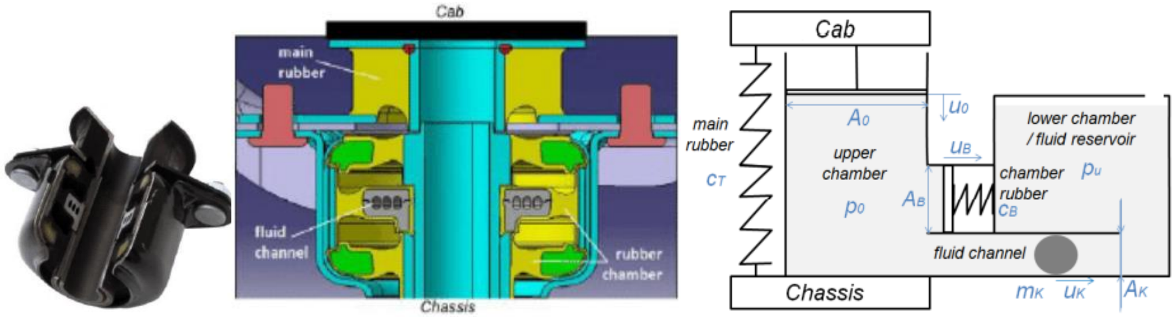

Fig. 6. Simple hydro mount model [7]

To characterize the mount's dynamic behaviour the force-displacement loops are measured at sinusoidal excitation with increasing frequency, for different amplitudes. The resulting average dynamic stiffness k_{dyn} at sinusoidal excitation is much higher than the static stiffness and depends on the frequency and amplitude (dynamic stiffness range: 2500-4500 N/mm; frequency range: 10-25 Hz). Thus, the evaluation of this isolation model under transient excitations has covered a large amplitude range and simulation put into evidence very good response to measured loads, being recommended for use on a large scale on a varied range of heavy machines [7].

4. Modelling of the hydro pneumatic mounts for cab isolation

The research results show that the cab shaking and the vertical vibration of the operator's seat were improved compared to the constructive solution of the cab's hydraulic mount without control [8] and we remark the various solution for the semi-active hydraulic mounts seat suspension and cab's horizontal damper [8, 9] illustrated in the Figure 7.

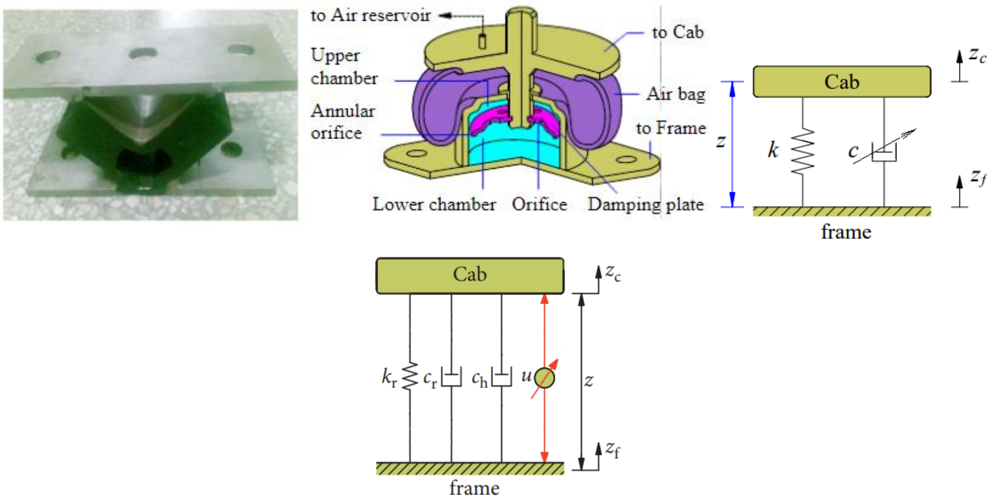

Fig. 7. Modelling of vibratory roller for ride comfort simulation with hydro-pneumatic mounts:

a) Hydro pneumatic mount; b) Semi-active lumped models of cab - frame isolation [12]

The force output of the PID control is governed by the next law:

$$u(t) = K_p e(t) + K_i \int_0^t e(t)dt + K_d \dot{e}(t), \tag{1}$$

where *e(t)* represents the displacement error the cab frame. The adequate values for K_p, K_i, and K_d, are chosen from a variable range as [K_{pmin}, K_{pmax}], [K_{imin}, K_{imax}], and [K_{dmin}, K_{dmax}], respectively, in function by the performance evaluation indexes regarding the ride comfort that we supposed to be achieved, for individual constructive and functional characteristics of each vibratory compactor type (with single or two vibratory rollers).

