



Mass Customization of Sheet Metal Parts by Numerically Controlled Driving [004-0047]

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Abstract

The manufacturing technique of driving is one of the oldest procedures for sheet metal forming and has been used for millenia. It is still utilized for niche applications but it has lost its importance today. The driving process is almost completely carried out manually and thus usually only appropriate for very small quantities. Since individualization of products is strongly gaining in significance, forming processes have to be found which are independent from expensive tools and machines. To use driving of sheet metal for individual manufacture, the grade of automation of the forming process has to be increased. Numerically controlled driving will need a conclusive simulation base. The multitude of influence factors, e.g. thickness and geometry of the sheet, forming forces, friction, strain hardening etc. and their influence on the process have to be identified and evaluated. Forming strategies will have to be automatically derived from the desired part geometry.

1 INTRODUCTION

A tendency for higher grades of individualization can be observed for an increasing number of consumer products. The individual character of such a product can manifest itself by simple alternatives like an increased selection of colors and materials, but also by more complex decisions for individually designed parts and elements, additional or altered functions or specifically adapted controls. This results in decreasing production output of identical products, while the allover output of similar products is going to increase in number. Especially when having to produce parts of customized geometry, manufacturers of such products will need to apply new production strategies and processes to cope with the different customers' demands 1.

Today, sheet metal forming processes, e.g. deep drawing, usually require high production numbers to compensate for the high investment costs for the forming machine and the manufacture of the one-geometry-only forming tools comprising punch, die and blank holder. Generally, the process chain for the manufacture of these tools is casting of the raw geometry, milling and manual grinding for tryout reasons. A number of different approaches to reduce costs and time for the manufacturing of personalized and mass customized sheet metal parts is broadly discussed in science. Attempts to use rapid prototyping technology, e.g. for manufacturing and tooling purposes, are described in 2 3. Since production numbers in mass customization are significantly lower than in conventional fabrication, tool life due to wear can be much shorter than that of traditional dies which allows new materials and new processes for the tools (e.g. plastics by laser sintering, paper by laminated object manufacturing). To use one tool for a variety of design geometries, flexible tools have been developed where the tooling concept is based on a programmable discrete die surface 4. The complexity of geometries is quite limited by this, however.

A different approach to the problem is using incremental forming processes. Those are characterized by the fact that the forming is not done by one single forming step but by a large number of steps which result in a defined modification of the part's geometry. An example for this is forming by shot peening through induction of axial stresses into the sheet by the kinetic energy of the particles 5. The formability by this is low, though.

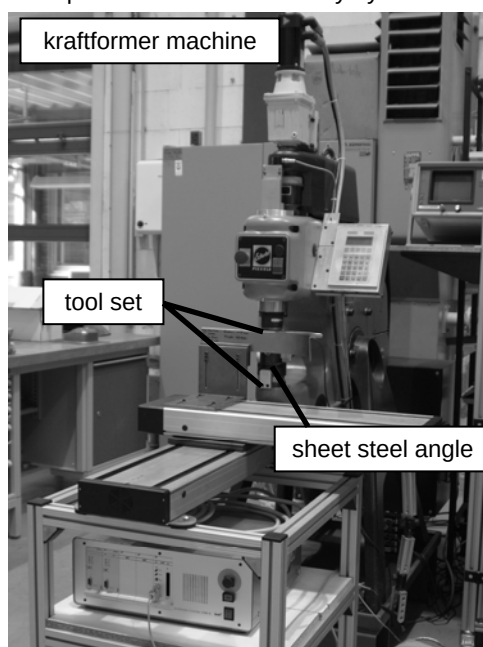


Figure 1: Kraftformer machine (with sheet metal between tool parts, manipulated by an x-y-table)

Another incremental method for sheet metal forming with significantly reduced investment expenses which has not yet had much relevance in scientific considerations is the driving process. This technique, one of the oldest metal forming processes available, has been used for centuries, e.g. to produce pots, vases and cauldrons from raw copper sheets. The manufacturing process today solely requires a small and lightweight low cost press (so called kraftformer machines, Figure 1) and universal tool sets (Figure 2). Parts are incrementally formed by a multitude of strokes into the sheet which has to be manually positioned and manipulated between the tools throughout the forming process 6 8



9. The variety of geometries that can be achieved by driving is greatly expanded by an additional combination of the strokes with stretching and shrinking of the sheet. These procedures are accomplished by special tool inserts which clamp the sheet and shrink or stretch it (Figure 3).

