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Controlling Product Stiffness by an Incremental Sheet Metal Forming Process

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Abstract

Each process and each machine is subject to fluctuations, which lead to deviations in the quality of the components to be manufactured. In order to counter these uncertainties, a flexible incremental sheet forming (ISF) process for the production of truncated cone components is presented. These flexible methods are in contradiction with conventional forming processes, which are mostly designed for steady processes with large batch size. However, with the multi-technology machine 3D Servo Press, such a highly flexible process can be implemented on a forming machine for the first time. Through a determination of influence parameters and derivation of a model by means of simulative and experimental investigations, a closed-loop control for axial stiffness of the part can be realized. The control of the stiffness is not trivial in that, it depends on the geometric features as well as on the material properties, i.e., Young's modulus. The fluctuations are inherently present and can be adjusted by a stiffness correction model as shown in the presented work.

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1. Introduction

Traditional stamping and deep drawing processes are extensively explored and extremely economical. Therefore, those processes are highly suitable for manufacturing components with large batch size. The greater demand for customized parts and parts with small batches simultaneously increases with the higher requirements on good quality and economical production. In this context it has become evident that incremental sheet forming (ISF) offers an

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outstanding opportunity in the field of rapid manufacturing to form complex shells without the need for a costly die. Thereby, additional advantages come into effect such as a higher forming limit, greater process flexibility and reduced forming forces due to a smaller formation zone [1]. However, process time and geometric accuracy are inferior to those of traditional processes. In recent years a series of works have been published to overcome those specific disadvantages. Lu et al. [2] deal with a new tool path generation method to improve the quality of the produced components and to reduce process time. A correction algorithm intends to reduce the geometrical error of the produced part within a limited number of iterations [3]. Attanasio et al. [4] also provide a possibility to increase geometric accuracy by an optimized tool path. More recent studies contribute to a better process understanding and enhance the quality and industrial capability of ISF [5,6].

However, the two common and most researched technologies of ISF processes are single-point incremental forming (SPIF) and two-point incremental forming (TPIF). During SPIF processes an evenly clamped sheet metal is being formed along a tool path by a forming tool. TPIF is characterized by two contact points on the surface since the sheet metal is formed against a male or female die. The TPIF process generates a more accurate geometry of the components, though requiring a significantly more complex tool and causing a decreased sheet formability [4]. An extension of these processes is presented by Lu et al. in a double side ISF process [6]. Here, a second forming tool is employed on the other side of the sheet metal. In general, according to He et al. [7] and Flores et al. [8], the prevailing strain in ISF processes occurs in radial direction while the tangential strain is near to zero. Thus, the deformation is nearly in a plane strain state [7]. In principle, almost any CNC-controlled three-axis machine is able to carry out ISF processes. At present, mainly CNC milling machines are used, because of their high processing speed, large working volume and sufficient stiffness [1]. Besides these, industrial robots have also been used as incremental forming machines [9,10]. These robot-based sheet metal forming processes offer a higher geometrical form flexibility compared to CNC processes [11]. A disadvantage in this connection is the low stiffness and reduced forming force available. Customized machines with parallel kinematics like a hexapod are rarely considered to implement the process; moreover no conventional forming press has been applied for an ISF process so far. For the first time, the multi-technology machine 3D Servo Press is used in this work for such an application. A press on which conventional forming processes can also be realized, if required. Forming presses provide higher forming forces and higher machine rigidity, this would be an advantage for incremental forming processes compared to CNC machines.

This paper presents a production process of truncated cones using a SPIF process. Besides the geometry, this work focusses on the axial stiffness of components as a target variable. The actual forming process is followed by a measurement step in which the stiffness of the component is determined. In a final postforming step, the ultimate outline with an exact stiffness is produced. The fields of application of components with a defined stiffness can be found in the field of cup springs. In principle, cup springs are mass products which are produced in large numbers. However, a specific stiffness at close tolerance range requires a flexible production on the one hand. On the other hand, a quality control of the target stiffness including the opportunity of having an influence on the outcome is mandatory. Additionally, this production process of axisymmetric components with a defined stiffness can be transferred on further fields of application like components with a specific eigenfrequency or anti vibration shock mounts. In the work of Jeswiet et al. [1] more geometries are described which can be produced by ISF and allow a measurement of axial stiffness.

However, the challenge during the examination of the presented process is to determine occurring fluctuations at the product in order to control target product properties during the manufacturing process [12]. Particularly in the case of small quantities or single products complex running-in procedures of processes to preserve the desired quality are rarely realizable due to economic efficiency. Hence, it is mandatory to search for new methods of process optimization and to adopt them in the field of forming technology. Even with a precise geometry, uncertainty in the initial Young’s modulus and its change due to plastic strain [13] lead to variations in the axial product stiffness. In the work of Allwood et al. [14] an overview of current research topics in the field of closed-loop control is given. Many control strategies for individual forming processes or even process chains such as a blanking-bending process [15] have shown the improvements that come along with process control. Control of component properties is nowadays of high importance in order to meet the increased quality requirements and should also be applied in this work. The following section deals with the process and requirements regarding the component to be produced.