



UNIVERSITI PUTRA MALAYSIA

***DESIGN AND DEVELOPMENT OF A SELF-PROPELLED
HYDRAULIC FLOOR CRANE***

DARYOUSH SAFARZADEH

FK 2012 19

**DESIGN AND DEVELOPMENT OF A SELF-PROPELLED HYDRAULIC
FLOOR CRANE**

BY

DARYOUSH SAFARZADEH

**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia,
in Fulfillment of the Requirements for the Degree of Doctor of Philosophy**

December 2011

Abstract of thesis presented to the Senate of Universiti Putra Malaysia
in fulfillment of the requirement for the degree of Doctor of Philosophy

**DESIGN AND DEVELOPMENT OF A SELF-PROPELLED HYDRAULIC
FLOOR CRANE**

By

DARYOUSH SAFARZADEH

December 2011

Chairman: Professor Shamsuddin Sulaiman, PhD

Faculty: Faculty of Engineering

Crane is a device utilized for loading, unloading and transporting the loads. There are many types of cranes for various applications. Although cranes are profitable devices, they have a lot of problems. One of the most important problems of cranes is that they frequently generate hazards and accidents. Other problems relate to their performance and imperfection of systems. The purpose of this research is to design of a self-propelled hydraulic floor crane to prevent the hazards which are normally associated with the crane application in workshops and factories. The main focus was aimed at the remote controlling of the crane operations to reduce the hazards and improving the performance features such as rapidity, flexibility and maneuverability.

The methodology employed in this thesis consists of design of crane's framework, design of systems, modeling of the crane by use of computer-aided design, and several investigations for development of the crane regarding payload sway, crane stability, field application and application of composite materials in the crane structure. Stability analysis of the crane was performed in static and dynamic

situations. Equations of stability were derived and a crane was designed for field application. The results indicated that stability is based on the weight and center of gravity of crane and payload. Dynamics of payload sway was studied in a system with seven-degrees-of-freedom and equations of motion were derived by use of Lagrange's equation. Based on these equations, effect of hook and boom parameters on sway angles was studied and an anti-sway controller was designed.

Results denoted that by increasing the mass and length of hook, sway of payload was diminished. Computer-aided finite element analysis was performed to compare three composite materials, carbon epoxy, graphite epoxy and glass epoxy with steel from the weight and strength point of view and glass epoxy was known as an appropriate substitute for steel in crane structure. The general research resulted in several findings and contributions such as: an advanced self-propelled hydraulic floor crane holding specifications in tables 5.8 and 5.9 for application in factories, workshops, fields and some of the hazardous environments, articulated hook, steer-by-switch system, sway brake system which is an autonomous system, and determination of the most appropriate composite material for crane frame-work. The hydraulic floor crane, articulated hook, steer-by-switch system and sway brake system are all new designs. For validating the research work, a scale-model prototype of the alternating current crane was built and tested. The entire crane operations could be controlled properly from afar via a control box located in the operator's hands. The estimated fabrication cost of a full-scale crane is 16000 RM. Finally, it was concluded that use of the wire remote control system reduced the hazards by keeping operator far from the crane. Use of platform and sway brake system eliminated payload sway. Use of

two electromotors, a three-piece boom, a compacted size, steering and drive systems, increased rapidity, flexibility and manueverability of the crane.



Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

**REKABENTUK DAN PEMBANGUNAN KREN LANTAI HYDRAULIK
BERGERAK SENDIRI**

Oleh

DARYOUSH SAFARZADEH

Disember 2011

Pengerusi: Profesor Shamsuddin Sulaiman, PhD

Fakulti: Fakulti Kejuruteraan

Kren adalah alatan yang digunakan untuk memunggah, mengeluarkan dan menghantar beban. Terdapat beberapa jenis kren dengan pelbagai penggunaan. Walaupun ia alatan yang menguntungkan, ia juga menghadapi berbagai masalah. Satu daripada masalah penting ialah kerap kali mengalami kemalangan dan bencana. Masalah lain adalah berkaitan prestasi dan sistem yang tidak sempurna. Oleh itu tujuan penyelidikan ini adalah untuk merekabentuk kren lantai bergerak sendiri secara hidraulik untuk menghalang dari bencana di mana biasanya di gunakan di bengkel dan kilang-kilang. Fokus utama adalah operasi kren kawalan jauh untuk mengurangkan bencana dan menambahbaik ciri prestasi seperti kepantasan, kelugsan dan cara menggerakkan. Kaedah yang digunakan dalam tesis termasuk rekabentuk kerangka kren, rekabentuk sistem, pemodelan kren secara Rekabentuk Berbantu Komputer dan beberapa kajian untuk pembangunan kren berkaitan beban tergantung, kestabilan kren, penggunaan di lapangan dan penggunaan bahan komposit pada struktur kren. Analisa kestabilan kren dilakukan dalam situasi statik dan dinamik. Persamaan kestabilan telah dibentuk dan kren direkebetuk untuk

penggunaan lapangan. Keputusan menunjukkan kestabilan adalah berdasarkan berat dan pusat graviti kren dan beban tergantung. Beban tergantung secara dinamik juga telah diselidiki dengan sistem tujuk-sudut pergerakan bebas dan persamaan gerakan diperolehi menggunakan persamaan Lagrange. Berdasarkan persamaan ini, kesan penyangkuk dan parameter boom pada sudut tergantung telah ditentukan dan kawalan anti-gantungan telah direkabentuk. Keputusan menunjukkan dengan menambah berat dan panjang penyangkuk, beban tergantung dapat dikurangkan.

Komputer Terbantu Unsur Terhingga telah dilaksanakan untuk melihat perbandingan tiga bahan komposit iaitu epoksi karbon, epoksi grafit dan epoksi kaca dengan keluli pada sudut berat dan kekuatan. Hasilnya epoksi kaca diketahui sebagai pengganti yang sesuai untuk struktur keluli kren. Keputusan dan penemuan serta sumbangan penyelidikan ini secara amnya ialah: kren hidraulik lantai bergerak sendiri termaju untuk penggunaan di kilang, bengkel, lapangan dan persekitaran bahaya, penyangkuk memunggah beban, sistem mengemudi-oleh-suis, sistem gantungan brek autonomi, penentuan bahan komposit untuk kerangka kren.

Kren lantai hidraulik, penyangkuk memunggah beban, system mengemudi-oleh-suis dan system gantungan brek adalah hasil rekabentuk baru. Untuk pengesahan kerja penyelidikan, kren prototaip model berskel dengan arus ulang-alik telah dibina dan diuji. Operasi keseluruhan kren dikawal dengan baik secara kawalan kotak di tangan pengendali. Kos pemasangan untuk skel penuh dianggarkan sebanyak RM 16000. Akhirnya, dapat disimpulkan bahawa kren system kawalan berwayar dapat mengurangkan bencana dan dikendalikan secara jauh. Penggunaan platform dan system brek tergantung menghapuskan ayunan beban tergantung. Kren dengan

menggunakan dua elektromotor, tiga-batang teras, saiz terpadat, system pemanduan dan pepandu dapat menambah kepantasan, keluesan dan cara pergerakan.



ACKNOWLEDGEMENTS

This thesis work was carried out in the Department of Mechanical and Manufacturing Engineering at University Putra Malaysia in Malaysia.

I would like to express my gratitude to all those who made it possible to complete this thesis work.

Most notably, I would like to convey my special thanks to my dear supervisor, Professor Shamsuddin Sulaiman for his kindness, generously assistance and providing advisory supports and professional advice of any kind. I am deeply indebted to him. I also want to thank my co-supervisor Dr. Faieza Abdul Aziz for her kindness, generously assistance and advisory supports. I also feel deeply indebted to her. I would also like to thank my co-supervisor and advisor Professor Desa Bin Ahmad for his precious helps and advisory supports. Finally, I would like to thank my professor in the Department of Mechanical Engineering at Bu-Ali Sina University in Iran, Professor Gholam Hossein Majzoubi for his precious helps and advices.

