Non-Contact Measurement in Plate Bending using Confocal Microscopy

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Abstract

In high precision bending machine the measurement in plate bending is important. To ensure high accuracy, non-contact measurement processes are preferred. This paper describes an application of confocal sensor for devising a non-contact measurement of physical parameters i.e. bending angle and bending radius measurement. The various other non-contact measurement methods has been discussed. This method is suitable for a 4 or 5-axis CNC machine serving the application of measurement and just requires installation of confocal sensor and simple fixture for holding the plate. Irrespective of the material, measurement can be performed easily. The C# program used for control and automation of the confocal and linear slide have been depicted using a flowchart. The basic methodology and equations adopted for measurement has been presented. Experimental results show the error to be 0.164% and 0.02% for bending angle and bending radius respectively.

Keywords: Confocal microscopy, bend angle, bend radius, measurement

1. INTRODUCTION

Measurement in plate bending is important in a plate bending machine. Laser forging [1] is used as an unconventional process for bending a plate. Another application that involves bending of plate is the use of bent plate in human bones. The structure of orthopedic plates is complex to bend and if done with precise measurements can eliminate the process of time taking hit-and-trial method. There are many methods available for the measurement of bent plate angle; primarily they are divided into two categories i.e. contact type and non-contact type. The contact type measurement method includes measurement using Bevel protractor [2], Sine bar [3] and Clinometer [4] while non-contact method [5] includes Laser ranging method, monocular camera method [6] and binocular active vision system [7].

The removal of workpiece for measurement during bending in a bending machine is not desired. In-situ measurement of plate bending angle in case of contact methods is cumbersome and when done after removal of workpiece might give inaccurate results and systematic errors [8] as the exact orientation of workpiece is not possible when mounted and dismounted repeatedly. Moreover, integration of contact type instrument for measurement of small plate angle is difficult as the size of instruments themselves are very large. Hence non-contact methods are devised and preferred. All above mentioned non-contact measurement systems are bit complex in setup. Laser ranging method and monocular methods are based on Machine vision development. These methods required calibration of both camera and laser. Overcoming the limitations binocular active vision system was developed which comprised of binocular camera and linear laser. However, this system requires the camera and laser setup to be installed at similar orientation and its assembly becomes critical.

This paper describes an application of confocal sensor for measurement of bending angle of a plate. Confocal sensor [9], based on confocal microscopy, can be used for distance and profile measurement and is light, compact and can be easily mounted on the machine. Using a simple automated technique comprising of a C# program and excel calculations plate bending angle measurements were done. Apart from the angle measurement, using confocal, bending radius calculation of a bent plate is also demonstrated.

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2. METHODOLOGY

The chromatic confocal sensor due to its light weight and compact size has been chosen for the measurement purpose. Table 1 shows the specifications of the selected confocal sensor.

Table 1

Confocal sensor specifications

Working distance	6 mm
Light spot dia	6 µm
Resolution (Z)	10 nm
Probe diameter	27 mm
Probe length	154 mm
Fibre core	50 µm
Range	300 µm

2.1 Calculation of Bent angle

For measurement of bending angle, the plate taken is having following parameters:
Length= 80mm,
Width=10mm,
Thickness=3mm
Given Bending angle: 120°
Given Bending radius: 50mm

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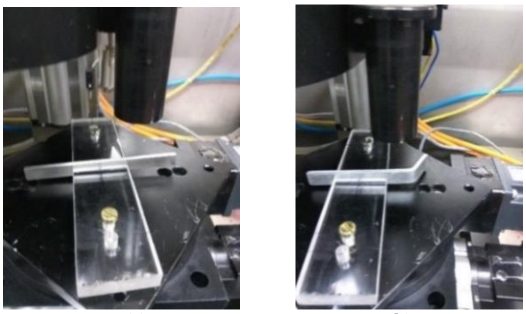


(a) (b)

Fig. 1: (a) Plate arrangement shown before bending (b) Plate arrangement shown after bending

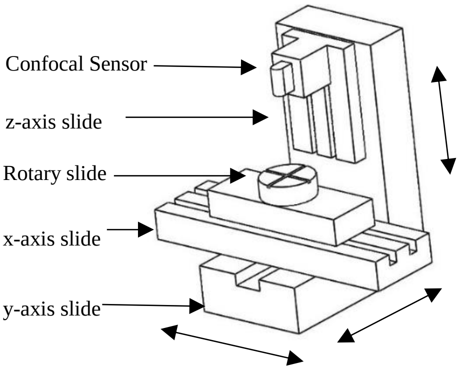


Fig. 2: Schematic diagram of Confocal mounted on z-axis slide with all 4-axis shown.

