The Static Analysis of Wearable Lower Extremity Exoskeleton Based on ANSYS Workbench

Li Mei-cheng
College of Mechanical and Electric Engineering
Changchun University of Science and Technology
ChangChun，China
252645480@qq.com
WANG Li-rong
College of Electronic and Information Engineering
Changchun University
ChangChun，China
CHEN Dai-min
College of Machinery and Vehicle Engineering
Changchun University
ChangChun，China
TAO Jing-jing,CHEN Dong
College of Electronic and Information Engineering
Changchun University of Science and Technology
ChangChun，China

***Abstract*—The new type wearable lower extremity exoskeleton was designed using anthropomorphic mechanical, according to the human walking postures, the static analysis was does on the exoskeleton under different postures, and the stress values was obtained. So the optimize the analysis of external skeletal structure was been, the foundation of study the wearable lower extremity was laid for the further.**

Keywords—Wearable lower extremity exoskeleton; ANSYS Workbench Static analysis; SolidWorks

I. PREFACE

The wearable exoskeleton robot is a wearable man-machine integration of intelligent mechanical devices. It's combined by human intelligence, robotics and "physical" organic, in order to improve exercise capacity of specific parts of the human body, enhance limb function,and complete activities that people cannot do it alone[1].It can do the rehabilitation of training on the lower disability limb and compensates the residual,weak,frail and elderly people effectively.The study of wearable exoskeleton research was first appeared in the USA,and Japan followed.The representative wearable exoskeleton of alien is BLEEX(Berkeley Lower Extremity Exoskeleton), HAL (Hybrid Assistive Leg) and Rex (Robotic Exoskeleton).In domestic,ZheJiang University and Institute of Intelligent Machines,Chinese Academy of Sciences have developed the wearable walking assist robot of prototype[2].All the research in domestic and abroad have some defects as following:

(1)The size of wearable exoskeleton robot is not adjustable ,so the robot cannot be widely used in various types of patients;

(2)The initiative joints are driven by cylinder ,because of the stroke length of the cylinder affects the exoskeleton joint motion range, The lower limbs do not get rehabilitation training efficiently and adequately;

(3)All the degrees of freedom of the lower extremity exoskeleton are not enough,and the lower extremity exoskeleton only can move in the two-dimensional plane.

Exoskeleton is worn outside of the human body, any "irrational" action of the exoskeleton could injure the wearer seriously,guaranting the user safety is particularly important for the rehabilitation exoskeleton[3].Therefore, the exoskeleton should have high strength, toughness, fatigue strength and security. In this paper, one new exoskeleton is designed with the anthropomorphic design method. This new exoskeleton has three characteristics:first,its size is adjustablely;second,the joints are drived by the motor directly;third,the degrees of freedom of the lower extremity exoskeleton are same to the human's leg.The lower limbs can be the rehabilitation trained comprehensivly, efficiently, fully and be moved in the three-dimensional plane. The exoskeleton is analysed in static,the result of the static analysis is ready for its mechanical structure optimization design and the data is provided for the transient dynamic analysis.

II. CONSTRUCT THE THREE-DIMENSIONAL MODEL AND SELECT THE POSE FOR STATIC ANALYSIS

A. Three-dimensional model of the wearable lower extremity exoskeleton

As a result of the actual situation of the human body and the use of actual demand, the wearable exoskeleton mechanical structure is devised by the anthropomorphic mechanical design.The anthropomorphic mechanical design is based on the body,the design of institutional space configuration is based on the human body.The institutions are moved by the human body, presented the same space motion with the human body.So the space character is specific to the hunman body,and its motion compatible for the human body.This mechanism is based on the human body,the movement of human nature as a reference,it reflects the body's natural motion,this design method is greatly difficult,but it can fully guarantee that the wearable exoskeleton is coordinated with the man-machine movement and worn comfortably[4].According to the China Youth average basic physical member of the human body , the size of exoskeleton was designed,the exoskeleton structure is shown in Figure1.The exoskeleton system includes four parts,such as the portion of weight-bearing,the hip part,the knee joint part,the ankle and the sensing part on the foot.When the exoskeleton is designed,the adduction/abduce is putted in the human body after the waist back,the pronation/supination and the antexion/extension are connected at the human hip;at the knee, there are two degrees of freedom: the

978-0-7695-5159-3/13 $31.00 © 2013 IEEE
DOI 10.1109/MSN.2013.104

pronation/supination and the antexion/extension;at the ankle, there are pronation/supination and the antexion/extension,the adduction/abduce three degrees of freedom,the antexion/extension are actived joints,the rest are passive joints.The actived joints are drived by the stepper motor,that executed the drive function of the joints.

