UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT OF CAD/CAM SYSTEM FOR COLD WORKING CLOSED DIE FORGING PROCESS

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By

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Thesis Submitted in Fulfilment of Requirements for the Degree of Master of Science in the Faculty of Engineering Universiti Putra Malaysia

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DEDICATED TO

MY PARENTS

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirements for the degree of Master of Science.

DEVELOPMENT OF CAD/CAM SYSTEM FOR CLOSE DIE FORGING PROCESS

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June 2000

Chairman: A. M. S. Hamouda, Ph D.

Faculty: Engineering

The application of computer-aided engineering (CAE), design (CAD), and manufacturing (CAM), is essential in modern metal forming technology. Thus, process of modelling for the investigation and understanding of deformation mechanics has become a major concern in recent and advanced research, and the finite element method (FEM.) has assumed increased importance, particularly in the modelling of deformation processes.

This work is devoted to the development of CAD/CAM system for closed die forging process. The system development consists of three stages: namely, metal flow simulation, die failure analysis and design optimisation, and development and implementation of machining code. In the first stage, the finite element method was used to simulate the axisymmetric closed die forging process of copper material. The method was used to study the metal flow, die filling retaining the non-linearity involved in the large change in the geometry, the continuous change in the contact surface condition and the isotropic material work-hardening characteristics. In the second stage, a finite element analysis and optimisation algorithm was developed to

examine the die fatigue life and to optimise the die design. The finite element analysis in the first and second stage was carried out using commercially available finite element software called LUSAS. In the third stage, a machining code for the optimised die was developed and implemented using CAD/CAM software called UniGraphics and CNC machine. A qualitative comparison between the computational results and experiments ware made.

It had been found that the early stage of the metal flow in closed die forging was very similar to a simple upsetting, then the material flows into the die cavity and towards the flash land leading to a very sharp increase in forging load. The die was designed to sustain the forging load and withstand 1000 load cycles.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Master Sains.

PEMBANGUNAN SISTEM CAD/CAM BAGI PROSES ACUAN TEMPAAN TERTUTUP

Oleh

MOHAMED A. ABDULMAWLLA

June 2000

Pengerusi: A.M.S. Hamouda, Ph.D.

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Aplikasi kejuruteraan terbantu komputer (CAE), reka bentuk terbantu komputer (CAD) dan pembuatan terbantu komputer (CAM) adalah penting dalam teknologi pembentukan logam moden. Jadi, pemodelan proses bagi kajian dan pemahaman mekanik ubah bentuk telah menjadi satu tumpuan utama dalam penyelidikan terkini dan maju, dan kaedah unsur terhingga (FEM) telah menjadi begitu penting, terutamanya dalam pemodelan proses ubah bentuk.

Penyelidikan ini ditumpukan kepada pembangunan sistem CAD/CAM bagi proses tempaan acuan tertutup. Pembangunan sistem terdiri dari 3 tahap: iaitu penyelakuan aliran logam, analisis kegagalan acuan dan pengoptimuman reka bentuk, dan pembangunan dan pelaksanaan kod pemesinan. Dalam tahap pertama, kaedah unsur terhingga telah digunakan untuk menyelaku proses tempaan acuan tertutup paksi simetri bagi bahan tembaga. Kaedah ini telah digunakan untuk mengkaji aliran logam, pengisian acuan dengan mengekalkan ketaklelurusan yang terlibat dalam perubahan besar geometri, perubahan berterusan dalam keadaan permukaan sentuhan dan ciri-ciri pengerasan kerja bahan isotropi. Dalam tahap

kedua, satu analisis unsur terhingga dan algorithma pengoptimuman telah dibangunkan untuk memeriksa hayat lesu acuan dan mengoptimum reka bentuk acuan. Analisis unsur terhingga dalam tahap pertama dan kedua telah dilaksanakan menggunakan perisian unsur terhingga yang wujud secara komersial yang dipanggil LUSAS. Dalam tahap ketiga, kod pemesinan bagi acuan teroptimum telah dibangunkan dan dilaksanakan menggunakan perisian CAD/CAM yang dipanggil UniGraphics dan mesin CNC. Satu perbandingan kualitatif di antara keputusan perkomputeran dan ujikaji telah dilakukan.