5. Methods for ride comfort simulation

To further improve the ride performance of the vibratory compactors, the cab insulation systems were controlled by multiple type of control: Fuzzy and PID-Fuzzy control applied in the frequency domain, in the time domain or in both [8-11]. The need for vibration control is based on the requirements of the Occupational Safety Standards that imposes maximum levels for the whole-body vibration (WBV) felts by the operator, to limited value 0.5 m/s^2. Therefore, it was suggested that a low-frequency range of 4–10 Hz for the vertical and of 0.5–2 Hz for the rotational vibrations seriously affected the driver's health and safety.
On the other hand, the root-mean-square (RMS) and power spectral density (PSD) acceleration responses on the vertical motion of the driver's seat and pitching cab angle were chosen as the objective functions (for performance evaluation indexes) under the working condition of the vibratory roller during the compaction process [12-15]. Thus, based on the international standard ISO 2631, the RMS of acceleration responses is determined by the formula:

$$a_{RMS} = \sqrt{\frac{1}{T}\int_0^T a^2(t)dt}, \tag{2}$$

where *a(t)* is the weighted acceleration (translational and rotational) as a function of time, in m/s^2; *T* is the duration of the measurements, in s.
Mostly, the numerical simulation of the vibratory behaviour of the cab in Matlab environment were performing with best accuracy results using dedicate modules for processing data measured or simulated. The processing algorithm on which the simulation is based derives from solving the differential equations of motion of the rheological model associated with the physical one, having multiple degrees of freedom. In some cases, only the damping element and the compactor cabin are considered, and in other cases, the heavy machine is approached as a whole system, subject to excitations given by the dynamic working regime or by the unevenness encountered on the terrain (as can be seen in the Fig. 8).

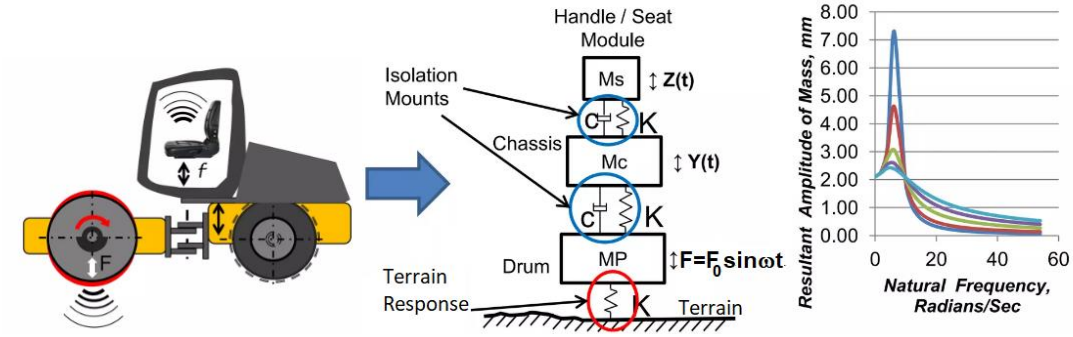

Fig. 8. Vibration mitigation at cab/operator's seat [16]

Generally, the motion equations of the vibratory compactor can be represented as matrix form thus:

$$[M]\{\ddot{Z}\} + [C]\{\dot{Z}\} + [K]\{Z\} = \{F(t)\}, \tag{3}$$

where: [M], [C], and [K] represent mass, damping, and stiffness matrices; {Z} is the displacement

vector; {F(t)} is the dynamic force vector. We have the number of lines and columns of the matrices equal to the number of degrees of freedom of the studied model.
Thus, taking into account by the Eq. (3), the dynamics of frame-cab systems and properties of the isolation system interpose between them can be surveyed and evaluated, from ride comfort of point of view, using the half-machine dynamic model or the complex 3-D nonlinear dynamic models. In this way, by detailing the component elements of the model with a significant influence on the comfort of the operator, results will be obtained with high accuracy and the model can be more easily verified and validated.