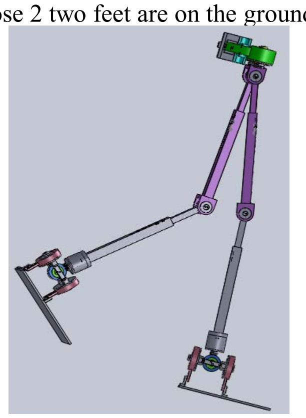
Figure 1 The framework of the exoskeleton

B. Select the pose of the exoskeleton for static analysis

The normal human lower limb is regularly landed and lift,it can be regarded as a periodic move about the left and right leg.The periodicity swing can be divided into some stages:the double legs are supported, the left leg is supported, the double legs are supported,and then the right leg ia supported.Standing on two legs with weight-bearing accounts for the entire cycle is 27%,standing on single leg with weight-bearing accounts for the entire cycle is 67%,so standing on two legs or on one leg is the most dangerous state of the exoskeleton.Standing on one foot,on two feet, one foot support and one foot is redundance are three analysis positions[5],Three positions are shown in Figure 2.In Figure 2(a) represents that a single foot support: Left foot stands on the ground, the right foot is forward,the body center of gravity is on the left, the weight of the human body are loaded in the left external exoskeleton;Figure 2 (b) represents that the two legs are supported:two feet stand on the ground at the same time, the body center of gravity are back to its original position,the body weight is average loaded on the left and right side of the exoskeleton;Figure2(c) represents that a foot redundancy and a foot is touched the ground:the right foot is on the ground and the left foot’s tip is touched the ground,most of the body weight is loaded on the right of the exoskeleton,a little part of weight is loaded on the left.

(a)Pose 1 the left foot is on the ground

(b)Pose 2 two feet are on the ground



(c)Pose 3 the right foot is on the ground,the left foot’s tip is touched the ground

Figure 2 Three positions

III. THE EXOSKELETON LINEAR STATIC STRUCTURAL ANALYSIS

A. Select the material and meshing

A. Select the material

The material of the wearable lower extremity exoskeleton mechanical structure is aluminium alloy,the modulus of elasticity is 7.2×1010Pa,the Poisson Ratio of the aluminium alloy is 0.33,the density of it is 2700kg/m^3.

Identify applicable sponsor/s here. If no sponsors, delete this text box (*sponsors*).

B. Meshing

Meshing is the most important step of the finite element simulation analysis[6], the Automatic meshing method is used in this paper.This method has no special requirements about the entity model shape,any geometric model,even then the irregular geometric model,all can be meshed.Comparated with some complex geometry model,this method saves time and are effortly.The grid resolution is 8mm,the exoskeleton assembly contact is custom contacting.The result of meshing is shown in Figure 3.

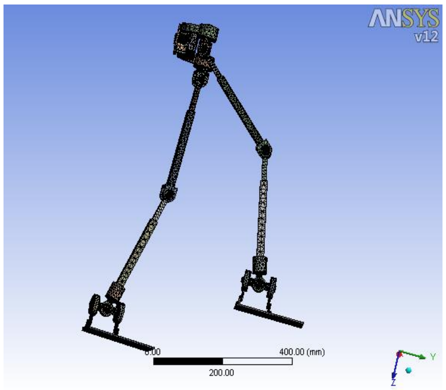
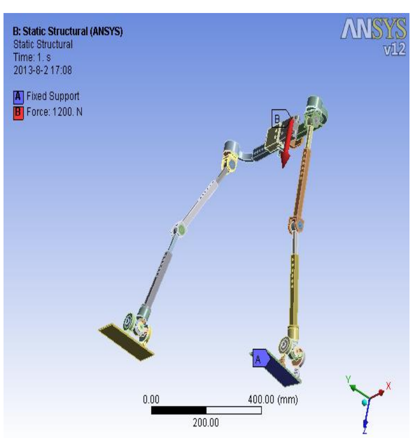


