

ANALYTICAL AND NUMERICAL DEVELOPMENT ON
THE INDENTATION MECHANISM IN A ROTARY
HAMMER FORGING PROCESS

BY

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ABSTRACT

Rotary hammer forging process is getting popular since it has many advantages as compared to the conventional forging process. The mechanism of the movement in terms of orbital motion of the conical upper die becomes a primary concern of this thesis. This thesis presents the three stages of the modeling of the rotary hammer forging. The first stage is the development of the orbital motion of the conical upper die. Three dimensional CAD model of the conical upper die was developed to determine the orbital motion as a function of the four parameters: Nutation, Precession, Spin and Rocking-Die mechanism. A reasonably accurate design of the conical upper die and the workpiece has been developed based on the motion as a result of interaction of conical upper die and upper part of workpiece geometries. The behavior of orbital motion with any active combination of those four parameters was observed. The second stage was the development of the conical upper die with the specific feature in order to generate a product with an unsymmetrical shape of upper part of the product. The forming sequence and mechanism of the formation of the upper part of product were generated. The third stage was the analysis of the stress strain state during the formation of the upper part of the workpiece. An elastic-plastic, dynamic analysis of 3D rotary hammer forging mechanism with the concern at the workpiece and their interaction with a model of dies have been performed. Verification of the indentation mechanism of the rotary hammer forging had been done by validating the result with the existing experimental results.

مُلخَّص البحث

أصبح التطريق الآلي للمثقاب الكهربائي "المطرقة الدورانية" شائعًا اليوم بسبب عدد من المزايا مقارنة بالتطريق التقليدي، ويهدف هذا البحث إلى دراسة آلية الحركة الدورانية للقاطع العلوي المخروطي، ويتناول المراحل الثلاث لعملية قولبة التطريق الآلي للمثقاب الكهربائي وتشكيله، فالمرحلة الأولى تصنيع الحركة الدورانية للقاطع العلوي المخروطي، وفيها صُنِعَ أنموذج ثلاثي الأبعاد (بوساطة الحاسوب) للقاطع العلوي المخروطي لتحديد وظيفة الحركة الدورانية بناءً على أربعة معاملات هي: الميلان، والبدارية، واللف المغزلي (التدويم)، وآلية اهتزاز القاطع، وصُنِعَ تصميم دقيق للقاطع العلوي المخروطي بناءً على الحركة الناتجة من التبادل بينه وبين الجزء العلوي للقطعة المصممة هندسيًا، مع مراقبة الحركة الدورانية وفق المعاملات الأربعة السابقة، والمرحلة الثانية كانت تطوير القاطع العلوي المخروطي مع ميزة محددة لإنشاء منتج غير متمائل الشكل من الجزء العلوي للمنتج، وصُنِعَت بنية متسلسلة وآلية تشكيل لذلك الجزء، وفي المرحلة الثالثة كان تحليل الجهد في أثناء تكوين الجزء العلوي من القطعة المصنعة، وإجراء تحليل ديناميكي لمعامل المرونة ثلاثي الأبعاد لآلية طرق المثقاب الكهربائي مع الأخذ في الحسبان القطعة المصممة هندسيًا وتناسبها مع قوالب القواطع، وفي النهاية كانت المرحلة الرابعة، وفيها التحقق من آلية التسنين (المسافة الفارغة) للمثقاب الكهربائي من خلال مقارنة نتائج هذا البحث.

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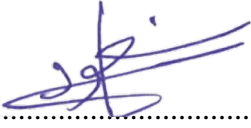
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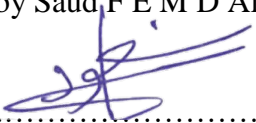
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Firstly, it is my utmost pleasure to dedicate this work to my dear parents and my family, who granted me the gift of their unwavering belief in my ability to accomplish this goal: thank you for your support and patience.

