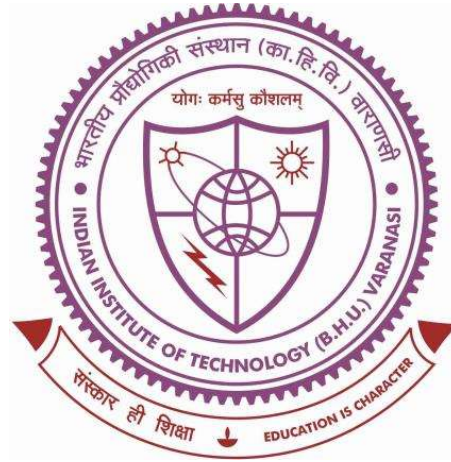


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# Design and Development of a Robot-Assisted Incremental Sheet Hydroforming Setup



THESIS SUBMITTED FOR THE AWARD OF THE DEGREE OF

Doctor of Philosophy

in

Mechanical Engineering

by

*Ravi Prakash Singh*

Under the Supervision of

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May 2023

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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 is 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**

$\sigma_{zz}$  = Normal stress in axial direction

$\sigma_{rr}$  = Normal stress in radial direction

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

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

$\tau_{rz}$  = 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

$t_0$  = 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

$\alpha$  = Wall angle of cone

$F_z$  = Axial force component

$F_r$  = Radial force component

$F_\theta$  = Tangential force component

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

$\sigma_t$  = Normal stress in thickness direction

$\sigma_\phi$  = Normal stress in meridional direction

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

$\sigma_y$  = Normal stress perpendicular to the tool in the vertical direction



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