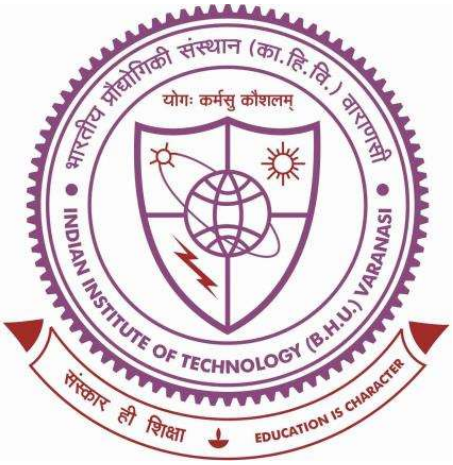
Design and Development of a Robot-Assisted Incremental Sheet Hydroforming Setup



THESIS SUBMITTED FOR THE AWARD OF THE DEGREE OF

Doctor of Philosophy

in

Mechanical Engineering

by

Ravi Prakash Singh

Under the Supervision of

Prof. Santosh Kumar

DEPARTMENT OF MECHANICAL ENGINEERING

INDIAN INSTITUTE OF TECHNOLOGY

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May 2023 **Roll No. 16131006**

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It is further certified that the student has fulfilled all the requirements of Comprehensive Examination, Candidacy and SOTA for the award of Ph.D. Degree.

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DECLARATION BY THE CANDIDATE

I, Ravi Prakash Singh, certify that the work embodied in this thesis is my own bonafide work and carried out by me under the supervision of Prof. Santosh Kumar from July 2016 to May 2023, at the Department of Mechanical Engineering, Indian Institute of Technology (Banaras Hindu University), Varanasi. The matter embodied in this thesis has not been submitted for the award of any other degree/diploma. I declare that I have faithfully acknowledged and given credits to the research workers wherever their works have been cited in my work in this thesis. I further declare that I have not wilfully copied any other's work, paragraphs, text, data, results, etc, reported in journals, books, magazines, reports dissertations, theses, etc, or available at websites and have not included them in this thesis or cited as my own work.

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Ravi Prakash Singh

In the Name of Almighty &

DEDICATED to my uncle

Late Subodh Kumar Singh

PREFACE

Robot Assisted Incremental sheet forming (RAISF) is a sheet metal forming process in which a sheet in deformed into desired shape in a stepwise manner without use of any dedicated dies. It is an emerging technology that has shown great potential in forming customized three-dimensional (3D) parts. In the current work a promising variant of RAISF has been studied in which effect of hydrostatic fluid pressure from the back of the sheet in RAISF has been studied. The process is called Robot Assisted Incremental sheet hydroforming (RAISHF). The fluid from the back of the sheet provides support to the sheet and ensures better strain distribution throughout the product. This thesis is the culmination of six years research and writing and comprises seven chapters. The layout of the dissertation is as follows:

Chapter 1 presents the brief definition of the ISF process and a literature review of the research that has been conducted on different aspects of ISF.

Chapter 2 presents a generalized mathematical model for calculating different force components in ISF process.

Chapter 3 presents the experimental setup that was used to perform the RAISF and RAISHF processes. It also includes design of experiments used to optimise the input parameters of tool speed, tool diameter, and step depth.

Chapter 4 presents comparative study of RAISF and RAISHF using various mechanical and metallurgical characterization techniques such as tensile test, surface roughness test, microhardness test, XRD, and EBSD.

Chapter 5 presents a comparative study of single and multi-stage RAISHF on surface quality of the formed product and thickness distribution in both the processes.

Chapter 6 presents comparative study of cold and warm RAISF and RAISHF using various mechanical and metallurgical characterization techniques such as tensile test, surface

roughness test, microhardness. Conclusion and future scope of work are discussed in chapter 7.

Abbreviations

EBSD	Electron Back Scattered Diffraction
FLD	Forming Limit Diagram
RAISF	Robot Assisted Incremental Sheet Forming
RAISHF	Robot Assisted Incremental Sheet Hydroforming
UTS	Ultimate Tensile Strength
HAGB	High Angle Grain boundary
LAGB	Low Angle Grain boundary
XRD	X-Ray Diffraction
CAM	Computer Aided Manufacturing
CAD	Computer Aided Design

Symbols

σ_{zz} = *Normal stress in axial direction*

σ_{rr} = *Normal stress in radial direction*

$\sigma_{\theta\theta}$ = $Normal\ stress\ in\ circumferential\ direction$

$\tau_{r\theta}$ = $Shear\ stress\ in\ radial\ plane\ in\ circumferential\ direction = \tau_{\theta r}$

τ_{rz} = $Shear\ stress\ in\ radial\ plane\ in\ axial\ direction = \tau_{zr}$

$\tau_{z\theta}$ = $Shear\ stress\ in\ axial\ plane\ in\ circumferential\ direction = \tau_{\theta z}$

f = $Coefficient\ of\ kinetic\ friction$

t_o = $Initial\ thickness\ of\ the\ sheet$

t = $Instantaneous\ thickness\ of\ the\ sheet$

r = $Radius\ of\ current\ pass\ (Instantaneous\ radius)$

R_t = $Tool\ radius$

R_m $R_m = Radius\ of\ curvature\ of\ neutral\ axis\ of\ the\ taken\ element$

α = $Wall\ angle\ of\ cone$

F_z = $Axial\ force\ component$

F_r = $Radial\ force\ component$

F_θ = $Tangential\ force\ component$

F_P = $Resultant\ force\ in\ r-\theta\ plane$

σ_t = *Normal stress in thickness direction*

σ_Φ = *Normal stress in meridional direction*

σ_θ = *Normal stress in circumferential direction*

σ_Y = *Normal stress perpendicular to the tool in the vertical direction*

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