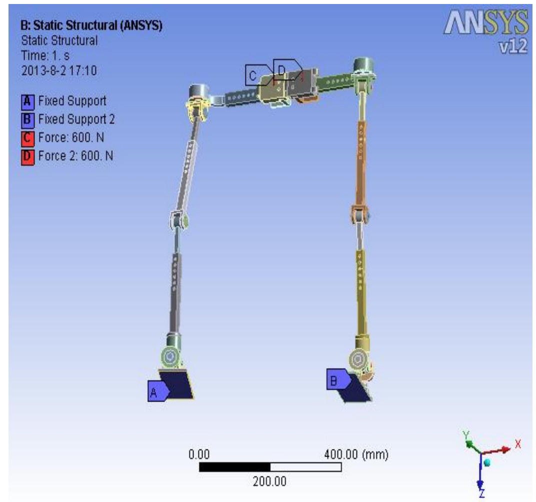
Figure 3 The exoskeleton grid graph

C. Applied the constraint and load

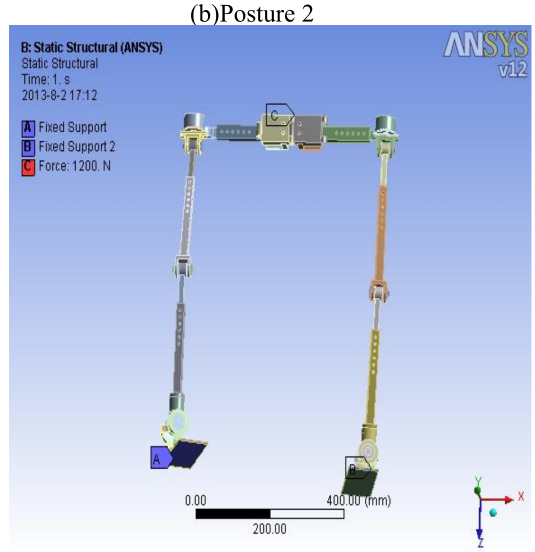
Exoskeleton is worn outside the human body,and beared the load of itself and the human body.Therefore, the design bearing capacity of the exoskeleton is 120Kg(including the weight of the back frame,battery,motor and other object),so, the force of 1200N is applied on the model in the Z direction.The constraint and the style of load applied method as shown in Figure 4,Figure 4(a)presents that the constraints of UX,UY,UZ are applied on the left foot in the posture 1,and the force of 1200N is applied on the left back in the direction of Z;Figure 4 (b) presents that the constraints of UX,UY,UZ are applied on both feet in the posture 2,and the force is loaded in the back middle;Figure 4(c)expresses that the constraints of UX,UY,UZ are loaded on the right foot,the point constraint is loaded on the left foot toe,and the force is loaded on the right back.