The steps involved in the measurement process for a specific angle is given below which can be used to find out any bent plate angle:

1. A fixture with groove equivalent to thickness of plate, as shown in fig. 3, is designed such that it will hold the plate along with its thickness in lateral position. The groove in fixture is made in such a way that it will lie on the center of the rotary table.

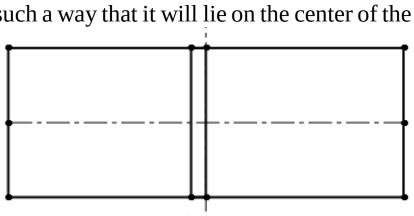
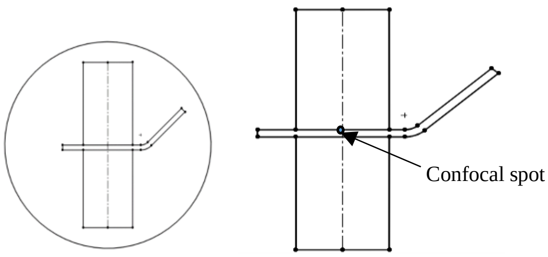


Fig. 3: Schematic diagram of fixture showing groove at the center

2. The white light of confocal sensor is focused at one end of edge of a 3mm plate which is fixed at center of the rotary table. As shown in fig. 4(b), the plate is fixed such that the fixture's right end is at least 5-10mm distance from start of bent radius.



(a) (b)

Fig. 4: Schematic diagram of (a) Plate arrangement shown at rotary table (b) Confocal spot shown at center of fixture

3. Linear slides are used to provide movement to workpiece against fixed confocal. Using C# program, as shown in fig. 7, the distance from center of fixture (and rotary table) to right end of the plate will be measured. An illustration of length which is measured is shown in fig.

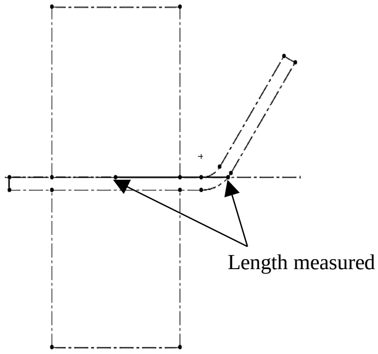
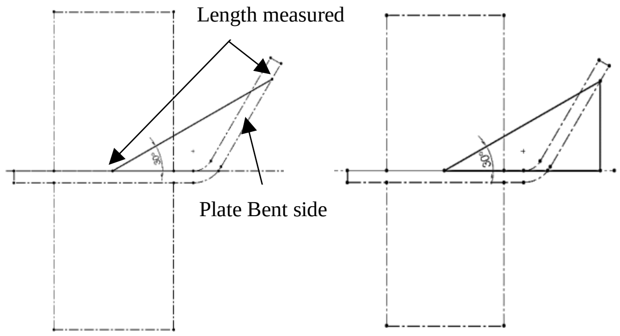


Fig. 5: Schematic diagram of two confocal spots shown which are taken into consideration for measurement

4. Then confocal center is brought back again to its initial position. The rotary table, C-axis, could be rotated at an angle ranging from 10 to 60 degrees depending on the length of the plate after the bent portion. The more the angle of rotation, the precise will be the measurement.

5. Now, the confocal point will again travel from its initial position, which is center of fixture/table, to horizontal direction. This time, reference is at 30° so confocal point will move at this reference line, as shown in fig. 6(a). Since rotary table has been rotated at some angle, confocal white light will first encounter no surface, after a few distance it will travel on the bent side and then reach at the end of the bent.



(a) (b)

Fig. 6: (a) Schematic diagram of two confocal spots shown which are taken for measurement (b) Schematic of triangle formed.

6. The length from center of the initial position to the end of the bent side plate is found out. This line will act as hypotenuse of the triangle formed as shown in fig. 6(b).

