Vibration Measurement And Analysis Of Knee-Ankle-Foot Orthosis (Kafo) Plastic-Metal Type

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Abstract:

The aim of present paper is to measure the stresses that results from vibration for knee-Ankle-Foot-orthosis (KAFO) at different position during dress up by patient by measuring of accelerometer of (KAFO).Also the pressure between leg and knee -Ankle-Foot-orthosis was measured by using piezoelectric sensor. Total stresses result from applied pressure and acceleration on the KAFO numerically calculated with ANSYS 14 package. The results showed that the values of stresses at the upper KAFO (thigh) are greater than the lower KAFO(shank).this is certainly because of the values of pressure in the upper leg (thigh muscles)are higher than the pressure in shank muscles.

***Keywords**: Knee, Ankle, foot, Orthosis, acceleration, Frequency, stress.*

قياس وتحليل الاهتزازات لمسند قدم كاحل ركبة نوع بلاستك –معدن

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الخلاصة :

الهدف من البحث دراسة الاجهادات الناتجة من تأثير الاهتزازات في مسند قدم كاحل ركبة نوع بلاستك في أماكن مختلفة أثناء أرتداء المريض للمسند يتم حساب التعجيل بواسطة متحسس التعجيل كذلك حساب ضغط التداخلي بين المسند والساق باستعمال متحسس الازاحة .الاجهاد الكلي ينتج من تسليط الضغط والتعجيل على المسند ويحسب عدديا ببرنامج التحليل العددي انسز 14.النتائج تبين الأجهادات في الجزء الاعلى من المسند (عضلات الفخذ) أعلى من الجزء الاسفل من المسند (عظلات الساق) وهذا واضح بسبب قيمة الضغط المقاس عند عضلات الفخذ اعلى من الضغط عند عضلات الساق.

الكلمات الرئيسية: قدم ، كاحل ، ركبة ، مسند، تعجيل ، تردد ، اجهاد.

1. Introduction

An orthosis is a device that is applied to a part of the body to correct deformity, improve function, or relieve symptoms of a disease. The word is derived from ortho, meaning straight [1].Orthoses added to the body to stabilize or immobilize a body part, prevent deformity, protect against injury or to assist with function. They can be divided into different types based on their intended function[2]. The term KAFO is an acronym that stands for Knee-Ankle-Foot Orthoses and describes the part of the body that the device encompasses. The device extends from the thigh to the foot and is generally used to control instabilities in the lower limb by maintaining alignment and controlling motion. Instabilities can be either due to skeletal problems: broken bones, arthritic joints, bowleg, knock-knee, knee hyperextension or muscular weakness and paralysis [3]. Typically, KAFOs are extremely mechanically simple and often have few moving parts. This simplicity is accompanied by ease of donning and durability but leaves functional abilities only partially improved. Historically, KAFOs have locked the knee joint, providing stance phase stability while preventing knee motion during swing. Alternatively, KAFOs with an eccentric knee joint allow knee motion during swing but provide limited stability during stance. Either design results in inefficient gait. More recently, stance control orthosis have emerged on the market. These devices use a knee joint that is mechanically stable during the stance phase but releases at swing phase. The resulting gait is much smoother than the gait with a traditional KAFO where the knee remains locked throughout the entire gait cycle. Continued engineering development and creativity will be required for evolution of these designs into viable components for use by patients with knee instability during stance.

2. Experimental procedure:

The measurements occurred on man under going from flexion knee and shorten leg in his left leg due to injected by needle in wrong position when he was child. The pathological subject is of age, weight, length and the residual palsy limb of 35years, 82kg, 172 cm, and 80 cm respectively.

so as to know the magnitude of stress that result from vibration in each position of knee Ankle Foot orthosis during dress up by patient must be measuring and calculate many necessary vibration data

1. **Measure acceleration** for KAFO by using portable acceleration sensor as shown in **Figure (1)** in different position the sensor was located in
   - **a.** The center of ankle.
   - **b.** The mide of knee.
   - **c.** The mide of the thigh

The sensor was recording data, while pathological subject was walking in his normal speed on the ground in straight way.

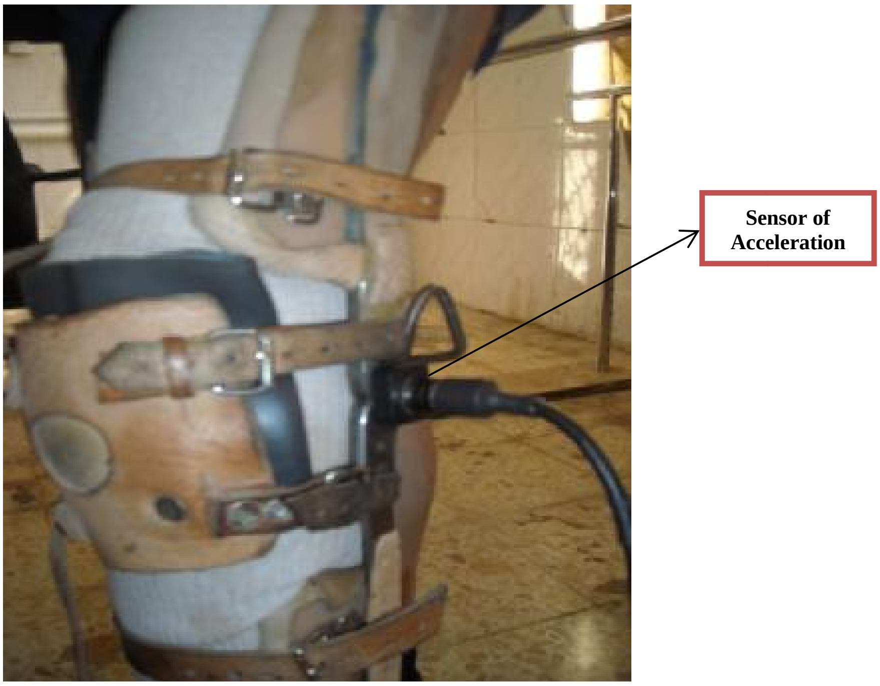

Fig.(1) : Acceleration sensor device.

