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Automated driving for individualized sheet metal part production—A neural network approach

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ABSTRACT

The manufacturing of individualized sheet metal components is one of the most important issues in industrial sheet metal working. Incremental forming methods, in particular driving, offer the opportunity for achieving this objective. However, these manual processes are very difficult to automate, as a result of their complexity and user interactivity. To resolve this problem, a knowledge-based approach is presented, which utilizes a special type of driving process. Initially, a neural network architecture is established which delivers manufacturing strategies allowing part production for simple component shapes. After providing a method for training data generation, training sessions are carried out. Strategies, computed by trained networks, are adopted for processing sheet blanks which are used for evaluating the framework. Finally, the developed procedure is generalized, and a concept is designed which allows a transfer, in order to facilitate the production of arbitrary individualized sheet metal parts.

1. Introduction

Incremental sheet metal forming enables the production of individualized components. Two point incremental forming (TPIF) and single point incremental forming (SPIF) have frequently been the subject of investigation, as these allow for producing asymmetric sheet metal shapes [1]. Nevertheless, these processes are fraught with different issues regarding shape accuracy and limitations on geometric bandwidth. Even though there are numerous approaches, computation time is still the main reason why mathematical tools cannot be applied reasonably to incremental forming [2]. Some of the results described in the relevant literature may be used for creating assistance systems [3–5]. Moreover, diverse tool path generation concepts are explored to enable fully automated manufacturing of the desired sheet metal component [6–8]. Multi-stage strategies are studied in particular, since these approaches provide the possibility to overcome geometric restrictions in incremental forming [9–12]. Currently, feature-based methods, as introduced in [13] and modified in [14], are implemented because these measurably reduce deviation and thus significantly increase size accuracy.

Nonetheless, TPIF and SPIF are still not comparable to strict industry standards and for some applications these processes are hardly practicable, e.g. for straightening applications or for manufacturing of very large sheet parts. However, many research results show the high potential of these incremental forming processes. In this paper, we consider a special type of driving process, which notionally enables the incremental production of almost any desired sheet metal component geometry, remedying the geometric limitations of TPIF and SPIF. In fact, this process does not allow for the production of sheet metal parts in the level of detail as TPIF and SPIF do. Nevertheless, the process actually turns out to be a reasonable complement to these processes, as for instance the main application area is straightening of individual parts or the production of large components. Fig. 1 outlines a selection of sheet metal components and illustrates the scope of component shapes producible by applying this specific driving process.

The process only makes use of cost-effective universal tool sets. Each tool set consists of a top and a bottom tool. The most interesting tool sets used in practical application can perform material stretching and shrinking in local forming areas. To this end, the top and the bottom tool have split jaw plates. During a forming stroke, the sheet is in contact with the top and the bottom tool. The blank is clamped by the tool because of the vertical stroke force. The vertical force is partially converted to horizontal movement. This introduces compressive (shrinking) or tensile (stretching) stress into the sheet and results in deformation. The associated modes of operation are outlined in Fig. 2 and are explained in [15,16].

This kind of driving process entails, however, one important difficulty. Since the blank is not fixed continuously during the

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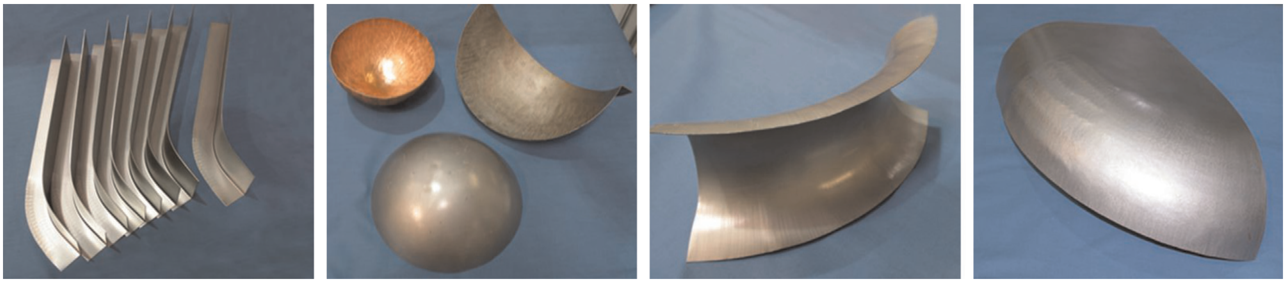

Fig. 1. Small selection of the component range producible by utilizing the special type of driving process under investigation.

