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INVESTIGATION OF CABIN VIBRATION EXPOSURE IN A BUCKET–WHEEL EXCAVATOR (BWE) DURING PERMANENT EXCAVATION REGIME WITH COMPUTER SIMULATION

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Abstract: The paper studies the effects of a damping device linking the seat of the operator to the cabin floor of an operating bucket–wheel (BW) excavator. The effects of vibrations on humans were briefly presented first, based on a relevant literature review. Next, to a previously developed and validated model of the BW arm, a cabin model was attached, and accelerations and displacement amplitudes were determined by simulation for the whole assembly, corresponding to the vibrations in all directions produced during the permanent regime of coal excavation. Finally, a virtual device comprised of a seat and its chassis, with a damper placed between, was built. Its behaviour was studied, considering the displacement of the dominant direction Z previously determined, as an input acting on the chassis.

Keywords: *damping, vibration, human body, cabin, simulation, excavation.*

1. INTRODUCTION

Worldwide in open cast mining operations, bucket-wheel excavators (BWEs) [1] are giant machines utilised to remove large amounts of overburden and coal, using a rotating wheel fitted with buckets. There are different sizes and configurations of such machines, depending on country and characteristics of the mine, but all operate under heavy conditions. Due to their operation environment and the large mass and forces exerted during the excavation process, vibration is always present, with impact on both the structural integrity of the machine, but also on the comfort and health of their operator, usually sitting in a cabin mounted on the main boom, close to the wheel.

All operators of heavy construction and industrial machines are very exposed to several factors of risk that can generate health issues.

Whole-body vibrations are one of the most important such factors. Figure 1 shows a brief mechanical model of such vibrations.

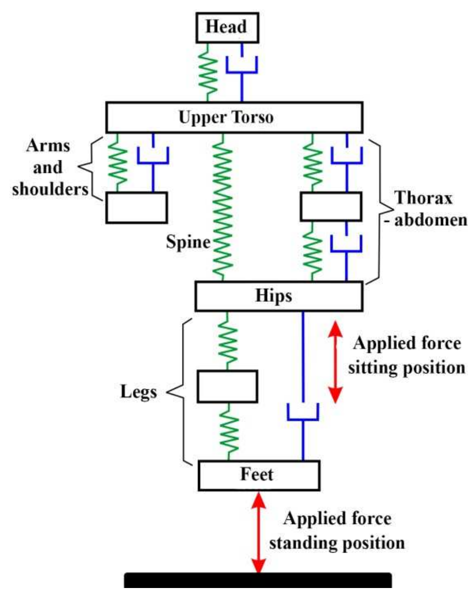

Fig.1. Whole-body vibrations model

Vibration in the interval of 2-30 Hz exerted on the human body corresponds to resonance frequency of parts and organs. Vibration exposure that is short-term can lead to loss of concentration, faster exhaustion or worsened vision, while long-term exposure can provoke

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musculoskeletal disorders, located especially at spine level, or significant blood circulatory dysfunction, especially at extremities and limbs level.

This is why health safe intervals are regulated both internationally by ISO [2] as safe between 0.44–0.80 m/s^2 for and exposure of eight hours, or under 1.15 m/s^2 according to EU Directives [3], as well as nationally by laws and regulations [4,5]. Besides the health concerns there is also the comfort of the operator.

There are several studies investigating the influence of vibrations on the human body, in case of passengers of small and middle size vehicles [6-8], operators of construction and industrial machines [9,10] or mega-machines used in the mining industry [11-14].

In this context, we wanted to investigate the possibility of damping vibrations that appear in the cabin of the ERC 1400 excavator, which is the most widespread in our country.

2. MODEL DESIGN AND TIME DOMAIN ANALYSIS

2.1. Model of the arm–cabin assembly

BWEs have a movement system (on rails or crawlers), a slewing system allowing rotation about a vertical axis, and a superstructure made of several components. The part that is most exposed to stress and vibration during excavation is the main bucket wheel boom.

For this type of excavator, our research team previously developed and validated an arm model [15].