2. Measuring pressure:

The pressure between the leg and knee Ankle foot orthotic measured by using piezoelectric sensor as shown in **Figure (2)** .the pole of sensor connected with multi-meter devise to obtain the magnitude of voltage that result from response of sensor through the stance phase .the multi-meter and piezoelectric are interface with the computer and recording data as shown in **Figure. (3)**. The pressure measured in shank and thigh region each position was divided into three parts longitudinal, in the middle and two parts on the terminal of the piece as shown in **Figure.(4)**.The program of multi-meter giving maximum and minimum value of voltage with time .we take maximum value of this to be the pressure in this point .the procedure will be recurred to another part so as to obtain on the pressure values in all position that contact with muscles of leg as shown in **Figure. (5)**.

Fig.(2): The piezoelectric sensor

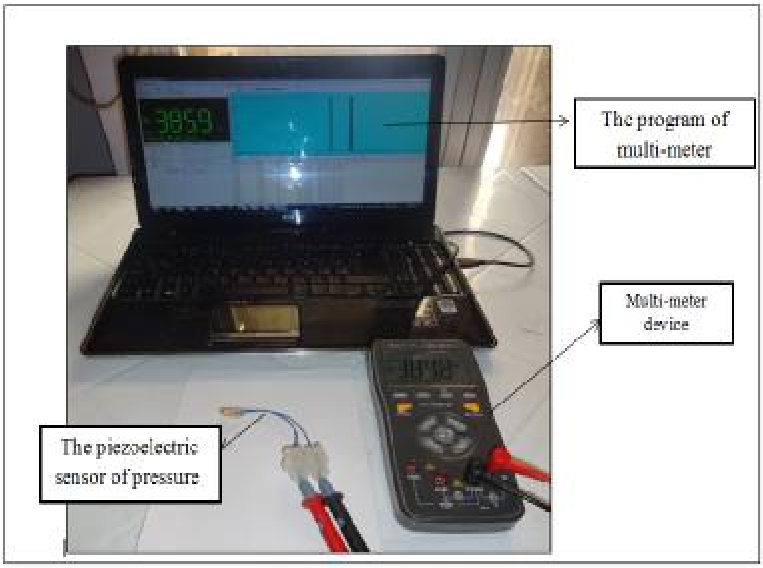

Fig. (3) : the multi-meter and piezoelectric are interface with the computer

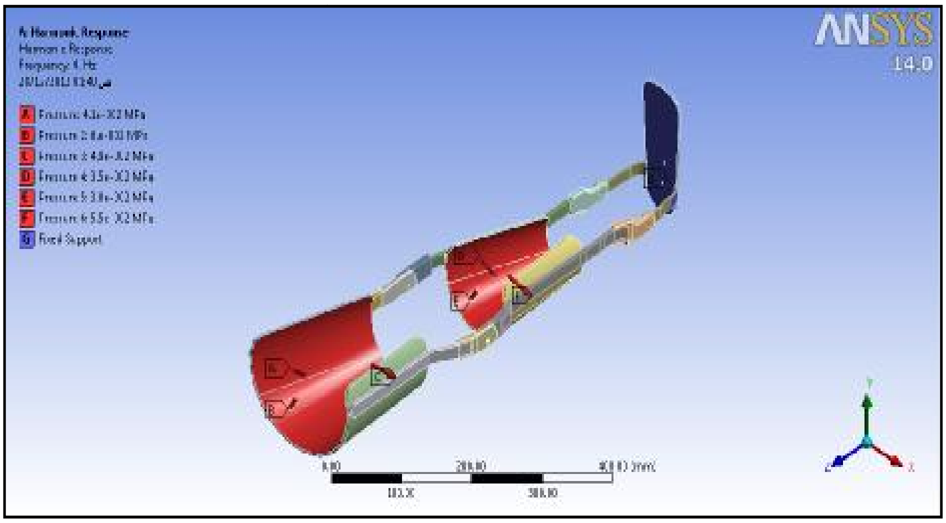

Fig .(4): The model subjected to maximum pressure load

Fig .(5): The pressure measured in thigh region

3. The Numerical Analysis

Finite element analysis (FEA) is consists of computer model of a material or design that is stressed and analyzed for specific results. It is used in new product design, and existing product refinement. In other words, FEA is a numerical method to find out an approximate solution for variables in a problem which is difficult to be obtained analytically. The calculation of potential design changes such as temperature, buckling and deflection are usually complicated. A numerical method that is able to solve these engineering problems in the finite element analysis. In case of structural models failure, FEA may be use to help determining the design modifications to meet the new condition. The concept of the finite element analysis is solving a continuum by a discrete model. It is done by dividing the problem into small several elements. Each element is in simple geometry and this is easier to be analyzed than the actual problem or the real structure. Each element is then applied with known physical laws. The equation which is formed by each element or parameters then will combined to form a global equation. The new equation can be used to solve the field variables such as displacement, buckling, temperature and so on[4].

