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Frequency and Acceleration Measurement for the Above Knee Prosthetic Limb and its Comparison with the Healthy Limb

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Abstract

Comfort, stability, weightiness, stiffness, flexibility, toughness and cost are the most important goals during which all researchers try to reach. In this work, the first challenge is to design and manufacture vibration measurement system which consists of a shaker ,cam, motors, speed varitor and accelerometer. This system is used to measure displacement ,velocity ,acceleration and frequency in amputation joint in the whole body in the selected eleven points with four speed motor (500,600,700 and 800 rpm).The amputee case study is of age, weight, length and the residual amputee limb of 28 years, 75kg, 175cm and 38 cm respectively. The amputee lost his lower limb due to a car accident since 2002.

Results show that the value of acceleration and frequency increases when motor speed increases. While the acceleration and frequency decreases when accelerometer position from the shaking table increases . Moreover , the acceleration values for prosthetic limb will be more than of the healthy limb with percent of about (10.3,8.1,8.4,11.6,2.7,6.8)% for foot, ankle, leg, knee, thigh and hip respectively. While the acceleration values of artificial limb with liner are less than those of artificial limb without liner with (7.8,0.86,23.05,1.01,2.6 and 5.04)% for foot, ankle, leg, knee, thigh and hip respectively .Finally ,the frequency results show that the frequency values of the prosthetic limb will be more than of the healthy limb with percent of about (65.5,63.8,60.2,60,54.5,46.9)% for foot, ankle, leg, knee, thigh and hip respectively. Also the frequency values of the prosthetic limb with liner are less than of prosthetic limb without liner with (14.02,3.2,4.8.6.7,10.5and 9.3)% for foot, ankle, leg, knee, thigh and hip respectively.

Keywords: Prosthetic, amputation, artificial limb, above knee accelerometer,

قياس التردد والتعجيل في طرف صناعي لبتر فوق الركبة ومقارنتة مع الطرف السليم

الخلاصة

الراحة ,الاتزان ,الوزن ,المتانة,المرونة والكلفة هذة اهم الاهداف التي يحاول الباحثون الوصول اليها. في هذا العمل كان التحدي الاكبر هو تصميم وتصنيع منظومة لقياس التردد والتعجيل للطرف الصناعي لبتر فوق الركبة تلك المنظومة تالفت من منضدة اهتزازية,كامة,ماطور,منظم سرعة ومتحسس تعجيل بهدف قياس البيانات الاهتزازية لاربع سرع (800,700,600,500) دورة في الدقيقة لاحد عشر موقع تبعد من ارضية الاهتزاز صعودا للطرفين الصناعي والسليم لمعوق بترت ساقة اثناء حادث مروري منذ العام 2002 ,كتلة وطول وعمر وطول البتر للمعوق كانت 75 كيلو غرام , 175سم, 28 سنة و38 سم على التوالي.

النتائج اظهرت انة كلما زادت السرعة الدورانية لماطور الاهتزاز كلما زاد التعجيل والتردد لكل النقاط الاحد عشر التي تم تثبيت المتحسس فيها , بينما اظهرت النتائج انة كلما ابتعدنا من ارضية السطح الاهتزازي صعودا للطرف الصناعي والسليم كلما انخفضت قيم التعجيل والتردد .نتائج التعجيل اظهرت انة بمقارنة قيم التعجيل للطرف الصناعي نسبة للطرف السليم فان قيم التعجيل تزداد بنسب (10.3,8.1,8.4,11.6,2.7,6.8)% لكل من القدم,الكاحل,الساق, الركبة , الفخذ والورك على التوالي , بينما اظهرت المقارنة بين الطرف الصناعي بالبطانة المرنة مع الطرف الصناعي بدون بطانة مرنة فان التعجيل للطرف بالبطانة المرنة تكون اقل من نظيرتها في الطرف الصناعي بدون بطانة مرنة بنسب (7.8,0.86,23.05,1.01,2.6 and 5.04)% لكل من القدم,الكاحل,الساق, الركبة , الفخذ والورك على التوالي. واخيرا اظهرت نتائج التردد انة بمقارنة قيم التردد للطرف الصناعي نسبة للطرف السليم فان قيم التردد تزداد بنسب (65.5,63.8,60.2,60,54.5,46.9)% لكل من القدم,الكاحل,الساق, الركبة , الفخذ والورك على التوالي , بينما اظهرت المقارنة بين الطرف الصناعي بالبطانة المرنة مع الطرف الصناعي بدون بطانة مرنة فان التردد للطرف بالبطانة المرنة تكون اقل من نظيرتها في الطرف الصناعي بدون بطانة مرنة بنسب (14.02,3.2,4.8.6.7,10.5and 9.3)% لكل من القدم,الكاحل,الساق, الركبة , الفخذ والورك على التوالي.