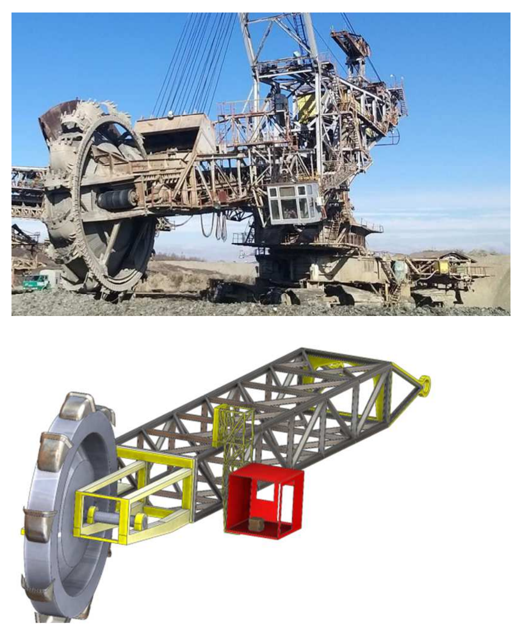
Based on the technical specifications of a real operator cabin (fig. 2), a model of the cabin and of the connection structure to the arm was built in SolidWorks at real scale (fig. 3) being placed on the existing model similarly to its real position. The comparative real / model layout of the arm–cabin assembly is presented in figure 4a and b.

In order to simulate the excavation process and its effect on the cabin, the nodal network along with the virtual sensor used for interrogation of the response of the arm–cabin assembly is highlighted in figure 5.

Fig.2. The real operator cabin

Fig.3. Model of the cabin and connection structure to the arm, created in SolidWorks

a).



b).

Fig.4. Arm–cabin assembly:
a). Real layout; b). SolidWorks model.

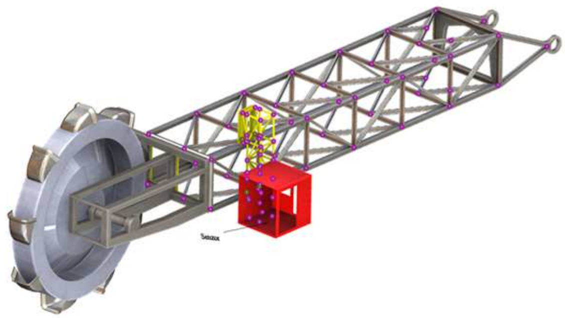


Fig.5. The nodal network and interrogation sensor

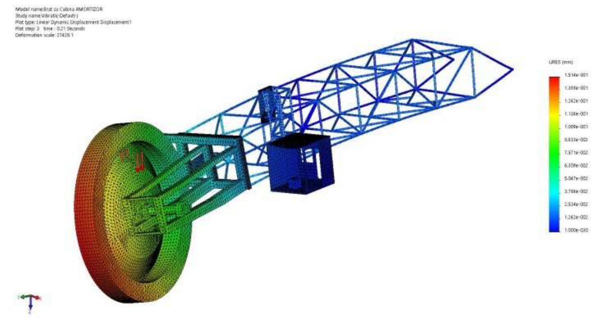


Fig.8. Displacement of the assembly

2.2. Time domain analysis

The resultant cutting force during excavation is applied on the bucket wheel shaft, and then the assembly (arm – connection structure – cabin) is subjected to a time domain analysis.

This is performed in SolidWorks Simulation, for 11 modal frequencies and a duration of 26 seconds, considering a global damping of 2%.

Prior to running the simulation, the FEA meshing of the assembly is defined. In figure 6 the mesh is shown along with the coordinate system.

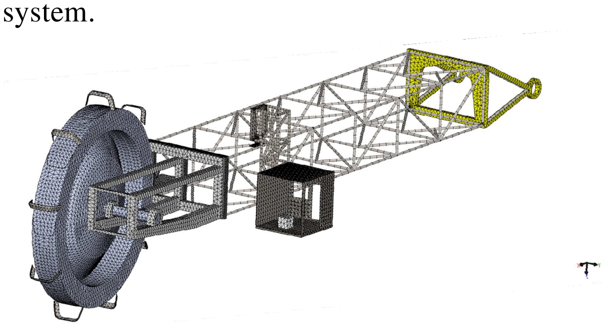


Fig.6. The mesh of the assembly and the coordinate system

The resulted von Mises stress for the assembly and its displacement are shown in figures 7 and 8.

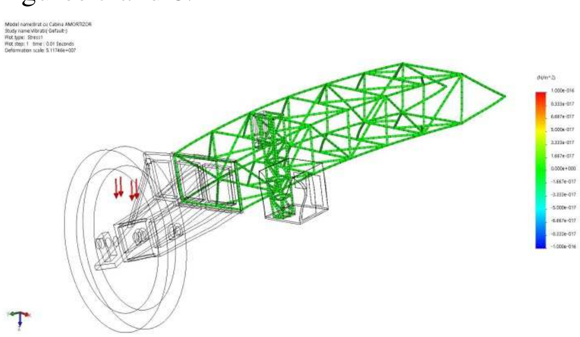


Fig.7. Von Mises stress in the assembly

Figure 9 and 10 show the graphs of the acceleration and displacement, resulting in all directions, following the time domain simulation during excavation in permanent regime.

