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# THE SIMULATION OF VIBRATION ATTENUATION IN THE HAND-ARM SISTEM

Aurora Felicia CRISTEA[1], Radu MORARIU-GLIGOR[2]

*The aim of this paper is to present the ways in which we could reduce mechanical vibrations that are transmitted through the arm at the human operator at the workplace. This objective is accomplished by means of a damper mounted on the forearm, between the wrist and the elbow, alongside.*

*In this respect, we use a simulation of the chosen model (hand-arm system). All these studies are done in order to reduce/minimize the mechanical vibrations transmitted to the hand-arm system with the main aim of avoiding/reducing the development of professional hand illnesses.*

*The conclusions of the paper show us that, by using a mechanical vibration damper mounted on the forearm (between the wrist and the elbow) can reduce the transmission of mechanical vibrations along the arm, these vibrations being generally absorbed in more than 50% of the cases.*

**Key words:** hand-arm system, vibration attenuator, professional diseases.

## 1. Introduction

The subject of this paper has as starting point the analysis of the measurements of mechanical vibrations transmitted from a machine-tool to the human operator. It was observed that transmitting vibrations, at low frequencies (< 20Hz), cause negative issues on the individual's health, respectively professionally diseases (for example Vibration White Finger, joint disorders, etc) in time. It was found that these disorders are especially associated to the intensity of the vibrations the individual is subjected to, i.e. the duration of the exposure and their frequency. Apart from the exposure and their frequency, there are other factors that influence the occurrence of these disorders, such as: the environment, the health status, stature, weight and sex [1, 2, 3 and 4].

[1]Lecturer, PhD., Mechanical Engineering System Department, Technical University of Cluj-Napoca, Romania, e-mail: cristea_fa@yahoo.de

[2] Lecturer, PhD., Mechanical Engineering System Department, Technical University of Cluj-Napoca, Romania, e-mail: mogli70@yahoo.com

Referring of the protective measures for the person exposure of vibration especially, one may think to the design of the machines with incorporated attenuators, and the ergonomic constructions of such vibratory tools and devices. Sometimes, the construction material for these is the one that facilitates the vibration reduction (such as rubber) [1, 2]. This paper however focuses on the part, namely protective gear against the transmission of vibrations to the hand-arm system, which is being mounted on.

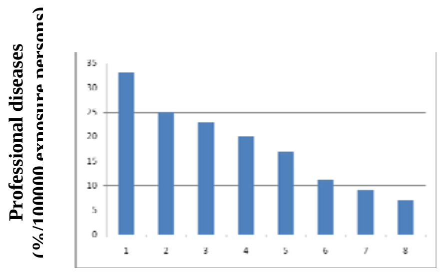


Fig. 1 Professional disorders in our country (1992-2011) [5].

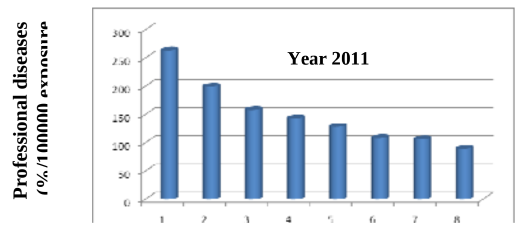


Fig. 2 The new cases apparition of professional diseases in 2011 [5].

Figs. 1 and 2 present us the fact, that in our country, in the period 1992-2011 the professional diseases due to work are high and continue to remain at high levels, although compared to 1992, they show a decrease for industrial power. From this perspective, the most affected from the occupational point of view were: locksmiths, miners, smelters, foundry-workers, welders, medical assistants, carpenters and mechanics workers (Fig. 1, Fig. 2). Also, Figs. 1 and 2 present a comparison of professional disorders on trade categories, noticing that locksmiths occupy the top of the list. On the other hand, the transmission of mechanical vibrations is the number one cause of professional disorders in our country.

## 2. Simulation of the displacements of the hand-arm model under the action of vibrations

### *2.1. Mechanical model*

In the following, we will refer to the mechanical model presented in figure 3 and with reference to tables 1-3. These present the initial conditions regarding the anthropometric, viscous-elastic and mechanical models.

