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Comparative study on the behaviour of a serial robot RRR and hand-arm human systems

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Abstract. The paper creates a preamble in the comparative study regarding the loading of vibrations on a robotic system RRR or 3R and hand-arm homologous system. In this study, vibration measurements and comparative analyze are conducted for the two systems, trying to correlate similarities between them, but of the different scale.

1. Introduction

The subject of this paper has as a starting point the analysis of the mechanical vibration measurements transmitted from a machine - tool to the human operator. It has been observed that transmitting vibrations, at low frequencies, in this paper up to 25Hz, could cause it the negative effects on individual's health, respectively professional diseases (for example Vibration White Finger, joint disorders, etc.). Specialty literature [6] reminds that vibrations between certain limits <25Hz are destructive to humans, as the highest 2000 Hz (in special conditions) are harmful to robots, especially in couplings / joints. As a means of protection against vibration in humans, protective equipment or avoidance of prolonged exposure to them, but the effect of vibrations on machines and machines and robots is only felt at maintenance checks, through the wear on the rotation couplers or in case of high precision work, where their reliability should be 100% completely.

2. Notions about hand-arm system

To begin with, we will briefly present some data about the mechanical hand-arm system, thus, according to figure 1, the mechanical system takes into account anthropometric parameters such as masses, lengths, given in the tables 2, for a human operator who work under the conditions given in Table 1.

Table 1. Initial conditions.

Direction of excitation	z_h (along of the forearm)
Excitation	Displacement $z(t) = z_0 \sin \omega t$
Subject Position	(vertical position)
Frequency scale	0 – 20 Hz
Pressure Force	25 N, according to ISO 15230/2007
Place of pressure	Hand

Table 2. Anthropometrical parameters (determined in the other studies).

Anthropometrical parameters		
m_1 = 0.45 k	Forearm length	J_{c3} = 0.0149 kgm^2 (mechanical moment of inertia in the elbow joint)
m_2 = 1.15 k	0.98m	
m_3 = 1.9 k		

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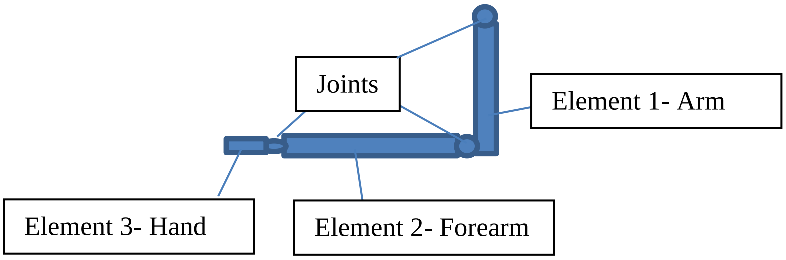


Figure 1. Schematic model of the hand-arm system.

This type of tool has been chosen, because it uses frequencies appropriate to those of small robots. Machine operation is tested by drilling through a chemically treated MDF board using a 10cm drill. The experiment measured the vibrations transmitted by the machine when operating without percussion (Fig.2-4). If should describe it the conditions of vibration measurements, they are effectuated about human operator, he is a 40-year-old male, weighing 85 kg and 1.85m tall, used and handled the drilling machine. The measurements used an inductive triaxial transducer (accelerometer type K_3), being able to simultaneously measure vibrations on three axes: Ox_h – perpendicular of the hand palm, Oy_h – direction along of the thumb, Oz_h – direction to from the hand to the shoulder. The study was done only for the vibration transmission on the Oz_h axis. This was connected to a vibration measuring device type SVAN 958.

The accelerometer was mounted on the anatomical locations: the wrist and the elbow were fastened directly under the metallic bracelet by tightening it, and directly on the arm (taped), it is trying the keep the position of the robot joints.

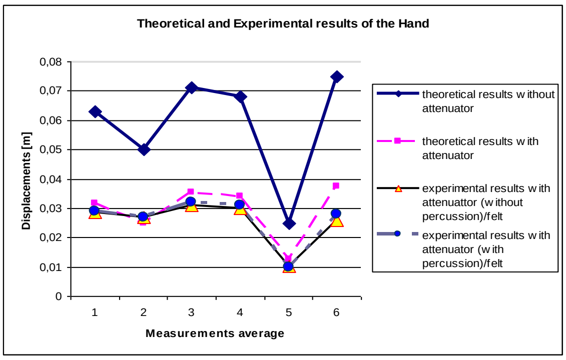


Figure. 2 Vibrations transmitted to the *hand* (theoretical and experimental) with and without attenuator with felt padding and using a drilling machine with and without percussion.