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TABLE OF CONTENTS

Abstract	ii
Abstract in Arabic	iii
Approval Page	iv
Declaration	v
Acknowledgements	vii
Table of Contents	viii
List of Tables	x
List of Figures	xii
List of Equation	xvii
List of Abbreviation	xviii
List of Symbols	xix
CHAPTER ONE INTRODUCTION	1
1.1 Overview	1
1.2 Problem Statement and Motivation	1
1.3 Aims and Objectives	2
1.4 Research Gaps	2
1.5 Research Philosophy	3
1.6 Research Hypotheses	4
1.7 Thesis Scope	4
1.8 Limitations	4
1.9 Thesis Organization	5
1.10 Chapter Summary	6
CHAPTER TWO LITERATURE REVIEW	7
2.1 Overview	7
2.2 Classification of Forging Processes	9
2.3 History of Rotary Forging Machine	16
2.4 Characteristic of Rotary Forging	17
2.5 Mechanism of Rotary Forging	18
2.6 Features of Rotary Forging Machine	19
2.7 Orbital Motion in Rotary Forging	21
2.8 Development of the Rotary Forging Machines	24
2.9 Rotary Press Forging and Hammer Forging	26
2.10 Load Component in Rotary Hammer Forging	31
2.11 Dies in Rotary Forging	31
2.12 Advantages and Limitations	32
2.13 Friction in Rotary Forging	34
2.13.1 Friction in a Cold Rotary Forging	34
2.13.2 Evaluating Friction in a Cold Rotary Forging	35
2.13.3 Lubrication	39
2.13.4 Type of Lubrication	40
2.14 Friction Models	44
2.14.1 Coulomb Model	45
2.14.2 Constant Friction Model	47
2.14.3 General Friction Model	47
2.15 Workpiece Materials	49

2.15.1 Alloy-Metal based Forging	49
2.15.2 Strengthening Mechanisms in Alloy Steels	53
2.15.3 Material Selection in Forging	55
2.16 Latest Rotary Forging Models and Work	59
2.17 Chapter Summary	61
CHAPTER THREE METHODOLOGY	62
3.1 Overview.....	62
3.2 Defining Eulerian Parameters.....	64
3.3 Mathematical Modeling.....	66
3.4 Analytical Model	67
3.5 Validation	70
3.6 Benefit of Forging Simulation	70
3.7 Flow of the Modeling	73
3.8 Finite Element Modeling in AFDEX.....	76
3.9 AFDEX Analysis Method	77
3.10 Geometry of Basic Shape	78
3.11 Meshing Technique	79
3.12 AFDEX Material Library	81
3.13 AFDEX Friction Model.....	83
3.14 AFDEX Dies Movement	85
3.15 AFDEX Forming Control.....	86
3.16 Chapter Summary	88
CHAPTER FOUR RESULTS AND DISCUSSION	89
4.1 Overview.....	89
4.2 Identifying the Orbital Motion of Conical Die.....	89
4.3 Orbital Motion of the Rotary Press Forging.....	90
4.4 Orbital Motion of the Rotary Hammer Forging	95
4.5 Analysis on Indention Mechanism	98
4.6 CAD Design of the Upper Conical Die and Workpiece.....	99
4.7 Meshing of the Upper Conical Die and Workpiece.....	100
4.8 Determining the Boundary Condition	101
4.9 Result of the Indentation Process	103
4.10 Discussion.....	105
4.11 Chapter Summary	110
CHAPTER FIVE CONCLUSION AND FUTURE WORKS	111
5.1 Conclusion	111
5.2 Thesis Contribution	112
5.3 Future Work.....	113
REFERENCES	115
PUBLICATIONS.....	122

