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ANALYSIS AND MITIGATION OF HAND ARM POWER TOOLS VIBRATION

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Abstract: The hard workers are usually suffering from big medical problems after working with vibrating equipment such as compressor and different type of drills. These and many relative problems give a big motivation to study, measuring and analysis the vibration. The data were resulting from the vibration of the power tools to the human hand of the user that is in touch with this vibrating equipment are considered one of the most interesting Biomechanical Engineering. This work studies the vibration frequency, displacement, velocity acceleration that will be measured at different hand points. Examination was conducted to two workers (subjects) which are different in age, weight and height. This investigation requires a design and manufacture of vibration measurement system according to international standard(ISO 28927-10).ANSYS 15 program was chosen in order to evaluate the numerical results and then to compare with experimental results. Different types were used of Anti-vibration gloves in order to reduce the vibration connecting to hand-arm worker. The results show that values of acceleration and frequency are increased with the decreasing the distance of sensor point from the drill handle. When using the subject (1) as grand foundation , the reduction in frequency and acceleration when wearing gloves, The reduction percentage in the metacarpal for the sponge handle is (34.4 %) while in the working gloves is (30.6 %) , silicon gloves is (28.6 %), cloth gloves is (26.6 %), and leather gloves is (25.9 %). It was found that the reduction percentage in the carpal for the sponge handle is (44.8 %) while in silicon gloves is (40.8 %), the working gloves is (25.4 %), leather gloves is (19.5 %), and cloth gloves is (18 %). It was found that the reduction percentage in the elbow for the sponge handle is (42.6 %) while in silicon gloves are (28.3 %), and the working gloves is (15.4 %). The reduction percentage in the shoulder for the silicon gloves was (38.1 %) while in the leather gloves is (21.7 %), and the sponge handle is (1.5 %).

Keywords: *hand vibration, acceleration, frequency, accelerometer*

دراسة تأثير الاهتزاز على اليد البشرية وكيفية تقليله

الخلاصة: غالباً ما يعاني العاملين في الاعمال الشاقة خصوصا الذين يستخدمون معدات ذات طبيعة اهتزازية كالمثقاب والضواغط من مشاكل صحية كبيرة.هذه المشاكل شجعت على دراسة وقياس وتحليل الاهتزاز للعاملين في هذا المجال. و البيانات التي تم استنتاجها من اهتزاز المعدات ذات الطبيعة الاهتزازية التي اجريت على يد المستخدم والتي كانت بتلامس مباشر مع الالة هي واحدة من اكثر تطبيقات الهندسة الحيوية اثارة للاهتمام. يتناول هذا العمل تردد الاهتزاز، والتشوه، والسرعة والتعجيل التي سيتم قياسها في نقاط مختلفة من اليد.أجريت دراسة لاثنين من العمال (موضوعات) والتي تختلف في العمر والوزن والطول. ولدراسة الاهتزاز وقياسه تم تصميم منظومة قياس بموجب النظام العالمي (ISO 28927-10).تم اختيار برنامج ANSYS 15 من أجل ايجاد النتائج العددية ومن ثم مقارنتها مع النتائج التجريبية. تم استخدام أنواع مختلفة من القفازات المضادة للاهتزاز وذلك للحد من الاهتزاز الواصل الى ذراع العامل. خمسة انواع من القفازات المستخدمة وهي قفازات السيليكون، وقفازات القماش، والقفازات الجلدية، قفازات العمل ومقبض الإسفنج.اظهرت النتائج انه

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بزيادة المسافة عن مقبض المثقاب فان التعجيل والتردد المقاس سوف يتناقص بشكل ملحوظ. تم اختيار الشخص الاول كاساس للمقارنة بين التعجيل والتردد عند ارتداء القفازات، وجدنا أن نسبة الانخفاض في المشط لمقبض الاسفنج هي (٣٤,٤٪)، في حين قفاز العمل هو (٣٠,٦٪)، وقفاز السيليكون هي (٢٨,٦٪)، وقفاز القماش هي (٢٦,٦٪)، وقفازالجلد هي (٢٥,٩٪). كما وجد أن نسبة الانخفاض في الرسغ لمقبض الاسفنج هي (٤٤,٨٪) في حين قفاز السيليكون هي (٤٠,٨٪)، وقفاز العمل هي (٢٥,٤٪)، وقفاز الجلد هي (١٩,٥٪)، وقفاز القماش هي (١٨٪). كما وجد أن نسبة الانخفاض في الكوع لمقبض الاسفنج هي (٤٢,٦٪) في حين قفاز السيليكون هي (٢٨,٣٪)، وقفاز العمل هي (١٥,٤٪). كما وجدنا أن نسبة الانخفاض في الكتف لقفاز السيليكون هي (٣٨,١٪)، في حين قفاز الجلد هي (٢١,٧٪)، ومقبض الاسفنج (١,٥٪).

1. Introduction

Human vibration is defined as the effect of mechanical vibration in the environment on the human body. During the normal daily lives the human is exposed to various sources of vibration, for example, in buses, trains and cars. Many people are also exposed to other vibrations during their working day, for example, vibrations produced by hand-tools, machinery or heavy vehicles [1].

Vibration in the human body is divided into two main parts, the first one is hand-arm vibration (HAV)during which the vibration is transmitted by the use of vibrating hand-held power tools, such as pneumatic jack hammers, drills or electrical tools such as grinders. Hand-arm vibrations impair subjective perception, fine motor skills and performance, and may, after years of exposure, cause circulation disorders, nerve function disorders, muscular tissue changes and bone and joint damage.

While the second is whole-body vibration (HBV) during which the mechanical vibrations are transmitted to the body via the buttocks or back in the case of sedentary work, via the feet in the case of work performed while standing or the head and back when working in supine position [2].

From an exposure point of view, the low frequency range of vibration is the most interesting. Exposure to vertical vibrations in the 5-10 Hz range generally causes resonance in the thoracic-abdominal system, at 20-30 Hz in the head-neck-shoulder system, and at 60-90 Hz in the eyeball. When vibrations are attenuated in the body, its energy is absorbed by the tissue and organs. The muscles are important in this respect. Vibration leads to both voluntary and involuntary contractions of muscles, and can cause local muscle fatigue, particularly when the vibration is at the resonant-frequency level. Furthermore, it may cause reflex contractions, which will reduce motor performance capabilities [3].

Directives and Guidelines based on measurement standards define allowable exposure limits for HAV. The exposure values can generally be obtained using the same sampling methods but the results of the measurements must be applied appropriately.
exposure limit values and action values for hand-arm vibration[4]:

(a) the daily exposure limit value standardized to an eight-hour reference period shall be 5 m/s2; *(DELV)*

(b) the daily exposure action value standardized to an eight-hour reference period shall be 2.5 m/s2. *(DEAV)*

Steve Kihlberg[5] studied whether the dynamic response of the hand-arm system depend on the type of exposure and/or the frequency of the vibration. He found that exposures with lower frequencies (< 50 Hz) cause greater load on the elbow and shoulder joints than exposures with higher frequencies (> 100 Hz). Up to about 250 Hz, the finger acts like a rigid body. But exposures with higher frequencies caused a greater load on the hand and fingers. R.G. Dong et al. [6] studied the vibration energy absorption (VEA) in human fingers-hand-arm system. The results of the study suggest that the VEA into the fingers is considerably less than that into the palm at low frequencies (<25 Hz). They are, however, comparable under the excitations in the 250–1000 Hz frequency range. The finger VEA at high frequencies (>100 Hz) is practically independent of the hand-handle coupling condition.