Thus, Fig. 3b presents the working position of the hand-arm system on the machine tool, namely the grip of the human operator. This position is considered for the research, with the elbow bent at $90^o$ (presented in Fig. 3a).

*Table1*

**Initial simplifying conditions**

| | |
|---|---|
| Direction of excitation | $z_h$, in conformity with anatomical coordinate system given by SR EN 5349-2001 |
| Excitation | Harmonic displacement $z(t) = z_0 \sin \omega t$ |
| Position of the subject | Standing (vertical position) |
| Frequency scale | 0 – 20 Hz |
| Force of pressure of the tool | 25 N , according to ISO 15230/2007 |
| Place of pressure | Hand (palm and fingers) |

*Table 2*

**Anthropometrical parameters**

| Anthropometrical parameters | | |
|---|---|---|
| $m_1$ = 0.45 kg | $l_3^{'} = 0{,}298$ m | $J_{c3}$ = 0.0149 $kgm^2$ |
| $m_2$ = 1.15 kg | $l_3$ = 0.178 m | |
| $m_3$ = 1.9 kg | $l_3 / l_3^{'} = 0{,}6$ | |

*Table 3*

**Viscous-elastic coefficients of the hand-arm system, under the conditions imposed by table 1**

| Viscous-elastic parameters of the hand-arm system | | | |
|---|---|---|---|
| $k_0$ = 155.8 x$10^3$ N/m [7] | | $c_0$ = 30 Ns/m [7] | |
| $k_1$ = 23.6 x$10^3$ N/m [7] | $k_{t1}$ = 2 Nm/rad [7] | $c_1$ = 202.8 Ns/m [7] | $c_{t1}$ = 4,9 Nms/rad [7] |
| $k_2$ = 444.6 x$10^3$ N/m [7] | $k_{t2}$ = 2 Nm/rad [7] | $c_2$ = 500 Ns/m [7] | $c_{t2}$ = 6,14 Nms/rad [7] |
| $k_3$ = 415.4 x$10^3$ N/m [7] | | $c_3$ = 164.6 Ns/m [7] | |
| $k_4$ = 50.25 x$10^3$ N/m [7] | | $c_4$ = 50 Ns/m [7] | |
| $k = k^d = k^d$ = 365.75N/m | | $c = c^d = c^d$ = 58.5 Ns/m | |

