



UNIVERSITI TEKNIKAL MALAYSIA MELAKA

**DESIGN AND ANALYSIS OF PASSIVE HIP
EXOSKELETON**

This report is submitted in accordance with the requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor's Degree of Manufacturing Engineering Technology (Product Design) with Honours.

by

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I hereby declare that I have read this dissertation/report and in my opinion this dissertation/report is sufficient in terms of scope and quality as a partial fulfillment of Bachelor Degree of Manufacturing Engineering (Product Design).

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ABSTRACT

The external skeletons, exoskeletons, are not a new study area in this high-technology world. Exoskeleton are first invented for the reason of augmenting human strength but then the rehabilitation purposed exoskeletons are also widely developed. In this thesis, a passive hip exoskeleton is designed and analyzed by a series of biomechanics simulations. The design objectives were to reduce the risk of developing work-related musculoskeletal disorder (WMSD) among the industry workers who need to perform manual handling tasks in their daily routine work. This thesis presented a brand new design of three degree of freedoms (DOFs) passive hip exoskeleton. The passive hip exoskeleton introduced in this thesis is quite different with the ordinary exoskeletons since the typical exoskeleton will usually designed for the entire leg or entire body, but the exoskeleton presented in this thesis will only focus on the hip. The reason for design a passive exoskeleton instead of the active one is because the passive exoskeletons have relative lightweight, easy to wear and low cost compare with the active one. This thesis focused on the design and analysis of the passive hip exoskeleton and verifies if the design has a reliable and stability structure. Hence, a series of analysis will undergo to support it. The design of the passive hip exoskeleton drew by using Solidwork software and performance of the exoskeleton model has been checked by the finite element analysis in Solidthinking software according to the applied forced and moment. Lastly, the future recommendation or optimization suggestion is provided for a better design. After undergoing all the analysis needed, the passive hip exoskeleton designed in this thesis is achieved the objectives.

ABSTRAK

Kerangka luaran, exoskeleton, bukan bidang kajian baru dalam dunia teknologi tinggi ini. Exoskeleton mula-mula dicipta untuk meningkatkan kekuatan manusia, kemudian exoskeleton untuk pemulihan juga berkembang secara meluas. Dalam tesis ini, exoskeleton pinggul pasif direka dan dianalisis oleh satu siri simulasi biomekanik. Objektif reka bentuk adalah untuk mengurangkan risiko membangunkan kesakitan muskuloskeletal (WMSD) di kalangan pekerja industri yang perlu melakukan tugas mengangkat manual dalam kerja rutin harian mereka. Tesis ini membentangkan reka bentuk tiga derajat kebebasan (DOFs) exoskeleton pinggul pasif. Eksoskeleton pinggul pasif diperkenalkan dalam tesis ini agak berbeza dengan exoskeleton biasa kerana exoskeleton biasa biasanya akan direka untuk seluruh kaki atau seluruh badan, tetapi exoskeleton yang dibentangkan dalam tesis ini hanya akan menumpukan pada pinggul. Sebab untuk reka bentuk exoskeleton pasif bukannya aktif adalah kerana exoskeleton pasif lebih ringan, mudah dipakai dan kos rendah berbanding dengan yang aktif. Tesis ini memberi tumpuan kepada reka bentuk dan analisis exoskeleton pinggul pasif dan mengesahkan jika reka bentuk mempunyai struktur yang boleh dipercayai dan stabil. Oleh itu, satu siri analisis akan menjalani untuk menyokongnya. Reka bentuk exoskeleton pinggul pasif akan dibuat dengan menggunakan Solidwork dan prestasi model exoskeleton telah diperiksa oleh analisis unsur dengan menggunakan Solidthinking mengikut keberatan dan momen yang digunakan. Terakhirnya, cadangan masa depan atau cadangan penambahbaikan disediakan untuk reka bentuk yang lebih baik. Selepas menjalani semua analisis yang diperlukan, exoskeleton pinggul pasif yang direka dalam tesis ini dapat mencapai matlamat.

DEDICATION

To my beloved family.