S. Adewusi et al.[7] covered the vibration power absorption of the human hand-arm system in different postures coupled with vibrating handle and power. The results showed that the extended arm posture should be avoided since higher power (1.63 Watts) was absorbed in the hand-arm system in the extended arm posture than in the bent-arm posture (0.67 Watts) for identical hand forces and excitation level. The VPAs in the arms are greater in the low frequency region (below 25 Hz) than those of the hand. The VPA distributions of the hand are however greater than those of the arms above 100 Hz, the VPA values are however smaller than those below 25 Hz. The study revealed the need for different frequency weightings for assessment of potential injury risk of different hand-arm substructures.

J. Singh, A.A. Khan [8] studied the effect of different coatings on the handle of hand-held drilling machines. And the results showed that Coating on handles of a hand-held vibrating tool is an effective way of reducing vibrations. The results showed that coating on handles is effective way of reducing vibrations. This coating was able to reduce root mean square (RMS) value of vibrations by 59%. D.E. Welcome et al. [9] study determined whether vibration reducing (VR) gloves can attenuate the vibration transmitted to the fingers and to enhance the understanding of the mechanisms of how these gloves work. This study found that the effect of VR gloves on the finger vibration depends on not only the gloves but also their influence on the distribution of the finger contact stiffness and the grip effort. As a result, the gloves increase the vibration in the fingertip area but marginally reduce the vibration in the proximal area at some frequencies below 100 Hz. On average, the gloves reduce the vibration of the entire fingers by less than 3% at frequencies below 80 Hz but increase at frequencies from 80 to 400 Hz.

K.N. Dewangan, V.K. Tewari [10] studied the characteristics of hand-transmitted vibration of a hand tractor used in three operational modes. The results indicate that (1)Vibration acceleration was significantly affected by axis of measurement. Xh-axis resulted more than 50% hand-arm vibration as compared to Yh-axis and about 30% higher than Zh-axis. (2)The peak vibration acceleration (rms) was 5.52, 8.07 and 5.27 m/s2 during transportation on tarmacadam road, rota-tilling in dry condition and rota-puddling in wet condition, respectively. (3) Frequency-weighted vibration acceleration was significantly affected by forward speed of operation. It was highest during transportation followed by rota-tilling and rota-puddling operations.

This work aims to study the effects of power tool (Hammers) vibrations on to the hand human body, Measurement and analysis of displacement, velocity, and acceleration along the human hand-arm resulting from using vibration equipment, Suggest a completed 3D hand arm finite element model and solving it using ANSYS 15 program and compare between the experimental and a numerical one, and investigate the effect of using special reduction working gloves on different subjects.

2. Experimental Work

2.1. *General*

The idea of measuring the vibration in the human arm of hard workers is based namely on design and manufacturing new vibration measurement system according to international standard(ISO 28927-10) [11] which consists of foundation structure, working structure, drill, worker arm and vibration measuring system as shown in "Fig. 1" . The suggested vibration measurement system was used to measure vibration in the hard worker arm as a case study . The worker is of age, weight, and length as shown in the “table 1” .

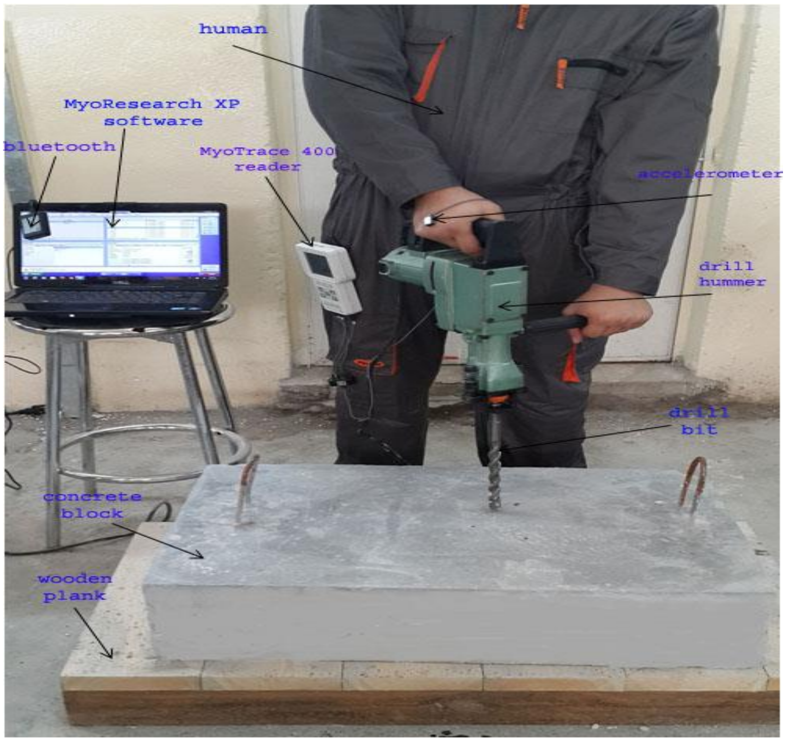

Figure 1.vibration measuring system

Table 1.The specifications of workers

No.	*Age*	*Weight*	*Length*
Subject (1)	25	80	170
Subject (2)	45	87	167

2.2. *Power Tools*

A common wide spread used hummer is used in carrying out the experiment, which has been selected according to ISO 28927-10 specifications shows in the “table 2”.

Table 2.The specifications of power tool

Model	*38mm*
Voltage	220V
Input	1050W
Capacity: Drill bit	38mm
No-load speed	400/min
Full-load impact rate	3000/min
Weight	7.5kg

2.3. Accelerometer

The very small size (22 * 16 mm) and lightweight (2.8 g) acceleration sensor is especially designed for use with human and animal surfaces and body segments. Due to its small weight and mass, it is easy to attach and provides accurate data. Attached to nonbiological materials and bodies, it can measure the impact forces up to 10G, shown in "Fig. 1".

2.4. Anti-Vibration Gloves

Different types of gloves are used to decrease the vibration that workers might feel; these are as shows in the "Fig. 2".

a- Cloth gloves

b- Leather gloves

c- Sponge handle

d- Working gloves

e- Silicon gloves

Figure 2. Types of gloves

2.5. *Experimental Procedure*

The action steps can be explained in the following points:

1- The concrete block is placed on damping material such as wooden planks to compensate for any unevenness of the surface . the concrete block shall not have any resonances within the frequency range for the hand-arm vibration as this can influence the test result.

