



PREDICTION OF DEFECTS IN NON-CIRCULAR DEEP DRAWN PARTS  
USING  
FINITE ELEMENT ANALYSIS AND RESPONSE SURFACE METHODOLOGY

By  
Eng.\Mustafa Mubarak Semman

A Thesis Submitted to the  
Faculty of Engineering at Cairo University  
In Partial Fulfillment of the  
Requirements for the Degree of  
MASTER OF SCIENCE  
In  
MECHANICAL DESIGN  
AND PRODUCTION ENGINEERING

FACULTY OF ENGINEERING, CAIRO UNIVERSITY  
GIZA-EGYPT  
2017



PREDICTION OF DEFECTS IN NON-CIRCULAR DEEP DRAWN PARTS  
USING  
FINITE ELEMENT ANALYSIS AND RESPONSE SURFACE METHODOLOGY

By  
Eng.\Mustafa Mubarak Semman

A Thesis Submitted to the  
Faculty of Engineering at Cairo University  
In Partial Fulfillment of the  
Requirements for the Degree of  
MASTER OF SCIENCE  
In  
MECHANICAL DESIGN  
AND PRODUCTION ENGINEERING

Under the Supervision of

Prof. Dr. Abdalla S. Wifi

.....  
Professor of Material and Manufacturing Engineering  
Mechanical Design and Production Department  
Faculty of Engineering, Cairo University

Prof. Dr. Mohamed H. Gadullah

.....  
Professor of Industrial Engineering  
Mechanical Design and Production Department  
Faculty of Engineering, Cairo University

Dr. Mostafa H. Shazly

.....  
Associate Professor of Mechanical Engineering  
Mechanical Engineering Department  
Faculty of Engineering, the British University in Egypt

FACULTY OF ENGINEERING, CAIRO UNIVERSITY  
GIZA-EGYPT  
2017



PREDICTION OF DEFECTS IN NON-CIRCULAR DEEP DRAWN PARTS  
USING  
FINITE ELEMENT ANALYSIS AND RESPONSE SURFACE METHODOLOGY

By  
Eng. Mustafa Mubarak Semman

A Thesis Submitted to the  
Faculty of Engineering at Cairo University  
In Partial Fulfillment of the  
Requirements for the Degree of  
MASTER OF SCIENCE  
In  
MECHANICAL DESIGN  
AND PRODUCTION ENGINEERING

Approved by the  
Examining Committee

Prof. Dr. Abdalla S. Wifi,

Thesis Main Advisor

---

Prof. Dr. Ahmed Ali Al-Zoghby,

Internal Examiner

---

Prof. Dr. Mohamed Naguib Al-Shaikh,

External Examiner

Faculty of Industrial Education – Beni-Suef University

FACULTY OF ENGINEERING, CAIRO UNIVERSITY  
GIZA-EGYPT  
2017



**Engineer's Name:** Mostafa Mubarak Semman  
**Date of Birth:** 16/06/1980  
**Nationality:** Egyptian  
**E-Mail:** engmosmoba@yahoo.com  
**Phone:** 01060684099  
**Address:** Future City - Building 885-  
El Nozha District - Cairo  
**Registration Date:** 1/10/2009  
**Awarding Date:** 2017  
**Degree:** Master of Science  
**Department:** Mechanical design and production engineering



**Supervisors:** Prof. Dr. Abdalla S. Wifi  
Prof. Dr. Mohammed H. Gadullah  
Dr. Mostafa H. Shazly  
(Associate Professor, Mechanical Engineering Department, BUE)

**Examiners:** Prof. Dr. Mohamed Naguib Al-Shaikh (External Examiner)  
Prof. Dr. Ahmed Ali Al-Zoghby (Internal Examiner)  
Prof. Dr. Abdalla S. Wifi (Thesis Main Advisor)

**Title of Thesis:**

Prediction of defects in non-circular deep drawn parts using finite element analysis and response surface methodology.

**Key Words:**

Earing, Thinning, Finite element analysis, Design of Experiments, Response Surface Methodology.

**Summary:**

Deep drawing defects such as thinning and earing present challenges to sheet metal forming industry while designers tend to favor the usage of new materials and production processes. The present work introduces an integrated approach using design of experiment approach, FEA experimentation and response surface methodology (RSM) to develop linear regression equation that is capable of predicting earing and thinning defects in deep drawing of non-circular parts (rectangular and elliptical) and determine the optimum process parameters which lead to minimum defects.



# **Acknowledgements**

I would like to express my deepest gratitude and appreciation to my supervisors Prof. Dr. Abdalla Wifi, Prof. Dr. Mohamed Hassan Gadullah and Assoc. Prof. Dr. Mostafa Shazly for their support, inspiration, criticism and patience throughout this study. I would also like to thank Assoc. Prof. Dr. Tamer Adel Mohamed, whose support and suggestions made great contributions to this work. Finally, I would like to thank my family for being there all the time. You are the inspiration of my life.