Introduction

Leather straps for suspension ,an iron socket with leather inside, an iron knee, a shank and foot with iron cover and steel spiral spring to flex the footplate during stance was of the first modern prostheses for above knee prosthesis design by ambroise around 1560,it weighted about 7kg. Development over the centuries have drastically changed during which carbon fiber,nylon,perlon ,polypropylene and fiber glass were used in the above knee prosthetic lamination with total weight less than 3Kg[1].The percentage of the above knee amputation (transfemoral) forms about 31% from the total percentage of the amputation in the world[2].The Gait cycle is defined as heel strike to heel strike of the same foot while walking .The two main phases of the gait cycle are the stance phase(62%)and swing phase(38%)[3],[4].In general ,prostheses for individuals with above knee amputation are comprised of four major components specifically :socket interface to the residual limb, a knee joint ma shank and foot-ankle assembly [5].

Accelerometers are used to specify the vibration data for the vibrating bodies ; the accelerometers are fixed to the body In the conventional method of vibration measurement, and the amplitude of vibration is obtained after signal processing [6]. In this method , there is a systemic error due to the contact-type of measurements. The main advantage of this method is its ability to be started by a simple user familiar hardware with no external device

attached to the subject and also a user-friendly-software. While dealing with the effects of vibration on humans , it is essential to study the physical characteristics of the body. The effect on body due to vibrations is mechanical, physiological & subjective responses. It also affects the human's performance .

Von Gierke [7] found out that the natural frequency of the abdomen system of a human is between 3 and 4 Hz and the resonance occurs between 18 and 25 Hz. Therefore maximum effect and maximum damage occur at different vibration frequencies . In determining the effects of shock and vibration on humans, the mechanical force environment ,to which the human body is exposed , must be clearly defined. Force and vibration amplitudes should be specified for the area of contact with the body. Vibration measurements of the body's response should be made whenever possible by noncontact methods. X-ray methods can be used successfully to measure the displacement of internal organs. Optical, cinematographic, and stroboscopic observation can give the displacement amplitudes of parts of the body. Misheal Griffin and etl [8] used high-performance (electrical power, 60 kW) servo-controlled electromagnetic vibrator Dynamic Systems equipped with a rigid expander and handrails (for safety)to find the frequency and amplitude of the vibration part of human . Juha Kiiski[9] studied the whole body vibration introduced to the body over a wide range of vibration amplitudes (from 0.05 to 3 mm) and frequencies (from 10 to 90 Hz),he found out that the very ranges of amplitudes and frequencies pertinent both to clinical studies and to commercial vibration devices. Because the vibration-induced accelerations can augment at frequencies <20 Hz because of body segment resonances, amplitudes and frequencies that together could substantially amplify the acceleration and create a potential hazard for fragile skeleton. Monica mikhael and etl[10] used a speed motor controller to vibrate at a frequency of 12 Hz. This frequency setting was achieved by attaching a spring-loaded potentiometer underneath the platform base and measuring the vibration rate. The amplitude of the vibration was determined by the size of the cam fitted to the motor shaft. All participants stood on the vibration platform with their feet shoulder-width apart, hands by their sides, and wore tandardized thick cotton socks to prevent any dampening that might result from footwear

Katu U.S., Desavale R.G. and Kanai R.A. [11]studied the vehicle vibration analysis. For this analysis , it was proposed to perform vibration tests for different vehicle models. Vibration data for each model at three different road and speed conditions were taken by using Fast Fourier Transform (FFT). People are most sensitive for vertical vibrations between 5 & 16 Hz & to the lateral vibration between about 1 & 2 Hz. Women are more sensitive than mens to vertical vibration above about 10 Hz. Most responses of seated subjects implicated the lower abdomen at 2 Hz moving up to body at 4 & 8 Hz, with most responses implicating head at 16 Hz. At 32 Hz the responses are divided between the head & lower abdomen.