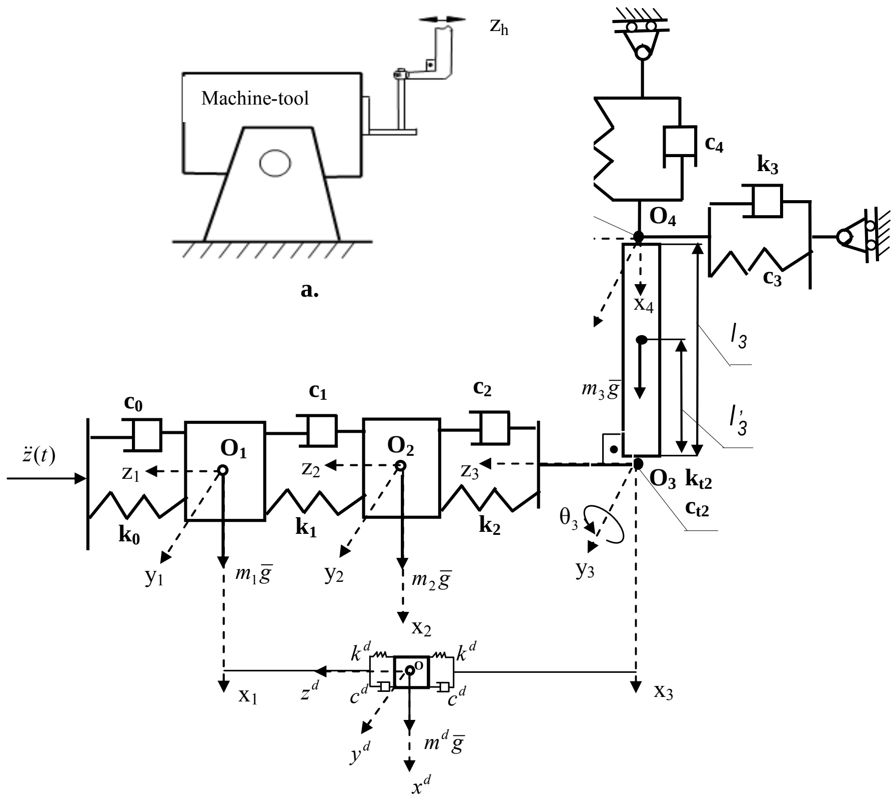


Fig. 3

**a.** Excitation source;

**b.** Mechanical model of the human hand-arm system with mounting vibration attenuator device.

The differential equation in matrix form that characterizes the model depicted in Fig. 3 is:

$$[M]\{\frac{d^2U}{dt^2}\}+[C]\{\frac{dU}{dt}\}+[K]\{U\}=\{F\} \tag{1}$$

In relation (1), [M], [C] and [K] are the matrices for the masses, damper constants and the system elasticity. The size of the matrices [M], [C] and [K] is (5x5), in the case of the system without a damper and (6x1) in the case of the system with a damper mounted along the forearm. The matrix of the exciting force {F} is (5x1) or (6x1) in the case of the second instance, when the hand-arm system receives a damper. {U} is the vector of the generalized coordinates, that is the displacements, with the value of (5x1) or (6x1) in the second case, whose transposed matrix is $\{U\}^T = \{z_1, z_2, z_3, x_3, \theta_3\}$ $or$ $\{U\}^T = \{z_1, z_2, z_3, x_3, \theta_3, z^d\}$.

The relation (1) that characterizes the equation system of the hand-arm model is a second-degree differential, non-linear, homogeneous and transcendent one, where: $\mathbf{z_1}$ represents the displacement on the $Oz_h$ direction, corresponding to mass $m_1$. This direction is in accordance with the anatomic system given by SREN 5349/2001; $\mathbf{z_2}$ represents the displacement on the $Oz_h$ direction, corresponding to mass $m_2$; $\mathbf{z_3}$ represents the displacement on the $Oz_h$ direction, corresponding to mass $m_3$; $\mathbf{x_3}$ represents the displacement on the $Ox_h$, corresponding to mass $m_3$; $\boldsymbol{\theta_3}$ represents the angle corresponding to the elbow rotation on the $Oy_h$, characterizing mass $m_3$.

At the same time, the figure 3 has the following elements: *$m_1$ – the mass of the palm [kg]; $m_2$ –the mass of the forearm [kg]; $m_3$ – the mass of the arm [kg]; $k_0$ – longitudinal elasticity constant of the palm tissue [N/m]; $k_1$ – longitudinal elasticity constant of the wrist [N/m]; $k_2$ – longitudinal elasticity constant of the forearm [N/m]; $k_3$ – longitudinal elasticity constant of the arm [N/m]; $k_{t1}$ – torsion elasticity constant of the shoulder [Nm/rad]; $k_{t2}$ – torsion elasticity constant of the joint elbow [Nm/rad]; $c_0$ – damping constant of the palm [Ns/m]; $c_1$ – damping constant of the wrist [Ns/m]; $c_2$ – damping constant of the forearm [Ns/m]; $c_3$ – damping constant of the arm [Ns/m]; $c_{t1}$ – torsion damping constant of the shoulder [Nms/rad]; $c_{t2}$ – torsion damping constant of the elbow joint [Nms/rad]; $l_3$ – the length measured from the mass center $m_3$ to the elbow [m]; $l_3^{'}$ – the length between elbow joint and the shoulder [m]; $J_{c3}$ – the axial mechanical inertial moment of the arm [kg $m^2$].*

Tables 2 and 3 present the viscous-elastic and anthropometric characteristics of the hand-arm system. The viscous-elastic characteristics have been taken from the literature [7] and the anthropometric ones have been determined by measuring a group of five male subjects. Subsequently, we took into account an average of these measurements, in order to obtain the values for the hand, forearm, arm masses and the inertial moment of the arm.