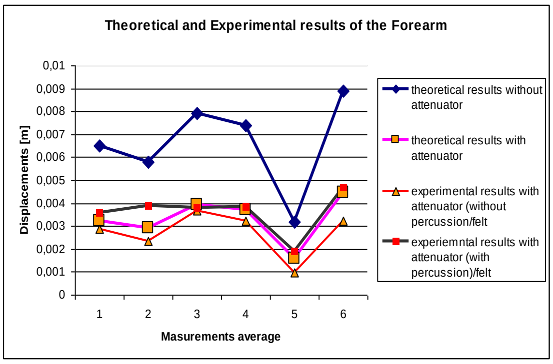


Figure. 3 Vibrations transmitted to the *forearm* (theoretical and experimental) with and without attenuator with felt padding and using a drilling machine with and without percussion.

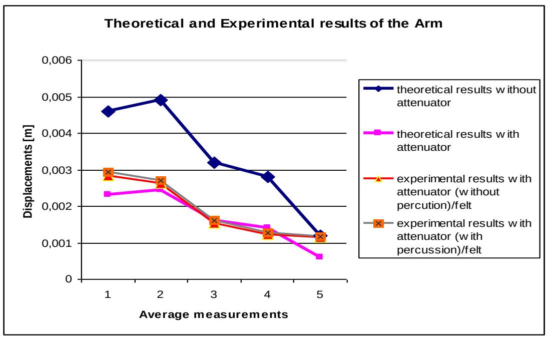


Figure. 4 Vibrations transmitted to the *arm* (theoretical and experimental) with and without attenuator with felt padding and using a drilling machine with and without percussion.

The figures 2-4 present the vibration influence of the hand-arm system, note that the bigger value is for the hand (superior curve of the graph) following of the forearm and arm, indifferently of the dumping system used it. That aspect shows us that exist owner dumping in our body (like muscular, sanguine systems).

It to keep a certain connection with the robot in terms of deacceleration, it was mounting one auxiliary vibration attenuator device (500 g) along the forearm; this could minimize the transmitted vibration, by hand to the arm (Fig.4). The vibration attenuator device (containing 2 dampers) was mounted along the forearm and fixed with a complex shank (bracelets). The interior padding of the metallic bracelets has been made to prevent skin lesions and prevent blocking the worker's forearm movements. Figures 5a and 5b present the way the dampers (element 1) are fixed in the structure. The results are analysed in figures 2-4 for all cases considered by the experiment and considering the anatomical location (the wrist, elbow and shoulder), the way in which the bracelets were fastened on the skin, and whether drilling machine without percussion. The measured results were analysed, and an average was calculated. They have been recorded directly by the machine and then downloaded on the computer using a special program.

The first analysis of the results presented in the figures 2-4 show that the mechanical vibration was transmitted along the hand-arm system to a lower extent if:

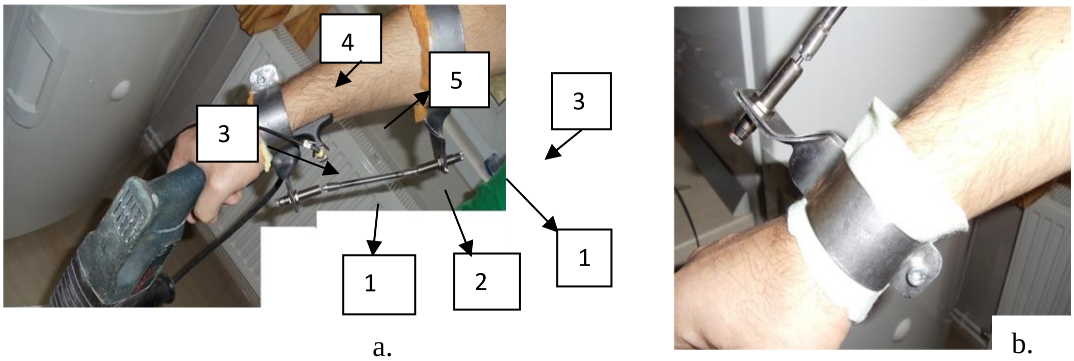


Figure. 5 Fastening the attenuator device on the forearm. a. Technical characteristics of mini-attenuator (element 1); b. Interior padding with sponge.