There is limited reliable information about the effects of shock and vibration forces on the amputee human body. This work studies the frequency and acceleration which will be measured at foot ,leg, knee, hip, abdomen, chest, nick and head in the above knee prosthetic

lower limb amputation .Also a comparison of the vibration data between healthy and amputee leg will be achieved .

Experimental Work

The idea of measuring the vibration in the above knee prosthetic lower limb is based namely on design and manufacturing new vibration measurement system which consists of shaker ,cam, motors, speed varitor and accelerometer as shown in Fig.(1). The suggested vibration measurement system was used to measure vibration in the above knee amputation as a case study .The amputee is of age, weight, length and the residual amputee limb of 28 years,75kg,175cm and 38 cm respectively. The amputee lost his lower limb due to a car accident since 2002 .

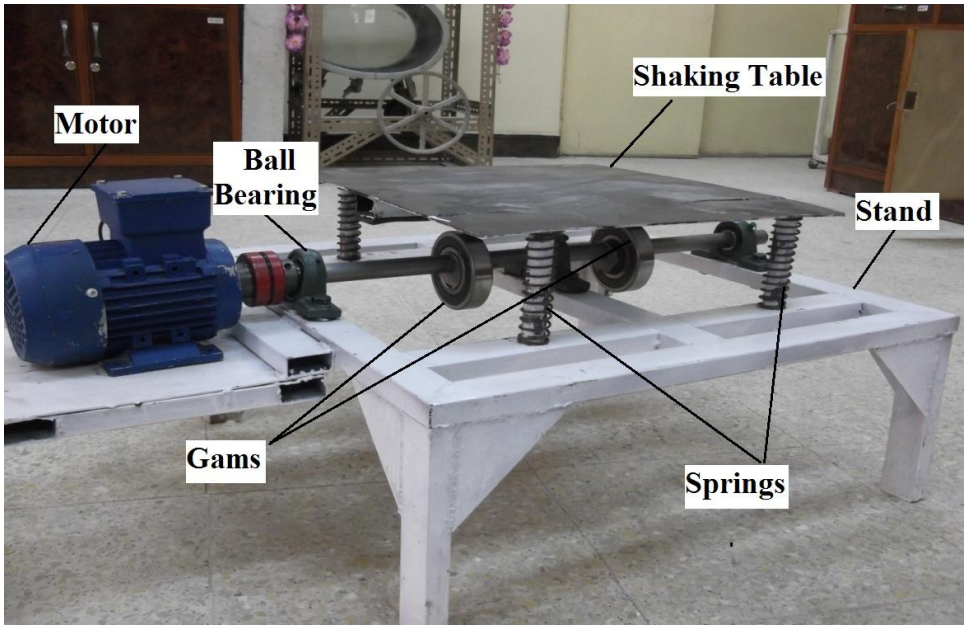


Fig . (1) The Shaking Table with all its parts

Experimental Procedure

The idea of the vibration measurement system was plate accelerated vertically up and down by the cam mechanism with different velocities during which the amputee was stand on the table as shown in fig.(2) .

The accelerometer is firmly fixed on different points on the prosthetic and healthy parts of body fig.(3) . The data transmitted to a computer through USB interface and a special program (EI-Calc- Erbessd instruments ®) used to get various parameters such as (acceleration, velocity ,displacement and frequency) at each point .