2- The accelerometer is firmly fixed on different points on the arm parts of body as shown in the "Fig. 3". At the first, the accelerometer placed in the metacarpal and then in the carpal and then in the elbow and in the end was placed in the shoulder.

Figure 3. Accelerometer Points positions along Human arm

3- Rotary hummer is prepared and the drill bit is connected and then placed above the concrete block in order to work. Reading started once the drill bit comes into contact with concrete block and stopped when the bit has reached a depth which is 80 % of the drill rod working length or before the bit breaks through the lower surface of the block .

4- The accelerometer may be connected to the MyoTrace 400, and the MyoTrace 400 may be optionally connected to a PC by bluetooth and used for more advanced analysis with our MyoResearch XP software. "Fig. 4" shows MyoResearch XP software which includes a measure to accelerate in three directional x, y and z.

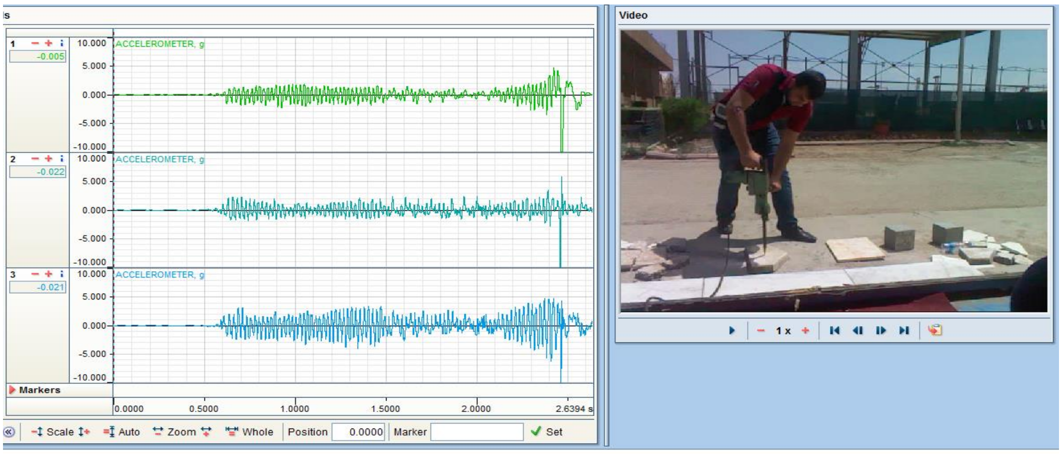

Figure 4.The vibration measurement system using a MyoTrace 400 software

5- After recording acceleration readings, this reading is used to extract various parameters such as (velocity, displacement, and frequency) at each point by using another EI-Calculator software,as shown in "Fig. 5".

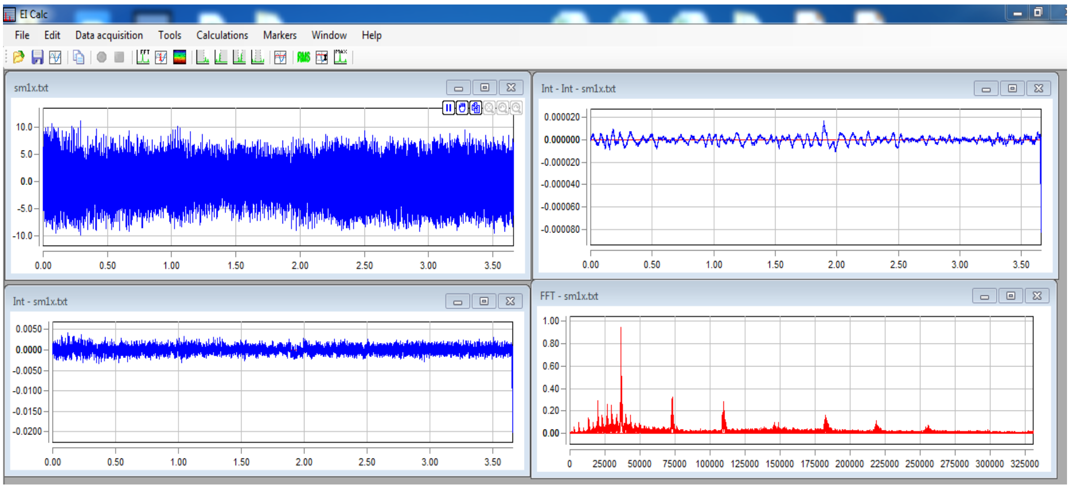

Figure 5.EI-Calculator software

6- The examiniation have been achieved on two different human in terms of age, height and weight. and then re-test by using Anti-vibration gloves for the purpose of reducing vibration, using five different types of gloves that have been mentioned previously.

2.6. *Finite Element and Numerical Analysis*

The finite element method (FEM), is a computational technique used to obtain approximate solutions of boundary value problems in engineering. Simply stated, a boundary value problem is a mathematical problem in which one or more dependent variables must satisfy a differential equation everywhere within a known domain of independent variables and satisfy specific conditions on the boundary of the domain. Boundary value problems are also sometimes called field problems. The field is the domain of interest and most often represents a physical structure. The field variables are the dependent variables of interest governed by the differential equation. The boundary conditions are the specified values of the field variables (or related variables such as derivatives) on the boundaries of the field. Depending on the type of physical problem being analyzed, the field variables may include physical displacement, temperature, heat flux, and fluid velocity to name only a few.

The finite element method has become a powerful tool for the numerical solution of a wide range of engineering problems. The use of ANSYS-15 to create the finite element model is adopted**.** Different boundary conditions such as fixed-fixed and fixed-free are varied to simulate the best conditions for real human bone case. We observed that fixed-fixed boundary condition is more comparable to out experimental result therefor, we depend on it and ignore the results of fixed-free. The material properties for standard upper limbs bones are recorded in “table 3”.

Table 3.Material characteristics for human upper limbs bones [12]

Material Property	
Young's Modulus, E	21 GPa
Poisson's Ration, v	0.3
Density	413 Kg/m3

3. Results and discussions

3.1. *Acceleration and Frequency Measurement*

Wave length recorded for time interval of 40 second of different bones selected as a critical path for the vibrations to upper bones and tissues. Also one of the most important thing that this wave length is converted to FFT curves to see and investigate the effected frequency and sample rate used subject (1). The values of acceleration and frequency in "tables 4 and 5" are taken from RMS acceleration. Figures (6) through (9) show the acceleration for subject (1).

When comparing the results of the two tables it is found that the value of acceleration decreases from metacarpal region to shoulder joint. Also it is found that the values of acceleration in subject (2) are less than that of subject (1) and this difference is related to the muscle stiffness which is increased with increasing the age and psychological effects of the subject during test. This comparison can be seen in the figure (14). Figures (10) through (13) show the frequency for subject (1). The values of frequencies decrease from the metacarpal region to shoulder joint. This difference is related to the distance between one region and another. Skin and muscle works like a damper.