A1. a vibration attenuator is mounted along the forearm (starting with 0.07 till 0.03m for the hand, 0.08-0.03 m for the forearm and 0.005 till 0.0025 m for the arm);

A2. the percussion of the drilling machine is not used;

A3. the internal padding of the bracelets that are part of the attenuator device is done with sponge and not felt.

Figures 5 *a* and *b* present the fastening methods for the attenuator device on the forearm and the interior padding of the bracelets with felt.

3. Robots 3R generalities and behavior

If we refer to the similarity of the 3R (model FANUC, small class) and the hand-arm system, we can see that the robot studied (Fig. 6) has three rigid-arm elements, which as with humans are assimilated to the arm, forearm and hand. The study will lead us to higher acceleration values transmitted to the robot arms, but these values, reported on a certain scale, should show similitudes in the vibration-like mode of transmission of the hand-arm vibration. Robot vibrations are transmitted from the engine at the base of the robot to his arms, observing that element 3, which includes the prehension, has a similar behavior to its hand-to-hand transmission, but it remains to be demonstrated, also the robots include technical characteristics such as those related to gauge, trajectory, precision, profitability, number of degrees of freedom etc. [1, 2, 3, 6].

Among the steps followed in this paper were studied and designed the components of a robot (Fig.6), in this case consisting of three rigid elements and three rotation couplers (base - element 1, element 1 - element 2, element 2 - element 3).

A1. Robot component design was performed in SolidWorks (Fig. 6) that respects the overall dimensions of a small FANUC robot.

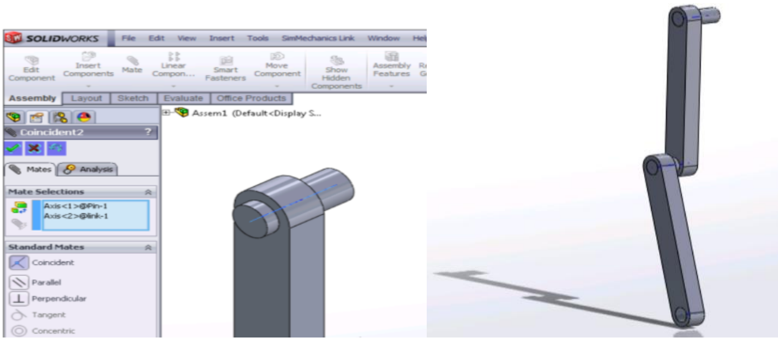
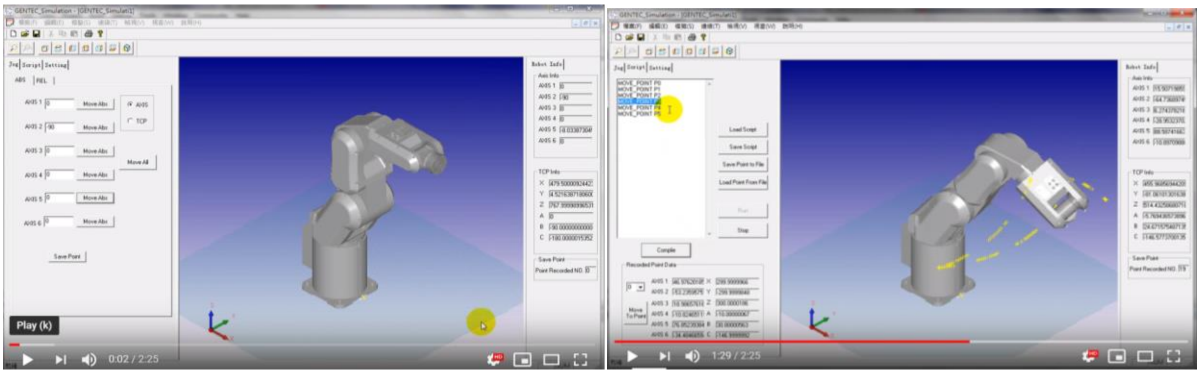


Figure 6. Designing of robot.