(a)Posture 1



(b)Posture 2



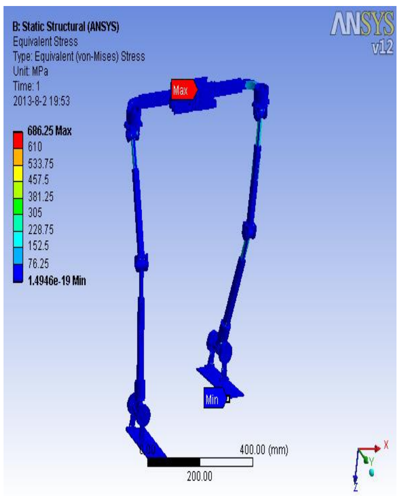
(c)Posture 3

Figure 4 The constraints and load in all the postures

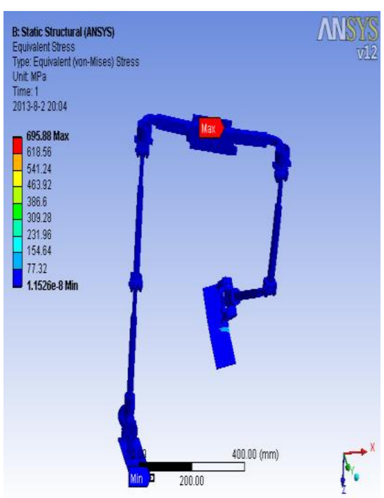
D. Simulation and analysis

After the constraints and load are applied down, and then do the simulation and analysis ,and the stress diagram is obtained,and those are shown in Figure 5.Figure 5 (a) shows that in posture 1,the max stress is 1330.1MP ,and it is in the back frame on the right,the value is greater than the material allowable stress value;Figure 5(b) expresses that in posture 2,the max stress is 686.25MP,and it is on the hip rotation axis of the left back,the value is greater than the material allowable stress value;Figure 5(c) shows that in posture 3,the max stress is 695.88MP,and it is on the hip rotation axis of the left back,its value is also greater than the material allowable stress.

(a)Posture 1



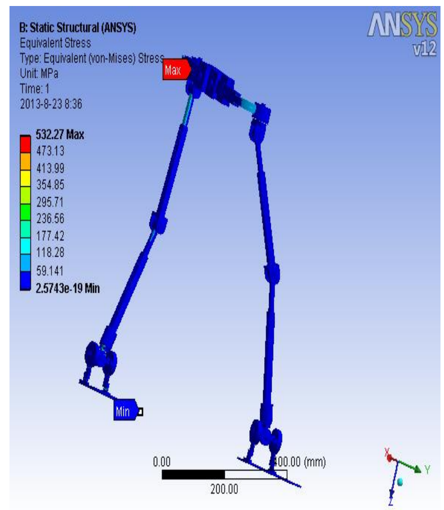
(b)Posture 2



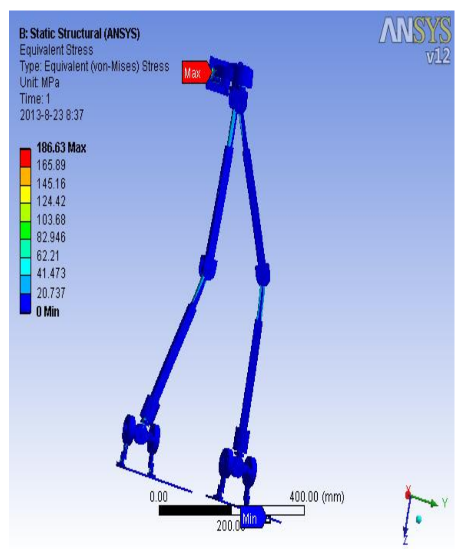
(c)Posture 3

Figure 5 The simulation diagram in all the postures

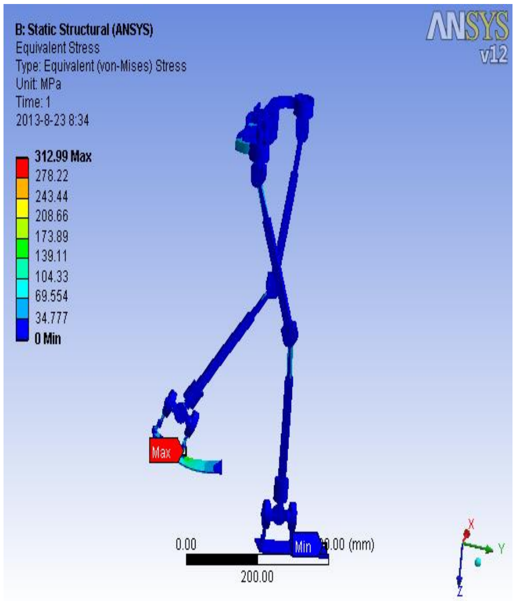
Through the simulation analysis,each maximum stress in each posture are all appeared on the back bracket,all the values are greater than the aluminum alloy allowable stress value([δs]=570MP),the results shows that the structure is fail to meet design requirements.Thus,some of the smaller size of the positioning hole,angle of chamfer,chamfering and others are optimized,then the simulation analysis is done again,the optimized result is shown in Figure 6.From Figure 6(a) it can be seen that the maximum value is 532.27MP,it is on the left hip beam,and it is smaller than the material allowable stress after the optimized;Figure 6(b) presents that the maximum value is 186.63MP,it is on the on the hip rotation axis of the left back,the value is smaller than the material allowable stress value;Figure 6(c)shows that he maximum value is 312.99MP,it is on the on the left ankle joint,the value is smaller than the material allowable stress value.