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TABLE OF CONTENT

DECLARATION	
APPROVAL	i
ABSTRAK	ii
ABSTRACT	iii
DEDICATION	iv
ACKNOWLEDGEMENT	v
TABLE OF CONTENTS	vii
LIST OF FIGURES AND TABLES	ix
LIST OF ABBREVIATIONS	xiii
LIST OF APPENDICES	xiv
CHAPTER	
1. INTRODUCTION	1
1.1 Background of Study	1
1.2 Problem Statement	3
1.3 Objectives	3
1.4 Scope of Study	3
1.5 Thesis Outline	4
1.6 Gantt Chart	6
2. LITERATURE REVIEW	7
2.0 Introduction	7
2.1 Trend of Exoskeleton	11
2.2 Application of Exoskeleton	12
2.3 Mechanism of Exoskeleton	15
2.3.1 Joint Mechanism of Exoskeleton	15
2.3.2 Mechanism Structure of Exoskeleton	16
2.3.3 Machine Element of Passive Exoskeleton	17
2.4 Biomechanical Design	21
2.4.1 Biological Hip Joint	21
2.4.2 Kinematics and Kinetic Analysis of Hip	26
2.4.3 Gait Analysis	29
2.5 Summary	32
3. METHODOLOGY	33
3.0 Introduction	33
3.1 3D Design CAD	35

3.1.1 Pugh Method	38
3.2 Kinematics and Kinetic Analysis	40
3.3 Inverse Dynamic	42
3.4 Parametric Study	43
3.5 Concluding Remarks	43
4. RESULT & DISCUSSION	
4.0 Design of Passive Hip Exoskeleton	
4.0.1 Pugh Method	45
4.0.2 Design and Mechanism of Passive Hip Exoskeleton	46
4.0.3 Bill of Material (BOM) of Passive Hip Exoskeleton	48
4.1 Human Model Creation and Insertion Motion	51
4.2 Analysis Result	
4.2.1 Analysis Method	54
4.2.2 Result	56
4.3 Long Term Analysis	57
4.4 Inverse Dynamic	
4.4.1 Global Response	59
4.4.2 Local Response	60
4.5 Parametric Study & Optimization	61
4.6 Summary	64
5. CONCLUSION	
5.0 Conclusion	62
5.1 Future Work	62
REFERENCES	63
APPENDIX	68

LIST OF FIGURES AND TABLES

TABLE/FIGURE	TITLE	PAGE
Table 1.1.1	Classification of Exoskeletons	2
Figure 2.0.1	The Hardiman Exoskeleton Prototype	8
Figure 2.0.2	Walking Assistive Exoskeleton	9
Figure 2.0.3	Rehabilitation Exoskeleton	10
Figure 2.1.1	Development History of Exoskeleton	12
Table 2.2.1	Overview of Currently Available LEEs	14
Figure 2.3.3.1	Passive Exoskeleton Design	19
Figure 2.3.3.2	The Passive Exoskeleton Designed by Grabowski and Herr	19
Figure 2.3.3.3	The Stiffness Profiles of SLE and MLE	20
Figure 2.4.1.1	Hip Bone Anatomy	22
Figure 2.4.1.2	Cross Sectional View of Hip Joint	22
Figure 2.4.1.3	Neck Shaft Angle	23
Figure 2.4.1.4	Ligaments of Hip	24
Figure 2.4.1.5	Plane of Motions	25
Figure 2.4.1.6	Movement of Hip Joint	25
Figure 2.4.1.7	Hip Normal Range of Motion (ROM)	26
Figure 2.4.2.1	Schematic Steps in the Calculation of the Moment of Force	28
Figure 2.4.3.1	Human Walking Gait Through One Cycle	30
Figure 2.4.3.2	Human Anatomical Planes	30
Figure 3.0.1	Flow Chart of Methodology	34
Figure 3.1.1	CAD Model and FBD of the Human with the Exoskeleton on the Sagittal Phase	35
Figure 3.1.2	The Six Basic Models of Synovial Joint	36
Figure 3.1.3	Design of Exoskeleton Leg Structure	37
Figure 3.1.1.1	Example of Pugh Method	38