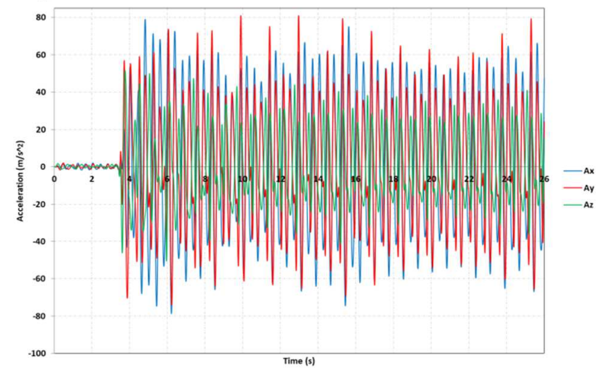


Fig.9. Acceleration on all directions (Ax, Ay, Az)

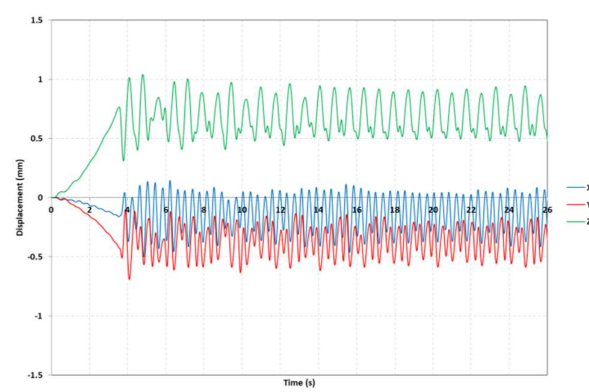


Fig.10. Displacement on all directions

From the graphs and the time domain simulation it's visible that the highest accelerations during permanent regime are in directions X (lateral) and Y (longitudinal) while the highest deformation of the assembly structure is in direction Z (vertical). This displacement in the dominant direction will be considered as input for the next phase.

3. VIRTUAL DEVICE FOR VIBRATION DAMPING SIMULATION

The proposed virtual device (figure 11) is composed from a mobile structure, a vibrating plate and a fix reference surface linked by mates. Between the inferior plane of the mobile structure and the upper plane of the vibrating plate a damper and a spring were attached. The study of vibrations effects on the mobile structure was performed using the *Motion Study* menu *Motion Analysis* option of SolidWorks Simulation.

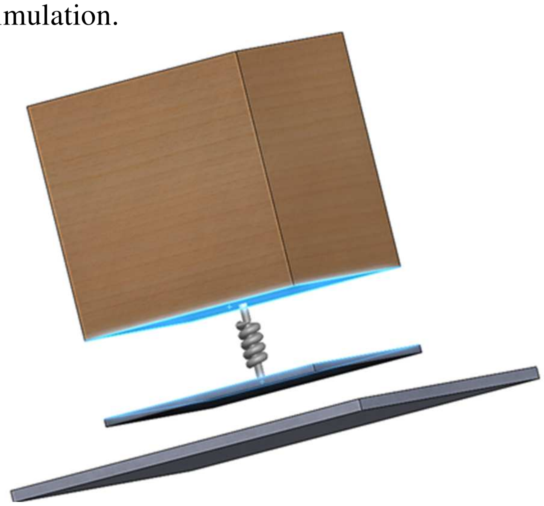


Fig.11. The virtual device and its mates

To the vibrating plate, a linear motor was attached whose motion was defined by data points. These points were imported as a displacement function of time (figure 12), with the values taken from the results of the time domain simulation of the arm–cabin assembly, considering the dominant direction Z.

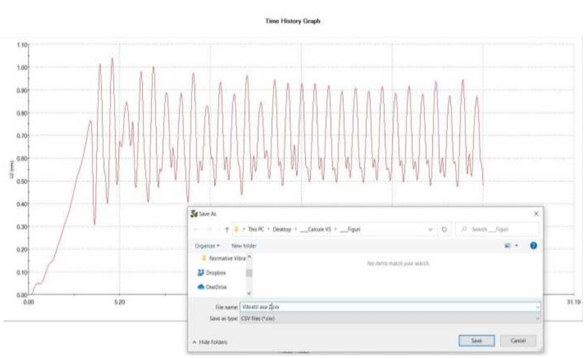


Fig.12. Defining the linear motor motion

After the input definition, the simulation is run and the graphs of acceleration and displacement were obtained for both the vibrating plate (figure 13) and the mobile structure (figure 14) about the fixed reference surface.

a).

b).

