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DEVELOPMENT OF A NEW FLEXIBLE TOOL SET-UP FOR AIR BENDING WITH ONLINE MEASUREMENT OF ANGLE, FORCE, AND DISPLACEMENT

Nader Ridane and Matthias Kleiner
Institute of Forming Technology and Lightweight Construction
University of Dortmund
Dortmund, Germany

ABSTRACT

Due to its flexibility the air bending process allows the manufacturing of a great variety of bending parts with just a single tool. However, the accuracy that can be achieved by air bending depends on a large number of influencing variables such as the springback of the material, the batch variations even in the same batch, the variation of material properties, or the deflections of the bending machine and tools. These influencing variables either have to be taken into account in the generation of the NC-data or they have to be compensated later in the manufacturing process itself. In order to improve the accuracy of the air bending process a new flexible tool set-up for air bending with integrated online-measurement of the bend angle, the bend force, and the punch displacement has been developed and successfully been tested at the Institute of Forming Technology and Lightweight Construction (IUL), University of Dortmund, Germany. With the new tool system it is possible to produce sheet metal parts within narrow tolerances for such small batch sizes as "1".
Keywords: Flexible tools, Air bending, Online measurement

1. INTRODUCTION

The air bending process is one of the most widely used processes for the manufacturing of sheet metal bending parts. Although it offers a very high production potential due to its great flexibility, it is associated with certain problems which can negatively influence the shape and dimensional accuracy of the bending parts. These differences have to be compensated either in the determination of the bending parameters using for instance process simulations or they have to be compensated later on in the manufacturing process itself. The latter strategy gains more and more significance because it is extremely difficult, if not impossible, to consider all variables influencing the air bending process in the generation of the NC-data for the numerical control of press brakes. In order to compensate the aforementioned disturbances in air bending processes, several control systems have been developed over the last three decades [1, 2, 3]. Most of these strategies are based on an online-measurement of the punch displacement, the bend angle, and the bend force, which is in the focus of this paper. At the IUL a new flexible tool set-up for air bending has been developed in order to contribute to the further improvement of the online-measurement of bending parameters for more accurate bending results by accomplishing control tasks.

2. A NEW FLEXIBLE TOOL SET-UP FOR AIR BENDING

Nowadays, the necessity of new robust devices with in-process measurement of the bending parameters is more important than ever. Accurate measuring systems automatically lead to accurate bending results. As a consequence, the rejections of sheet metal parts decrease and can shrink even to "0" with the use of intelligent strategies.

In this context, a new flexible tool set-up for air bending with integrated online-measurement of the punch displacement, the bend angle, and the bend force, which is based on the device described in [1], has been developed and successfully been tested. It consists of three major measuring devices. The first simple device permits the acquisition of the punch displacement with a digital length gauge close to the conventional bending tools (see Figure 1a). The developed tool system has two parts. The lower part fixes the length gauge. The upper part is clamped to the vertically moveable punch and directly touches the length sensor in order to continuously record the punch displacement, starting from its initial position.

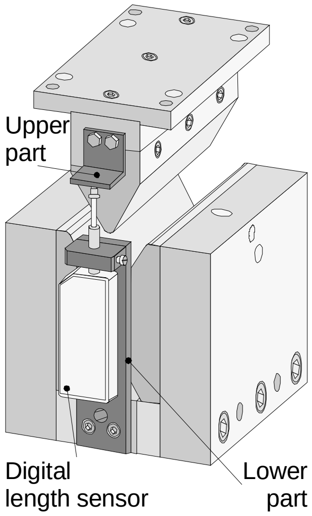

Figure 1a. Measurement of the punch displacement

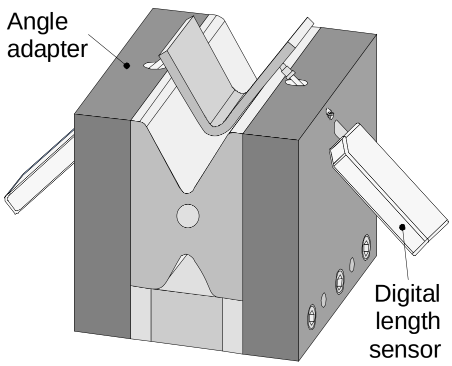

Figure 1b. Measurement of the bend angle

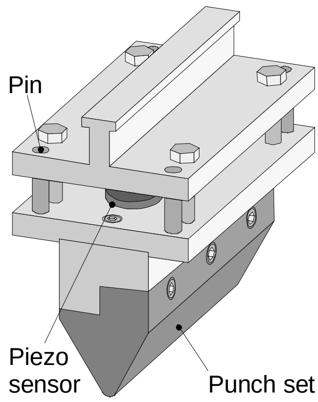

Figure 1c. Measurement of the punch force

For the detection of the bend angle there are two different methods. One possible way is the use of contactless sensors such as optical or laser based devices. The second method is the application of tactile sensors. In this work and for reasons of lower costs and greater robustness two digital length gauges are selected for the angle measurement and applied to the front and back side of a special flexible adapter of conventional dies. Figure 1b shows for a better understanding, the newly developed flexible tool for air bending of sheet metal parts with the integrated bend angle sensor. It can be applied for any conventional dies because the digital length gauges are attached to the adjustable angle adapters. The relationship between the distance measured with the aforementioned angle sensor and the desired bend angle as well as the calibration of the angle device will be discussed separately in the next chapter.