The general analysis by using ANSYS has three distinct steps that:

- Building the geometry as a model.
- Applying the boundary conditions load and obtaining the solution.
- Reviewing the results.

4. Graphing of the geometry

In this thesis selection plastic-metal knee ankle foot orthosis (KAFO) model was drawn by using CAD system (Auto CAD) which processed according to an default pattern in three dimensions .the dimension was taken from the same KAFO that done on it measurement of experimental part. The aim of drawing models by AUTOCAD so as to use in ANSYS workbench program for modeling, meshing and defining boundary condition like such as applied load. The models is illustrate in the **Figure (6).**

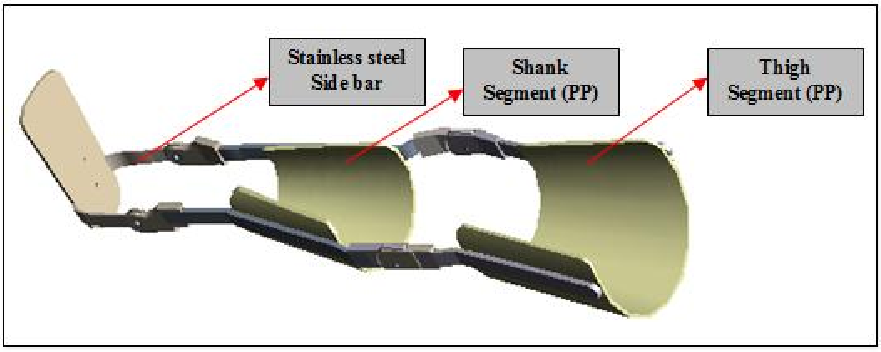

Fig.(6) : Graphing of the geometry and material selection in KAFO's

5. Material selection in KAFO's

Various materials used in the manufacturing of KAFO depending on the type of KAFO such as (metal-metal, plastic –metal) and position of each section that building structure of KAFO like material used in the knee joint different from used in sole , **the materials are:**

1- Stainless steel.

2- Polypropylene.

5.1. Stainless steel

Stainless steel used for making The uprights side bars, knee joint system, ankle joint system and system shoe stirrup in of Plastic – Metal KAFOas shown in **Figures(6).** Stainless steel using in this sections because of the good characteristics like resistance to corrosion in many environments, their good mechanical properties over an extremely wide range of temperatures, and their superior resistance to oxidation and scaling at very high temperatures [5], The mechanical properties of standard Stainless steel are listed in the **Table (1)**[5].

Table (1): The mechanical properties of standard Stainless steel

Young's Modulus (GPa)	Poisson ratio	Density ($^{kg}/_{m^3}$)
210	0.3	7800

5.2. Polypropylene

PP has low density and good flexibility and resistance to chemicals, abrasion and moisture, but decreased dimensional stability, mechanical strength, and resistance to UV (ultraviolet) light and heat [6].Polypropylene used for making the shank section and thigh section Plastic – Metal KAFO, The mechanical properties of standard polypropylene are listed in the table (2)[6].

Table (2): The mechanical properties of standard polypropylene.

Young's Modulus (GPa)	Poisson ratio	Density($^{kg}/_{m^3}$)
0.9	0.3	890

6. Mesh of the model

The meshing process has been done by choosing the volume, and then the shape of element was selected as tetrahedron (Automatic meshing), for metal-metal model as shown in **Figure (7)** contain total number of elements was (95298 elements) with total a number of nodes of (182108 nodes) according to automatic ANSYS elements and nodes counter .

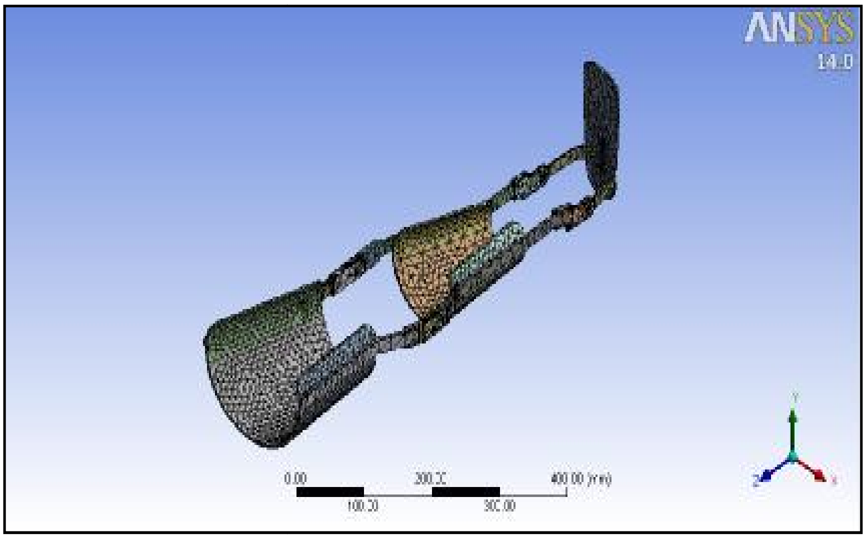

Fig.(7) : mesh of the model

7. Defining element types

The element (solid, Brick 8node 45) was used in this work, Solid45 is used for the 3-D modeling of solid structures. The element is defined by eight nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions, as shown in **Figure (8)**[7].