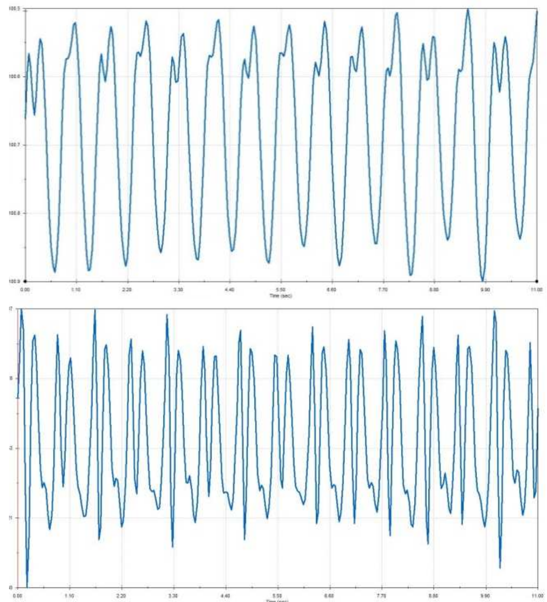


Fig.13. Graphs of displacement (a) and acceleration (b) for the vibrating plate.

a).

b).

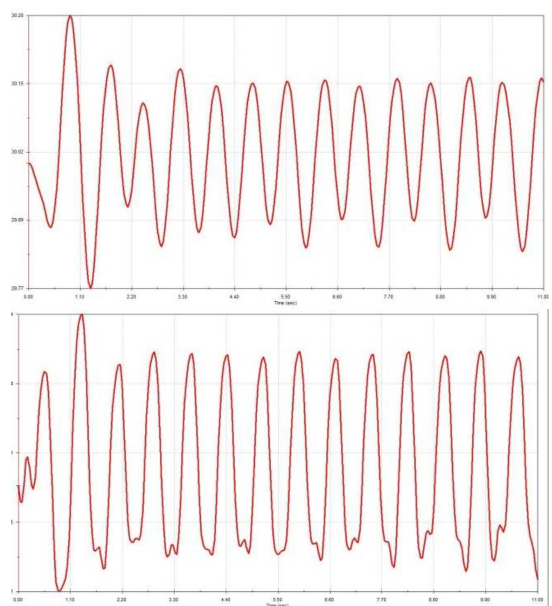


Fig.14. Graphs of displacement (a) and acceleration (b) for the mobile structure.

4. CONCLUSIONS

The damping device reduces the effects of vibrations on the body. To show this, Microsoft Excel was used to overlap the graphs of the vibrations during excavation in a permanent regime, for both the vibrating plate and the mobile structure in relation to the fixed reference surface, as seen in figure 15.

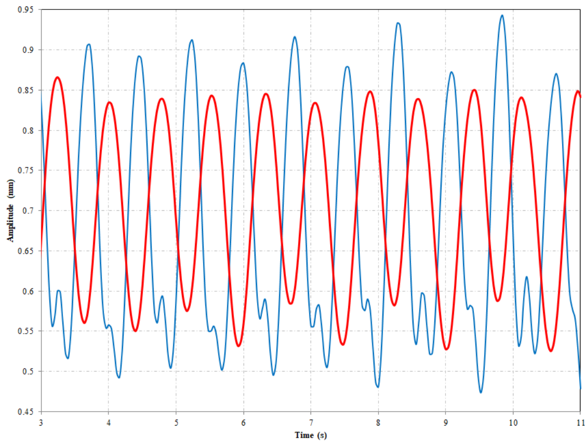


Fig.15. Overlapped graphs of the vibration for the mobile structure (red) and the vibrating plate (blue)

It is visible that the damper determines a decrease of the oscillation amplitude and a flattening of the variation curve.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

