Hand vibration analysis due to agricultural machine vibration

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Abstract. This study aims to present vibration's effects on the human hand of agricultural machine drivers, often neglected, which are related to work and cause serious health issues. The chosen equipment does not produce an extreme vibration, such as cement breakers, in order to show that even minor vibration can generate stress and strain on the body. In addition, the continuous exposure to this situation can cause fatigue, unpredictable health issues, performance decrease, nausea, among others. The vibration used in this article was smaller than the ones found in the literature.

Keywords: hand-arm, vibration, agricultural machine

1 Introduction

As a result of technological progress, the incidence and prevalence of occupational and work-related diseases are changing. While exposure to some risks is decreasing, overuse persistent tendinopathy, employment related musculoskeletal disorders and mental health issues are becoming more frequent. According to Brazilian social security data, the most affected body parts are hands and upper limbs. Moreover, hand trauma can cause important temporary or permanent occupational incapacity along with psychological and economic damage [1]. Even minor hand injuries regularly results in absence from work due to functional impairment [2].

Hands are necessary for performing a diverse range of activities with different complexity levels, besides that it is the upper limb's most important segment. Its anatomy is very complex and detailed so this paper will be focused on bones. The main ones are: carpal bones, metacarpal bones and phalanges, which is divided in proximal, medial and distal [3].

Five metacarpal bones compose the palm of the hand and they articulate with fingers and fist, also called carpus. Fingers are composed by three phalanges (proximal, medial and distal), except the thumb which has only proximal and distal [3]. Hand muscles are divided in five compartments, each one responsible for different actions. These compartments are: tenar, adductor, hypotenate, central and interosseous.

Several occupational hazards are known, but this article will approach vibration, a subtype of the physicals hazards. Vibration can be defined as a body movement around a set point with constant or variable acceleration.

There are two main types of vibration exposure to the human body: whole-body vibration (WBV) and hand-transmitted vibration (HTV) [2]. Possible sources of HTV are concrete breakers, chain-saws, hand-held grinders, metal polishers, power hammers and chisels, needle scalers, scabblers, powered sanders, hammer drills, and even powered lawnmowers and motorcycle handlebars. Vibration outcomes in the human body depends on excitation frequency, acceleration or displacement and speed [2]. Since there are different variables to consider and some of them are hard to measure, it is difficult to accurately determine magnitude and exposure time [4]. Despite this difficulty, Brazilian Health Ministry considers vibration as an occupational risk [5].

The World Health Organization (WHO) listed injuries, carcinogens, airborne particulates, ergonomic risks for back pain and noise as some of the occupational risks associated to vibration exposure. Furthermore WHO points out that 16% of hearing loss, 13% of chronic obstructive pulmonary diseases and 37% of back pain causes are related to the work environment. Fortunately, those numbers can be reduced by creating a less aggressive and harmful workplace [4].

In addition, HTV can cause other health issues, such as Raynaud's syndrome (vibration-induced white finger), digits sensorineural impairment, carpal tunnel syndrome and hand-arm vibration syndrome (HAVS) [2]. Hearing loss can also be associated with vibration, it is called noise-induced hearing loss (NIHL), and it occurs with workers who are exposed to noisy vibratory tools [2].

2 Literature Review

Several mechanical equipment produce vibration. Some of them depend on it to work and others generate it, but does not need it to work correctly. In the first case, it is not adequate to reduce its amplitude, since this adjustment harms its functionality.

An example of intentional and important vibration to the quality of the process is the agricultural machine used to harvest coffee. It works with the vibration of the stem on the tree. Reference [6] has shown that it's efficiency is directly related to the vibration of the stem executing the task. Unfortunately this vibration is transferred to the operator, so despite it being necessary, it is also potentially harmful to the operator.

Farm tractors, on the other hand, usually do not need vibration to work, but are an important source of it, causing Whole Body Vibration (WBV). This has been a major problem for its operators, because this exposure can provoke discomfort, minor and major injuries and in some situations leads to temporary or permanent absence from work. Also, it is important to take into account that vibration in those vehicles are directly related to speed and path irregularities, therefore it is a hard task to find data to simulate a real life work condition [4]. Considering how important occupational health is, this paper aims to discuss how to create a safer and more comfortable work environment.