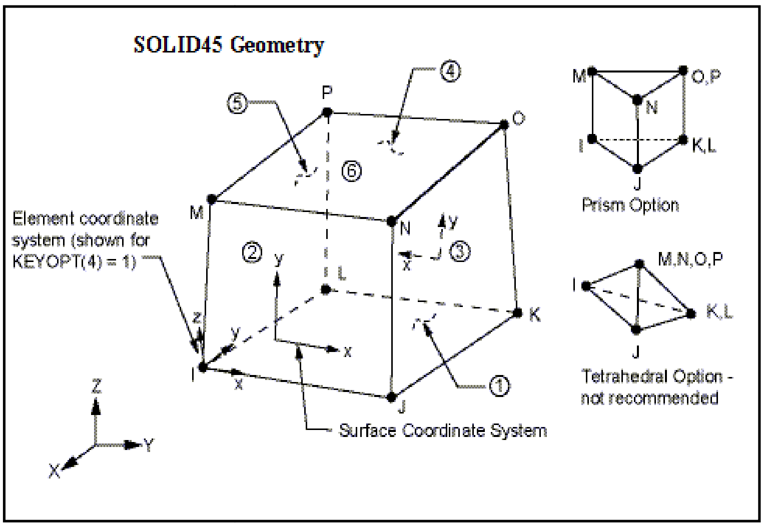

Fig.(8): Solid 45 element geometry

8. Defining the analysis type and applying load

The term 'load' includes the boundary conditions (constraints, supports, or boundary field specification), as well as other externally and internally applied loads. The load used in the ANSYS Workbench software will be fixed support at the sole. While, the interface pressure was distributed on the calf for both of shank and thigh segments, and enters the values of acceleration measured in thigh, knee and ankle. The ANSYS workbench consists of the following sequence: At the first, the drawing of the geometry (KAFO model), then by transforming into meshing options (mesh generation), and by using the option map of analysis types, modal and harmonic analysis can be selected. In order to complete the total solution of this case, many of the other important parameters are added, such as Young's modulus, Poisson ratio, and density.

9. Result and discussion

Observed by comparing the results of accelerated at three joints foot,ankle and thigh in the case of plastic - metal knee ankle foot orthosis in **Table (3)** to a person suffering from curvature of the knee and the short leg there a marked increase in the value of accelerating the knee joint and this is normal as a result of the movement of the knee during the walk gait cycle where natural that precede each of the ankle and thigh. As shown in table(3),the maximum value of frequency was recorded in knee joint with the value 5.995 Hz and maximum value of acceleration at knee joint about 8.589 $m/_{s^2}$ due to patient wearing plastic KAFO have effective muscles.

The interface pressure results are shown in Fig(4) ,this figure shows that the max value of interface pressure in KAFO upper calf was recorded at semitendinosus muscles with values of 60 Kpa While the max value of interface pressure in KAFO lower calf was recorded atgastrocnemius muscles with values of 55Kpa.

Figures (9),(10) shows the general contour of Von Mises stress for KAFO resulted from the ANSYS 14 program. The figure also shows that the values of stresses at bar contact with Gracilis muscle for KAFO plastic model is more than stresses at side bars for lateral and interior shown in **Figure (11, 12, 13, 14, 15, 16**) ,stresses at thigh calf that contact with semitendinosus muscle for KAFO plastic model as shown in **Figures (17),(18)** and stress at shank calf contact with gastrocnemius muscle for KAFO plastic model as shown in **Figures (19),(20)** .that due to Gracilis muscle is more effective than semitendinosus muscle and gastrocnemius muscle And weight of body is sheer to internal .

The **Figure(21)** shows that the values of stresses at the upper KAFO (thigh)are greater than the lower KAFO (shank).This is certainly because of the values of pressure in the upper leg (thigh muscles)are higher than the pressure in shank muscles as shown in **Figure(4).**

Table 3: vibration data for plastic KAFO

Vibration data for the plastic knee ankle foot orthosis			Normal Person
Point	RMS Acceleration amplitude (m/s^2)	Frequency(Hz)	Frequency Range(Hz)[8]
Ankle	7.921	4.197	10-40
Knee	8.589	5.995	10-25
thigh	3.659	4.2	10-20

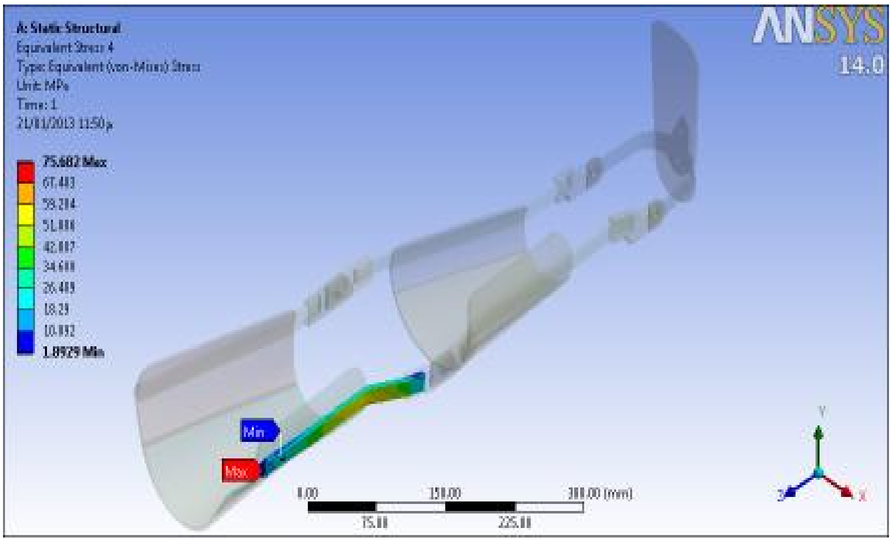

Fig.(9) : The Von-Misses stress due to loading boundary condition (IP) at bar contact with Gracilis muscle.