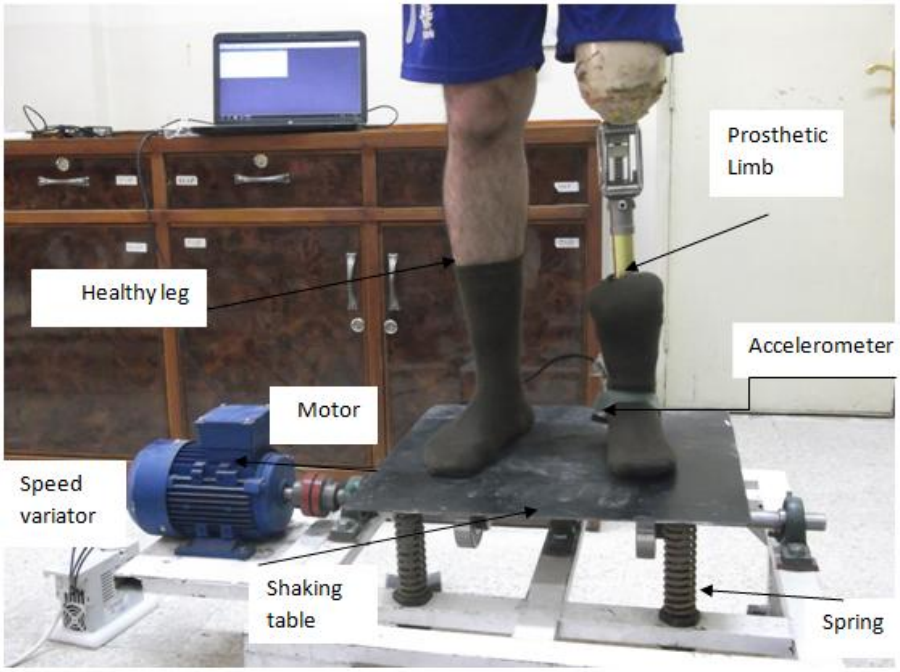


Fig.(2)The vibration measurement system used with The A-K amputee

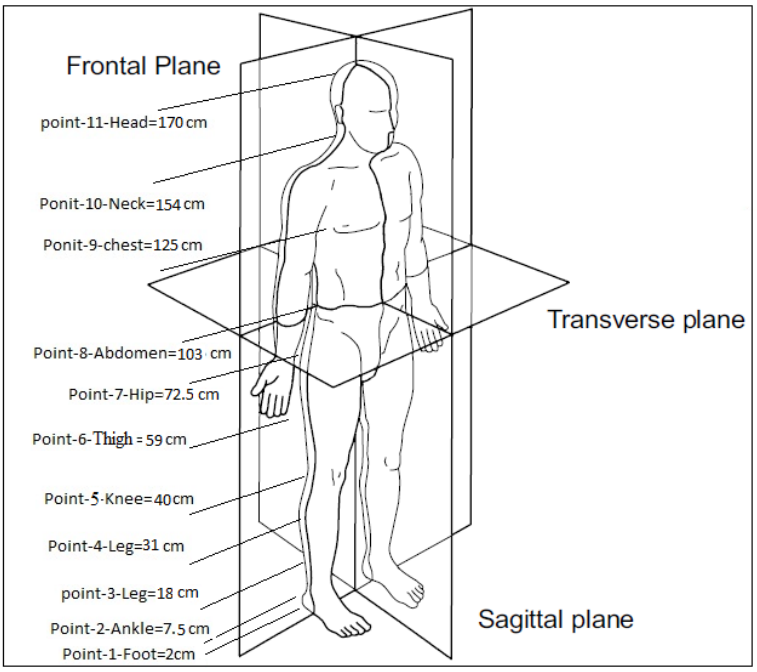


Fig.(3) Accelerometer Points positions along Human body

Results and discussions

The vibration data which are acceleration, velocity, displacement and frequency are measured with four speed motor (500,600,700 and 800 rpm) for patient who lost his leg due to a car accident since 2002 . The vibration data was measured for the healthy limb and then for the prosthetic limb and finally for the prosthetic limb without liner. Each point was measured five times for 10 minutes and the mean was taken. Acceleration ,velocity ,displacement and frequency result are recorded in table 1, table 2 ,Fig.(5) and Fig.(6) .These results show that the value of acceleration and frequency increased with the increasing of rotating speed of the motor .It happens due to the increasing of the reciprocating of cam with the increasing of the speed of the rotating motor. The results also show that as the sensor point height increased from the shaking table , the acceleration and frequency decreases .The reason behind this behavior is that , when the sensor position height increased ,this mean the distance from the excitation source increased and then the frequency and acceleration decreased. In addition to that the muscles and fat may function as a damper reducing the frequency and acceleration. The Results show that the acceleration for prosthetic limb will be more than of the healthy limb with percent of (10.3,8.1,8.4,11.6,2.7,6.8)% for foot, ankle, leg, knee, thigh and hip respectively. The comparison of the acceleration values between the prosthetic limb with liner with those of the prosthetic limb without liner shows that the acceleration value of the artificial limb with liner will be less with percent of (7.8,0.86,23.05,1.01,2.6 and 5.04)% for foot, ankle, leg, knee, thigh and hip respectively . While the frequency results show that the values of frequency for prosthetic limb will be more than of the healthy limb with percent of (65.5,63.8,60.2,60,54.5,46.9)% for foot, ankle, leg, knee, thigh and hip respectively. Finally, the comparison between prosthetic limb with liner with the prosthetic limb without liner shows that the frequency value of artificial limb with liner will be less with percent of (14.02,3.2,4.8.6.7,10.5and 9.3)% for foot, ankle, leg, knee, thigh and hip respectively.