To appropriately approach vibration it is crucial to describe transmissibility, apparent mass or mechanical impedance. The apparent mass is calculated by the ratio between force and acceleration during a harmonic movement and the mechanical impedance by the ratio between applied force and resulting velocity. In addition, transmissibility must be analyzed to each and every frequency present on a spectrum, by calculating the ratio between the measured vibration at the exit point and the measured vibration at the entry point. Transmissibility value greater than 1 means amplification of the vibration, smaller than 1, vibration attenuation and equal to 1, both input and output vibration are equal [4].

The human body has a vast type of components, such as muscles, bones, nerves, cartilage, among others. Each body segment, as well as each body tissue, carries a specific vibration frequency, however most of those frequencies are below 100 Hz. Consequently, exposure to this frequency range is highly detrimental. The human body has several natural frequencies as they are shown in [4]. From those, it is important to mention that hands have frequencies from 30-50 Hz. There are other models presenting hand frequencies from 50-200 Hz [4].

It is also important to consider that each vibration frequency range leads to specific impairments. For example, frequencies below 2 Hz can cause discomfort and motion sickness, which decrease worker's performance in executing tasks. Also, frequencies between 2 Hz and 20 Hz can generate serious diseases, such as degenerative spinal cord conditions [4].

Bones have a porous structure and have to be modeled as linear solid, heterogenous and anisotropic material. Silva et al [7] measured its Young, Poisson and torsion modules, and the results are presented on table 1.

Figure 1. Natural body frquencies [4].

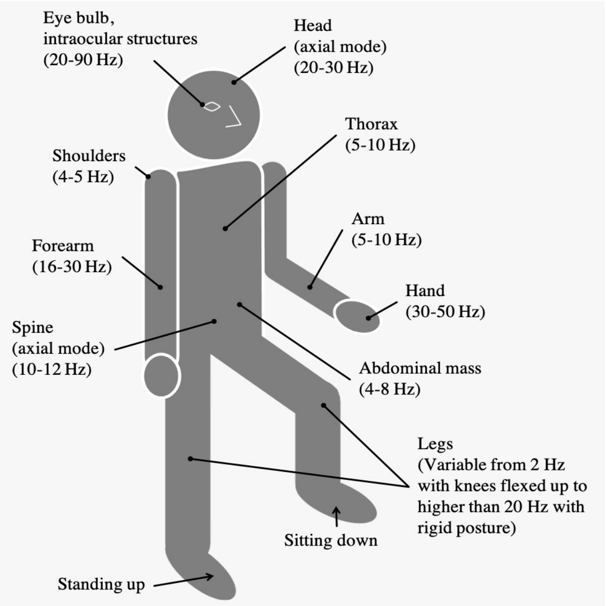


Table 1. Bone's mechanical properties

	Young module	
$E_1 = 294MPa$	$E_2 = 258MPa$	$E_3 = 153MPa$
	Torsion module	
$G_{23} = 86MPa$	$G_{31} = 103MPa$	$G_{12} = 100MPa$
	Poisson module	
$\upsilon_{21} = 0,121$	$\upsilon_{31} = 0,076$	$\upsilon_{12} = 0,137$
$\upsilon_{32} = 0,077$	$\upsilon_{13} = 0,141$	$\upsilon_{23} = 0,140$

3 Methods

The main focus of this paper is to study the vibration transmitted to the hand by a steering wheel of an agricultural machine. This vehicle also exposes the operator to whole body vibration, but this aspect will not be approached. This study uses geometry developed on the software SolidWorks [8] and sequentially generated a mesh using the software HyperMesh 19.1 [9], which was also the solver used to evaluate the hand. Since organic systems simulations are very complex, the authors opted out to simplify the hand's geometry. A simulation involving all hand's components, such as muscles, fat, tendons, blood vessels, lymphatic vessels, among others, would demand a data analysis much more robust. Therefore those elements were excluded from this study. Figure 2 shows the mesh used, which is a simplification of bone's structure.

The element chosen was the one which could best represents organic geometry accurately without harming the model's processing. In conclusion, the one chosen was the tetrahedral element (CTETRA). In the case approached by this study, the steering wheel forces are transferred to the hands. In figure 3, the vibrations efforts applied to the steering wheel can be viewed.

