Development of springback tester and the effect of forming speed on the springback of four sheet metal bending processes

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Abstract. With the current increasing emphasis on issues of energy saving, emission reduction, driver and passenger safety in automotive industry, lightweight bodywork is an effective measure to reduce vehicle energy consumption. And also, high-strength bodywork structure can improve automobile safety performance because of its high impact absorption energy, and high fatigue resistance. In sheet metal forming, springback is a main defect with using high strength steel. Aiming to investigate sheet metal springback phenomenon for high-strength steel, a multi-functional springback test machine is built. The testing machine can perform four types of springback tests: V-bend, U-bend, stretchbend and drawbend, and all these tests have been carried out to investigate the effect of springback factor in sheet metal forming processes for example forming speed. The research found that the springback angle of U-bend and drawbend increase with enlarging speed, however, V-bend and stretchbend show the opposite trend.

1. Introduction
At present, one of the main ways to solve the problem of energy saving and emission reduction of automobiles is to use high-strength steel instead of traditional steel plates. The application of high-strength steel can not only improve the lightweight of the car, but also improve the safety performance. However, springback is one of the most serious problems in the current forming of high-strength steel sheets for automobiles, and it has become a bottleneck restricting application of high-strength steels [1]. Therefore, it is of great significance to study the springback of high-strength steels in order to improve the forming accuracy of high-strength steel parts and to promote their applications.

Drawbend was proposed by R.H.Wagoner et al [2]. It can describe the complex deformation
of the material when it flows into the inner wall through the fillet radius of the die, and can control the axial tensile stress individually, accurately and quantitatively. The test principle is shown in figure 1 (a). T. Kuwabara et al [3] proposed the stretchbend springback. The test principle is shown in figure 1 (b). At present, this test method has become Japan’s national industrial standard JIS H 7702 and international standard ISO_24213_2008 (E). V-bend and U-bend are also commonly used test methods to measure the springback. They are shown in figure 1 (c) and figure 1 (d) respectively. It’s known that different springback tests need different testers. So it’s necessary to develop one tester which can do four bending tests such as drawbend, stretchbend, V-bend and U-bend.

![Figure 1](image)

Figure 1. Schematic of four tests: (a) V-bend. (b) U-bend. (c) Stretchbend. (d) Drawbend. (unit: mm)

Scholars from various countries have conducted different bending test to analyze the influence of die parameters (male die fillet radius, female die fillet radius, female die’s angle or curvature), process parameters (blank holder force, punch displacement), and sheet parameters (sheet thickness, mechanical property) on the springback amount. However, there is not much research on the influence of forming speed on springback. Mori K et al [4] studied the effects of three high-strength steel sheets (SPFC440, 780Y, 980Y) properties, excessive displacement of punches, forming rate and holding time on the V-bend springback using a CNC servo press. It’s found that the effect of forming rate on springback is not obvious. Min Kuk Choi et al [5] carried out U-bend with different punch speed (0.07, 0.7, 7, 70mm/s) of 1mm thick DP780 steel sheets. The springback angle of the side wall increased from 117° to 118.57°, while the angle between the side wall and the blank holder decreased from 68.39° to 66.72°. O Çavuşoğlu et al [6] conducted a 60-degree V-bend test at different strain rates (0.0083s⁻¹,0.16s⁻¹) for 1mm thick DP1000 steel sheets, and found that the springback increased from 9° to 13° as the strain rate increased.

Most of researches about effect of forming speed on springback are carried out by using V-bend or U-bend. With the application of servo presses in the field of high-strength steel sheet
stamping, it is possible to flexibly adjust the stamping speed. So it’s meaningful to investigate the effect of forming speed on springback by using different bending tests including drawbend and stretchbend.

The article consists of two parts. The design principle and implementation process of the test platform are introduced in first part. The effect of forming speed on springback by using four kinds of bending tests are analyzed.

2. Design and implementation of test platform

2.1. Overall plan

The developed testing machine can be divided into two sets of test modes: stretchbend and drawbend. The tensioning and blank holder cylinders are controlled by force, and the drawing and punching cylinders are controlled by speed. Stretchbend, U-bend, and V-bend adopt a set of test modes, and drawbend has a separate set of test modes, and the die can be easily changed when performing different tests. Mechanical system adopts three beams and four columns structure. The device is used to automatically or manually control the movements of the various components of the hydraulic system by means of "computer/manual control panel-PLC-electro-hydraulic proportional control". The overall schematic is shown in figure 2 and each die set is shown in figure 3.

![Figure 2](image)

Figure 2. Test machine overall: (a) Schematic. (b) Physical.

![Figure 3](image)

Figure 3. Various dies: (a) V-bend. (b) U-bend. (c) Stretchbend. (d) Drawbend.