Thus, the mass of the hand ($m_1$), the forearm ($m_2$), and the arm ($m_3$) (see Table 2) have been determined using the mathematical rule of three: we took into consideration the volume and the weight of the five human subjects at the same time with the volumes of the hand, forearm and arm (these being approximated with truncated cones. The calculus formula for the truncated cone is:

$$\mathrm{V} = \frac{1}{3}\pi h (R^2 + r^2 + R r) \tag{2}$$

where: *R* is the radius of the circle (the circumference of the thickest part of the hand, forearm and arm), *r* is the circle (circumference) of the thinnest part of these anatomical parts, and $h$ is their length. The obtained results are in accordance to the ones given by the literature [7].

► The expression $l_3/l_3^{'} = 0{,}6$ defines the relation between the two lengths defined previously;

► the calculus formula for the axial inertial mechanical moment is ($J_{c3}$):

$$J_{c3} = \frac{m_3 l_3^{'2}}{12}. \tag{3}$$

where, with approximation from the point of view of the material strength, we approximated the arm with a rigid shaft supported at both ends (respectively the elbow and the shoulder).

*OBERVATIONS: with the purpose of solving the problems that might occur when solving the equation system corresponding to the hand-arm system, we adopted a series of simplifications of the real model. This is a model of distributed masses and its resolution is done taking into account the mass concentration in the mass centers of the hand, forearm and arm, and the arm is considered a rigid shaft, which helps us determine the inertial mechanical moment ($J_{c3}$).*

*- this case study neglects the wrist because the hand is positioned on the machine tool and the hand does not rotate while cutting a piece for example. This is why we have simply approximated the wrist using a spring ($k_1$) and a damper ($c_1$).*

*- The rotation of the shoulder is considered to be $0^o$.*

*- the direction of the damper excitation is built to be: for mass $m_1$ ($c_1$) for mass $m_2$ ($c_2$), for mass $m_3$ ($c_3$). All of them are aligned on the $Oz_h$ and $Ox_h$ ($c_4$) a simple rotation on the $Oy_h$ axis, given by the $\theta_3$ angle.*

*Thus, all the studies have been done by analyzing the displacements of the hand, forearm and arm along the $Oz_h$ axis, excepting the arm, whose displacement has been analyzed along the $Oy_h$ and $Ox_h$ axes also.*

In figure 3, mass $m^d$ = 0.5 Kg represents the damper mass mounted on the hand-arm system and which includes elasticity and damping components, marked with $k^d$ and $c^d$, given by::

$$k_1^d = \omega^2 m = (26.17)^2 \cdot 0.5 = 342.43^{**}\ N/m \tag{4}$$

(these relations have taken into account the minimum studied frequency of the machine tool $\omega$ = 26.17 *rad/s* ($n$ = 250*rpm* (*rotations per minute*));

** we chose $\boldsymbol{k^d}$ **= 731.5 *N/m***, whose value is the closest from the real value of elasticity coefficients of the forearm and represent 2 x $k_1^d$ ~ 731.5 *N/m*, respectively the two values for the dampers mounted in parallel with the forearm (as shown in figure 3).

The damping coefficient $\boldsymbol{c^d}$ is determined by::

$$c_1^d = 2\sqrt{k^d m^d} = 2\sqrt{731.5 \cdot 0{,}5} = 38.24^{***}\ Ns/m; \tag{5}$$

*** we chose the value of $\boldsymbol{c^d}$ **= 58.5 *Ns/m***, which is regarded to be the closest to the real and total one of the forearm damper coefficient, respectively the summed value of the two damping coefficients included in the damper. These are mounted in parallel with the forearm 2 x $c_1^d$ ~ 58.5 *Ns/m*, ($c^d < c_{critical}$; $c_{critical}$= 162.092 *Ns/m*. This value has been calculated for the inherent pulsation of the system 162.093 *rad/s,* which has been determined experimentally);

$z^d$ is the generalized coordinate, that is the displacement along the $Oz_h$ direction of mass $m^d$ of the damper mounted in parallel to the forearm.