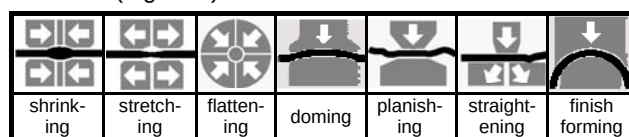


Figure 2: Sub groups of forming by driving and associated tool concepts

Since the production process requires a very high proportion of manual work, driving is usually employed for the manufacture of niche products, e.g. for repairing and maintenance purposes in the aerospace industry, for paneling parts of railway cars or for the restoration of vintage car bodies 10, i.e. for single parts and small quantities, or where cost effectiveness is a minor issue or where other forming processes fail.

Another typical example for customized steel sheet parts are casings for neon advertising signs. In this case usually L-shape profiles are bent accordant to the shape of the writing or the icons and to the size of the sign, to house the neon tubes.

2 FORMING PROCESS

Pure driving is a free forming process by hammering of sheet metal. Thinning and by that enlargement of the surface area of the sheet occur. An appropriate forming strategy, i.e. location, force and number of the hammer strokes, is needed to generate the desired part. Mechanizing this process with a krafthformer machine today reduces the amount of manual work to blank handling and positioning. In addition, the use of a machine allows the use of special sophisticated tools (Figure 2) to expand the possibilities of driving enormously. These tool sets induce different stresses into the sheet (mainly tensile, compressive and bending stresses) which result in corresponding deformations. By combination of those tool sets a variety of very complex shapes can be customized and easily be produced. At the same time strain hardening occurs along with deformation, but can also be selectively induced into the sheet for stiffness reasons into certain parts without change of shape. Driving, especially when using the flattening or straightening tool sets, can also be used to remove unwanted deformation in the sheet (buckles, wrinkles, wrong bending radius etc.). Presently, personal expert knowledge of a skilled worker is necessary to fashion customized sheet steel parts.

The easiest to describe effects can be observed when using the shrinking and stretching tool inserts (Figure 3). When shrinking or stretching L-shape (or, in a more complex way, also Z-shape and U-shape) sheet profiles, every stroke results in a certain bending angle of the whole profile depending on the process (force, location of profile) and the material and profile parameters (Figure 4). Combinations of several strokes set at small distances to one another create certain bending radii of such profiles.

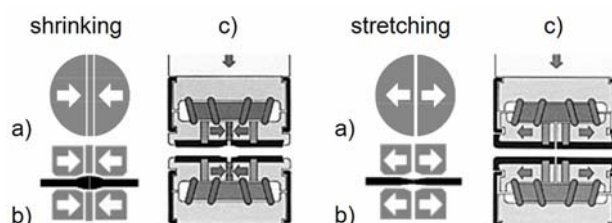


Figure 3: Operation mode of shrinking and stretching tool inserts: a) top view, b) side view, c) section of the tools, arrows indicate horizontal movement of tool jaw plates



Figure 4: Different directions of bending of angles by shrinking and stretching

The advantage of shrinking and stretching for scientific research is that forming experiments are highly reproducible, and considerable forming grades can be achieved. Moreover, the geometry obtained by forming sheet metal angles (L-shape) by shrinking and stretching can be easily measured and analyzed. By shrinking one leg of a sheet metal angle the resulting work piece will be curved concave, while stretching will produce a convex angle (Figure 4). Overall, shrinking and stretching can be considered as the most convenient sub-groups of driving for automation in mass customization.



Forming is done by a kraftformer machine with shrinking and stretching tool inserts. Those tool sets consist of an upper and a lower tool part and each of these tool parts is divided into two jaw plates. The machine is a C-base frame press and endues a constant number of strokes per minute and a constant up and down movement within every stroke. During every forming stroke, i.e. every stroke when the tool jaw plates are in contact with the sheet, the tools clamp the sheet and transform the vertical strokes of the machine into horizontal movement and by that induce compressive (shrinking) or tensile (stretching) stress into the sheet (Figure 3). The infeed – which is the distance between the upper and the lower tool part –, and by that, if the upper tool part hits the sheet, the forming force, can be applied manually or automatically by lifting or lowering the upper tool part.

The tool geometries for shrinking and stretching (Figure 5) differ in the distance of the horizontal tool jaw plates in the unloaded and the loaded state. In addition, the jaw plates for shrinking are divided angularly, with the dividing angle having opposite directions for upper and lower tool. This is to inhibit wrinkling of the sheet during the forming process.

With a given tool set, a defined profile geometry of known material properties and sheet thickness, a single stroke with a certain force with the same degree of covering will always result in a predetermined bending angle. By combining more strokes at given distances, the curvature bending radius can be as well predetermined.