Table 4.Acceleration data for subject (1)

Installation zone	*NO.*	*r.m.s. acceleration values (m/s^2)*				*Frequency (HZ)*		
		a_{hwx}	a_{hwy}	a_{hwz}	a_{hv}	F_x	F_y	F_z
Metacarpals	1	3.15	3.04	4.13	6.02	36.52	36.74	36.52
	2	3.89	4.25	4.22	7.14	36.89	36.89	36.89
	3	4.41	4.28	4.28	7.5	36.91	36.91	37.09
	4	3.61	3.58	4.03	6.49	36.93	36.86	36.93
	5	3.9	3.43	3.73	6.4	36.36	36.36	72.7
	Mean				6.71	36.72	36.75	44.03
Wrist	1	3.77	3.71	2.95	6.05	36.93	37.09	37.09
	2	5.15	2.7	3.52	6.8	36.72	36.72	36.72
	3	3.19	3.13	2.75	5.25	36.76	36.76	36.76
	4	3.78	3.06	3.26	5.85	36.93	36.72	36.72
	5	3.45	3.47	2.38	5.44	36.85	36.8	36.8
	Mean				5.88	36.84	36.82	36.82
Elbow	1	0.3	0.63	0.95	1.18	6.85	13.4	36.6
	2	0.31	0.64	1.06	1.28	6.8	36.7	36.86
	3	0.36	0.62	1.1	1.31	36.76	36.76	36.76
	4	0.32	0.6	1	1.21	36.64	36.91	36.95
	5	0.36	0.62	1.1	1.31	36.76	36.76	36.76
	Mean				1.26	24.76	32.11	36.79
Shoulder	1	0.23	0.18	0.23	0.37	19.4	12.98	35.39
	2	0.25	0.23	0.22	0.4	34.99	12.8	34.99
	3	0.24	0.24	0.18	0.38	34.95	12.94	35.01

	4	0.31	0.3	0.26	0.5	35.01	35.01	35.01
	5	0.24	0.21	0.19	0.37	34.85	12.78	34.68
	Mean				0.404	31.84	17.3	35.02

Table 5. Acceleration data for subject (2)

Installation zone	N0.	r.m.s. acceleration values (m/s^2)				Frequency (HZ)		
		a_{hwx}	a_{hwy}	a_{hwz}	a_{hv}	F_x	F_y	F_z
Metacarpals	1	3.63	2.7	2.42	5.13	34.34	34.36	34.34
	2	4.89	2.87	2.95	6.39	35.47	35.47	35.47
	3	4.29	2.76	2.87	5.85	34.97	34.97	34.97
	4	4.35	2.77	2.86	5.9	35.37	35.43	35.37
	5	3.52	2.02	2.16	4.6	34.34	34.32	34.34
	Mean				5.57	34.89	34.91	34.89
Wrist	1	2.77	2.02	2.13	4.04	35.23	35.19	35.13
	2	2.37	1.94	1.69	3.49	35	28.63	35.07
	3	3.03	2.44	2.06	4.4	35.33	35.29	35.33
	4	2.62	3.18	2.01	4.58	35.57	35.47	35.51
	5	2.39	2.38	1.91	3.88	35.31	35.31	35.31
	Mean				4.08	35.29	33.98	35.27
Elbow	1	1.2	0.5	0.77	1.51	35.21	35.19	35.21
	2	1.22	0.51	0.99	1.65	35.55	35.51	35.37
	3	1.02	0.39	0.72	1.31	35.75	13.18	35.75
	4	0.96	0.41	0.73	1.27	35.13	35.75	35.15
	5	1.15	0.45	0.86	1.5	35.82	13.06	35.82
	Mean				1.45	35.49	26.54	35.46
Shoulder	1	0.18	0.16	0.14	0.28	13.06	6.56	19.65
	2	0.22	0.13	0.14	0.29	13.23	6.62	36.04
	3	0.26	0.17	0.17	0.35	35.92	6.6	35.92
	4	0.2	0.16	0.14	0.29	35.33	6.48	35.29
	5	0.2	0.22	0.16	0.34	3.25	3.25	6.5
	Mean				0.31	20.16	5.9	26.68

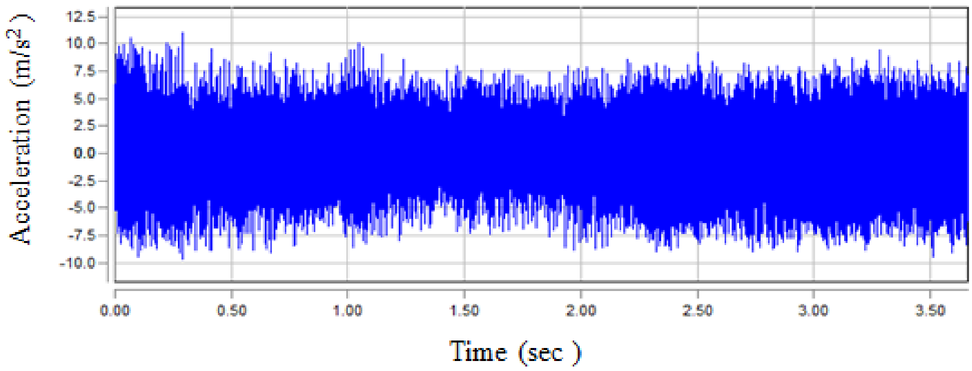

Figure 6.The acceleration at the metacarpal for subject (1)

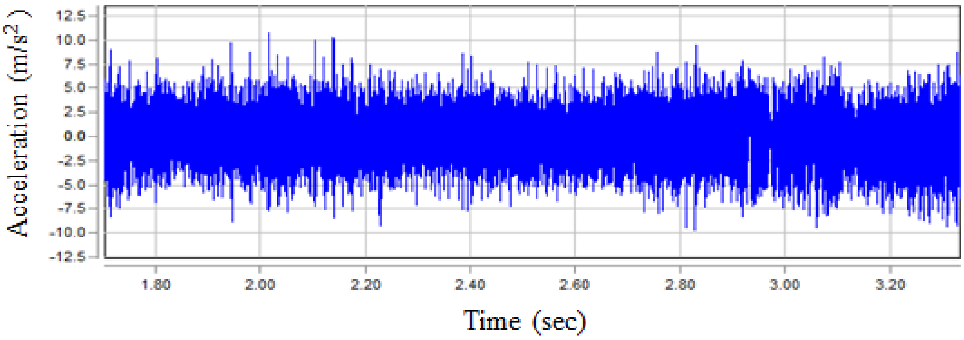

Figure 7.The acceleration at the carpal for subject (1)

