Flexible Asymmetric Spinning

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Abstract

In the past twenty years, growing interest in customisation has driven research in the area of flexible forming processes. This study focuses on an incremental forming process, metal spinning, where a roller is used to form a metal sheet onto a rotating rigid mandrel. As such, metal spinning is inflexible since the product geometry is defined by an axisymmetric rigid mandrel. This thesis presents a novel flexible forming process, flexible asymmetric spinning, which aims to overcome the constraints of requiring an axisymmetric rigid mandrel.

A thorough review of the metal spinning literature revealed two main points: the mechanics of the process are not well understood; the spinning process has the potential to be more flexible and to produce a wider range of shapes.

To address the first point, a novel method, developed in analogy with time domain control engineering is applied to characterisation, analysis and control of flexible forming processes, concentrating on metal spinning. Physical and numerical trials show that metal spinning has two stages: a transient and a steady-state stage after which the deformation mechanism remains insensitive to both process and material parameters. Using the proposed method, closed-loop control for flexible forming processes is demonstrated for incremental sheet forming of an axisymmetric cone, and shows a major improvement in geometric accuracy of the product.

Furthermore, a new approach to numerical modelling is proposed and applied to study the mechanics of spinning, leading to two main conclusions: early stage deformation is largely elastic and dominated by bending; at later stages, deformation is mainly plastic, localised, and is a combination of circumferential compression and radial stretching.

To address the second point, the function of the mandrel in spinning is analysed, leading to the conclusion that the role of the mandrel is limited to contact in three regions. Therefore, the mandrel can be replaced by three rolls. This insight has lead to the design of a novel flexible asymmetric spinning process.

A seven-axis flexible asymmetric spinning machine is designed, built and used to spin trial parts. Trials demonstrate the mandrel-free capability, tight geometrical tolerance and high surface quality of spun parts.

Lastly, developed numerical models are applied to study the mechanism of failure and toolpath design in metal spinning. The results suggest that there are two different causes of wrinkling in spinning, the toolpath geometry should be different for the early and later stages, and that toolpath geometry should be higher-order rather than linear.

Thus, this thesis attempts to make five contributions to knowledge in metal forming. An exhaustive review of literature on metal spinning is conducted, identifying the key areas that require further research. An innovative methodology for analysis and control of flexible forming processes is developed and applied to give insight into mechanics of these processes. A new approach to numerical modelling of flexible forming processes is developed and used to generate knowledge of mechanics of spinning. The understanding of the mechanics of spinning generated using the two approaches has lead to the development of a novel flexible asymmetric spinning process and construction of a prototype machine. Finally, the numerical models are used to generate a basic understanding of mechanism of failure and its application to toolpath design in the spinning process in general.