6. Conclusions

The isolation solution chosen to ensure ride comfort of operator in the case of vibratory compactors (when the frequencies and amplitudes are varied in different ranges of interest in function by the working conditions of the machine) are based on the next aspects:

- the establishment of technical solutions with the increased efficiency of reducing the harmful effects generated by the cumulative action of vibrations (generated by the working condition and/or the motion on uneven terrain);
- using of the modular anti-vibration devices, which offer to possibility of adjusting the isolation parameters in accordance with the effective values of the vibration parameters for each cabin type of the compactor equipment (using various method for vibration control, as Fuzzy or PID-Fuzzy control);
- system analysis (as lumped mass-stiffness model) and mathematical modelling of the motion equations (in function by the number of degrees of freedom of the proposed model);
- data processing for highlighting of the performances obtained compared to other systems used;
- the selection criteria of the isolation mounts: load capacity, stiffness, constructive type;
- the objective functions proposed to be achieved: RMS and PSD of the signal of the acceleration response on the vertical motion of the driver's seat and pitching cab angle;
- parameters adopted in the dynamic behaviour of the analysed model: mass, spring stiffness and damping coefficient;
- the parameter that requires to be controlled: natural frequency in order to avoid resonance vibration at roller's cab for low frequency (results obtained by the modal analysis of the system parameters);
- experimental verification and validation of the proposed isolation device.

All the aspects presented in this paper provide an overview of the design and work principle of the vibration isolation systems for vibratory compactors.

References

[1] International Organization for Standardization. "Mechanical Vibration and Shock-Evaluation of Human Exposure to Whole Body Vibration-Part 2: General Requirements." ISO 2631-1:1997, 1997.
[2] Jiao, R., V. Nguyen, and V. Le. "Ride comfort performance of hydro pneumatic isolation for soil compactors cab in low frequency region." *Journal of Vibroengineering* 22, no. 5 (2020): 1174-1186.
[3] Nguyen, V. and V. Le. "Development of cab isolation systems of off-road vibratory rollers: review research." *Mathematical Models in Engineering* 6, no. 2 (2020): 93–102.
[4] Scheiblegger, C., N. Roy, P. Pfeffer, and A. Hillis. "Modeling hydro mounts in vehicles for durability load analyses, ride comfort and vehicle dynamics simulation." Paper presented at the International Symposium on Advanced Vehicle Control, September 13-16, 2016, Munich, Germany.
[5] Scheiblegger, C. *Modelling of bushes and hydro mounts in vehicles using a multi body simulation environment*. Doctoral Thesis. University of Bath, 2018.
[6] Sun, X., and J. Zhang. "Performance of earth-moving machinery cab with hydraulic mounts in low frequency." *Journal of Vibration and Control* 20, no. 5 (2012): 724-735.
[7] Higuchi, T., and K. Miyaki. *Work machine with operator's cabin*. US Patent No. 5984036, 1999.
[8] Zhang, B., V. Nguyen, and Y. Wang. "Control the ride comfort of soil compactor with semi-active seat suspension and cab's horizontal damper." *Vibroengineering Procedia* 30 (2020): 91-96.

[9] Nguyen, V., R. Jiao, V. Le, and A. Hoang. "Performance of PID-Fuzzy control for cab isolation mounts of soil compactors." *Journal of Mathematical Models in Engineering* 5, no. 4 (2019): 137-145.
[10] Nastac, S. "On Fuzzy Logic Techniques for Vibration Isolation Active Systems." *Romanian Journal of Acoustics and Vibration* 4, no. 2 (2007): 97-102.
[11] Nguyen, V., R. Jiao, V. Le, and P. Wang. "Study to control the cab shaking of vibratory rollers using the horizontal auxiliary damping mount." *Mathematical Models in Engineering* 6, no. 1 (2020): 57-65.
[12] Nguyen, V., J. Zhang, V. Le, and R. Jiao. "Vibration analysis and modeling of an off-road vibratory roller equipped with three different cab's isolation mounts." *Shock and Vibration* (2018): ID 8527574.
[13] Jiao, R., and V. Nguyen. "Improving ride comfort for vibratory roller utilizing semi-active hydraulic cab mounts with control optimization." *Vibroengineering Procedia* 28 (2019): 75-80.
[14] Wang, Min, Guo-feng Yao, Jing-zhou Zhao, and Min Qin. "A novel design of semi-active hydraulic mount with wide-band tunable notch frequency." *Journal of Vibration and Control* 333 (2014): 2196-2211.
[15] Van Quynh, L., L.A. Vu, B. Van Cuong, H.A. Tan, and L.X. Long. "A Comparative Analysis of Ride Performance of Double-Drum Vibratory Roller with Two Cab Mount Systems." *Advances in Engineering Research and Application* 366 (2022):19-30.
[16] ***. "Design of vibration isolation for vibratory compactors." June 06, 2017. Accessed on October 24, 2022. https://www.slideshare.net/ManoharMHegde/design-of-vibration-isolation-for-vibratory-compactors.