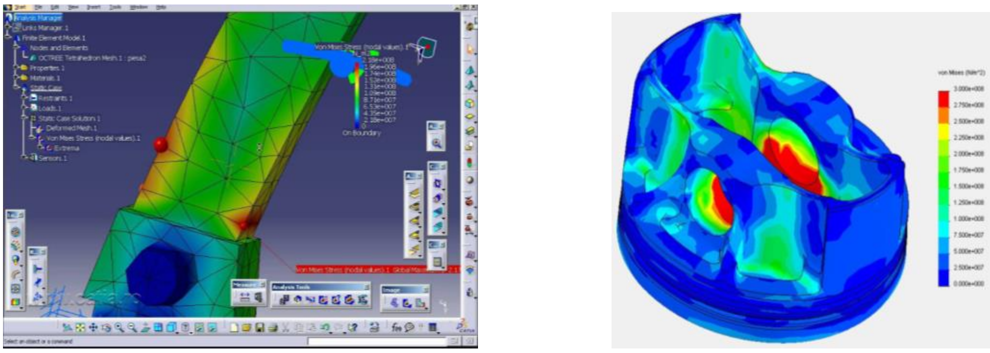
A2. The components of the 3R designed robot, respectively the base and the three arms called elements 1, 2 and 3, are taken over and assembled in CATIA (Fig.7 a-b).



a. b.

Figure 7. Designing of robot and working his area simulating.

A2.1 The simulation of the robot behavior in terms of the resistance of the elements (arms) and their response to vibration exposure was performed with a software called FEA (Finite Element Analysis) (Fig. 8) under CATIA.



a. b.

Figure 8. Legend: blue - small vibrations (<500 Hz), yellow-green - moderate vibrations (500-2000 Hz), red - large loads (> 2000 Hz).

A simulation of the rigidity of the robot arms, especially of the element 1, will be carried out so that its resistance to vibration loads is observed. These data, estimated from the hand-arm system, on a larger scale of 10^3 times, that are recorded in special windows in the simulation environment. It is specified that the study took into account the weight and the power of the engines at the base of the small and medium robots, where the power required for the operation does not exceed the order of 3-5 kW, in which case the gauge fits in the desiderata of the form and suppleness of the mechanical structure [4], [5]. Thus, on a loaded arm and subject to a maximum load of 5 kg, the engine 1 in the base mass, 1-2 kg and supporting element 1, can carry such a load and its effort does not produce vibrations small or not to produce at all. Figures 8a. represents a simulation in the FEA of loading the robot arms to the vibrations (elements 1 near base, 2 intermediaries, 3 including prehension), as well as the beam, or fixed support thereon. It is noted that elements 1, 2 and 3, there are loaded on vibrations in the following order: bumper, element 1, element 2 and element 3. This load is due to the power of the engines that fall in power and the mass from the frame to the prehension element. Compared with robotic arms, study its resistance to the frame, namely in the joint basis, it showed that this is one of the most requested areas (Fig. 8b.) the efforts and loads, possibly due to weakening material for drilling holes fixing element 1 (area marked with point near t = 2s).

A3. In the following, a real-time measurement study will be carried out during robot arm movements. Analysis of vibration measurements. The measurements of vibrations or accelerations measured on small robots have shown that the effect of the vibrations is amplified, and bouncing at high speeds (for example, the acceleration peaks $a_{rms} = 80 m/s^2$ shown in figure 9 at the start of the movement, which then attenuates. Unlike the robot [4] the hand-arm system does not have these start-up shocks, or even if it exists, they are on a very small scale, unimaginable compared to the robot. Analog measurements of vibrations from hand-arm and the robot, the measurements were performed with a triaxial fixed with magnetic base, successively, the three elements of the robot, inquiring us the vibrations about the axis Oz, as shown in figure 5 and similitude with hand-arm system analysis. The arm 1 performs a 45-degree rotation motion, the arm 2 performs a 30- degrees, and the arm 3 at 45 degrees counter-clockwise. Figures 9a - b will show the theoretical vibrations compared to those measured on the manned system and those measured on the robot elements and are aggregated as maximum and minimum values in Table 3. To be comparable acceleration from hand-arm and measured the robot, displacement values [meter] in charts 2-4 are integrated through a data acquisition system and have emerged RMS accelerations. (root mean square) [m/s^2], who maximum and minimum are given by the table 3.