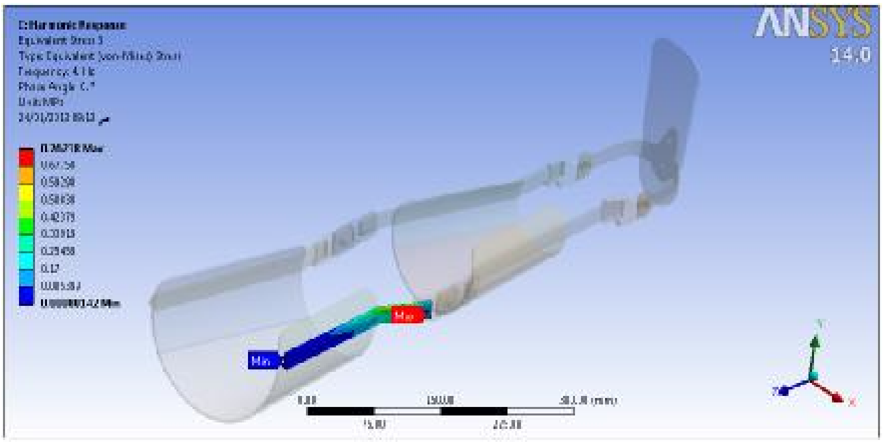

Fig.(10) : The Von-Misses stress due to harmonic body motion (acceleration) at bar contact with Gracilis muscle.

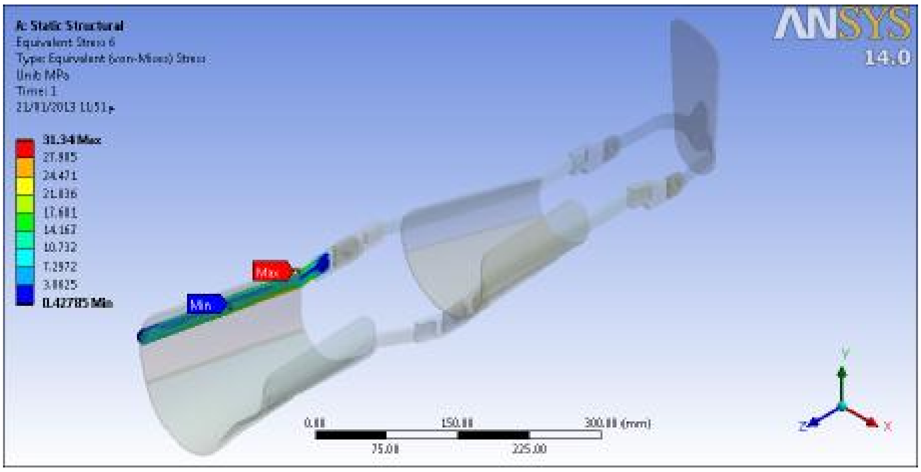

Fig.(11) : The Von-Misses stress due to loading boundary condition at bar contact with vastuslateralis muscle

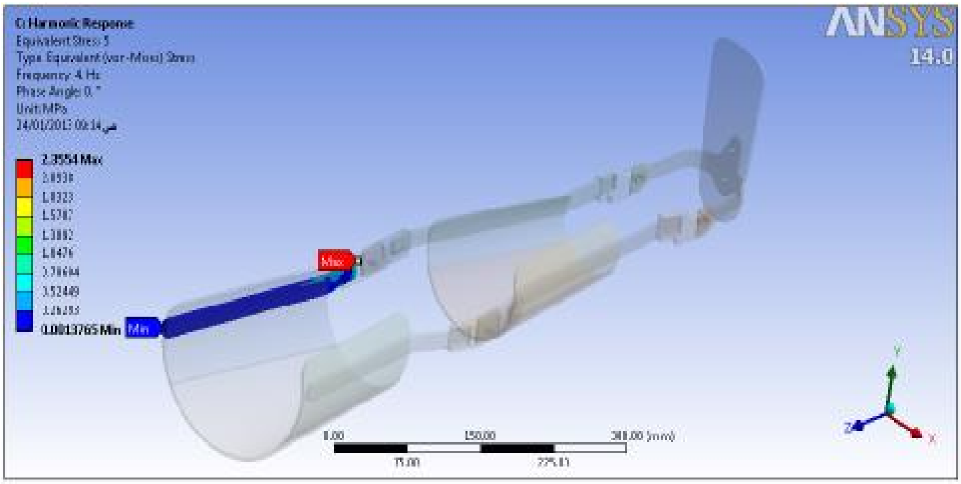

Fig.(12) The Von-Misses stress due to harmonic body motion (acceleration) at bar contact with vastuslateralis muscle.

