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Precision deformation technology as an alternative for high precision manufacturing

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Abstract

In this paper high precision deformation technology is presented as an alternative for high precision part manufacturing. Accurate deformation is possible because force and displacement are continuously monitored during deformation. Therefore, this technology is insensitive for work hardening and anisotropy of the material. Two example applications are given in which this technology is used successfully.

Precision deformation, precision bending

1. Introduction

High precision deformation technology can be used as an alternative for high precision part manufacturing, e.g. during crank shaft manufacturing [1]. In this paper, it will be demonstrated that this technology can also be used after parts have been assembled. In this way, an expensive manufacturing step can be avoided.

2. Method

With the presented method, force and displacement are continuously monitored during deformation. During elastic deformation (figure 1a), the displacement to which the tool must proceed is predicted. Movement proceeds to get plastic deformation until the desired return line is intersected (figure 1b). By releasing the force, elastic deformation is released as well and the work piece obtains the desired shape (figure 1c).

The main advantage of this approach is the accuracy of deformation. With conventional deformation technology, the reproducibility of the spring back is limited [2]. Because force and displacement are continuously monitored, the deformation accuracy is not affected by:

- variation of the yield strength of the material, e.g. due to work hardening,
- anisotropic behaviour of the material, e.g. due to cold rolling,
- take-over errors between the deformation tool and the measurement tool.

Factors that do limit the achievable accuracy are:

- relaxation of material after deformation, which can only be compensated partially,
- stiffness of contact points, which requires a proper statically determined design,
- the ability of the contact points to remain exactly constrained even at large elastic deformations,
- the overall accuracy (e.g. hysteresis) of the drive and measurement chain.

The presented method will be illustrated by two applications that use this technology.

3. Application 1: Pin straightening tool

The first application is a pin straightening tool depicted in figure 2. A ball (2a) is welded on top of a pin (2b). The centre of the ball has to be aligned with respect to the reference cylinder (2d) on the lower end of the pin.

The main advantage of this assembly method is that a commercially available ball with accurate diameter, roundness, roughness and hardness can be used. The disadvantage is that a small misalignment between centreline of the pin and centre of the ball is caused by the welding process. This misalignment will be corrected using precision bending.

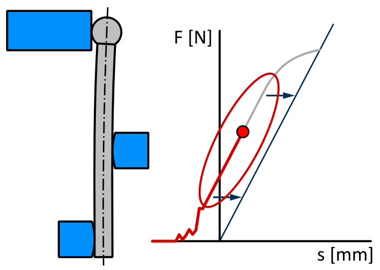

Figure 1a. Elastic deformation

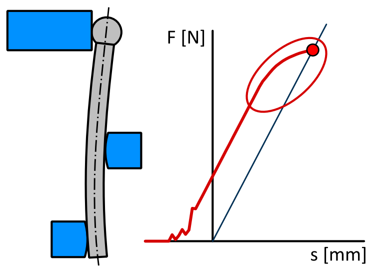

Figure 1b. Plastic deformation

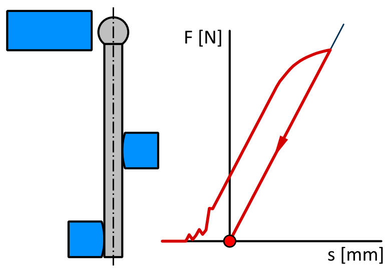

Figure 1c. Workpiece released

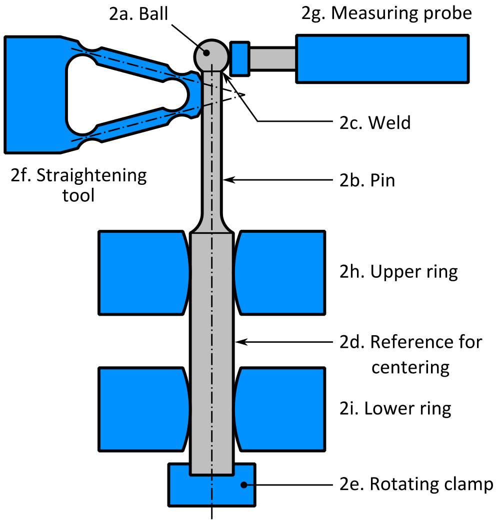

Figure 2. Application 1: pin straightening tool.