2.2. Design and implementation
2.2.1. Mechanical system. (1) Stretchbend module. It includes two blank holder and one stamping cylinders, upper beam and movable beam, and die assembly. Magnetostrictive displacement sensors are installed at the rear of the blank holder and the punching cylinder, and the force sensors are installed in the middle. The upper beam and the movable cross beam are connected by bolts, and an upper die is installed under the movable beam. The die part includes three types: U-bend, V-bend and stretchbend. The male die is installed under the punching cylinder’s force sensor, and the female die is installed on the work platform. Different dies need to be replaced during different tests. (2) Drawbend module. Tensioning cylinder, drawing cylinder, work platform and die assembly are includws. The two inclined planes of the working platform are at 90 °, and the tensioning cylinder and the drawing cylinder are respectively installed. The tensioning cylinder adopts a compound structure of large and small cylinders to meet the wide range of controllable tension force. A clamping cylinder assembly is installed at the front of the force sensor, and the scale is connected to the moving part through an adapter card to control the displacement of the hydraulic cylinder. The die part includes five sets of round rolls with different radii, a series of pads of different heights to accommodate different thickness samples, and it is ensured that the initial angle of the test sheet are accurate 90 °.

2.2.2. Hydraulic system. The hydraulic system uses dual pumps to supply oil to provide the required power for the test machine to achieve various actions. The movement of the hydraulic cylinder is controlled by the action of the electromagnetic reversing valve. The German Rexroth proportional valve is selected as the main control valve, the tension and blank holding force is adjusted by the proportional relief valve, and the speed of the drawing cylinder and the punching cylinder is adjusted by the proportional speed regulating valve. The hydraulic system consists of a pumping station, a cooler, an oil pipeline, a hydraulic valve, a valve plate and related accessories.

2.2.3. Control System. The control system is composed of Delphi software, OMRON PLC, Advantech data acquisition control card, etc., which can realize closed-loop control of tension and blank holder force, and close-loop control of punching displacement and drawing displacement. The testing machine can send the signal to PLC and proportional valve through the control software to realize automatic operation, and also can realize the manual operation directly through the button on the manual console. The software system is equipped with force sensor out-of-tolerance alarm and break alarm to provide safety guarantee.

3. The springback tests by using different bending methods
In order to verify the reliability of the testing machine, V-bend, U-bend, stretchbend and drawbend were tested in multiple groups to study the effects of conditions such as force, distance, speed, and lubrication on different springback tests, as shown in table 1. The samples after test are shown in figure 4. It shows that the testing machine can complete the four types of tests. Springback index of V-bend, U-bend and stretchbend is shown in figure 5 and one of drawbend is shown in figure 1 (a).
Table 1. Experiment matrix to verify the reliability of the test machine.

| Material       | Sample size (mm) | Test conditions                                      |
|----------------|------------------|------------------------------------------------------|
| **V-bend**     | DP980/780/500    | Die angle: 60 °, 90 °, and 120 °                    |
| **U-bend**     | DP590            | Punch depth: 100mm, speed: 40mm/s, blank holding force: 30, 100, and 200kN from left to right. |
| **Stretchbend**| DP590            | Speed: 20mm/s, blank holding force: 30kN, punch depth: 50mm, 77mm, and 100mm from left to right. |
| **Drawbend**   | DP980            | Tension: 11.5kN, speed: 40mm/s, radius of the punch depth: 25.4mm, drawing distance: 25.4mm, 76.2mm, and 127mm from top to bottom |

![Figure 4](image1.png)
![Figure 4](image2.png)
![Figure 4](image3.png)
![Figure 4](image4.png)

**Figure 4.** Various samples: (a) V-bend. (b) U-bend. (c) Stretchbend. (d) Drawbend.

![Figure 5](image5.png)
![Figure 5](image6.png)
![Figure 5](image7.png)

**Figure 5.** Springback index: (a) V-bend. (b) U-bend. (c) Stretchbend.

This paper studies the effect of forming speed on the springback of each test. The size of the V-bend springback specimen is 150 × 50 × 1.2mm, the punch angle is 90 °, and the test termination condition is that the punch pressure reaches 6kN, forming speeds are 2, 30, and 60mm/min. The size of the U-bend sample is 150 × 50 × 1.5mm, the blank holding force is 50kN, and the punching depth is 80mm, forming speeds are 10, 20, and 40mm/s. The size of stretchbend sample is the same as that of the U-bend, blank holder force is 30kN, and the punching depth is 77mm, forming speeds are 2, 20, and 40mm/s. The drawbend sample size is 660 × 50 × 0.8mm, tension force is 6.24kN, drawing distance 127mm, round roller radius is 25.4mm, and speeds are 5, 20, and 40mm/s. The above test materials are DP780, and the test is performed once. The results of the test are shown in figure 6.

It can be seen from the test results that V-bend and stretchbend decrease the springback amount with increasing speed, while U-bend and drawbend are opposite. The contrary is interesting because it is also found in testing of DP590 although the test of DP780 here are not repeated. The cause will be discovered by using FE modelling and experiment in the future.
Figure 6. Springback amount of each test: (a) V-bend. (b) U-bend. (c) Stretchbend. (d) Drawbend.

4. Summary

- The multifunctional springback tester is developed which can do V-bend, U-bend, stretchbend and drawbend tests in the same machine.
- The tester’s reliability are validated by different springback test of high strength steel. Especially, effect of forming speed on the springback amount are investigated using different method. It’s found that the springback amount of the V-bend and stretchbend decreases as the forming speed increases and the U-bend and the drawbend are opposite.

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