LIST OF TABLES

Table 2.1: Application of forging in general	8
Table 2.2: Cold and hot forging characteristic (Abachi et al., 2010).	13
Table 2.3: Temperature range for various process (Abachi et al., 2010)	14
Table 2.4: Comparison of press and drop forging (Mao, 2009)	15
Table 2.5: Rotary forging machines and their respective motion	23
Table 2.6: Lubricant and their respective coefficient of friction (Shenoy, 2009)	41
Table 2.7: Advantages and disadvantages of some lubricants (Shenoy, 2009)	42
Table 2.8: Model of friction as extracted from some experiments.	45
Table 2.9: SAE-AISI code of alloy steel	50
Table 2.10: The effect of the additional alloy element to the alloy steel	51
Table 2.11: Alloy and their respective working temperature range (Adapted from Ashby, 1999)	53
Table 2.12: Comparison of property for different forging treatment. (Adapted from Ashby, 1999)	56
Table 2.13: Grouping of alloy with their respective characteristic and application. (Adapted from Ashby, 1999)	57
Table 2.14: Relation between flow strength and forge ability (Adapted from Ashby, 1999)	58
Table 2.15: Maximum die loads for some materials (Adapted from Ashby, 1999)	59
Table 2.16: A comparison of the modeling and simulation methods.	60
Table 3.1: Model approaches used for the current FEA	72
Table 3.2: Some of the available AFDEX modules	78
Table 3.3: Profile of the local mesh density	80
Table 3.4: Flow stress model available in AFDEX	83
Table 3.5: Type of lubrication for forging process.	84
Table 3.6: Type of dies movement	85

Table 3.7: Machine forging configuration in AFDEX	86
Table 3.8: The configuration of the forming control	87

LIST OF FIGURES

Figure 2.1: Some forged components in the automotive industry. Retrieved from Batliboi (2020)	7
Figure 2.2: Structural Components. (Retrieved from NTRS, 2020)	8
Figure 2.3: [Online Image.]. (1893). Classic blacksmith scene showing the open die forging. Archived from Edison National Historic Site.	9
Figure 2.4: David Darling. (1850). Forging at the beginning of the industrial era Retrieved from https://www.steelavailable.com/en/history-steel-forging/	10
Figure 2.5: Open die forging (a) Initial condition, (b) and (c) Forging process. (Adapted from Rathi & Jakhede, 2014)	10
Figure 2.6: Closed die or impression die-forging from starting point until finish. (Adapted from Groover, 2007)	11
Figure 2.7: Some closed die forging product. (n.d).	12
Figure 2.8: Classification of forming process based on working temperature. (Adapted from Dieter, 2005)	13
Figure 2.9: A large press forging machine. (2011).	15
Figure 2.10: Concept of Rotary Forging	19
Figure 2.11: Detail view of the rotary forging machine. (Adapted from Han and Hua, 2009).	20
Figure 2.12: Zooming view around workpiece region. (Adapted from Han and Hua, 2009)	21
Figure 2.13: Three angular movements: (a) Nutation, (b) Precession and (c) Spin	22
Figure 2.14: Nutation movement (Adapted from Grieve, 1991)	23
Figure 2.15: Modern Rotary Forging mechanism. (Adapted from Nowak et al., 2008).	24
Figure 2.16: First generation of rotary forging machine. (Adapted from Staler, 1969)	25
Figure 2.17: Two types rotary forging machines. Retrieved from https://mjcengineering.com/machines/additional-equipment/rotary-forging-equipment/	25

Figure 2.18: Configuration of the Rotary Forging. (Adapted from Hamdy, 2014).	27
Figure 2.19: Detail of the rotary forging configuration. (Adapted from Hopkins & Sewell, 2016)	28
Figure 2.20: Type of rotary forging mechanism. (Adapted from Hopkins & Sewell, 2016)	28
Figure 2.21: Typical pattern of the upper die motion. (Adapted from Hopkins & Sewell, 2016)	29
Figure 2.22: Rock-rolling motion angle variation (Adapted from Hopkins & Sewell, 2016)	30
Figure 2.23: Product with the result of rotary forging at the upper part. (Adapted from Han et al, 2014)	31
Figure 2.24: Some popular test to determine the friction coefficient. (Adapted from Reddy et al., 2010)	36
Figure 2.25: Result of ring test for (a) low friction and (b) high friction coefficient. (Adapted from Guangchun et al., 2005)	37
Figure 2.26: Flow direction of the ring test specimen. (Adapted from Guangchun et al., 2005)	37
Figure 2.27: Internal diameter reduction vs. height reduction. (Adapted from Chung & Hwang, 2002)	39
Figure 2.28: Change of diameter as a function of axial compression. (Adapted from Kubo, 1985)	43
Figure 2.29: The relation between lateral and longitudinal strain. (Adapted from Kubo, 1985)	44
Figure 2.30: Friction model of the two contacted surfaces (Adapted from Yang, 2019)	46
Figure 2.31: Stick-slip behavior of Coulomb model (Adapted from Yang, 2019)	46
Figure 2.32: Friction stress as a function of friction factor and pressure (Adapted from Yang, 2019)	48
Figure 2.33: Flow stress for different type of steel (Adapted from Ashby, 1999)	49
Figure 2.34: Comparison of the mechanical properties for various alloy (Adapted from Ashby, 1999)	52
Figure 2.35: Effect of the grain size to the yield stress and ITT (Adapted from Meyersm & Ashworth, 1982)	54