The pin is mounted on a rotating clamp (2e). The direction of the misalignment is detected by subsequently rotating and measuring the pin. Then, the misalignment is corrected with the straightening tool (2f). The straightening tool incorporates a force sensor. To prevent damage of the ball or the weld, the force is applied on the pin below the weld. Displacement is measured with a separate measuring probe (2g) which measures the location of the ball. During measuring and deformation, the pin is clamped in an upper ring (2h) and a lower ring (2i). The pin has a reduced diameter above the rings. Deformation only occurs in the top part, the thick lower part remains straight.

The initial misalignment between ball and reference cylinder is about 100 μm. The elastic deformation of the ball during bending is as large as 1000 μm. The achieved accuracy after deformation is 10 μm (2σ).

The accuracy is determined by several factors. The factors with the largest error contributions are listed in table 1. It appears that the tool is most susceptible to position variations of the contact points between pin, lower and upper ring.

Table 1. Error breakdown example 1, based on theoretical analysis.

Uncertainty	**Error contribu-tion/μm (2σ)**
Alignment error of pin in upper and lower ring	9.4
Distance upper ring to ball	2.0
Delivered force by straightening tool	0.8
Measured force in measuring probe	0.4
Overall accuracy of drive and measurement chain	0.1

To obtain well defined contact points, the following design measures need to be taken:

- Each ring has a V-shaped notch to guarantee the exactly constrained position of the pin.
- Contact surfaces have to be dimensioned such that contact stresses and deformations are minimized and contact stiffness is maximized. However, large contact radii are not favourable for the position accuracy of the contact points. Therefore, a trade off has to be made.
- Care has been taken to avoid contamination of the contact points.

4. Application 2: Two dimensional bending

In the second application, two dimensional bending has been applied for a part of a stairlift. A stairlift consists of a generic chair and a customer specific rail. The rail is made of a pipe and a rack. The pipe can be bent by a standard pipe bending machine, but the shaping of the rack is more complex. First, the flat blank of the rack is laser cut out of steel plate. Next, the flat shape is simultaneously bent and twisted in many subsequent steps to obtain the required complex 3D shape.

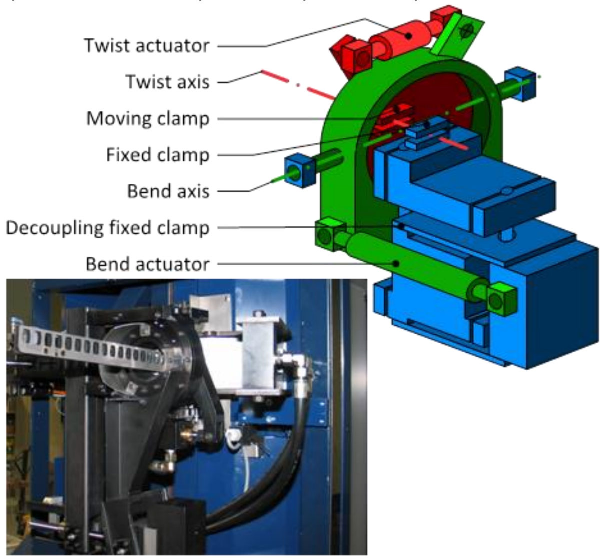

Figure 3. Application 2: a rack bending machine.

A dedicated four-axis CNC machine is built, see figure 3. Two axes are dedicated to the bending and twisting of the rack, the other two to accurately position the flat part of the blank. If the natural axes of rotation determined by the geometry of the blank do not exactly coincide with the bend and twist axes of the deformation head, the system would be overconstraint. This would obscure the precision deformation algorithm. Therefore, the fixed clamp is only fixed around the bend and twist axes, and decoupled in all other degrees of freedom.

The blanks are made from cold rolled steel with significant work-hardening and anisotropy. The magnitude of the work-hardening varies from blank to blank and the direction of anisotropy is random. This means that the spring back during deformation can vary up to 50% within one rack. Because the force and displacement are continuously monitored, this technology is insensitive for work hardening and anisotropy.

This machine has achieved bend and twist accuracies less than 0.2° per step, and the cycle time is less than 20 seconds per step.

5. Conclusion

This paper shows that high precision deformation technology after assembly can be used as an alternative for high precision part manufacturing. Two successful applications are presented. Because force and displacement are continuously monitored during deformation, this technology is insensitive for work hardening and anisotropy. In order to obtain a high deformation accuracy it is essential to pay much attention to proper force initiation between tool and work piece.

References

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