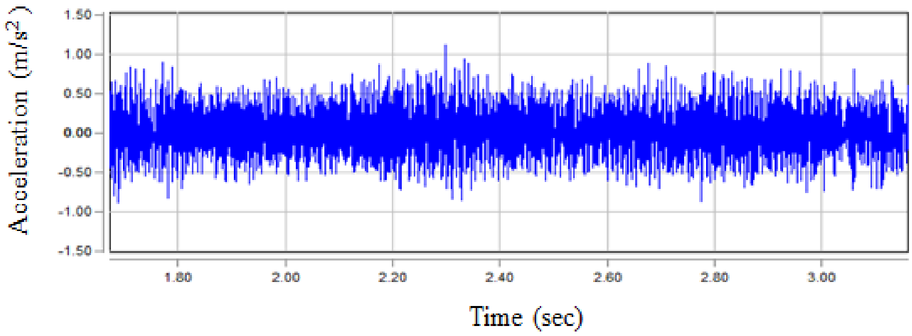

Figure 8.The acceleration at the elbow for subject (1)

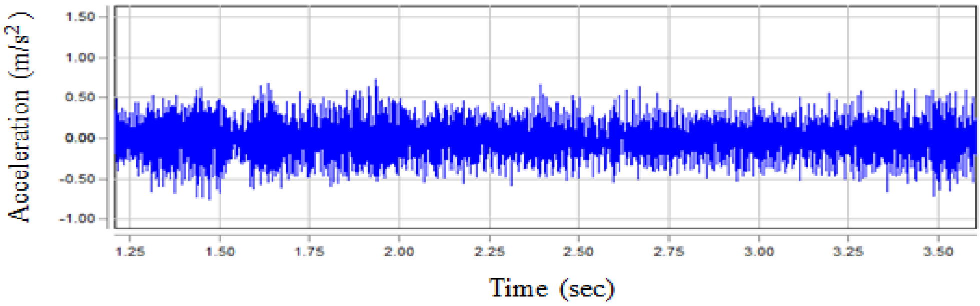

Figure 9.The acceleration at the shoulder for subject (1)

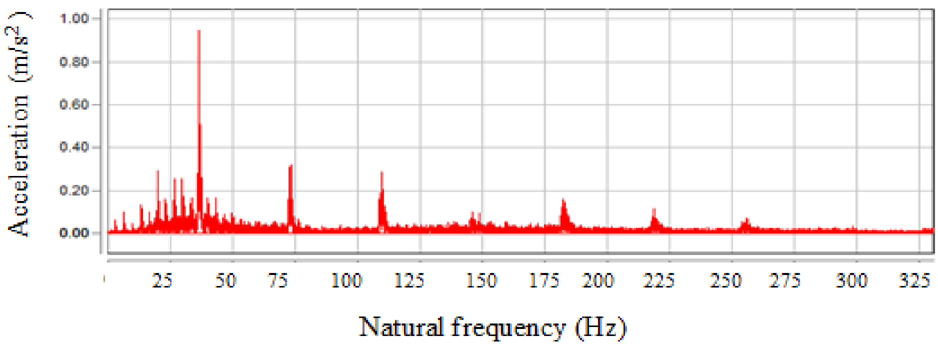

Figure 10.FFT analysis function of metacarpal for subject (1)

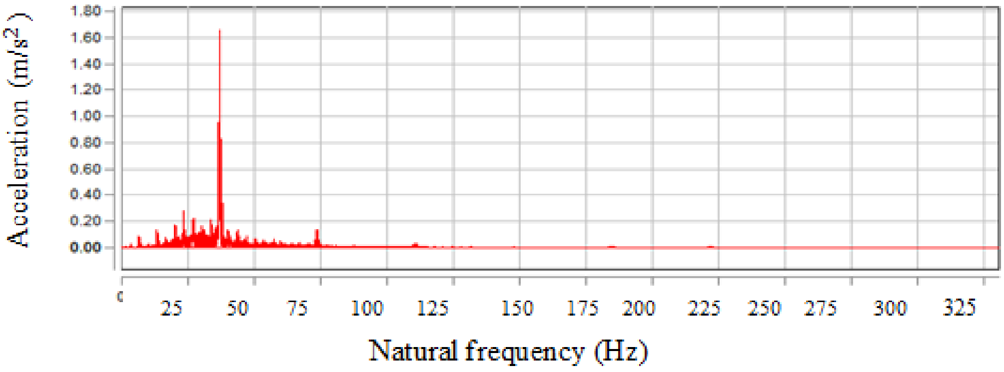

Figure 11.FFT analysis function of carpal for subject (1)

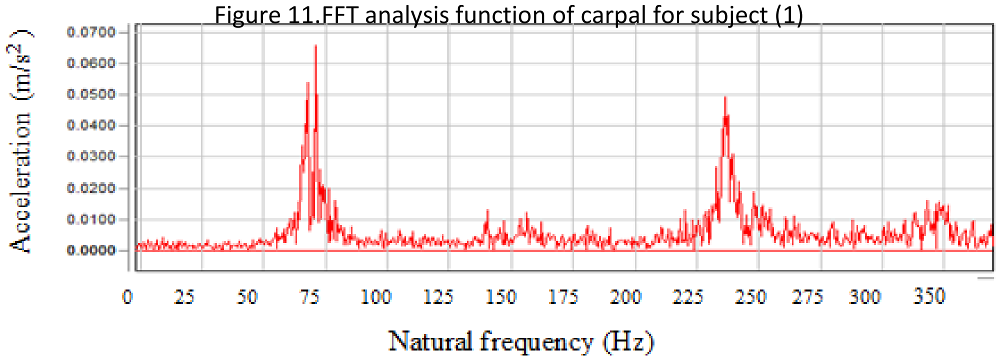

Figure 12.FFT analysis function of ulna for subject (1)

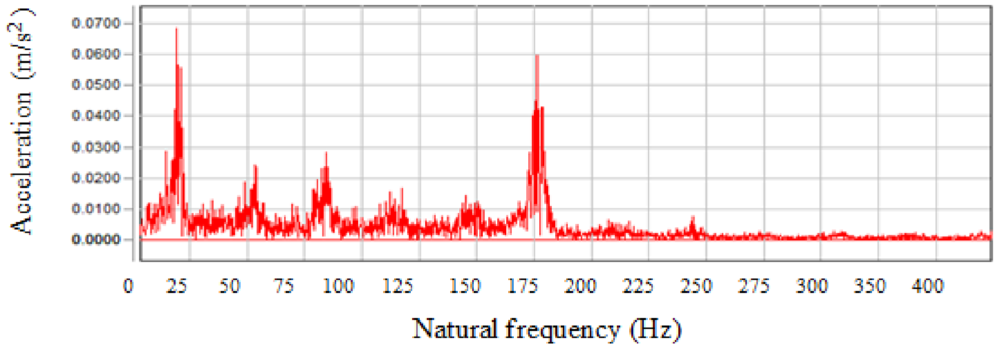

Figure 13.FFT analysis function of humerous for subject (1)

