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

BY

SAUD F E M D ALAZEMI

A thesis submitted in fulfillment of the requirement for the degree of Doctor of Philosophy (Engineering)

Kulliyyah of Engineering
International Islamic University Malaysia

NOVEMBER 2020

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 صُنع أنموذج ثلاثي الأبعاد (بوساطة الحاسوب) للقاطع العلوي المخروطي لتحديد وظيفة الحركة الدورانية بناء على أربعة معاملات هي: الميلان، والبدارية، واللف المغزلي (التدويم)، وآلية اهتزاز القاطع، وصُنع تصميم دقيق للقاطع العلوي المخروطي بناء على الحركة الناتجة من التبادل بينه وبين الجزء العلوي للقطعة المصممة هندسيًّا، مع مراقبة الحركة الدورانية وفق المعاملات الأربعة السابقة، والمرحلة الثانية كانت تطوير القاطع العلوي المخروطي مع ميزة محددة لإنشاء منتج غير متماثل الشكل من الجزء العلوي للمنتج، وصُنعت 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 هندسيًّا وتناسبها مع قوالب القواطع، وفي النهاية كانت المرحلة الرابعة، وفيها التحقق من آلية التسنين (المسافة الفارغة) للمثقاب الكهربائي من خلال مقارنة نتائج هذا البحث.

APPROVAL PAGE

The thesis of Saud F E M D Alazemi has been approved by the following:

Erry Yulian T. Adesta
Supervisor

Co-Supervisor

Mohammad Yeakab Ali
Internal Examiner

Mohd Hamdi Abd Shukor
External Examiner

Safian Sharif
External Examiner

Saim Kayadibi
Chairman

DECLARATION

I hereby declare that this thesis is the result of my own investigations, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

(Saud F E M D Alazemi)

Signature... Date.....17 Nov 2020.............

INTERNATIONAL ISLAMIC UNIVERSITY MALAYSIA

DECLARATION OF COPYRIGHT AND AFFIRMATION OF FAIR USE OF UNPUBLISHED RESEARCH

ANALYTICAL AND NUMERICAL INVESTIGATION ON THE IDENTATION MECHANISM IN A ROTARY HAMMER FORGING PROCESS

I declare that the copyright holders of this thesis are jointly owned by the student and IIUM.

By signing this form, I acknowledged that I have read and understand the IIUM Intellectual Property Right and Commercialization policy.

Affirmed by Saud F E M D Alazemi

……..…………………….. ……17 Nov 2020…..

Signature Date

ACKNOWLEDGEMENTS

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.

I wish to express my appreciation and thanks to those who provided their time, effort and support for this project. To the members of my dissertation committee, thank you for sticking with me.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF EQUATION

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

∅	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.