### *2.2 Simulation of the hand-arm system not using/using a vibration attenuator*

This paragraph presents the main blocks using Simulink to simulate the movement of the hand-arm system. When simulating the masses of the studied anatomical parts (hand, forearm and arm), we used the same simplifying conditions and the same elasticity and dampness coefficients, like in the model presented in figure 3 for both models developed in Simulink (with and without a damper) [3, 4, 16, 17].

Thus, the two models created by Simulink (*SimMechanics*) are: **a.** one of them represents the hand-arm system without a damper (attenuator), and the second **b.** with a damper (attenuator) that has been mounted in parallel to the forearm, much like the one in Fig. 3. The two SimMechanics models are presented in Figs. 4 and 5. In addition, figures 4 and 5 symbolize the main block components used in SimMechanics:

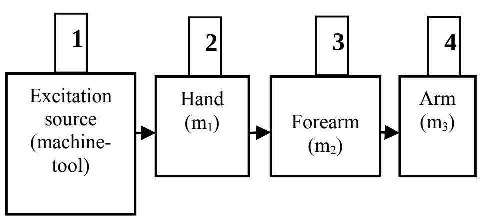


Fig. 4a The schematic model, per ensemble of the hand-arm system;
Excitation source Block named **1**;
Hand (mass $m_1$) Block named **2**;
Forearm (mass $m_2$) Block named **3**;
Arm (mass $m_3$) Block named **4**.

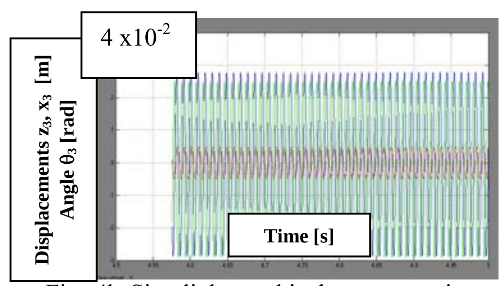


Fig. 4b Simulink graphical representation, given us of the *Scope Block*, in this case the displacements corresponding the $m_3$ mass (arm) for n = 250rpm, using attenuator device.

Thus, by applying the same mechanical and initial conditions as in the mathematical model, we obtain the solutions for the hand-arm system that are graphically represented by Scope blocks. Thus, we have the ($z_1$) displacement for the hand, ($z_2$) the displacement for the forearm, ($x_3$, $z_3$) the displacements for the arm and the ($\theta_3$) rotation on the $Oy_h$ axis, this rotation being developed in the elbow.

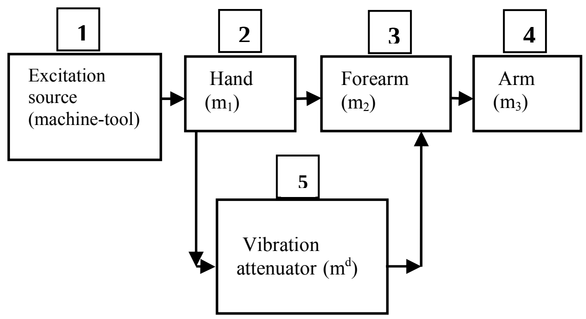


Fig. 5 The schematic ensemble model of the hand-arm system;
Excitation source Block named **1**; Hand (mass $m_1$) Block named **2**; Forearm (mass $m_2$) Block named **3**; Arm (mass $m_3$) Block named **4**; Block named **5** - Mechanic vibration attenuator ($m^d$).

The solutions have been obtained as a result of integrating the differential equations using the Runge-Kutta method at the order 4 (ODE 45) and their integration within a time frame of 5s, which resulted from the development of the hand-arm system model using SimMechanics (Fig. 4b).

Also, the **assembly 1** (Figs. 4, 5) contains the following block from SimMechanics: *blocks Env* and *Ground* , which are specific to the excitation source (machine tool) and *Signal block* , which can receive the movement simulation frequency of the system. The excitation source is in this case given by the rotation of the machine tool at 250 *rpm* (f = 4.16 *Hz*) and respectively by the rotation 1000 *rpm* (f = 16.66 *Hz*), much like the ones used in the theoretical model presented in figure 3.