**Dedication**  
**To my Father**



# Table of contents

|                                                                        |             |
|------------------------------------------------------------------------|-------------|
| <b>ACKNOWLEDGEMENTS.....</b>                                           | <b>I</b>    |
| <b>DEDICATION.....</b>                                                 | <b>II</b>   |
| <b>TABLE OF CONTENTS.....</b>                                          | <b>III</b>  |
| <b>LIST OF TABLES.....</b>                                             | <b>VI</b>   |
| <b>LIST OF FIGURES.....</b>                                            | <b>VII</b>  |
| <b>NOMENCLATURE.....</b>                                               | <b>XII</b>  |
| <b>ABSTRACT.....</b>                                                   | <b>XIII</b> |
| <b>CHAPTER 1: INTRODUCTION AND LITERATURE REVIEW .....</b>             | <b>1</b>    |
| 1.1. BACKGROUND.....                                                   | 1           |
| 1.2. AIM AND SCOPE.....                                                | 3           |
| 1.3. LITERATURE REVIEW .....                                           | 4           |
| 1.3.1. MAIN PARAMETERS AFFECTING DEEP DRAWING PROCESS .....            | 4           |
| 1.3.1.1. PUNCH AND DIE GEOMETRY.....                                   | 4           |
| 1.3.1.2. BLANK HOLDER WITH FIXED HEIGHT GAP .....                      | 7           |
| 1.3.1.3. ASPECT RATIO OF FINAL PRODUCT .....                           | 8           |
| 1.3.1.4. DRAWING RATIO OF FINAL PRODUCT .....                          | 8           |
| 1.3.1.4.1 MAXIMUM DRAWING RATIO $\beta_{max}$ .....                    | 8           |
| 1.3.1.4.2 FACTORS AFFECTING $\beta_{max}$ .....                        | 9           |
| 1.3.1.5. BLANK GEOMETRY .....                                          | 10          |
| 1.3.1.5.1 CONVENTIONAL TECHNIQUE.....                                  | 11          |
| 1.3.1.5.2 ENHANCED BLANK GEOMETRY DESIGNS.....                         | 12          |
| 1.3.2. MAIN DEFECTS OF DEEP DRAWING PROCESS.....                       | 13          |
| 1.3.2.1. EARING DEFECT.....                                            | 13          |
| 1.3.2.1.1. ANISOTROPY.....                                             | 14          |
| 1.3.2.1.2. EFFECT OF ANISOTROPY ON DEEP DRAWING PROCESS.....           | 14          |
| 1.3.2.2. THINNING DEFECT.....                                          | 16          |
| 1.3.3. FEA SOFTWARE OVERVIEW.....                                      | 16          |
| 1.4. THESIS ORGANIZATION .....                                         | 16          |
| <b>CHAPTER 2: FINITE ELEMENT MODEL DEVELOPMENT AND VALIDATION.....</b> | <b>18</b>   |



|                                                                                                                   |           |
|-------------------------------------------------------------------------------------------------------------------|-----------|
| 2.1. INTRODUCTION.....                                                                                            | 18        |
| 2.2. PROCESS PARAMETER.....                                                                                       | 20        |
| 2.2.1. PUNCH AND DIE GEOMETRY.....                                                                                | 20        |
| 2.2.2. BLANK HOLDER GEOMETRY.....                                                                                 | 20        |
| 2.2.3. BLANK GEOMETRY.....                                                                                        | 21        |
| 2.2.4. MATERIAL PROPERTIES.....                                                                                   | 25        |
| 2.2.4.1. ISOTROPIC MATERIAL.....                                                                                  | 25        |
| 2.2.4.2. ANISOTROPIC MATERIAL.....                                                                                | 26        |
| 2.2.5. BLANK HOLDER FORCE.....                                                                                    | 27        |
| 2.2.6. FRICTION COEFFICIENT.....                                                                                  | 27        |
| 2.2.8. BLANK MESHING.....                                                                                         | 28        |
| 2.3. MODELS VALIDATION.....                                                                                       | 28        |
| 2.3.1. CASE 1: FEA FOR DEEP DRAWING PROCESS OF A SQUARE CUP .....                                                 | 28        |
| 2.3.1.1. COMPARISON OF DEFORMED SHAPES.....                                                                       | 30        |
| 2.3.1.2. STRAIN MEASUREMENTS ALONG PART'S DIAGONAL .....                                                          | 31        |
| 2.3.2. CASE 2: FEA VALIDATION FOR DEEP DRAWING PROCESS OF<br>A DIFFERENT SHAPES USING ANISOTROPIC MATERIALS ..... | 34        |
| 2.3.2.1. VALIDATION OF PRODUCED MODELS.....                                                                       | 37        |
| <b>CHAPTER 3: PARAMETRIC FEM DESIGN FOR DEEP DRAWING<br/>PROCESS.....</b>                                         | <b>38</b> |
| 3.1. BACKGROUND.....                                                                                              | 38        |
| 3.1.1. INFLUENCE OF PUNCH FILLET RADIUS ON THE MINIMUM SHEET<br>THICKNESS OF THE DEEP DRAWN PRODUCTS .....        | 38        |
| 3.1.2. INFLUENCE OF DIE FILLET RADIUS ON THE MINIMUM SHEET<br>THICKNESS OF THE DEEP DRAWN PRODUCTS .....          | 41        |
| 3.1.3. INFLUENCE OF PUNCH/DIE CLEARANCE ON THE MINIMUM SHEET<br>THICKNESS OF THE DEEP DRAWN PRODUCTS .....        | 43        |
| 3.1.4. INFLUENCE OF BLANK HOLDER GAP HEIGHT ON THE MINIMUM<br>SHEET THICKNESS OF THE DEEP DRAWN PRODUCTS .....    | 45        |
| 3.1.5. INFLUENCE OF THE ASPECT RATIO ON THE MINIMUM SHEET<br>THICKNESS OF THE DEEP DRAWN PRODUCTS .....           | 47        |
| 3.1.6. INFLUENCE OF THE DRAWING RATIO ON THE MINIMUM SHEET<br>THICKNESS OF THE DEEP DRAWN PRODUCTS .....          | 48        |
| 3.2. PARAMETRIC DESIGN BASED ON COMBINED FACTORS.....                                                             | 50        |