Table (1) Vibration data for the healthy and prosthetic limbs

Point	Distance cm	Status	Speed RPM	RMS Acceleration amplitude(m/s^2)	RMS Velocity amplitude (mm/s)	RMS Displacement Amplitude mm
Foot	2	With amputation	500	4.69	24.67	0.3
			600	6.71	30.76	0.36
			700	7.46	47.15	0.58
			800	9.57	55.8	0.68
		Without liner	500	5.1	26.1	0.41
			600	6.98	33.01	.49
			700	9.1	50.09	0.62
			800	10.32	63.72	0.73
		healthy	500	4.56	26.43	0.34
			600	6.43	34.6	0.43
			700	7.58	43.3	0.55
			800	8.58	44.86	0.58
Ankle	7.5	With amputation	500	3.94	32.6	0.43
			600	5.66	43.3	0.55
			700	6.54	49.05	0.57
			800	7.17	51.1	0.59
		Without liner	500	4	25.8	0.32
			600	5.86	32.1	0.3
			700	6.96	41.4	0.4
			800	7.23	47.12	0.39
		Healthy	500	3.68	30.7	0.39
			600	4.73	42.14	0.52
			700	5.75	54.2	0.66
			800	6.59	53.5	0.68
Leg-1-	18	With amputation	500	3.8	28.61	0.36
			600	5.48	41.8	0.51
			700	6.86	48.4	0.58
			800	8.2	54.8	0.67
		Without liner	500	4.8	26.1	0.44
			600	6.48	38.3	0.49
			700	8.96	42.7	0.66
			800	10.09	58.5	0.57
		Healthy	500	3.14	39.98	0.46
			600	5.199	53.9	0.65
			700	6.306	62.9	0.83
			800	7.509	49.1	0.56
Leg-2-	31	With amputation	500	3.48	29.39	0.37
			600	5.17	40.02	0.51
			700	6.2	44.56	0.54

			800	7.5	49.1	0.58
		Without liner	500	3.51	24.68	0.31
			600	5.71	34.15	0.41
			700	6.82	42.39	0.5
			800	7.84	48.3	0.6
		Healthy	500	3.2	5.68	0.6
			600	4.96	7.8	0.99
			700	5.67	43.11	1.14
			800	6.27	96.4	1.25
knee	40	With amputation	500	3.86	27.9	0.35
			600	5.45	38.85	0.49
			700	6.99	48.54	0.57
			800	7.95	52.56	0.63
		Without liner	500	3.94	29.28	0.36
			600	5.96	37.1	0.43
			700	7.02	47.65	0.5
			800	8.03	51.78	0.63
		Healthy	500	3.08	32.7	0.43
			600	4.84	54.76	0.7
			700	6.99	76.57	1.0
			800	6.67	83.81	1.21
Thigh -1-	59	With amputation	500	4	29.65	0.37
			600	5.5	39.24	0.47
			700	7.13	122.9	1.73
			800	8.42	55.48	0.68
		Without liner	500	4.9	31.5	0.32
			600	5.69	37.75	0.45
			700	7.23	46.8	0.56
			800	8.64	52.6	0.69
		Healthy	500	3.86	59.2	0.8
			600	5.38	77.5	1
			700	6.133	122.9	1.73
			800	8.19	159.7	2.33
Hip-2-	72.5	With amputation	500	4.15	29.16	0.36
			600	5.85	38.61	0.48
			700	7.02	48.73	0.56
			800	8.33	57.23	0.69
		Without liner	500	4.48	25.62	0.36
			600	5.9	37.24	0.48
			700	7.25	48.73	0.56
			800	8.75	57.23	0.69
		Healthy	500	3.45	54.9	0.75
			600	4.85	38.61	0.41
			700	6.43	93.07	1.29
			800	7.76	128.27	1.82
Abdomen	103	500		2.36	28.93	0.3
		600		4.02	51.97	0.69
		700		6.03	82.4	1.16
		800		5.71	78.66	1.13
Chest	125	500		2.99	31.48	0.36
		600		3.3	41.1	0.53
		700		2.94	36.9	0.5