In addition to the bend angle bending forces were recorded too by means of two pressure-sensitive piezo sensors integrated into the punch between two plates, which are fixed with screws as well as pins in order to avoid the clamping of the force sensors, which leads directly to undesirable false measurements. Furthermore, the new force device is horizontally segmented in the punch region so that in case of tool changing only the adapter has to be disassembled (see Figure 1c).

Figure 2 illustrates the above described devices as a new efficient tool set-up for air bending with in-process measurement of the punch displacement, the bend angle, and the bend force.

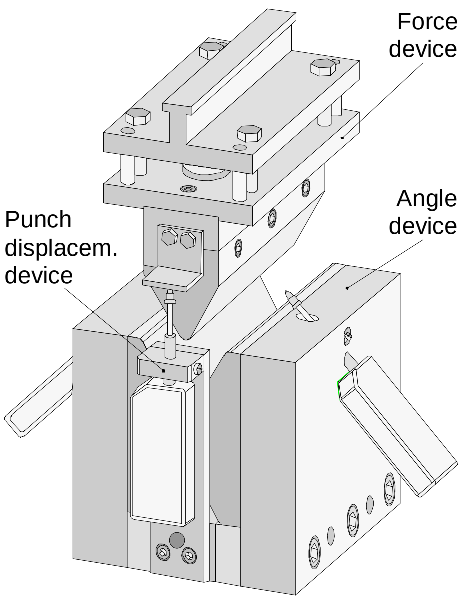

Figure 2. New flexible tool set-up for air bending with onlin measrement of punch displacement, bend angle, and punch force

3. DEVELOPMENT OF A NEW CALIBRATION SYSTEM FOR THE DEVELOPED ANGLE TOOL SET-UP

The bend angle can be mathematically determined from the measured change in distance of the sheet relative to its initial position *m*, considering the following geometrical parameters: the radius of the die r_D, the radius of the head of the digital length gauge r_{DLG}, and the installation angle of the length sensor γ as well as the geometric distance *e* (see Figure 3).

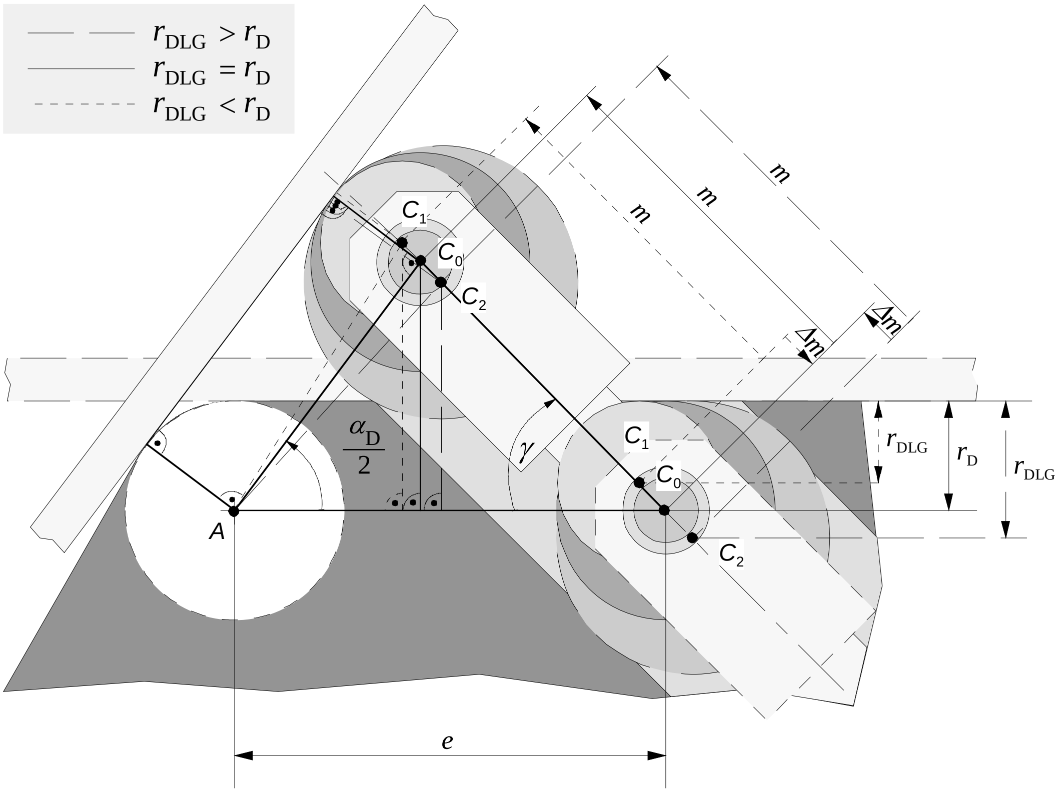

Figure 3. Geometrical relation between the sensor and the shoulders of the die

According to Figure 2, the following equations for the calculation of the desired bend angle α_D depending on the geometrical relation between the sensor and the shoulders of the die are set up:

$$\frac{\alpha_D}{2} = \arctan\frac{A}{B} - \arctan\left[\frac{r}{A}\cdot\sin\left(\arctan\frac{A}{B}\right)\right], \tag{1}$$

where

$$A = m\cdot\sin\gamma - r,$$

$$B = e - m\cdot\cos\gamma - r\cdot\tan\gamma,$$

and

$$r = r_{DLG} - r_D.$$

However, an accurate detection of the bend angle $\alpha_D/2$ depends in the first instance on the aforementioned geometrical parameters, which depend, again, on the manufacturing of the developed angle device. While both radii r_D and r_{DLG} can experimentally be exactly detected, for example with a three-dimensional coordinate measuring machine, γ and *e* are difficult to find out and can be determined only with large experimental efforts. Precisely, these last two parameters (γ and *e*) have a significant influence on the total result of the bend angle acquisition. An error of ±1° and of ±1.5 mm in γ and *e* leads to a deviation of the bend angle in the magnitude of ±4°. So for this measuring method the precise determination of the geometrical parameters γ and *e* is vitally important for a proper detection of the bend angle.

The most effective way to overcome this problem is the use of calibration sets with well defined opening angles α_C. For this idea a new angle calibration tool set-up has been designed and manufactured, which allows a better determination of the geometrical parameters γ and e. Figure 4 shows the developed calibration device.

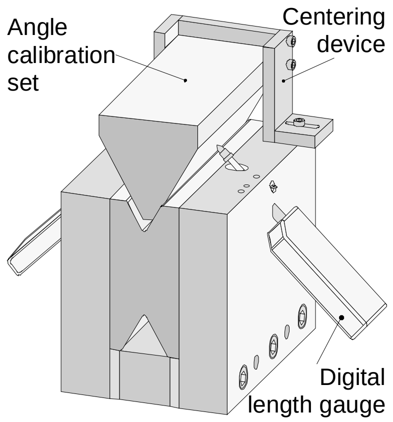

Figure 4. New developed angle calibration device

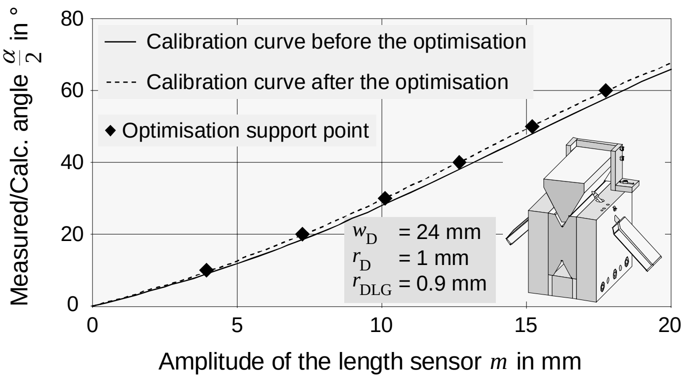

Figure 5. Calibration curves before and after the optimisation operation

In order to accurately determine the geometrical parameters γ and e for each die, 7 angle calibration sets covering the hole measured angle interval with α_C ranging from 15° to 60° have been developed. For each opening angle α_C the amplitude of the digital length gauge m starting from the initial position has been recorded and saved. By means of equation (1) and the experimental results, γ and e have to be calculated. In this context, the Sequential Quadratic Programming (SQP) method integrated in MATLAB, the so-called "fmincon"-Optimisation-Tool-Box is applied considering all measured couples (m, α_C). First of all, a new quadratic function, which considers the sum of the error between α_C and α_D, has to be generated for the chosen optimisation algorithm. The results of the optimisation operation are illustrated in figure 5. The maximum deviation found for bend angles after unloading was ±0.4° using the newly developed angle measurement system. These tolerances represent a very good result compared to other industrial angle measurement devices [5].

4. CONCLUSIONS

Air bending is a very common manufacturing process in the production of simple as well as complex sheet metal bending parts. The precision of the bend angle is affected by variations of the material properties, variations in the sheet thickness, and the like. Therefore, methods are needed to encounter these disturbances of the bending process in order to obtain more accurate bending parts. In this regard control strategies gain more and more significance in order to compensate the aforementioned disturbances. Without the use of adequate systems with online measurement these control operations loose their potential. At the IUL, a new flexible tool set-up for air bending with integrated online measurement of the bend angle, the bend force, and the punch displacement has been developed and successfully been tested. With the new tool system sheet metal parts have been produced within narrow tolerances less than ±0.4°.

5. REFERENCES

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