Figure 2.36: Effect of microstructure treatment to the ITT (Adapted from Meyersm & Ashworth, 1982)	55
Figure 3.1: The Simulation Steps	64
Figure 3.2: General rotary forging tool and workpiece	65
Figure 3.3: The three Eulerian motions	66
Figure 3.4: Schematic diagram of the geometrical and kinematic relationship between the upper die and upper profile of the workpiece.	68
Figure 3.5: Analytical design process of the base of the conical upper die.	69
Figure 3.6: Role of FEM in the overall development process	71
Figure 3.7: Material model based on their flow stress	73
Figure 3.8: Benefit of forging simulation	73
Figure 3.9: Flowchart of the forging simulation	74
Figure 3.10: Shape sensitivity flow chart	75
Figure 3.11: The cycle of forging simulation	75
Figure 3.12: Modeling flow in AFDEX	77
Figure 3.13: Basic shapes in AFDEX	78
Figure 3.14: Model of product/structure as 1D, 2D and 3D elements	79
Figure 3.15: Local Meshing with mesh density feature	81
Figure 3.16: Flow stress of SCM440 alloy steel in the AFDEX library	82
Figure 4.1: The geometrical setup of orbital motion analysis	90
Figure 4.2: Orbital plot of point Pt1 with N (Nutation angle) = $5^{\circ} \pm 30^{\circ}$ with P (Precession) and S (Spin) are rotated simultaneously	91
Figure 4.3: Orbital plot of point Pt1 with N (Nutation angle) = $5^{\circ} \pm 30^{\circ}$ with P (Precession angle) is maintained stationary and S (spin) rotate 1 cycle	91
Figure 4.4: Orbital Plot of point P1 with N (Nutation angle) = $5^{\circ} \pm 30^{\circ}$ with S (spin angle) maintained stationary but the P (Precession angle) rotates 1 cycle.	92
Figure 4.5: Orbital plot of point Pt1 with N (Nutation angle) = $5^{\circ} \pm 30^{\circ}$, P and S stationary.	92

Figure 4.6: Orbital plot of point Pt1 with N is stationary while P and S stationary are both active.	93
Figure 4.7: Orbital plot of point Pt1 with N (Nutation angle) stationary at 5° with P and S rotated simultaneously	93
Figure 4.8: Orbital plot of point Pt1 with N (Nutation angle) rotate at $5^{\circ}\pm 30^{\circ}$, P rotates and S is rotated faster twice the cycle of P	94
Figure 4.9: Orbital plot of point Pt1 with N (Nutation angle) rotates at $5^{\circ}\pm 30^{\circ}$, P rotates twice faster and S is stationary	94
Figure 4.10: Orbital plot of point Pt1 with R (Rocking-Die) at 10 mm amplitude, N (Nutation angle) rotates at $5^{\circ}\pm 30^{\circ}$, P and S are rotating simultaneously	95
Figure 4.11: Orbital plot of point Pt1 with R (Rocking-Die) at 10 mm amplitude, N (Nutation angle) rotates at $5^{\circ}\pm 30^{\circ}$, S rotates and P is stationary.	96
Figure 4.12: Orbital plot of point Pt1 with R (Rocking-Die) at 10 mm amplitude, N (Nutation angle) rotates at $5^{\circ}\pm 30^{\circ}$, P rotates and S is stationary	96
Figure 4.13: Orbital plot of point Pt1 with R (Rocking-Die) at 10 mm amplitude, N (Nutation angle) rotates at $5^{\circ}\pm 30^{\circ}$, P and S are stationary	97
Figure 4.14: Orbital plot of point Pt1 with R (Rocking-Die) at 10 mm amplitude, N (Nutation angle) stationary at 5° , P and S are rotated simultaneously	97
Figure 4.15: Orbital plot of point Pt1 with R (Rocking-Die) at 10 mm stroke N (Nutation angle) rotates at $5^{\circ}\pm 30^{\circ}$, P is stationary and S rotates two times faster	98
Figure 4.16: The CAD model of upper conical die	99
Figure 4.17: The CAD model of the workpiece	99
Figure 4.18: The meshing model of the conical upper die.	100
Figure 4.19: The initial meshing of the workpiece	101
Figure 4.20: Boundary condition of the rotary hammer forging	102
Figure 4.21: Incorporating the orbital motion into the boundary condition	103
Figure 4.22: Pressure contour result of the first indentation deformation	103
Figure 4.23: Pressure contour result of the second indentation deformation	104
Figure 4.24: Pressure contour result of the third indentation deformation	104
Figure 4.25: Pressure contour result of the fourth indentation deformation	105