(a)Posture 1



(b)Posture 2



(c)Posture 3

Figure 6 The stress diagram of each posture after the modified

Table 1 the data before the modified and after

	NO.	Maxi stress (MP)	Maxi stress on the hip (MP)		Maxi stress on the knee (MP)		Maxi stress on the ankle (MP)		TD (mm)
			left	right	left	right	left	right	
Before the modify	1	1330	389	311	275	338	387	496	52
	2	686	271	271	130	85	91	33	4
	3	695	512	512	619	118	318	59	10
After the modify	1	532	211	211	130	70	275	102	10
	2	186	44	62	43	52	89	24	3
	3	312	33	86	31	96	191	41	7

Comparing the results before and after modified,as they are shown in table 1,it can be seen that the max stess is 532MP after modified and it is smaller than the allowable value ([δs]=570MP),So the strength of the exoskeleton is met the requirement of design;the total deformation is 10 mm ,the tension and compression stiffness is met the requirement of design.

IV. Conclusion

Based on the finite element analysis of different posture,stress value of each component is obtained,the stress value provided theoretical numerical value for the optimization design of wearable lower extremity exoskeleton,and set the foundation for the further research on wearable lower extremity exoskeleton.

References

[1] Niu Bin.Study on the Design and Control of a Wearable Exoskeleton Leg for Human's Walking Power Augmentation.ZheJiang:ZheJiang University,2006.

[2] Chen Feng,Bian Li-qin,Wu Bao-yuan. Dynam icsAnalysis and Simulation of theW earable Power Assistance Robot.Experimental science and technology,(2009)01-0030-05.

[3] Zhang Rui,Zhang Jia-fan,Zhang Wen-wei.Research on safety evaluation of wearable exoskeleton man-machine system.Mechanical and Electrical Engineering Magazine,(2008)12-0085-04.

[4] Yin Jun-mao.Analysis and Design of Wearable Lower Extremity Exoskeleton.Bei Jing:Bei Jing University of Technology,2010.

[5] Zhao Yan-jun.Research on Mechanism of Human Lower Extremity Exoskeleton.Nan Jing:Nan Jing University of Science and Technology,2006

[6] Pu Guang-yi.Basic Tutorial and Examples of ANSYS Workbench 12.Bei Jing:China WaterPower Press,2013.4.

[7] Xu Xing-zhi.Finite Element Analysis of Operating Arm of Pipe Clearing Ash Robot based on SolidWorks,ANSYS.Mechanical Drive,2010,(2010)02-0066-02.

[8] K.H.Lee,D.H.Kang,Structural optimization of an automotive door using the kriging interpola-tion method,Journal of Automobile Engineering,2007,221(12):1525~1534.

[9] Keitaro Naruse,Satoshi Kawai and Takichi.Three-di-mensional lifting-up motion analysis for wearable power Assist device of lower back support[A].IEEE/RSJ International Conference on Intelligent Robots and Systems[C],2005(1):3126-3131.

[10] Liu Fang,Cheng Wen-ming,Zhao Nan.Mechanical Structure Strength Analysis of the Portable Exoskeleton Based on ANSYS.Mechinery Design and Manufacture,(2012)-09-0078-02.

[11] Liu Fang,Cheng Wen-ming,Wu Qian-yong.Research of Back Shelf in Portable Exoskeleton Based on ANSYS.Machinery and Manufacture,2011(2):204-206.