Figure 3.2.1	Sagittal Plane Hip Motion	40
Figure 3.2.2	Moment and Power Profiles of Hip Motion	41
Figure 3.2.3	Joint Angles in Sagittal Plane During Squat and Stoop Lifting	42
Table 4.0.1	Spring Selection for Passive Hip Exoskeleton	45
Figure 4.0.2.1	Total Weight of Passive Hip Exoskeleton	47
Figure 4.0.2.2	Front View of Passive Hip Exoskeleton	48
Figure 4.0.2.3	Side View of Passive Hip Exoskeleton	48
Figure 4.0.2.4	Back View of Passive Hip Exoskeleton	48
Figure 4.0.2.5	Isometric View of Passive Hip Exoskeleton	48
Table 4.0.3	Bill of material of the passive hip exoskeleton	48
Figure 4.1.1	Human Model	
Figure 4.1.2	Squat Lifting Posture	52
Figure 4.1.3	Stoop Lifting Posture	52
Figure 4.1.4	Walking Posture	53
Figure 4.1.5	Human-Exoskeleton Model	53
Figure 4.2.1.1	S-type Load Cell	54
Figure 4.2.1.2	Rectus Femoris	54
Figure 4.2.1.3	Maximum Lifting Force	54
Figure 4.2.1.4	Force applied to the passive hip exoskeleton without gas spring force	55
Figure 4.2.1.5	Force applied to the passive hip exoskeleton with gas spring force.	56
Figure 4.2.2.1	Angular acceleration versus time graph without gas spring force.	56
Figure 4.2.2.2	Angular acceleration versus time graph with gas spring force.	57
Table 4.3.1	Peak of angular acceleration and human lifting force in five cycles.	59
Figure 4.3.1	Angular acceleration versus cycle graph with and without gas spring force.	59
Figure 4.4.1.1	Displacement result of passive hip exoskeleton	60

Figure 4.4.2.1	Von Mises Stress result of leg structure of the passive hip exoskeleton	61
Figure 4.5.1	Swift & Sure gas spring with 60mm stroke length and 90mm tube length	62
Figure 4.5.2	Swift & Sure gas spring with 150mm stroke length and 180mm tube length	63
Figure 4.5.3	Swift & Sure gas spring with 100mm stroke length and 130mm tube length	63

LIST OF ABBREVIATIONS

ALEX	Active Leg Exoskeleton
BLEEX	Berkeley Lower Extremity Exoskeleton
BOM	Bill of Material
CAD	Computer-Aided Design
DARPA	Defense Advanced Research Projects Agency
DOFs	Degree of Freedoms
DC	Direct current
EHPA	Exoskeleton for Human Performance Augmentation
FEA	Finite Element Analysis
FF	Foot Flat
HO	Heel off
HS	Heel strike
HAA	Hip abduction/adduction
HFE	Hip flexion/extension
HAL	Hybrid assistive limb
LBD	Low back disorder
LEEs	Lower extremity exoskeletons
MLE	Multiple Leaf Exoskeleton
NIOSH	Nasional Institute of Occupational Safety and Health
BNDR	Bending Non-Demand Return
OSHA	Occupational Safety and Health Administration
PLAD	Personal Lifting Assistive Device
ROM	Range of Motion
SLE	Single Leaf Exoskeleton

SCI	Spinal cord injury
TO	Toe off
WMSD	Work-related musculoskeletal disorder

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
Appendix 1	Conceptual Design 1	72
Appendix 2	Conceptual Design 2	73
Appendix 3	Conceptual Design 3	74
Appendix 4	Catalogue of Swift & Sure Gas Spring	75
Appendix 5	Drawing of Articulation	77
Appendix 6	Drawing of Female Buckle	78
Appendix 7	Drawing of Male Buckle	79
Appendix 8	Drawing of Handle	80
Appendix 9	Drawing of Leg Structure	81
Appendix 10	Drawing of Leg Support Arm Left	82
Appendix 11	Drawing of Leg Support Arm Right	83
Appendix 12	Drawing of Leg Pad	84
Appendix 13	Drawing of Pivot A	85
Appendix 14	Drawing of Pivot B	86
Appendix 15	Drawing of Hip Pad Left	87
Appendix 16	Drawing of Hip Pad Right	88
Appendix 17	Drawing of Waist Support Back	89
Appendix 18	Drawing of Gas Spring Rod	90
Appendix 19	Drawing of Gas Spring Tube	91
Appendix 20	Drawing of Waist Support Left	92
Appendix 21	Drawing of Waist Support Right	93
Appendix 22	Drawing of Assembly Passive Hip Exoskeleton	94