A restriction, represented by a triangle, was positioned at the center of the steering wheel, so, the only displacement allowed would be the one caused by vibration. For this reason, the steering wheel can not move in any other axle, since this is the only point which the steering wheel is attached to the tractor.

The vibration effort, represented by the arrow, was placed at this same point. Since the hand and the steering wheel are two different structures, establishing a contact between them was necessary to transfer the efforts to the hand. A stiff element (RBE2) was used to guarantee an effort's transference with no damping. At the finger's joints, where cartilage takes place, rigid element (RBE2) were used too. At the finger's distal extremity a spring element (CBUSH) was used, because there is a spring effect when fingers vibrate and the hand and the fist are

Figure 2. Hand's mesh on the steering wheel.

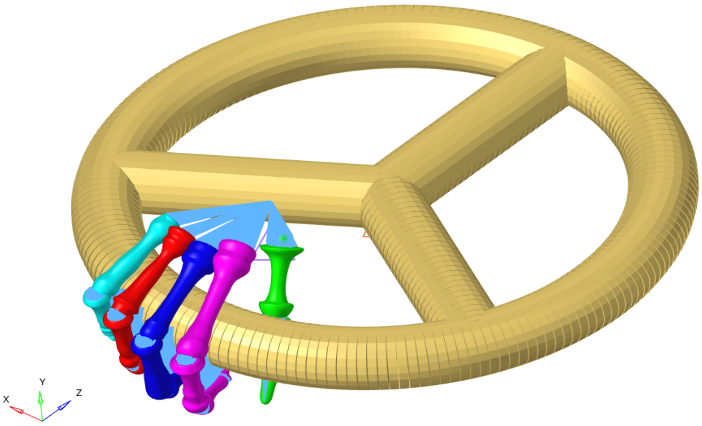
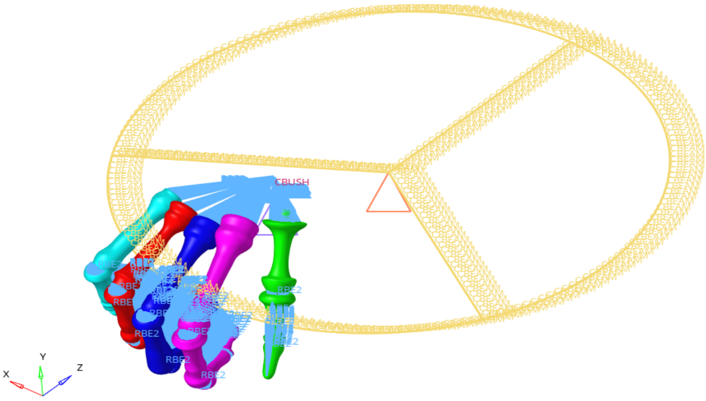


Figure 3. Application of forces and mechanical restrictions.



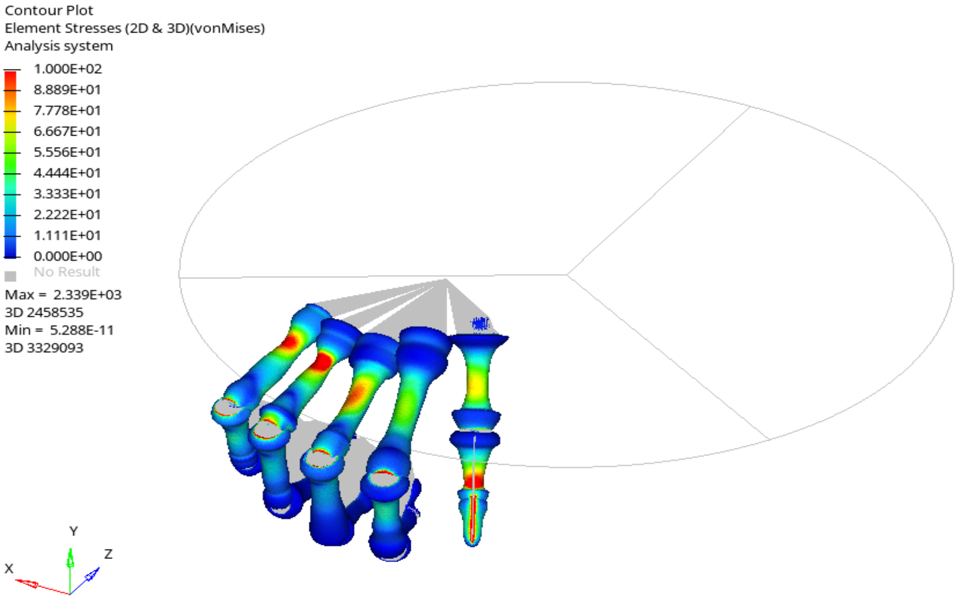
not rigid. Two analysis were made, one of them modal analysis, with no load application nor efforts, in order to determine the structures' natural frequency. Afterwards, vibration efforts described in the literature were included, and finally the results were obtained, as they are described in the following sections.