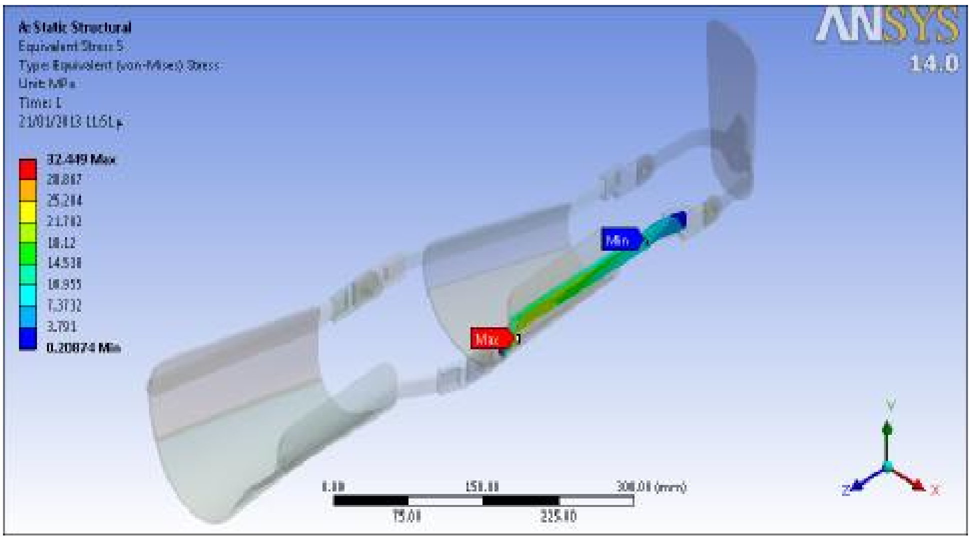

Fig.(13): The Von-Misses stress due to loading boundary condition (IP) at bar contact with soleus muscle.

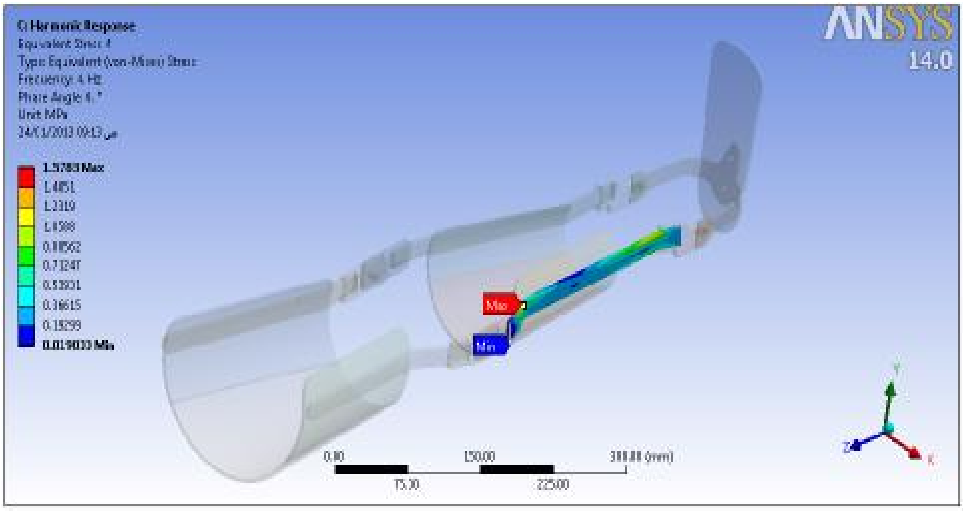

Fig.(14): The Von-Misses stress due to harmonic body motion (acceleration) at bar contact with soleus muscle.

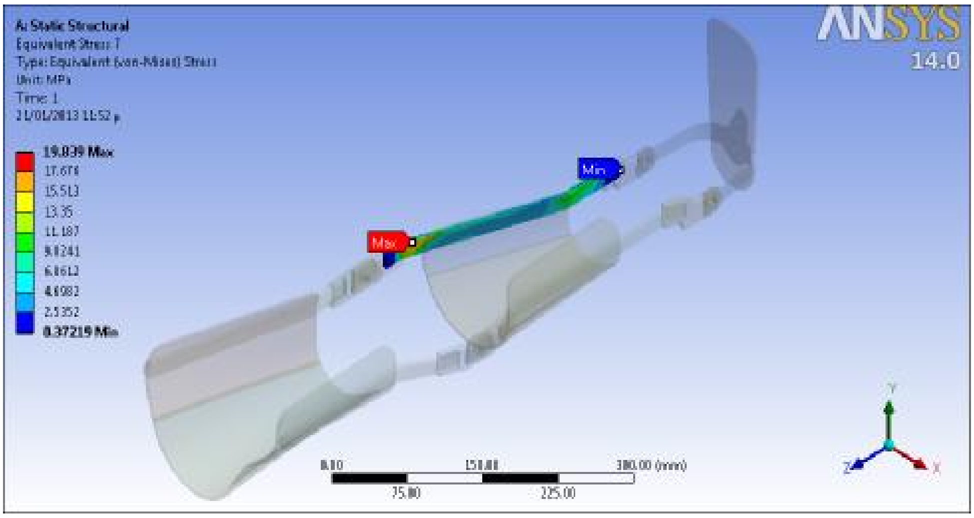

Fig.(15): The Von-Misses stress due to loading boundary condition (IP) at bar contact with peroneus longusmuscle