CHAPTER 1

INTRODUCTION

1.1 Background of study

Exoskeleton is a wearable device that possess the potential for integration into the factories of the future. From table 1.1.1 had shown the classification of exoskeleton and it is shown that there are three applications of exoskeleton which include performance augmentation, rehabilitation and assistance. In the last few decades, engineers around the world were focusing on developing rehabilitation exoskeleton but most of them are restricted to the laboratory environment. In recent year, the focus already shifted to power augmentation and assistance exoskeletons to enhance the power or augment the healthy individuals, soldiers and industries workers. In this thesis, performance augmentation exoskeleton will be focused and the body part to augment is hip. Besides, the passive exoskeleton will be selected because passive exoskeleton is relatively light in weight and not dependence on power sources. The passive hip exoskeleton designed will assists on industries workers who need to lifting and lowering the goods in the daily working life. The main purpose of designing the passive hip exoskeleton is to reduce the forces used when performing manual lifting tasks and then lower down the risk in developing the work-related musculoskeletal disorder (WMSD) among the industries workers.

The Nasional Institute of Occupational Safety and Health (NIOSH) announces issues guidelines and findings for safe manual lifting which are enforced by its parallel agency focused on regulations, the Occupational Safety and Health Administration (OSHA). The lift equation of NIOSH had recommended that the maximum lifting loads for repetitive lifting by healthy workers is 223N (51lb) [1]. Not only that, manual lifting tasks will involve bending and squatting postures will cause hips to generate a moment due to the weight of the workers of the body superior to the hip and any load being lifted, hence the recommended maximum spinal compression is about 3400N. To prevent toppling forward while lifting a load, the body must generate an equal and opposite moment and when moving superiorly from the hips,

there is less mass to support and cause the required restoring moment decrease. Hence, a passive hip exoskeleton could support the worker's hip to avoid toppling forward and perform lifting tasks easily.