**Assemblies 2, 3 and 4** from figures 4, 5, are interconnected by *Prismatic Blocks*, which induce the main direction for the vibration transmission on axis $Oz_h$, and $Ox_h$ and $Oy_h$ for the forearm and arm. Also, **assemblies 1, 2, 3 and 4** are interconnected by *Spring* and *Damper blocks*, representing blocks whose mechanical characteristics are introduced here (elasticity and dampness coefficients for the hand-arm system, according to table 2). **Assemblies 2, 3, 4** and respectively **assembly 5** (that includes the damper) (Figs. 4, 5), use the same mechanical characteristics presented in table 3 and identical with the ones used in Fig. 3, respectively *Body blocks* with masses $m_1$, $m_2$ and $m_3$ and subsequently using mass $m^d$ , corresponding to the damper. The *Body Sensor* and *Scope blocks* are needed for the graphic visualization (displacements and rotations) in SimMechanics, of the solutions for the studied system (Fig. 4b).

The simulated model took into account the simplifying conditions taken into account for Fig. 3, respectively the elbow at an angle of 90°, and the rotation of the shoulder of 0°, this being represented by *Weld* and *Ground blocks* from **assembly 4** (Fig.4) and **assembly 5** (Fig.5).

The results obtained in SimMechanics have been processed with Excel and the two cases (with and without a damper) have been compared (Table 4).

### *2.3 Analysis of the results obtained for the two case studies, after the simulation with SimMechanics*

The results (displacements and rotations) presented in table 4 have demonstrated that the vibrations transmitted from the machine tool to the shoulder are reduced to a minimum long the hand-arm system by over 50% and significantly reduced in most of the studied situations with over 80%. This is due to the employment of a damper (attenuator vibration device) mounted in parallel to the forearm.

*Table 4*

**Comparison between studied values for hand-arm system (based on the anatomical elements), without/with attenuator device mounted on forearm**

| | **250 *rpm*** | | | **1000 *rpm*** | | |
|---|---|---|---|---|---|---|
| | **1** | **2** | **3** | **4** | **5** | **6** |
| | **Without attenuator device** [m] | **With attenuator device** [m] | **Vibration minimization ε [%] 3 = [(1-2)/1]*100** | **Without attenuator device** [m] | **With attenuator device** [m] | **Vibration minimization ε [%] 6 = [(4-5)/4]*100** |
| **Hand** | 0.003 | 0.003 | **-** | 0.003 | 0.002 | **33%** |
| **Forearm** | 0.003 | 0.002 | **33%** | 0.025 | 0.0008 | **96,8%** |
| **Arm** | 0.012 | 0.0025 | **79%** | 0.01 | 0.00025 | **97,5%** |

## 3. Conclusions and discussions

The aim of the paper was to demonstrate that mechanical vibrations transmitted from an excitation source (machine tool) to the hand-arm system are minimized and very much reduced from the palm to the shoulder by mounting a damper (attenuator device) parallel to the forearm [18]. All these studies have been done with the purpose of avoiding and reducing the mechanical vibrations effect on the human body. These vibrations are transmitted at the workplace and they may cause several professional illnesses.

- the results obtained are conclusive in this respect and they correspond to the standard ones. *Standard 5439/2001* demands maximum values for the hand displacements of *0.05m.* Because of these studies, the values obtained using the damper (attenuator device) mounted parallel to the forearm (between the wrist and the elbow) are far from the standard values.

- Thus, for the machine tool spinning at n = 250rpm (4.16 Hz):

  **a.** the hand displacement is 0.003 m;

  **b.** the forearm displacement is 0.002 m;

**c.** the arm displacement is 0.0025 m;

- In the case of the machine tool at a rotation of n = 1000rpm (16,66 Hz):

**a.** the hand displacement is 0,002 m;
**b.** the forearm displacement is 0.0008 m;
**c.** the arm displacement is 0.00025 m,

Both cases study low frequencies (< 20 Hz).

In conclusion, these vibrations are highly reduced for the rotation of the machine tool of n =1000rpm (16.66 Hz), in comparison to n = 250rpm (4.16 Hz). In addition, the comparative study was done on the anatomical parts (hand, forearm and arm) and taking into account the two cases, that is with and without a damper mounted parallel to the forearm.