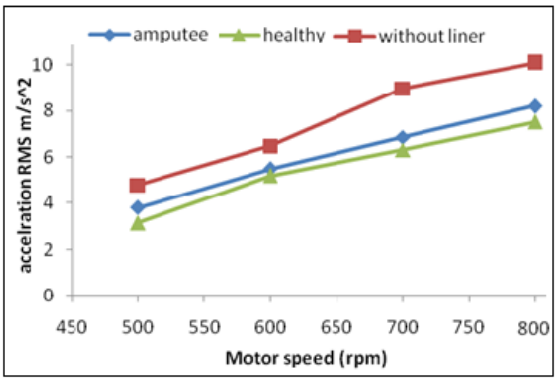
		800	2.96	37.47	0.52
neck	154	500	2.83	31.4	0.41
		600	4.77	58.7	0.78
		700	5.11	62.8	0.8
		800	5.78	71.03	0.94
head	170	500	2.445	27.86	0.37
		600	4.53	54.5	0.71
		700	5.36	64.84	0.82
		800	4.8	59.87	0.8

Table(2) Frequency for the healthy and prosthetic limbs

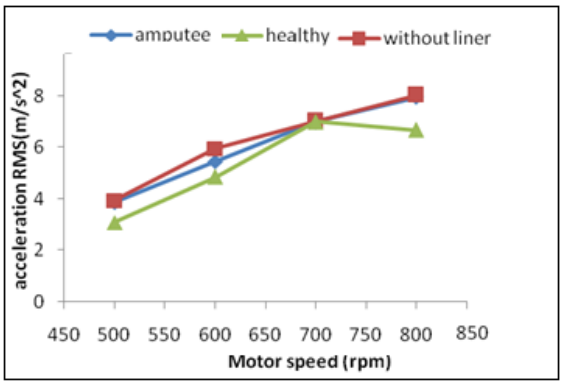
Point		Speed RPM	Frequency
Foot	With amputation	500	28.97
		600	34.04
		700	44.95
		800	51.41
	Without liner	500	30.1
		600	36.1
		700	49.32
		800	58.63
	Healthy	500	7.37
		600	9.08
		700	15.15
		800	15.75
Ankle	With amputation	500	22.1
		600	30.3
		700	37.2
		800	40.4
	Without liner	500	26.01
		600	28.7
		700	36.4
		800	39.1
	Healthy	500	7.01
		600	8.9
		700	14.1
		800	14.6
Leg1	With amputation	500	20.3
		600	27.4
		700	33.3
		800	35.4

Point		Speed RPM	Frequency
	Without liner	500	24
		600	27.9
		700	34.4
		800	37.1
	Healthy	500	6.8
		600	8.9
		700	13.2
		800	14.1
Leg2	With amputation	500	18.9
		600	24.3
		700	30.2
		800	32
	Without liner	500	21
		600	27
		700	33.4
		800	35.01
	Healthy	500	6.2
		600	8.1
		700	12.7
		800	13.4
Knee	With amputation	500	18
		600	23.1
		700	29.2
		800	31
	Without liner	500	20.1
		600	25.3
		700	32.1
		800	33.1
	Healthy	500	5.9
		600	8.1
		700	11.9
		800	12.4
Thigh	With amputation	500	13
		600	20.2
		700	22.08
		800	26.6
	Without liner	500	15.3
		600	23.5

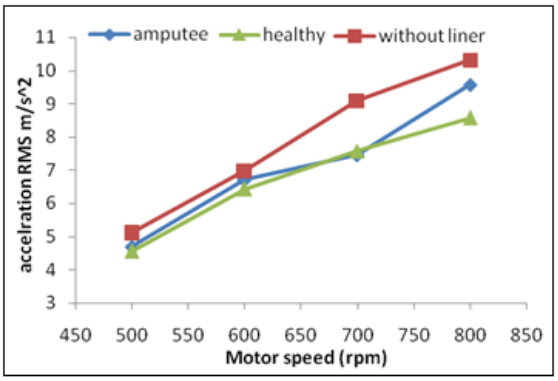
Point		Speed RPM	Frequency
		700	27.1
		800	29.3
	Healthy	500	6.01
		600	7.4
		700	11.2
		800	12.1
Hip 2	With amputation	500	12
		600	18.6
		700	19.2
		800	21.5
	Without liner	500	13.3
		600	19.7
		700	22.1
		800	23.5
	Healthy	500	5.7
		600	6.4
		700	10.01
		800	11.4
Abdomen		500	5.32
		600	6.1
		700	8.93
		800	10.22
Chest		500	4.8
		600	5.6
		700	8.05
		800	9.64
neck		500	4.2
		600	4.9
		700	6.54
		800	7.1
head		500	3.63
		600	4.34
		700	5.25
		800	5.45