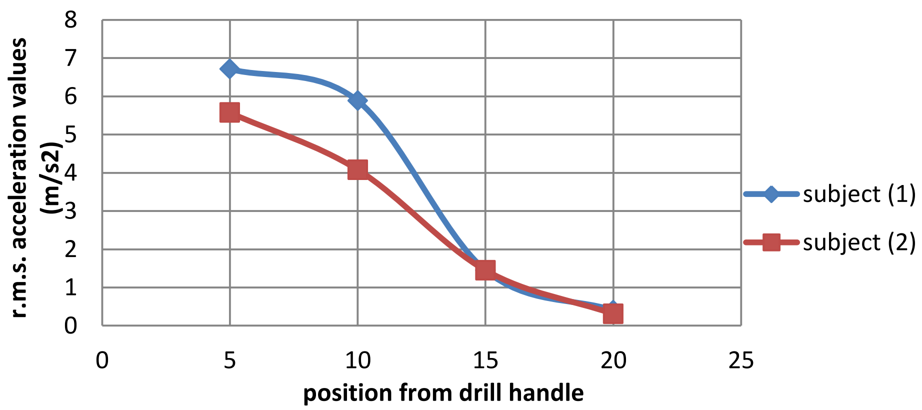

Figure 14.The comparing between subject (1) and subject (2)

3.2. *Numerical results*

Numerical works are those obtained using the ANSYS 15 program. The ANSYS workbench was used and by using the option map of analysis types, model and random vibration analysis can be selected. Figure (15) to (18) show the general contour of acceleration for four bones. It can be noted the difference between the experimental and numerical results as shown in the “table 6”.

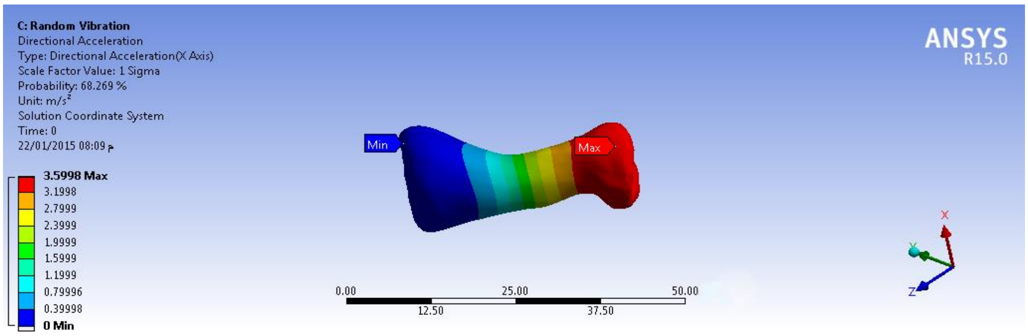

Figure 15.The directional acceleration in the Metacarpal

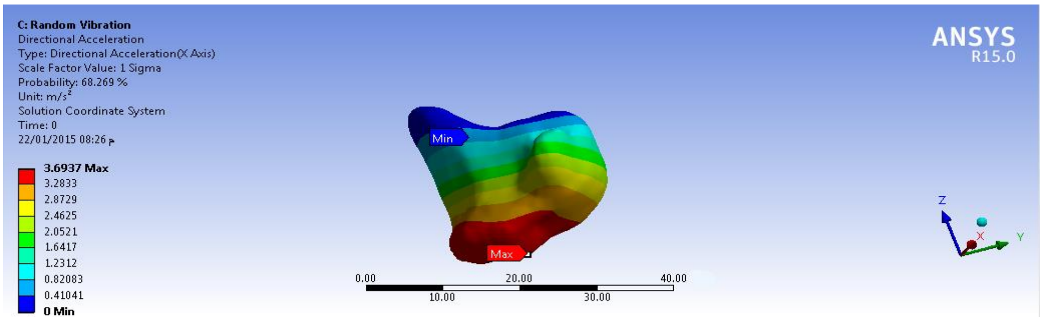

Figure 16.The directional acceleration in the Carpal

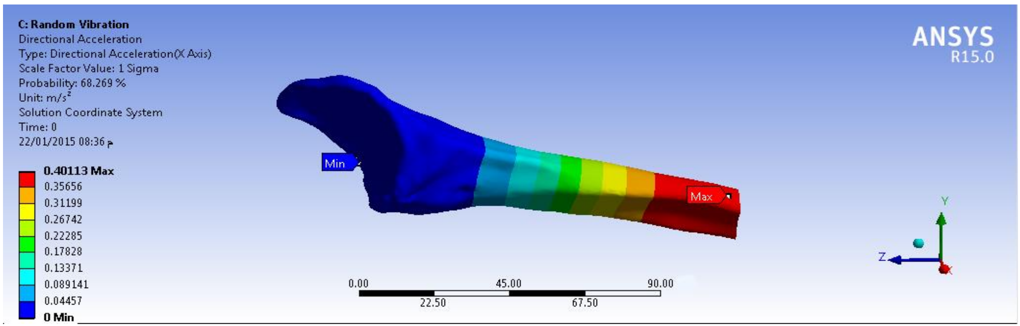

Figure 17.The directional acceleration in the Ulna

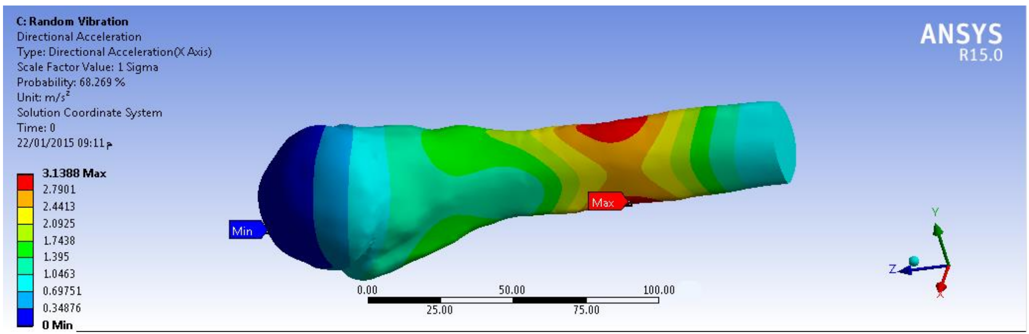

Figure 18.The directional acceleration in the Humerous

Table 6.Comparing acceleration between experimental and numerical results

Type of Bone	*Experimental Result of acceleration*	*Numerical result of acceleration*	*percentage for fixed-fixed B.C*
Metacarpals bones	3.15	3.599	11.5 %
Carpal bone(wrist)	3.77	3.69	2.1 %
Ulna (upper part)	0.3	0.401	25.1 %

3.3. *Effect of using vibration reduction gloves*

Different working gloves are selected to investigate minimizing vibration connecting to the human body and reduce its effects on subject (1). Five types of gloves were selected such as cloth gloves, leather gloves, silicon gloves, working gloves and sponge handle.