Figure 4.26: A validation of results for load vs time.	107
Figure 4.27: Height reduction vs diameter of workpiece (Experimental and Simulated results)	107
Figure 4.28: Load comparison of conventional and orbital forging	109

LIST OF EQUATION

Eq. 2.1: Euler motion in X axis	22
Eq. 2.2: Euler motion in Y axis	22
Eq. 2.3: Euler motion in Z axis	22
Eq. 2.4: Coulomb Friction	45
Eq. 2.5: Pure shear friction condition	47
Eq. 2.6: Slip line friction	48
Eq. 2.7: Friction factor f	48
Eq. 2.8: Limit of proportionality	48
Eq. 3.1: Co-ordinates of a point on a rigid body in X axis	68
Eq. 3.2: Co-ordinates of a point on a rigid body in Y axis	68
Eq. 3.3: Co-ordinates of a point on a rigid body in Z axis	68
Eq. 3.4: Geometrical relationship between arc length AB	68
Eq. 3.5: Geometrical relationship between arc length A'B'	69

LIST OF ABBREVIATIONS

AFDEX	Adviser for metal Forming Process Design EXpert
CAD	Computer Aided Design
MATLAB	MATrix LABoratory
PLC	Product Life Cycle
SAE-AISI	Society of Automotive Engineers - American Iron and Steel Institute

LIST OF SYMBOLS

\emptyset	Precession
φ	Spin
θ	Nutation
F	Lateral Force
P	Normal Force
A	Whole contact area
σ	Normal stress
τ	Shear stress
μ	Coefficient of friction
m	Shear friction factor
k	Shear flow stress
θ	The rotational angle of upper die
θ'	The sweeping angle of upper die
γ	The inclination angle

CHAPTER ONE

INTRODUCTION

1.1 OVERVIEW

Rotary Hammer Forging is one type of a forging process. It has another name which is called Wobble Die Forging. In this thesis, the term Rotary Hammer Forging will be used instead of the other names. Some parts which have a circular feature such as bearing housing, gears especially bevel type and differential type, chain sprocket, coupling and clutch hubs. Those parts can be found mostly in the automotive industry. Nearly 85% of all forged parts have a circular shape.

In the era of extreme global competition, especially in the forging industry, the company which can survive is the one that has better processes and material selection. Process improvement toward an efficient process will enhance the forging quality which will lead to the cost reduction and greater productivity. The use of advanced work piece material which has better mechanical properties allows the fabrication of the product with a more complex shape.

1.2 PROBLEM STATEMENT AND MOTIVATION

Designing new forging process for a more complicated shape of an object is a challenging activity. To compete and be able to survive in the manufacturing industry in general and specifically forging industry requires a relatively faster and accurate method of designing forging mechanism as well as the dies design (Han, et al., 2014). It is a quite complex issue that will increase the Product Life Cycle. In this era of rather competitive business, having a longer product life cycle will help the vendor to compete

and survive. There is a need to develop a new design method, especially in this case, for a forging product that can deliver a product design faster and reasonably accurate.

1.3 AIMS AND OBJECTIVES

Proposing a new method as a framework to design and develop a forging process as well as die design in a rotary hammer forging mechanism is the main objective of this research. Forging process refers to defining a set of configuration parameters which governs the hammer forging process.