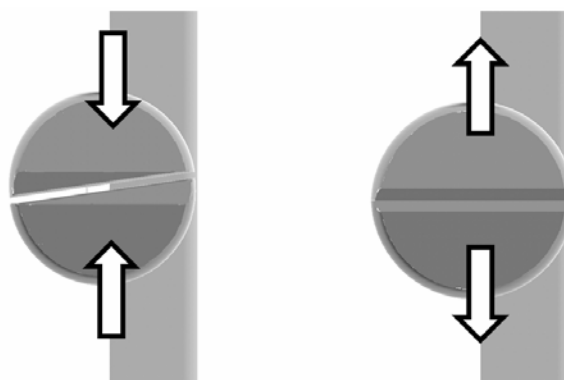


Figure 5: Top views of tools for shrinking (left) and stretching (right), each in unloaded state, arrows indicate horizontal movement of tool jaw plates when loaded by forming force

3 SIMULATION

3.1 FE model of a single stroke

The basic element of the driving process and its sub groups shrinking and stretching consists of a single stroke. Only by applying a multitude of these basic elements onto the sheet metal desired geometries can be obtained. To be able to describe the complex interdependencies of the multiple strokes in a production process, gaining knowledge about one single stroke is inevitable. For the basic strokes there have to be simulation models of sufficient accuracy. To understand the procedures during a stroke it is advisable to observe the forming process directly. Since every forming operation lasts only fractions of a second, recordings with a high speed video camera are advisable. This can provide valuable information on the movement-time-conditions of the forming tools for the simulation model. Additionally, movements of the jaw plates and forming forces have to be measured by adequate instrumentation, e.g. by eddy current distance sensors and load cells. This information is necessary as boundary conditions for the simulation.

Figure 6 shows an example of the measurement of a single shrinking stroke. The moment the upper tool part hits the sheet the force starts to increase. At the same time the vertical movement of the stroke is transformed by the tool into the horizontal tool jaw plate movement. In the case of shrinking this movement starts with a motion against its operating direction, and then turns to its actual direction. Only when the stroke force has reached its maximum and has started to decrease again, the tool movement reaches its maximum. This effect can be explained by the hysteresis of the tool's rubber inlays which transform the movement like mentioned above. Stretching curves show similar behavior. The recorded curves have to be imported into the simulation system.

Simulation can be done by shell element based (e.g. PAM-STAMP 2G) and by volume element based (e.g. DEFORM, ABAQUS) systems. While shell elements provide results much faster than volume elements, they usually have limited ability to interpret compressive stress and its result in material flow correctly.

Friction factors are essential for FE simulations. Those will have to be correctly determined by comparison of forming experiments with simulations using different friction coefficients, since they cannot be determined experimentally. Friction in shrinking and stretching is usually much higher than for other forming processes, since the metal tool jaw plates are roughened to minimize slip between sheet and tools.

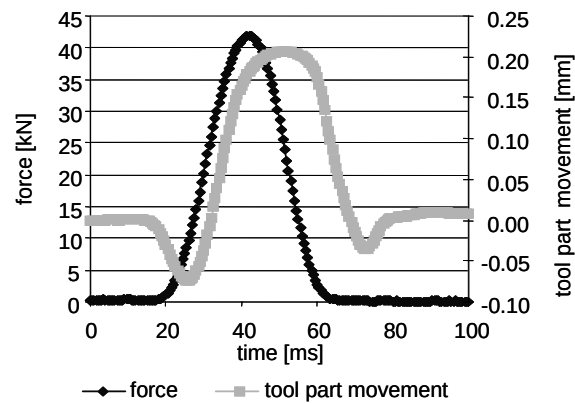


Figure 6: Example of measurement curves of stroke force and horizontal movement of tool jaw plates for shrinking

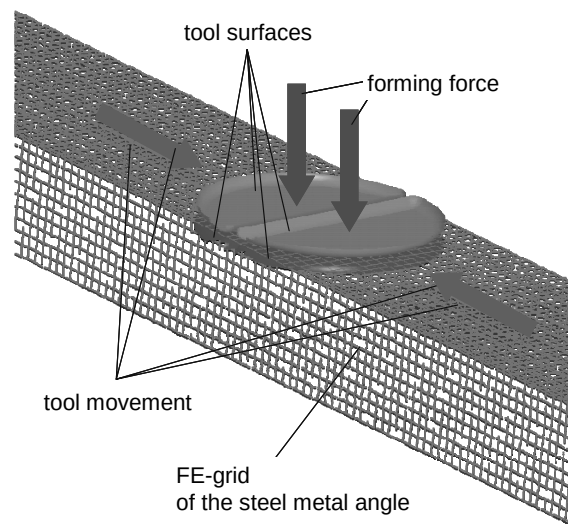


Figure 7: FE-model for shrinking of a steel metal angle

Figure 7 gives an impression of a simulation model for the shrinking process, depicting the tools, the work piece as well as indicating tool kinematics and force gradient according to Figure 6.