Other conclusions show that a damper (attenuator device) mounted on the forearm has a positive influence even at different rotations of the machine tool, namely n = 250 rpm (4.16 Hz), when the hand does no present displacements from 0.003m, and they are barely felt by the operator. However, they are felt in the shoulder and in this case, they are minimized. Unlike the second case, at a rotation of n = 1000 rpm (16.66 Hz) , when the displacements are reduced in the hand from 0.002m to 0.003m by means of a damper, this already presents a minimization of the vibrations, even if it is not very significant in the hand (0.001 m). One possible explanation for such small values concerning the minimization could be that the damper is mounted after the hand, on the wrist. However, these values at a rotation of 1000rpm are much reduced towards the shoulder by 80%.

*Referring back to the literature, we wish to remind that professional illnesses occur after long-term exposures to vibrations (tens of years).* Professional illnesses affecting the hand usually present loss of dexterity, cold sensations in the fingers, losing the grip, tiredness, discomfort, all these being amplified by external factors at the workplace (temperature, humidity, etc.).

The mechanical models studied in this paper try to get as close as possible to the real hand-arm system from the point of view of initial conditions, viscous-elastic coefficients, etc. The solutions obtained are in accordance to the ones provided by the literature [7], in the range of millimeters.

The paper demonstrates that both theoretical studies taken into account in the simulations, that is using and not using a damper (attenuator device), have minimized and even reduced the mechanical vibrations transmitted from the machine tool to the hand-arm system with more than 50% and reaching more than 80% in the case of some of the anatomical parts (Table 4).

These results are outstanding from the point of view of the reduction of the vibrations transmitted to the hand-arm system at the workplace by using a damper (attenuator device), thus avoiding professional illness symptoms (the White Fingers Disease - VWF, etc [1,5,19]).

Further research in this field will focus on the creation and the development of a damper, taking into account the economic issues (production costs and market development), as well as its optimization. We would like to measure mechanical vibrations in the case of the hand-arm system receiving a damper (attenuator device) mounted along the forearm and the recorded values will be compared to the ones given by the ongoing standards (ex. 5349/2001) [20-23]. Another aspect is related to the ergonomic aspect, so that the damper (attenuator device) would not disturb the working process (dexterity, etc.), and improving the damper (attenuator) design.

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## R E F E R E N C E S

[1] *Palmer KT, Coggon, D, NSyddall HE, et. al.* Occupational exposure to noise and hearing difficulties in Great Britain University of Southampton for Health and Safety Executive., Contract research report 361/2001, Great Britain, Southampton, ISBN 071762087-5, http://www.hse.sov.uk/research/crr-pdf/2001/crr01361.pdf, pg. 1-70, 2001

[2] *Griffin MJ.* Hand-transmitted Vibration: Occupational Exposures and their Health Effects in Great Britain, 2001. University of Southampton, U.K. 1999

[3] *Mao H, Yang KH, Albert I, et. al.* Computational neurotrauma—design, simulation, and analysis of controlled cortical impact model, http://www.Springerlink.com, Received: 4 August 2009 / Accepted: 19 March 2010 / Published online: 7 April 2010 © The Author(s), 2010

[4] *Rong B, Rui X, Wang* G, et. al. New efficient method for dynamic modelling and simulation of flexible multibody systems moving in plane. Multibody System Dynamics. **24: Number 2**. pg. 181-200, DOI: 10.1007/s11044-010-9196-9, Biomech Model Mechanobiol (2010) 9:763–772, DOI 10.1007/s10237-010-0212-z, 2010

[5] *Todea A. and Ferencz A.* Boli profesionale, Professional Morbidity in 2006 in Romania, 2006. Publish Health Institute, Work Medicine Institute, Bucharest, Romania, 2006

[6] *Pop AF, Truța A and Arghir M.* The mechanical stability for the hand-arm system. **Vol.8. 1**: 79th Annual Meeting of the International Association of Applied Mathematics and Mechanics (GAMM). Bremen. Germany. pg. 10187–10188, http://www3.interscience.wiley.com/journal/122217852/abstract?CRETRY=1&SRETRY=0. Article first PAMM published online: 25 FEB 2009, DOI: 10.1002/pamm.200810187, 2009