The values of acceleration and frequency are taken from RMS acceleration. It was found that the sponge handle reduces the acceleration more than the working glove which reduces it more than the silicon glove, but the silicon glove reduces the acceleration more than the cloth, the later reduces the acceleration more than the leather. This is related to the difference in the thickness and stiffness of these gloves and this comparison can be seen in the figure (19). Comparison between the gloves can be made by finding the reduction percentage, according to the following law (Reduction percentage % = $\frac{maximum\ value - minimum\ value}{maximum\ value} \times 100$). It was found that the reduction percentage in the metacarpal for the sponge handle is (34.4 %) while in the working gloves is (30.6 %) , silicon gloves is (28.6 %), cloth gloves is (26.6 %), and leather gloves is (25.9 %). Also it was found that the reduction percentage in the carpal for the sponge handle is (44.8 %) while in silicon gloves is (40.8 %), the working gloves is (25.4 %), leather gloves is (19.5 %), and cloth gloves is (18 %). Also it was found that the reduction percentage in the elbow for the sponge handle is (42.6 %) while in silicon gloves is (28.3 %), and the working gloves is (15.4 %). Also it was found that the reduction percentage in the shoulder for the silicon gloves is (38.1 %) while in the leather gloves is (21.7 %), and the sponge handle is (1.5 %).

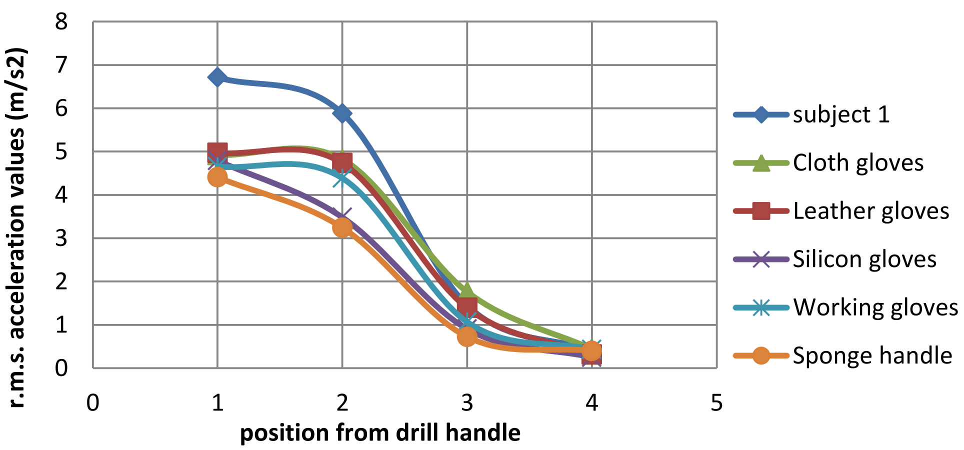

Figure 19. Comparison between different gloves

3.4. Deformation measurement

The values of deformation (displacement) are taken from double integration of acceleration, and the acceleration measured by the test. Figures (20) to (23) show the deformation of four bones by experimental. Also shows the deformation of numerical result by ANSYS 15program for fixed-fixed boundary condition from figure (24) to (27). The comparing between these results can be shown “table 7”.