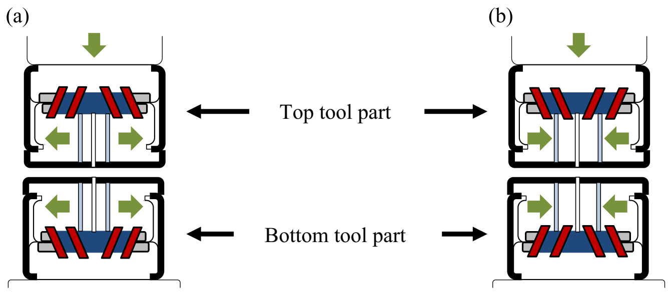

Fig. 2. Principle of tool sets for the driving process which enables local material stretching (a) and shrinking (b): the split jaws of the top and the bottom tool move because of the conversion of the stroke force to movement in horizontal direction; depending on whether the jaws move towards each other or apart, compressive (b) or tensile stress (a) is induced.

process, and the sheet metal deformation depends considerably on the tool orientation while punching, the degree of freedom is increased compared to TPIF and SPIF. This turns tool path generation into a great challenge. As the strategy for part production is not related to the component shape, tool path strategies cannot be derived directly from CAD data. Up to now, no method for strategy generation was known, and part production was based on the experience of the worker. In this context, users have to struggle with high manual effort and poor reproducibility. Fig. 3 shows the driving machine used for carrying out the process and a range of tool sets which can be utilized for the forming procedures.

There have already been studies relating to the process, e.g. the concept of automated copied driving, as described in [17,18]. Unfortunately, this concept depends mainly on the proposed database which first has to be provided. Hence, there is still no way to generate tool paths in advance, so as to facilitate automated production of sheet metal components, utilizing this special process type.

This paper develops and evaluates a concept enabling the generation of tool path strategies for the introduced driving process. A neural network architecture is established and utilized for computing tool paths for the production of individualized components. To this end, an appropriate method for training data generation is presented. The neural network is evaluated by manufacturing individual parts out of L-shaped profiles. This specific shape of the part is used as a representative for the metal forming of basic sheet geometries. In Fig. 4, the manual production of components out of L-shaped profiles is shown, employing the tool sets described previously. These basic part shapes are crafted by simple flange shrinking or stretching.

Finally, a conceptual design is described for a neural network architecture, applicable for tool path generation when forming complex sheet geometries, and the procedure for training data generation is outlined for this scenario. Note that the main objective of this paper is the conceptual design of a method for automated driving. The optimization of concrete implementations, which will be presented in the following sections, does not fall within the scope of this paper and thus cannot be considered but in brief, where necessary.

2. Neural network architecture for simple component shapes

In general, driving is highly complex and very interactive. It is very difficult to directly model the complete process, since there is a huge amount of contributing parameters which change during the process, e.g. tribology, wear and work hardening. As it is virtually impossible to take all influences into account, the objective is to provide a model-free idea for generating tool path strategies for the investigated process, adopting neural networks. In this section, we restrict investigations to L-shaped profiles as unmachined parts.

In the beginning, an architecture for a neural network has to be designed which is able to handle the stated problem of tool path generation for the special type of driving process under investigation. The driving process itself is carried out on a driving machine in combination with an industrial robot for part handling, as shown in Fig. 5.

For architecture design, we focus on the main influencing factors which are the process parameters. On the one hand, the

Fig. 3. C-frame driving machine and appropriate tool sets for diverse forming procedures.

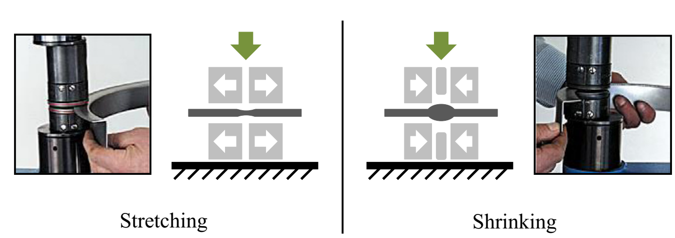

Fig. 4. Manual production of sheet components out of L-shaped profiles employing the stretching and shrinking tool sets; the part shape is the result of flange deformation.