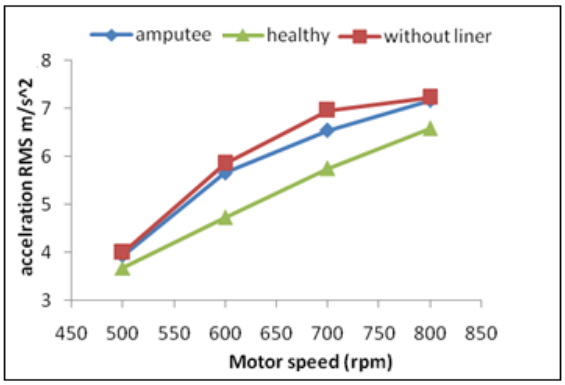
a) At point 1 foot



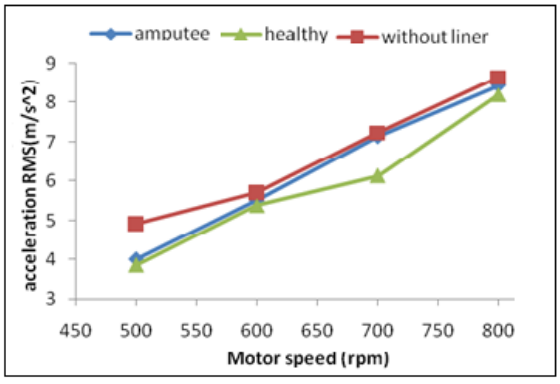
b) At point 2 Ankle



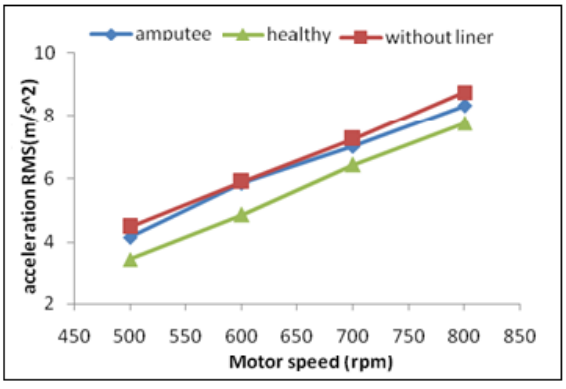
c)At point 3 leg 1



d)At point 5 Knee

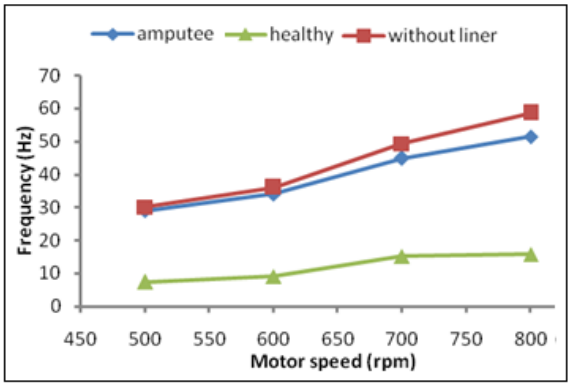


e)At point 6 Thigh

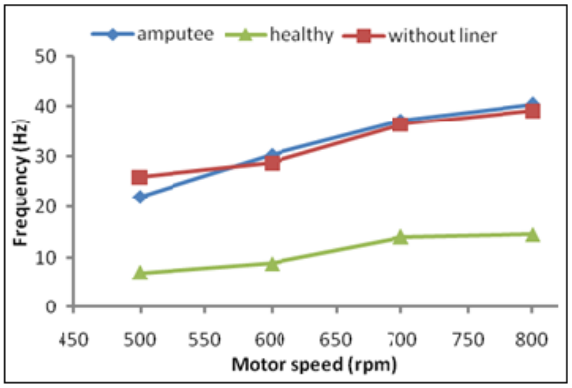


f) At point 7 Hip

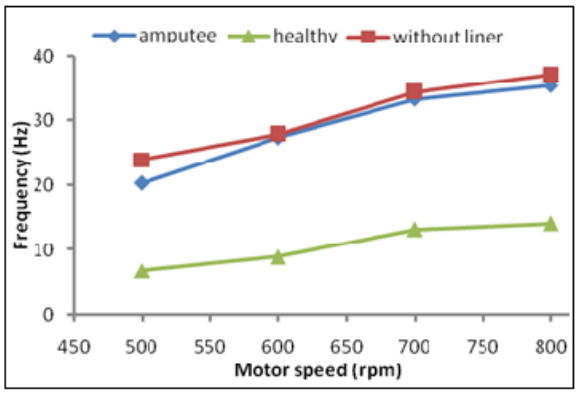
Fig.(5) Accelration vs motor speed at different sensor positions



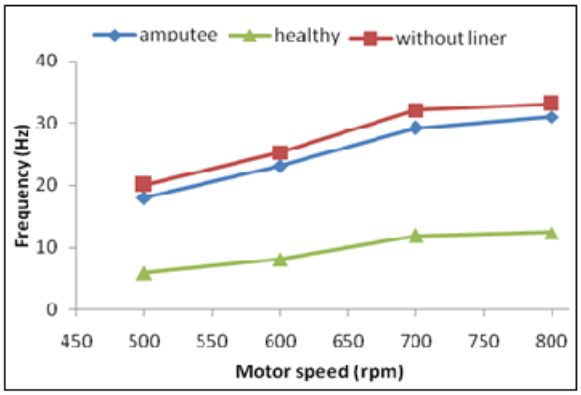
a)At point 1 foot



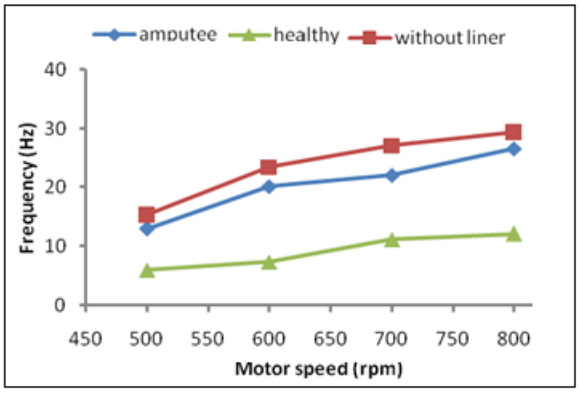
b) At point 2 Ankle



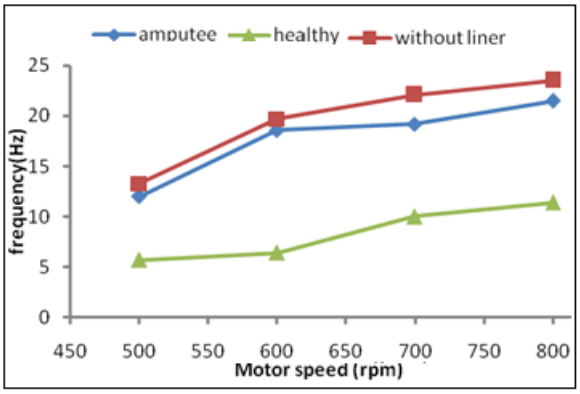
c)At point 3 leg 1



d) At point 5 Knee



e)At point 6 Thigh



f) At point 7 Hip

Fig.(6) Frequency vs motor speed at different sensor positions

Conclusions

1- The value of acceleration and frequency increase when the speed of the motor increases.
2- The acceleration values for prosthetic limb will be more than of the healthy limb with percent of (10.3,8.1,8.4,11.6,2.7,6.8)% for foot, ankle, leg, knee, thigh and hip respectively due to damping effects of the muscles in the healthy limb.
3- The acceleration values of artificial limb with liner is less than of artificial limb without liner with percent of (7.8,0.86,23.05,1.01,2.6 and 5.04)% for foot, ankle, leg, knee, thigh and hip respectively due to damping effects in the liner
4- The frequency values of the prosthetic limb will be more than of the healthy limb with percent of (65.5,63.8,60.2,60,54.5,46.9)% for foot, ankle, leg, knee, thigh and hip respectively due to damping effects of the muscles in the healthy limb.
5- The frequency values of the prosthetic limb with liner is less than of prosthetic limb without liner with percent of (14.02,3.2,4.8.6.7,10.5and 9.3)% for foot, ankle, leg, knee, thigh and hip respectively due to damping effects in the liner.

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