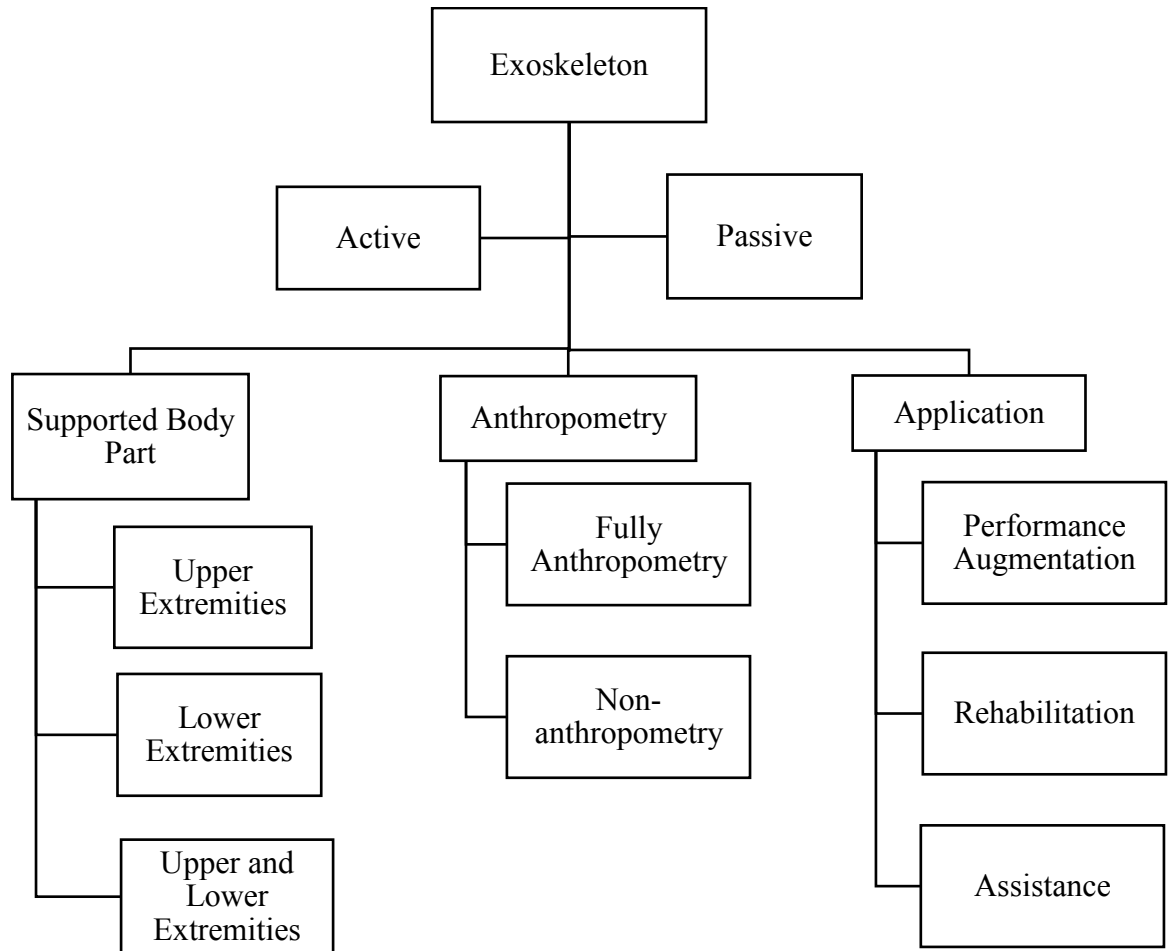


Chart 1.1.1: Classification of Exoskeletons.

1.2 Problem Statement

Low back disorder (LBD) and work-related musculoskeletal disorder (WMSDs) still affect a large number of industry workers although in this automation and mechanization era [2]. LBD and WMSDs are found that often develop on the workers who conduct repetitive material handling and prolonged stooped postures. The field of industry which involve repetitive and sustained tasks like squatting lifting and prolonged stooped posture are agriculture, construction and mining industries. Workers in both developed and developing country used to work with repetitive tasks and awkward postures, hence it is not surprising that many workers throughout the world keep performing tasks over and over again with high risks of developing LBDs and WMSDs.

There are several methods or ways have been proposed to prevent the LBD and WMSDs such as training the worker a proper lifting technique, to adjust the workstation and re-organize the work processes and use the mechanical aid like crane and balancers [3]. However, those methods cannot solve or avoid the development of LBDs and WMSDs effectively. Hence, it is necessary or the reason to design and develop an exoskeleton for solving the not feasible preventive measures that mentioned just now [4]. With the aid of exoskeleton, workers are able to reduce the burden while performing manual lifting in a feasible way.

1.3 Objectives

The objectives for this thesis are:

- i. To design and analysis of passive hip exoskeleton and reduce the risk of developing WMSD among industry workers.
- ii. To establish a design mechanism of passive hip exoskeleton.
- iii. To optimize the design parameters of the mechanism.

1.4 Scope of Study

- i.** The research object of this thesis is to design and analysis a passive hip exoskeleton to achieve the goal of reducing the risk of industry workers suffering from work-related musculoskeletal disorder (WMSD) due to repetition heavy lifting or other heavy physical workload tasks.
- ii.** The research focuses on the two dimensional (sagittal plane) hip flexion/extension (HFE) and hip abduction/adduction (HAA).
- iii.** The model of passive hip exoskeleton will develop by using SOLIDWORK software.
- iv.** The human model for testing the passive hip exoskeleton will be developed and created by using MAKE HUMAN software and the posture of the human model will be created in BLENDER software.
- v.** The Finite Element Analysis (FEA) and simulation will be undergoing by using SOLIDTHIKING software to prove that the passive hip exoskeleton designed is achieving the goals of reducing risks of developing WMSD.