[7] *Cherian T, Rakheja S, et. Bhat RB.* An analytical investigation of an energy flow divider to attenuate hand- transmitted vibration, Concordia University, Canada, pg. 455-467, 1996
[8] *Griffin MJ.* Hand-transmitted Vibration: Occupational Exposures and their Health Effects in Great Britain, University of Southampton, U.K, pg. 218-228, 1999
[9] *Harris CM and Piersol AG. Harris*'Shock and Vibration Handbook, Columbia University, Fifth Edition, New York, ISBN 0-07-137081, pg. 1.1-42.62, 2002
[10] *Awrejcewicz J.* Classical Mechanics. Dynamics. *Springer*, New York, http://www.amazon.com/s/ref=ntt_athr_dp_sr_1?_encoding=UTF8&sort=relevancerank&search-alias=books&ie=UTF8&field-author=Jan%20Awrejcewicz, 2012
[11] *Haider H. and Walker PS.* Measurements of Constraint of Total Knee Replacement. *Public Health Resources*. Paper 43, Journal of Biomechanics **38**. pg. 341–348, http://digitalcommons.unl.edu/publichealthresources/43. DOI:10.1016/j.jbiomech.2004.02.014, 2002
[12] *Kostin G and Saurin V.* The method of integro-differential relation for linear elasticity problems. *Arch. Appl. Mech*. **76** Springer. pg. 391-402. DOI 10.1007/S00419-006-0039-3, http://www.springerlink.com/content/91732586501kp800/fulltext.pdf, 2006
[13] *Kutz M.* Mechanical Engineers' Handbook, A Wiley-Interscience Publication John Wiley &Sns.Inc,. Second Edition. Canada. ISBN-0-471-13007-9. s%20Handbook%20(www.eBookByte.com)%20Ch-fm.pdf, 1998
[14] *Liu H, Ellison P J., Xu H. et al.* Coupling of dynamics and contact mechanics of artificial hip joints in a pendulum model. Proceedings of the Institution of Mechanical Engineers. Part H: Journal of Engineering in Medicine August 1, 224: 989-1003, DOI:10.1243/09544119JEIM687, 2010
[15] *Sims AM, Stait-Gardner T, Fong L. et. al.* Elastic and viscoelastic properties of porcine subdermal fat using MRI and inverse FEA Biomech Model Mechanobiol. **9**:703–71, 1DOI 10.1007/s10237-010-0207-9**.** Received: 17 November 2009 / Accepted: 4 March 2010 / Published online: 23 March 2010 © Springer-Verlag, 2009
[16] *Galton A and Duran T.* Memis-Mheg environment for multimedia information and simulation. University of Strathclyde, Glasgow, U. K. **6**: pg. 3813-3816, 1998
[17] *Gyu PJ.* Vibration simulation using Matlab, Department of Precision Engineering. Kyoto University. Japan. pg. 1-82. http://wenku.baidu.com/view/a02c33d5b9f3f90f76c61b29.html.
[18] *Jacobs JH.* Miniature vibration isolation system, Aerospace Conference Proceedings IEEE. USA. **vol. 4**, pg. 335-344. ISBN-0-7803-5846-5, 1998
[19] *Urban P and Lukas E.* Occupational diseases due to hand-arm vibration in the Czech Republic in the year. The Eight International Conference on Hand-Arm Vibration. Umeå. Sweden. pg. 153-155, 1997
[20] *SREN 5349-2:2003*. Mechanical Vibrations.Measurements and evaluation of human exposure at vibrations transmitted of hand.
[21] *SRCR 10 30-2:2000*. Hand-arm vibrations. Indications for reduce vibration risk. Part 2: the measure of prevention regarding the working place
[22] *SR ISO 7962*:1996. Mechanical vibrations. Transmissibility of mechanical vibrations of human body after z direction
[23] *SR ISO 8727*:2001. Mechanical vibrations and shocks. Human exposure, biodynamical system coordinates.