4 Discussion

Table 2. Comparison for different levels of vibrations frequencies.

Frequency (Hz)	Max displacement (m)	Min displacement (m)	Max stress (Pa)	Min stress (Pa)
02	2.88e-4	8.14e-5	2.14e3	2.24e-3
04	4.29e-4	8.01e-5	4.41e3	7.37e-3
06	1.39e-2	9.26e-6	3.35e5	9.49e-2
08	1.45e-3	3.38e-5	4.47e4	2.49e-3
10	1.20e-3	1.23e-5	2.43e4	3.20e-2
12	3.59e-5	2.33e-7	1.11e3	1.59e-3
14	9.30e-5	2.76e-6	4.94e3	1.16e-2
16	6.22e-5	6.44e-7	3.58e3	7.60e-3
18	4.12e-5	7.96e-8	2.34e3	4.68e-3
20	2.05e-5	1.11e-7	1.15e3	1.80e-3

Figure 4. Hand tension



After the simulation, it was possible to observe how vibration can affect the human body's bone structure. Even the lowest vibration values, can results in work withdrawal if present for a long period [4]. In addition, this vibration can be harmful to the worker's health over the years, and the damage will only be perceived many years later [4].

According to the literature [4], even low vibrations values cause problems to the operator, such as nausea. The vibration must be always analyzed, in order to the determine the risk that the operator is exposed to.

The results presented in figure 4 show the reality of a $2\,\mathrm{Hz}$ frequency process with displacement on the axes Y. The amplitude of the displacement was set to $0{,}20\,\mathrm{mm}$.

It can be observed that the maximum Von Mises tension in the bone structure was $100\,\mathrm{Pa}$. Table 2 shows a comparison for different vibration frequencies and stress/strain results. It is possible to observe that the stress increases from 2 Hz to 8 Hz and after it starts to decrease. The same happens with the displacement.

5 Conclusion

Employees safety has become a major public discussion. As a result, the studies approaching how to reduce the risk factors and, consequently, also the accidents, are increasing. Companies are developing safety protocols, such as workers shifts when exposed to damaging situations, such as vibration. Each limb and each organ are affected by an specific frequency type and those frequencies vary greatly. Since the hand is the most important and most versatile part of the upper limb, this paper chose to focus on it.

The methodology of this article can also be used to study other equipment in which the operator's hand is in touch with an vibratory device. If this device is an steering wheel of a different machine, it is only necessary to change the efforts. However, if it is another device it is required to adapt the geometry also, because it affects the efforts transferred to the hand.

It is also extremely import to notice that biological elements can be simulated using FEM, which literature corroborates with a wide range of studies that model and find the mechanical properties of body parts. In order to achieve more accurate results, it would be important to incorporate other hand's elements, such as muscles, fat, tendons, skin, vessels, to the simulation. Adding those components would demand a more robust data processing, so the authors opted to exclude them for the reason that they do not transfer vibration as the bones. Bones are the main rigid element responsible to transmit vibration, the other structures would absorb a good part of it.

This study is a proof of concept and the results are a illustration of a possible vibration that an operator can be exposed during his work. The aim was to test the method and to have more accurate results more tests must be done. The physical correspondence was not analyzed.

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Authorship Statement.

The authors hereby confirm that they are the sole liable persons responsible for the authorship of this work, and that all material that has been herein included as part of the present paper is either the property (and authorship) of the authors, or has the permission of the owners to be included here.

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