I certify that a Thesis Examination Committee has met on 16 December 2011 to conduct the final examination of Daryoush Safarzadeh on his thesis entitled "Design and Development of a Self-Propelled Hydraulic Floor Crane" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U. (A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

Members of the Thesis Examination Committee were as Follows:

Aidy bin Ali, PhD

Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Napsiah binti Ismail, PhD

Professor Datin
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Tang Sai Hong, PhD

Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Emin Bayraktar, PhD

Professor
School of Mechanical and Manufacturing Engineering
France
(External Examiner)

SEOW HENG FONG, PhD

Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 2 March 2012

This thesis was submitted to the senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

Shamsuddin Sulaiman, PhD

Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Desa Bin Ahmad, PhD

Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Faieza Abdul Aziz, PhD

Senior Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Member)

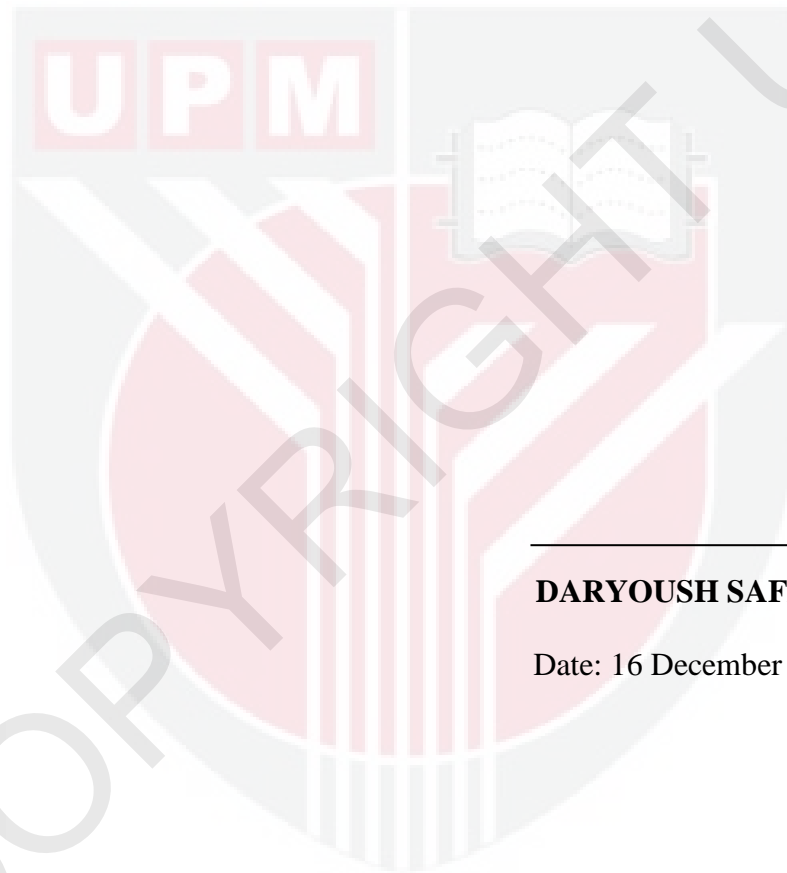
BUJANG BIN KIM HUAT, PhD

Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

DECLARATION

I declare that the thesis is my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or at any other institution.