3.0 Thesis Outline

This thesis focuses on the design and development of passive hip exoskeleton which could help to protect the industrial workers from suffering for the musculoskeletal disorder (MSD). Chapter 1 presents the introduction of the thesis which includes background study, objectives of the thesis, scope and outline. In background study, a brief explanation of the type of exoskeletons and mechanism were given to give the readers a preliminary concept about exoskeleton.

Chapter 2 is about the literature review about the exoskeleton. There are two separated parts in this chapter, one is the mechanism of the exoskeleton and the other is biomechanical of the hip. The various mechanisms that make the exoskeleton function will present here. Since this thesis title is design and development passive hip exoskeleton, hence the biomechanical of the hip is require to explain here for better understanding. In biomechanical of hip, anatomy, kinematic and kinetic of the hip was presented for giving the reader a deeper understanding how the hip work.

Next, chapter 3 is presented the methodology in design the passive hip exoskeleton. All the method that used in designing passive hip exoskeleton was presented here in detail. This chapter may involve theories, formulas and equations that used to design the exoskeleton. Besides, the methods of data collection that needed in designing the exoskeleton will also be presented.

Chapter 4 will be presented the simulation result and will be discussed in detail for making sure the exoskeleton is safe to use and prove that it achieves the goals of the thesis. In addition, the simulation result of the critical parts of the exoskeleton will be discussed and the further improvement or optimization may have needed according to the result that comes out.

Chapter 5 is the last chapter and a conclusion will be made in this chapter. This chapter will summing-up all the findings and the result of all the topics that discussed in this thesis. Lastly, this chapter will also determine the objectives in this thesis are successfully achieved or not.

3.0 Gantt Chart

No.	Task	WEEK																											
		PSM 1														PSM 2													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1.	Topic selection	■																											
2.	Journal research	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	
3.	Preparation of chapter 1		■	■	■	■	■	■	■	■	■	■	■	■															
4.	Preparation of chapter 2				■	■	■	■	■	■	■	■	■	■		■	■	■	■	■	■	■	■	■	■	■	■	■	
5.	Preparation of chapter 3					■	■	■	■	■	■	■	■	■		■													
6.	Submission of progress form and turn-it-in report 1 (Draft)									■	■	■	■	■															
7.	Submission of combined report, warning letter turn-it-in report 1 (Final)										■	■	■	■															
8.	FYP 1 Presentation													■															
9.	Preparation of chapter 4														■	■	■	■	■	■	■	■	■	■	■	■	■	■	
10.	Preparation of chapter 5																							■	■	■	■	■	
11.	Submission of progress form and turn-it-in report 2 (Draft)																							■	■	■	■	■	
12.	Submission of combined report, warning letter turn-it-in report 2 (Final)																								■	■	■	■	
13.	FYP 2 Presentation																											■	

CHAPTER 2

LITERATURE REVIEW

2.0 Introduction

Exoskeletons are wearable devices that work in parallel with the human body which can augment a user's physical abilities or increase human strength in carrying heavy objects, jump, squat and walk easier. Exoskeletons can be produced or manufacture by rigid materials such as carbon fibre and metal, or they could be made out of soft and elastic parts. The development of exoskeleton can be traced back to 1965, General Electric (in US) started to develop the Hardiman (Human Augmentation Research and Development Investigation). [5] Hardiman is a full body exoskeleton which designed aim to augment the user's strength to enable them to carry and lift heavy object frequently. Hardiman was found that able to assist user to lift up the load up to 1 500 Ibs (around 682kg). Hardiman was an enormous powered exoskeleton which has a mass of 680kg and it was hydraulically powered (Figure 2.0.1). However, Hardiman presented to have technical problems with the hydro-mechanical servos and balancing problems. Besides, the technical limitation at that time and lack of experience and knowledge impede further improvement of this exoskeleton. Nevertheless, Hardiman also gave engineer some inspiration in a further invention of a exoskeleton and they found that the main problem of Hardiman was the non-portable hydraulic powered supply and also the actuators of the exoskeleton were too heavy and bulky to use. [5]