Telah dapat diperhatikan bahwa pengaliran logam diperingkat awal penempaan acuan tertutup adalah bersamaan dengan tempa-dempak mudah. Bahan kemudiannya mengalir ke rongga acuan menuju ke flash-land. Fonomema ini mengakibatkan beban tempaan meningkat dengan mendadak.Acuan tersebut telah direkabentuk agar mampu menerima beban tempaan dengan selamat dan dapat menahan beban sehingga 1000 kitaran.

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I certify that an Examination Committee met on 19th June 2000 to conduct the final examination of Mohamed A Abdulmawlla on his Master of Science thesis entitled "Development of CAD/CAM System for Closed Die Forging Process" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981 The Committee recommends that the candidate be awarded the relevant degree Members of the Examination Committee are as follows

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This thesis submitted to the Senate of Universiti Putra Malaysia and was accepted as fulfilment of the requirements for the degree of Master of Science.

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Date: 13 JUL 2000

DECLARATION FORM

I hereby declare that the thesis is based on my original work except for quotations and citations, which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

Signed

Name: Mohamed A. Abdulmawlla
Date: 26 June 2000

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ABBREVIATIONS AND NOMENCLATURES

FE	Finite Element
CNC	Computer Numerical Control
NC	Numerical Control
CLSF	Cutter Location Source File
APT	Automatically Programmed Tools
D	Diameter
H	Height
P_t	Total load on the die
P	Load
P_y	Yielding load
σ_y	Yield stress of the forged material
A	Cross sectional area of the billet
E	Modulus of elasticity
CAD	Computer Aided Design
CAA	Computer Aided Analysis
CAM	Computer Aided Manufacturing
FEM	Finite Element Method
$f(\sigma_{ij})$	Yield function
σ_{ij}	Cauchy stress
σ_{ij}'	Deviatoric stress
$\bar{\sigma}$	Effective stress, flow stress
λ	Lagrangian multiplier
v_o	Initial velocity vector at nodal point

v : Velocity vector at nodal point

ν : Poisson's ratio

$\bar{\varepsilon}$: Effective strain

$\dot{\bar{\varepsilon}}$: Effective strain rate

$\dot{\lambda}$: Proportionality factor (rate) in flow rules

c : Constant

$\dot{\varepsilon}_{ij}$: Strain rate

u_t : Velocity component tangent to a surface

K : Penalty constant

F_i : Traction

α : Deceleration coefficient

V : Volume

S : Surface

S_F : Surface where traction is prescribed

E ($\dot{\varepsilon}_{ij}$) : Work function

π : Functional

$\delta\pi$: Variation of functional π

$\dot{\varepsilon}_v$: Volumetric strain rate

S_u : Surface where velocity is prescribed

Δv : Velocity corrections of nodal values

K : Stiffness matrix

f : Nodal point force vector

CHAPTER I

INTRODUCTION

In this chapter, the undertaking of the work is justified, identify the aims of the study and outline the method of approach adopted to achieve the set objectives. Finally, a summary of the content of different chapters is provided under the heading "Layout of thesis".

Importance of the Study

In manufacturing operations many parts are formed into various shapes by applying external forces to the workpiece by means of tools and dies. Typical operations are forging, extrusion and rolling. Because deforrnation in these processes is carried out by mechanical means, an understanding of the behaviour of the materials in response to applied forces is important. In addition, the behaviour of manufactured part during its expected service life is an important consideration.

Unlike rolling operation, which generally produce continuous plates, sheets, and strips, forging operation produce wide variety of discrete parts. Metal flow and the grain structure can be controlled, so forged parts have good strength and toughness. Thus they can be used reliably for highly stressed and critical applications. Die design material behaviour during deformation, as well as friction, and material flow characteristics in a die cavity, are important in design consideration. Also important is the proper selection of die-materials, temperature, speed, lubricant and equipment.

Recently, computer-aided design and manufacturing are being implemented increasingly in all aspects of forging design and manufacturing. Techniques being used include modelling of the deformation of the workpiece and finite element analysis during forging in the dies, die design, calculation of forces, and prediction of die failure.