[1] Durst, W. *Hydraulic Bucket Wheel Excavators - Design and Performance*, SAE Technical Paper 780489, 1978, https://doi.org/10.4271/780489.
[2] International Organization for Standardization. *ISO 2631-1:1997 – Part 1*, Geneva, Switzerland, 1997, https://www.iso.org/standard/7612.html.
[3] European Parliament and the Council of the European Union. *Directive 2002/44/EC*, http://data.europa.eu/eli/dir/2002/44/oj.
[4] Legea nr.319, 2006.
[5] Legea nr.198, 2018.
[6] Farcas, A.E., Arghir, M. *Theoretical Study of Spine Under the Action of the Mechanical Vibration Into an Autovehicle on the Human Body,* Acta Technica Napocensis Series - Applied Mathematics Mechanics and Engineering, 61(3), pp. 387–94, Cluj-Napoca, 2018.
[7] Jayachandran, R., Krishnapillai, S. Modeling and optimization of passive and semi-active suspension systems for passenger cars to improve ride comfort and isolate engine vibration, Journal of Vibration and Control, 19(10), pp. 1471–79, 2012, doi.org/10.1177/1077546312445199.
[8] Zhao, Y, Wang, X. *A Review of Low-Frequency Active Vibration Control of Seat Suspension Systems,* Applied Sciences, 9(16), pp. 3326, Basel, Switzerland, 2010, doi.org/10.3390/app9163326.
[9] Zhao, X., Kremb, M., Schindler, C. *Assessment of wheel loader vibration on the riding comfort according to ISO standards,* Vehicle System Dynamics, 51(10), pp. 1548–67, United Kingdom, 2013, doi.org/10.1080/00423114.2013.814798.
[10] Alphin, M.S., Sankaranarayanasamy, K., Sivapirakasam, S.P. *Experimental evaluation of whole body vibration exposure from tracked excavators with hydraulic breaker attachment in rock breaking operations, Journal of Low Frequency Noise,* Vibration and Active Control, 29(2), pp. 101–10, Sheffield, 2010, doi.org/10.1260/0263-0923.29.2.101.
[11] Mayton, A.G., Porter, W.L., Xu, X.S., Weston, E.B., Rubenstein, E.N. *Investigation of human body vibration exposures on haul trucks operating at U.S. surface mines/quarries relative to haul truck activity,* International Journal of Industrial Ergonomics, 64, pp. 188–98, 2018, doi.org/10.1016/j.ergon.2017.05.007.
[12] Wieckowski, J.S., Pietrusiak, D., Rafajlowicz, W. *Low frequency vibration in Heavy Machinery - preliminary identification and control*, Proceedings of the International Conference on Noise and Vibration Engineering (ISMA 2020) and International Conference on Uncertainty in Structural Dynamics (USD 2020), Desmet, W. et al. (eds.), pp. 3261–70, ISBN 9781713827054, Leuven, Belgium, 7-9 September 2020.
[13] Rafajlowicz, W., Wieckowski, J., Moczko, P., Rafajlowicz, E. *Iterative learning from suppressing vibrations in construction machinery using magneto-*

rheological dampers, Automation in Construction, 119, pp. 103326, 2020, doi.org/10.1016/j.autcon.2020.103326.

[14] van Niekerk, J.L., Heyns, P.S., Heyns, M. *Human vibration levels in the South African mining industry,* Journal of the Southern African Institute of Mining and Metallurgy, 100(4), pp. 235–42, 2000.

[15] Popescu, F.D., Radu, S.M., Kotwica, K., Andraș, A., Kertesz (Brînaș), I. *Simulation of the Time Response of the ERc 1400-30/7 Bucket Wheel Excavator's Boom during the Excavation Process,* Sustainability, 11(16), pp. 4357, MDPI, Basel, 2019, doi.org/10.3390/su11164357.

Investigarea vibrațiilor din cabina excavatorului cu roată port cupe în regim permanent de excavare prin simulare pe calculator

Rezumat: Scopul acestei lucrări este studiul efectului unui amortizor plasat între scaunul operatorului și cabină în cazul unui excavator cu roată port-cupe în timpul funcționării în regim permanent. În introducere, efectul vibrațiilor asupra corpului uman a fost prezentat pe scurt împreună cu analiza cercetărilor în domeniu. Apoi, unui model de braț dezvoltat și validat anterior, i s-a atașat o cabină, iar accelerațiile și amplitudinile deplasărilor au fost determinate prin simulare, la nivelul întregului ansamblu braț-cabină, pentru toate direcțiile, în regim permanent de excavare. În final, s-a construit un sistem virtual scaun – suport, cu un amortizor între ele, și s-a studiat comportamentul acestui sistem, considerând ca mărime de intrare care acționează asupra suportului, deplasarea pe direcția dominantă Z anterior determinată.

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