The research objectives can be broken down into three sub-research objectives which are described in the subsequent statements:

1. To develop an analytical of orbital motion of the conical upper die of a rotary hammer forging process, in order to identify the behavior under different configurations of forging parameters.
2. To design the conical upper die with a specific feature and specific forging configuration.
3. To develop a numerical stress analysis based on Finite Element Model of the indentation process of the conical upper die to the upper region of the work piece.

1.4 RESEARCH GAPS

The research was developed so that one may find the answers to the following research questions:

1. Is there any standard guideline to design the conical upper die of a rotary hammer forging?

2. How to predict or generate the motion of conical upper die based on a set of parameter configuration setting?
3. How to select the suitable material to be used for a work piece and the dies in the rotary hammer forging?
4. Which friction model is suitable in modeling interaction contact between work piece and upper conical and lower die?

1.5 RESEARCH PHILOSOPHY

In the development of indentation mechanism in a rotary hammer forging process, description of the research philosophy is discussed. The first stage of the research is the development of the analytical model. At this stage an integration of Solid works with the add-on Motion feature and Matlab script has been utilized. The CAD (Computer Aided Design) model of the conical upper die as well as the work piece has been developed. One point of interest has been identified and marked. Using the Euler law of motion, the orbital motion equation has been derived analytically involving the parameters of orbital motion: Nutation, Precession, Spin and the Rocking-Die mechanism.

The second stage is the development of the additional feature at the upper conical die in order to generate workpiece with more intricate shape. The model was developed using Solidworks software. The developed model refers to the existing upper conical die shape. The scenario of the indentation process by combining the orbital motion at different sets of parameters of the upper conical die developed in the previous stage has been generated.

The third stage is the stress analysis of the indentation process. The CAD model of the interaction of the upper conical die and the workpiece was transferred to the

AFDEX environment in order to perform a numerical, finite element based analysis of the rotary forging process.

1.6 RESEARCH HYPOTHESES

The research hypotheses on guidelines to the development of analytical and numerical model of the rotary hammer forging are as follows:

1. There is no unique way of the formation of the profile indented to the upper part of the workpiece. A different combination of the hammer forging parameters may offer alternate solutions.
2. Friction condition at the interfacial contact between the conical upper die and the workpiece will affect the process of the indentation.
3. Assumption of the conical upper dies as a rigid body object is reasonable

1.7 THESIS SCOPE

This study contributed to the research and development in the forging industry sector. Shortening the PLC (Product Life Cycle) of a forging product becomes a compulsory requirement at the time of high and critical competition in any sector, especially in the manufacturing field. The proposed method, hopefully, can speed up the design stage in a relatively significant amount of time.

1.8 LIMITATIONS

As opposed to the conventional bulk forging processes, the development of software for rotary forging is a competitive and viable alternative and involves the areas of simulation and machine control. However, a huge gap remains due to the fact that there are many commercially available finite element packages for forging but they are too

generalized for rotary forging. This is due to the difficulty in the accommodation of rotary forging motions and problems defining the boundary conditions for rotating dies, thus making the computing power requirements prohibitive, in a way. This is something that needs to be further worked on.

A further extensive study is needed to understand the cold rotary forging process better using both theoretical analysis and experimental studies hand-in-hand. It is the significance of this study that will help to escalate the overall design process in the manufacturing industry.

1.9 THESIS ORGANIZATION

The thesis structure proceeds as follows: Chapter 1 presents an introduction and brief overview on Rotary Hammer Forging. This chapter also covers problem statement, objectives, limitations and thesis scope.

Chapter 2 provides the details about history, literature review on the forging of rotary hammer process over time and the latest developments. This chapter discusses the utilization of all rotary forging parameters and how there is still a huge scope of improvement in this field. Additionally, this chapter covers the friction models and different workpiece materials as well.

In chapter 3, the selected research methodology and processes applied to fulfil the research objectives are described in detail. The chapter also illustrates the steps in the forging simulation. The use of Solidworks, AFDEX and MATLAB is further discussed in this chapter. The description on validation of the model is also discussed in this chapter.