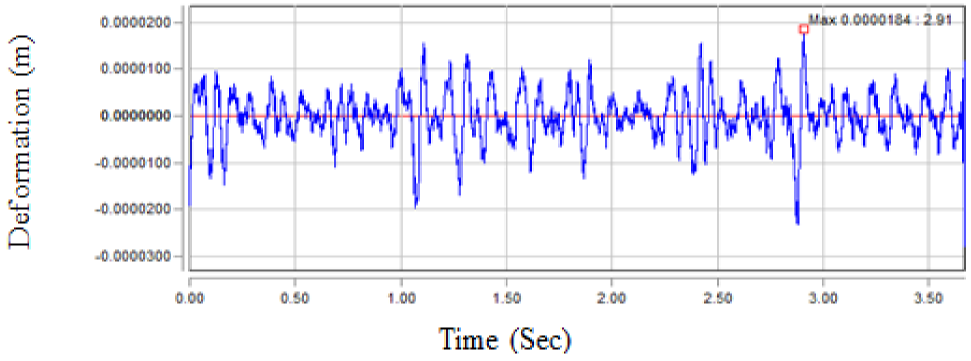

Figure 20.The deformation of metacarpal of experimental

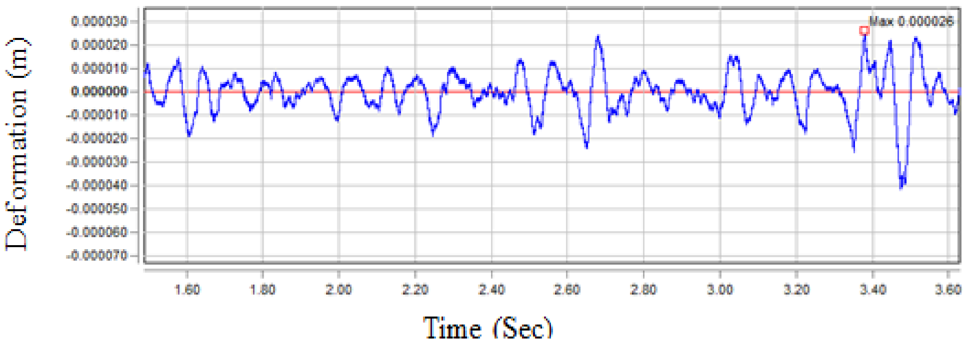

Figure 21.The deformation of carpal of experimental test

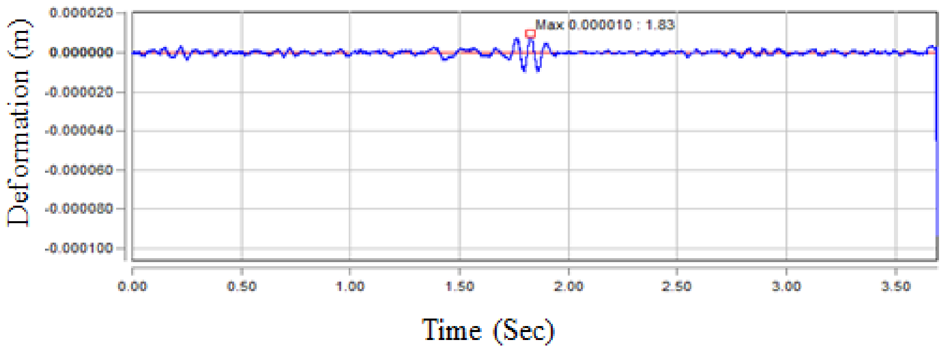

Figure 22.The deformation of Ulna of experimental test

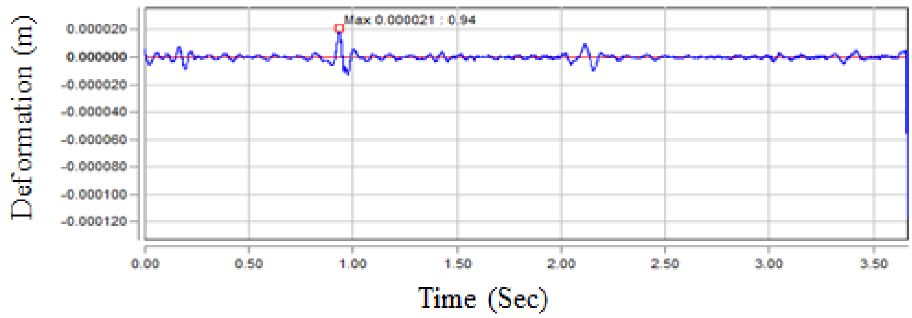

Figure 23.The deformation of Humerous of experimental test

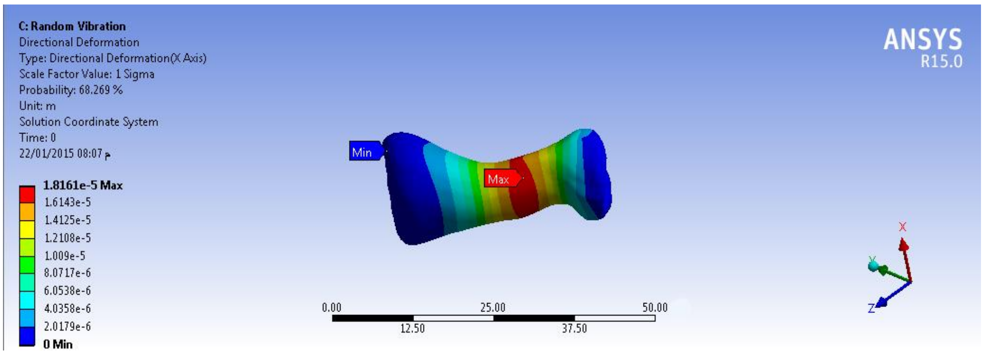

Figure 24.The directional Deformation of the metacarpal bone in the fixed-fixed boundary condition

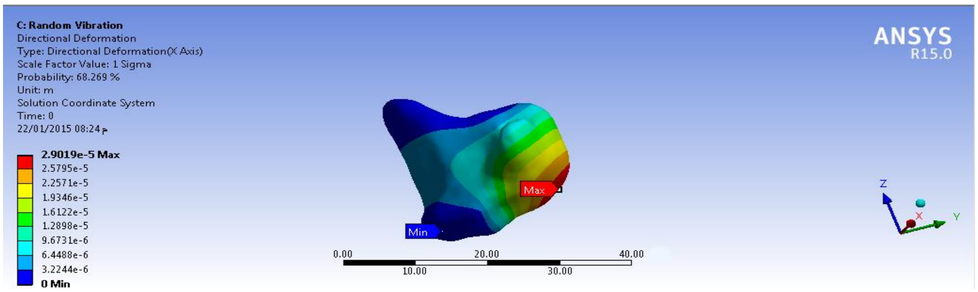

Figure 25.The directional Deformation of the carpal (wrist) bone in the fixed-fixed boundary condition

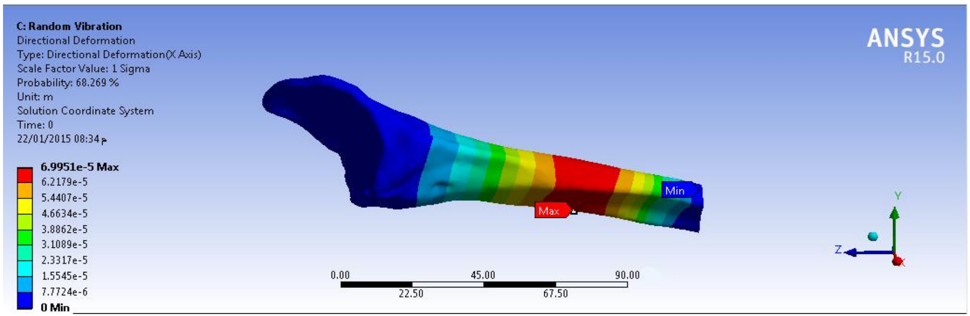

Figure 26.The directional Deformation of the Ulna (upper part) bone in the fixed-fixed boundary condition

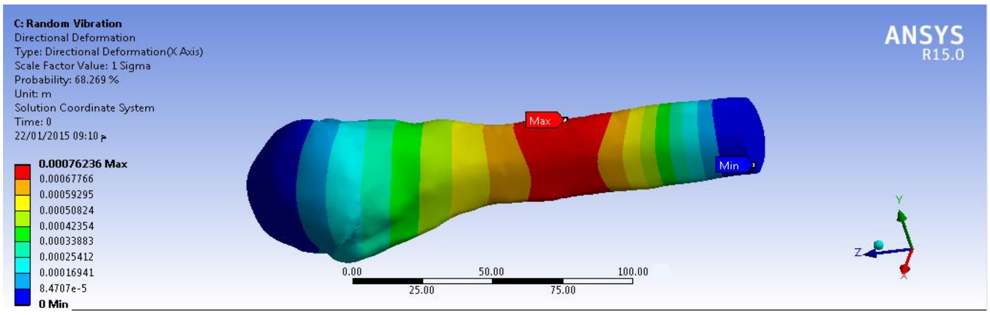

Figure 27.The directional Deformation of the Ulna (lower part) bone in the fixed-fixed boundary condition

Table 7.Comparison the deformation value between experimental and numerical results

Type of Bone	*Experimental Result*	*Numerical result Fixed-Fixed*	*Reduction percentage*
Metacarpals bones	1.8×10^{-5}	1.82×10^{-5}	1.1 %
Carpal bone(wrist)	2.6×10^{-5}	2.9×10^{-5}	10.3 %

4. Conclusions

The following conclusion are drawn from the results obtained in this work :

1- The values of acceleration and frequency are increased with the decreasing the distance of sensor point from the drill handle.

2- The value of acceleration decreases from metacarpal region to shoulder joint. Also it is found that the values of acceleration in subject (2) are less than that of subject (1) and this difference is related to the muscle stiffness which is increased with increasing the age and psychological effects of the subject during test.

3- Using the sponge handle, gives a reduction in frequency and acceleration at metacarpal is (34.4 %) while in the carpalis (44.8 %), elbow is (42.6 %), and in the shoulder is (1.5 %).

4- Using the silicon gloves, gives a reduction in frequency and acceleration at metacarpal is (28.6 %) while in the carpalis (40.8 %), elbow is (40.8 %), and in the shoulder is (38.1 %).

5- Using the leather gloves, gives a reduction in frequency and acceleration at metacarpal is (25.9 %) while in the carpalis (19.5 %), and in the shoulder is (21.7 %).

6- Using the working gloves, gives a reduction in frequency and acceleration at metacarpal is (30.6 %) while in the carpalis (25.4 %), elbow is (15.4 %).

7- Using the cloth gloves, gives a reduction in frequency and acceleration at metacarpal is (26.6 %) while in the carpalis (18 %).

8- Comparison between the experimental and numerical acceleration show a discrepancy, the percentage error in the metacarpal is (11.5 %) while in the carpal is (2.1 %).

9- Comparison between the experimental and numerical deformation show a discrepancy, the percentage error in the metacarpal is (1.1 %) while in the carpal is (10.3 %).

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