Table 3. Comparison between experimental and theoretical accelerations.

Robot	**a_{max} [m/s^2]**		**a_{min} [m/s^2]**	
Element 1	10		25	
Element 2	5		22	
Element 3	15		25	
Hand-Arm System (with attenuator)	**a_{max} [m/s^2] theoretical**	**a_{max} [m/s^2] experimental**	**a_{min} [m/s^2] theoretical**	**a_{min} [m/s^2] experimental**
Arm ~ element 1	0.015	0.018	0.010	0.015
Forearm ~ element 2	0.012	0.015	0.015	0.022
Hand ~ element 3	0.020	0.025	0.025	0.035

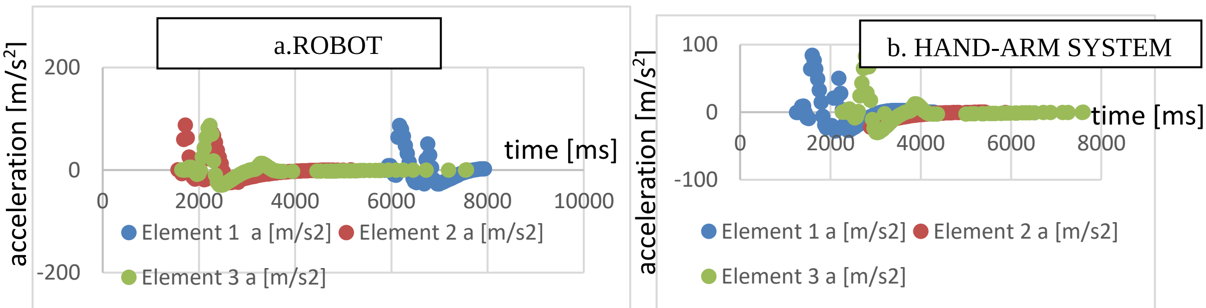


Figure 9. Robot behavior of suddenly moving.

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The 80m/s^2 acceleration leaps of the robot elements are omitted, occurring in the movement of the robot movement until the values of the movement move (Fig. 9a, b).

The comparative analysis of the vibration behavior of a robot and hand-arm system showed that:

- Vibrations are transmitted to both systems from the source of the motion generator, so at the robot the highest vibrations are at element 3 and element 1 the base articulated, where the exciting engine is. In the hand-arm system, the highest vibrations occur at the hand, where the exciting tool is and descending towards the shoulder.

Therefore, the largest robot vibration is obtained in element 3, followed by element 1, and in arm in element 3.

- Their transmission order is different in intensity (this is suspected) due to the stiffness of the component elements and the gauge, but the *new* consists in the fact that there is a scale of proportionality in transmitting the vibrations to the two systems, which seems to be orderly 10^3 times.

4. Conclusions and discussions

The work shows that there is an equivalence between the way the vibrations from the generating source to the robot and the human are transmitted. Respectively, in our case, there is a correlation between the transmitter elements 1 and 3 of the robot, where higher values were obtained at a scale 10^3 times larger than those obtained in the hand-arm system. This validates the concept that, the two systems are homologous as a construction to the extent that the robot construction materials can be adapted.

The FEA simulation study shows that resistance and vibrations in the 1, 3 and robot elements are very large (red (inside dark) area), a fact like the hand and source of excitement of the hand-arm system.

The paper wanted to highlight the fact that the two studied systems have similar structures, at different scales, so that each one meets the needs for which they were designed.

If the vibration damping / shrinking aspect is to be discussed, the literature shows that the protective means against mechanical vibration transmission at the workplace can be divided into two sub-categories.

The study can continue with concrete research on small robot types on the maximum vibration transmission a robot can withstand, so its reliability is not influenced, of course, considering industry standards.

5. References

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