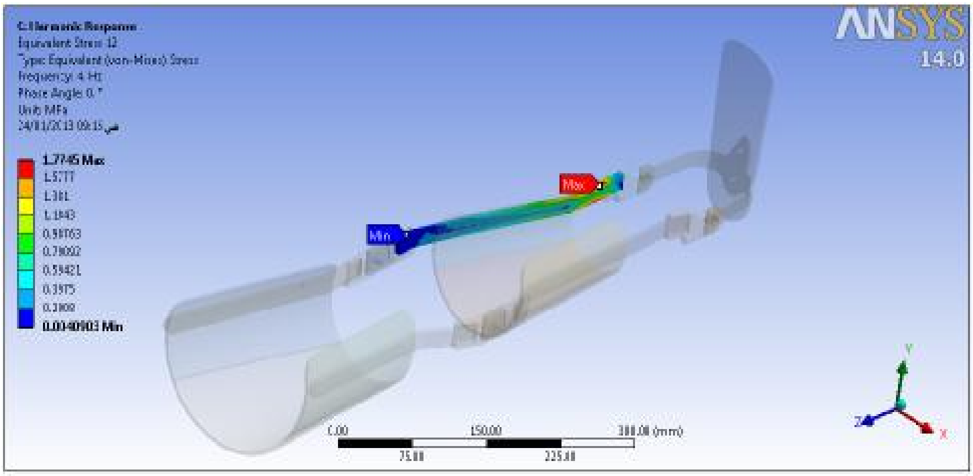

Fig.(16): The Von-Misses stress due to harmonic body motion (acceleration) at bar contact with peroneus longusmuscle

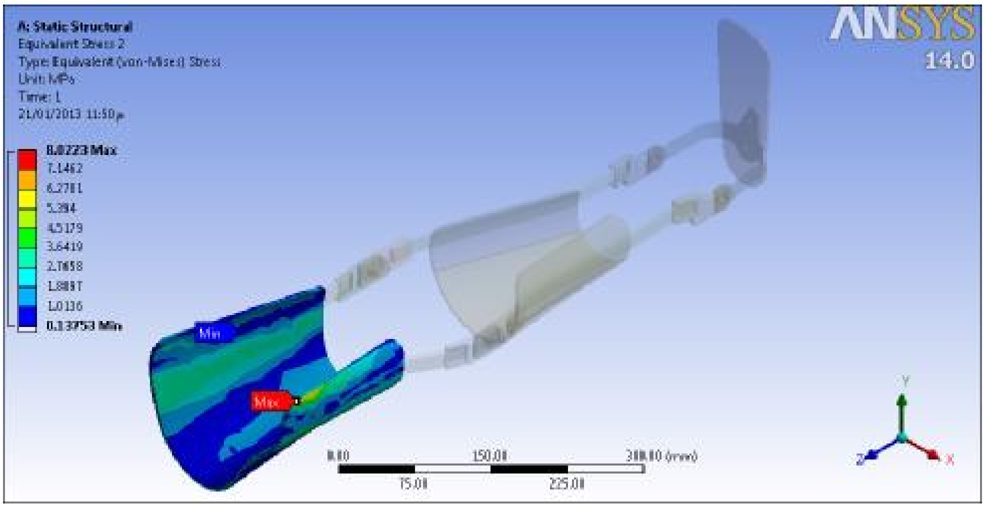

Fig .(17) : The Von-Misses stress due to loading boundary condition (IP) at thigh calf thigh contact with semitendinosus for KAFO

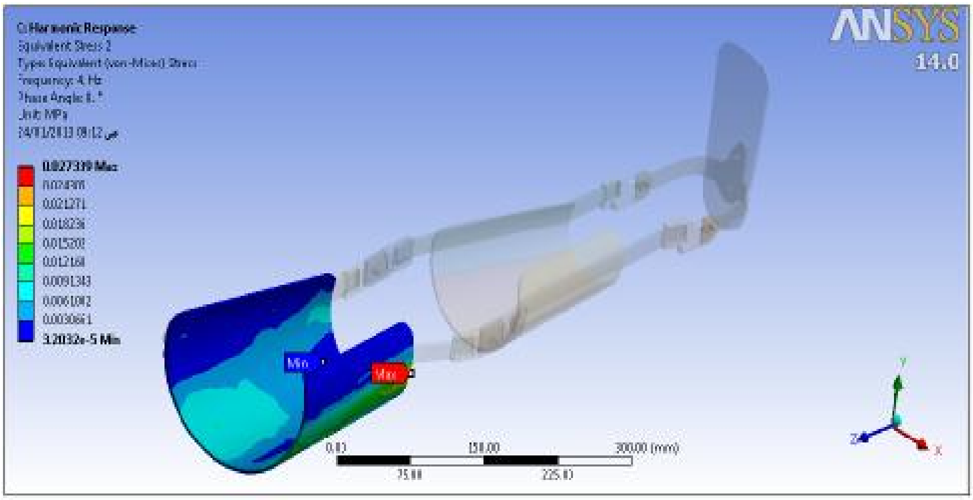

Fig.(18): The Von-Misses stress due to harmonic body motion (acceleration) at thigh calf contact with semitendinosus for KAFO