DARYOUSH SAFARZADEH

Date: 16 December 2011

TABLE OF CONTENTS

ABSTRACT	Page
	ii
ABSTRAK	v
ACKNOWLEDGEMENTS	viii
APPROVAL	ix
DECLARATION	xi
LIST OF TABLES	xvi
LIST OF FIGURES	xvii
LIST OF ABBREVIATIONS	xxiii
CHAPTER	
1 INTRODUCTION	1
1.1 Introduction	1
1.2 Problem statement	3
1.3 Objectives	8
1.4 Scope of the study	9
1.5 Thesis organization	9
2 LITERATURE REVIEW	10
2.1 Introduction	10
2.2 Recent development of cranes	10
2.3 Design, modeling and simulation of cranes	13
2.4 Dynamics of cranes	14
2.5 Ergonomics in cranes	16
2.6 Design Procedure	18
2.7 Development procedure	20
2.8 Materials of cranes	22
2.9 Stability of cranes	23
2.10 FEM/FEA	24
2.11 Control systems of cranes	26
2.12 Remote control	30
2.13 Hydraulic systems	33

2.14	Steering systems	35
2.15	Sway of payload	37
2.16	Self-propelled cranes	39
2.17	Floor cranes	43
2.18	Summary	49
3	METHODOLOGY	50
3.1	Introduction	50
3.2	Design of the frame-work of crane	54
3.2.1	Process of the crane performance	55
3.2.2	Selection of the materials	56
3.2.3	Determination of the shape and dimensions	57
3.2.4	Modeling of the crane structure	62
3.2.5	Determination of the center of mass	63
3.3	Static analyses	65
3.4	Determining a range for factor of safety	66
3.5	Finite element analyses	69
3.5.1	Static calculations for new position of boom 3	71
3.5.2	Determination of load capacity of holes in boom 3	73
3.5.3	Fortification and modification of the components	74
3.5.4	Calculations of center of mass for fortified components	77
3.6	Dynamics of the crane	78
3.6.1	Assumptions	78
3.6.2	Dynamic analysis of the components	79
3.6.3	Strength of materials after dynamic analyses	92
3.6.4	Finite element analysis to determine diameter of pins	92
3.6.5	Fortification of the crane's components	93
3.7	Summary	93
4	DESIGN, FABRICATION AND TESTING	94
4.1	Introduction	94
4.2	Design of the crane's systems	94
4.2.1	Design of the hydraulic system	95
4.2.2	Design of the drive system	102

4.2.3	Design of the steering system	109
4.2.4	Modeling of the steering system	120
4.2.5	Design of the brake system	127
4.2.6	Assembly of the hydraulic and drive systems on the crane	128
4.2.7	Design of the control system	129
4.2.8	Design of hook	134
4.3	Modeling of the crane by use of CAD	138
4.3.1	Assembly of the crane	139
4.3.2	2D and 3D drawing	140
4.3.3	Bills of materials	140
4.4	Scale-model prototype manufacturing	140
4.5	Dynamics of the payload sway	141
4.5.1	Mathematical model	142
4.5.2	Equations of motion	144
4.5.3	An investigation into the ways to reduce sway of payload	150
4.6	Application of composite materials in crane structure	162
4.6.1	Selection of the composite materials	163
4.6.2	Stress analyses on the components	164
4.7	Application of the crane on fields and rough lands	165
4.8	Stability analyses	168
4.8.1	Dynamic analyses of the longitudinal stability	169
4.8.2	Static analyses of the lateral stability	172
4.8.3	Dynamic analyses of the lateral stability	173
4.9	Determination of the crane gradeability	175
4.10	Determination of the rated capacity	176
4.11	Summary	178
5	RESULTS AND DISCUSSIONS	179
5.1	Introduction	179
5.2	Static, dynamic and FEM analyses	179
5.3	Design of systems	190
5.4	Design of the crane	191
5.5	Sway of payload	197
5.5.1	Effect of the hook parameters on the sway angles	197

5.5.2	Effect of the boom characteristics on the sway angles	205
5.6	Application of composite materials in cranes	210
5.7	Stability analyses and field application	214
5.8	Design of the steering system	216
5.9	Summary	222
6	CONCLUSION AND RECOMMENDATIONS	223
6.1	Conclusion	223
6.2	Recommendations	227
	REFERENCES	228
	APPENDICES	240
	BIODATA OF STUDENT	311
	LIST OF PUBLICATIONS	312