3.2 FE simulation of combinations of strokes

Studies on the simulation of more than one stroke into a steel sheet angle have been performed. It turned out to be useful and time-saving to define the sheet metal angle as a rigid body after every single stroke and to transfer the angle to its new position while the tools stay at a fixed position in space. After the transport the rigid-body-status has to be turned off again for the next forming stroke. The movement of the angle between the forming strokes can be stored in a batch file, which is being uploaded for calculation and executed.

4 FORMING STRATEGIES

In cases where the general geometry is given and is to be varied only by details like angles or radii, or sheet thickness, material or other elements might change, simulation does not seem to be the approach of choice. By forming experiments strategies can be gained to produce a whole variety of similar work pieces. By varying forming force and distance between the single strokes different shaping effects, e.g. bending radii, can be obtained.

A computer tool using a database storing the forming results together with the forming parameters can be established to predetermine the necessary forming strategy for desired geometries out of given raw parts. Appropriate interpolation and extrapolation algorithms are needed to minimize the number of forming experiments to be stored in the database, and still correct forming strategies can be calculated for shapes of similar design.

5 POTENTIAL OF DRIVING FOR MASS CUSTOMIZATION

The general economic framework is in a change towards higher grades of individualization in consumer goods. This results in lower manufacturing numbers of parts for these products. Well established strategies like using the economies of scale through mass production have to be reconsidered. Especially metal forming technologies strongly base on this effect. Since they generally utilize huge presses for high forces and expensive tools needed for one-step



geometry generation, the strongly rely on large production numbers. This contradicts the demands of mass customization.

In order to employ the advantages of sheet metal forming, e.g. high strength, damping of vibrations, fast production and high formability etc., in mass customization applications, new technologies will have to be found. Driving being a process of sheet metal forming with significantly lower invest than deep drawing. Since considerably lower forces are needed, small presses can be applied. Forming is not done in one step but incrementally, so that only simple universal tools are needed. Investment can be reduced by the factor 10 or more. Nevertheless, the forming costs are quite high due to the requirement of high manual work. Also the production time is much higher compared to traditional processes. Automation of the driving process is the answer to that problem. If forming strategies can be calculated and realized automatically, the potential of this technology for personalization and customization is remarkable.

The high reproducibility in the effect of single driving strokes provides the opportunity of automation. A kraftformer machine at the Institute of Metal Forming and Casting (Technische Universitaet Muenchen) has been equipped with measuring and controlling instrumentation and connected to an x-y-table for work piece manipulation (Figure 1). Simple bending operations of L-shape profiles can be automatically carried out. A desired bending radius for the profile can be entered into a software tool, the necessary force and distance between single strokes are calculated, and the work piece positioning is done by the x-y-table.

6 OUTLOOK

When an automatically controlled sheet manipulating system is installed for part handling and the forming procedure is automatically calculated and implemented, a system for online control is needed to detect discrepancies from the nominal shape and to develop correcting strategies. Due to inaccuracies in the calculation, determination and setting of all needed variables, e.g. material properties, forces, movements etc. a self-acting controlling system is inevitable to install numerical controlled driving as a manufacturing method for mass customization applications. Controlling would best be done by optical measuring technologies. Correction strategies, i.e. new calculations can comprise adaptation of the work piece positioning and a different force. Fast new calculation of process parameters will be necessary therefore. In extreme cases even the tool set will have to be changed to reverse too large deformations like overbending or undesired shaping effects like bulging. To increase the required accuracy of automatically controlled sheet manipulation a 6-axis-robot has been installed. In addition to the manipulation process 'copy-driving' will come into consideration. While a skilled worker performs the handling process once, his sheet manipulation will be recorded and worked up for a numerically controlled driving process to produce an optional number of parts (copies) with equal dimensions. The installment of optical deformation tracing and the integration of cognitive systems to develop forming strategies will greatly enhance the automatability of the driving process.

7 SUMMARY

The manufacturing technique of driving has a great potential for mass customization and personalization of sheet metal products close to the market. To establish numerically controlled driving as a new production process, an automation code for the positioning and handling of the work pieces has to be developed. A first step in that direction is to provide a simulation basis for the driving process and its sub groups, especially shrinking and stretching. Valid material models, accurate ascertainment of the force-time- and the movement-time-conditions as well as the exact determination of the friction factors are necessary fundamentals to supply. An appropriate means of backwards calculation will be needed for more complex shapes to automatically generate a production sequence of forces, movements and choice of necessary tool inserts. For simpler geometries like sheet steel angles forming strategies can be derived from actual tests stored in databases and interpolation of these results. Implementing expert knowledge into these considerations can complete these considerations.

8 ACKNOWLEDGEMENT

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World market leader in kraftformer machines is Eckold AG, Trimmis, Switzerland: www.eckold.ch. The robot was provided by KUKA: www.kuka.com.

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