Problem Definition and Scope of the Work

The ultimate goal of manufacturing engineer is to produce component of selected material with a required geometrical shape and a structure optimised for the proposed service environment. In general, forging processes tend to be complex system of independent variables, dependent variables and independent-dependent interrelations. Independent variables are those aspects of the process over which the engineer has a direct control and are generally selected or set up when setting up the process. Among the typical independent variables considered are: -

- Starting material. The engineer must specify the chemistry and the condition of the material to be machined.
- Starting workpiece geometry. This may be dictated by previous processing or may be selected by the engineer from a variety of available shapes, often on basis of economics.

- Tool or die geometry It has many aspects such as the die material, die angles and cavity details, which have wide variety and so different effect on the process
- Amount of deformation. The amount of deformation is limited by the material properties and its ability to deform It should be taken in consideration during die design according to the shape of the workpiece material

After the manufacturing engineer specifies the independent variables, the process then determines the nature and values for a second set of variables, known as dependent variables Examples include -

- Force and power requirements. To deform a given material from a given starting shape to a specified final shape, with a specified friction coefficient, speed and starting temperature, will require a certain amount of force or power A change in any of the independent variables will bring about a change in the force or power required
- Material properties of the product. While the engineer can specify the properties of the starting material, the combined deformation and temperature changes imparted by the process will certainly modify them. The customer is not interested in the starting properties, but rather the final properties of the product. Thus, while it is often desirable to select starting properties based on compatibility with the process, it is also necessary to know or be able to predict how the process will alter them.

- Surface finish and precision. Both are product characteristic and depends on the specific details of the process.
- Nature of material flow Deformation process exerts external constrains on the material through control and movement of its surfaces. Since properties depend on the deformation history, control here is vital

As illustrated in Table 1 the problem facing the metal forming engineer becomes quite obvious On one hand are the independent variables, those aspects of the process over which he/she has direct control On the other are the dependent variables, those aspect over which he/she must have control but for which his/her influence is indirect The dependent variables are determined by the process based on proper selection of the independent variables If a dependent variable is to be modified, the engineer must determine which independent variable (or variables) is to be changed, in what manner, and by how much Thus, the engineer must have knowledge of the independent-dependent variable interrelations

Table 1 Metal forming system

Independent variables		**Dependent variables**
Starting material Starting workpiece geometry Tool or die geometry Lubricant and friction Amount of deformation	Experience Experiment Theory	Force and power requirements Material properties of the product Surface finish and precision Nature of metal flow

The link between the independent and dependent variables is the most important area of knowledge for the manufacturing engineer Unfortunately, such links are often difficult to obtain Metal forming process is a complex system composed of the material being deformed, the tool performing the deformation and various other process parameters Also various materials often behave differently

The ability to predict and control dependent variables, therefore, comes about in one of three ways -

1 Experience This requires long-time exposure to the process and is often restricted in scope by the realm of past contact

2 Experiment While possibly the least likely to be in error, direct experiment is both costly and time consuming

3 Modelling. Here one attempt to develop a mathematical model of the process into which numerical values for the various independent variables can be inserted and compute a prediction for the dependent variables. Most techniques rely on the applied theory of plasticity with two-dimensional stresses. Alternatives vary from first-order approximations, such as slab equilibrium or uniform deformation energy calculation, to sophisticated, computer-based, solution, such as the finite element or finite difference methods

Objective

The present work focuses on simulating non-steady forging process using a finite element technique in order to come up with a clear and better understanding of metal flow and stress distribution in the process It is also to study the effect of independent and dependent variables on the die So the aims of this work are -

- To develop a finite element algorithm to model forging process
- To conduct finite element analysis and optimisation on the die life
- To develop a CNC code for the manufacturing of the die

Thesis Layout

The thesis is organised into seven chapters The first chapter gives an introduction to the research and its objectives The second chapter contains an up to date literature review metal forming history, basic aspects of forging and some important terms and definitions The third chapter contains a brief and general overview about this work and the finite element software used in analysing the forging process The fourth chapter contains application of FEA to non-steady state closed die forging process, die optimisation and die fatigue analysis using LUSAS software The fifth chapter contains die modelling using CAD/CAM software and generating the machining code for die manufacturing The sixth chapter contains the results and discussion The final chapter contains conclusion and suggestions for future work