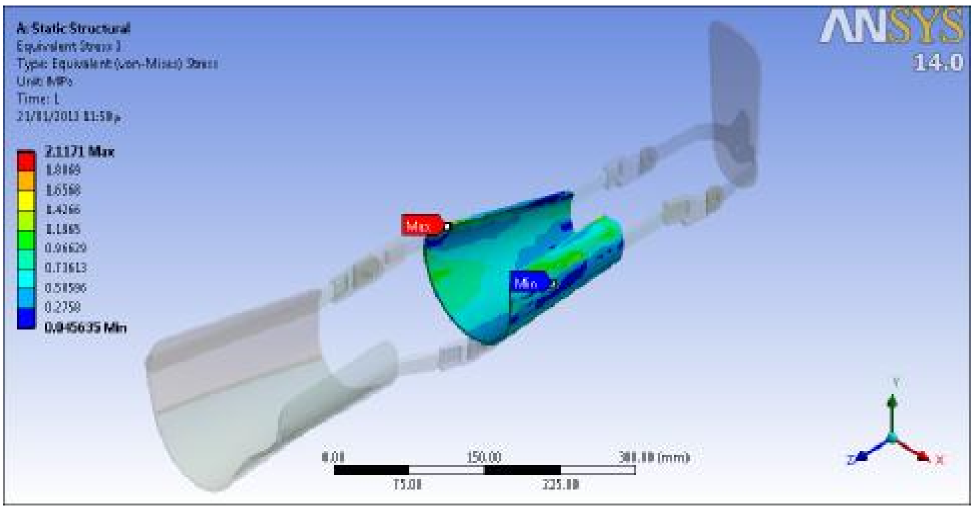

Fig.(19):The Von-Misses stress due to loading boundary condition (IP) at calf shank contact with gastrocnemius muscle for KAFO

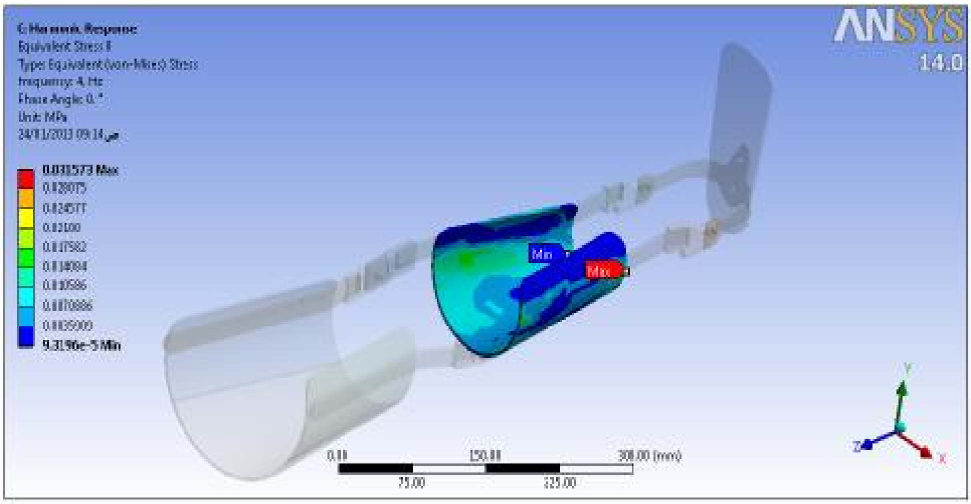

Fig.(20): The Von-Misses stress due to harmonic body motion (acceleration) at calf shank contact with gastrocnemius muscle for KAFO

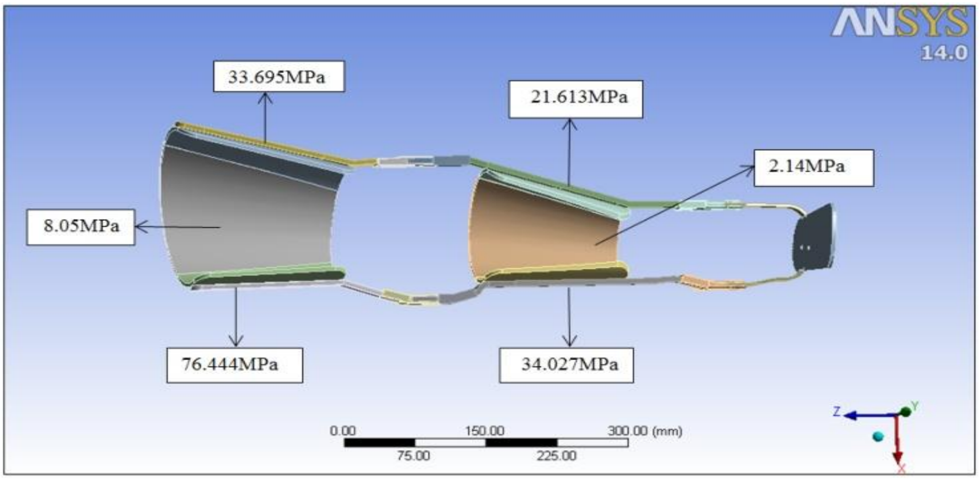

Fig.(21): Total stress result from applied pressure and acceleration on the model

10. Conclusion

1- The max value of interface pressure in KAFO upper calf was recorded at semitendinosus muscles with values of 60 Kpa While the max value of interface pressure in KAFO lower calf was recorded atgastrocnemius muscles with values of 55Kpa.
2- The level of stresses in the upper KAFO thigh calf is greater than the lower KAFO shank thigh due to the high activities of the thigh muscles in comparison to shank muscles.
3- The maximum stress in the KAFO which was calculated numerically recorded at the bar contact with Gracilis muscle for Knee Ankle Foot Orthosis Aluminum.

4- 4-Maximum value of frequency was recorded in knee joint with the value 5.995 Hz and maximum value of acceleration at knee joint about 8.589 m/s^2 due to patient wearing plastic KAFO have effective muscles.

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