7. Now, the angle of the triangle and the hypotenuse side is known. Using cosine and sine law the length of the base and the perpendicular side will be obtained as shown in fig. 7 and equations below:

$$AB = 46.11mm \quad (1)$$

$$Angle = 30° \quad (2)$$

$$BD = h * cos30° \quad (3)$$

$$BD = 46.11 * 0.866 = 39.929 \quad (4)$$

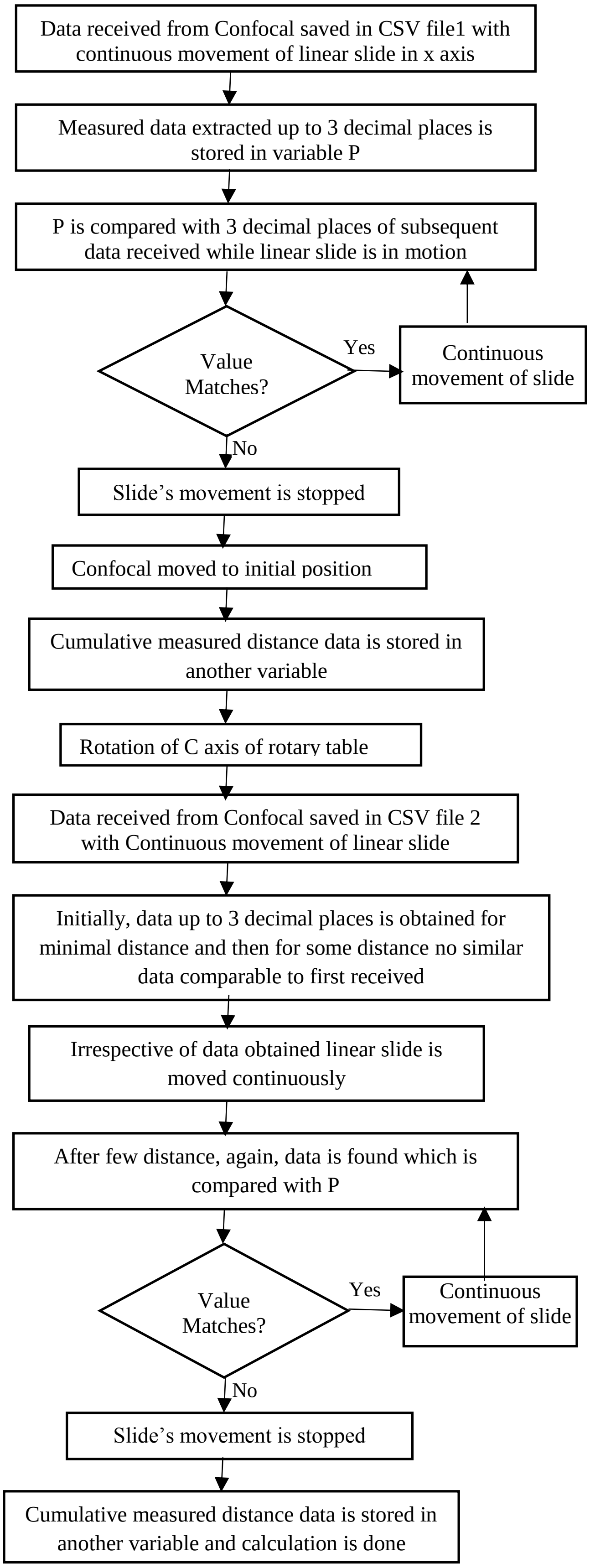


Fig 7: Flowchart of C# program for automated measurement of bending angle

8. Subtracting the length of base, BC, found due to movement of linear slide from triangle's base, BD, the length of base of new triangle is obtained.

$$CD = BD - BC = 39.93 - 26.51 = 13.42mm \quad (5)$$

9. Using sine rule, the length of the perpendicular side, AD, is known which is common side for the new triangle, ACD.

$$AD = AB * sin30 \quad (6)$$

$$AD = 46.108 * 0.5 = 23.054mm \quad (7)$$

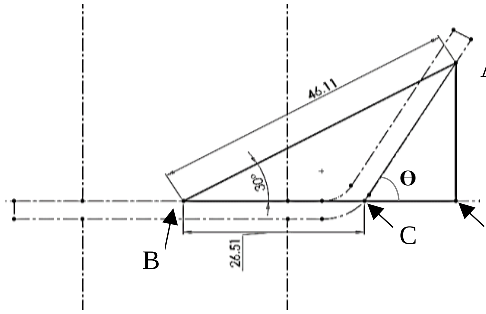


Fig 8: Schematic showing hypotenuse and base

10. Using tangent rule, the angle of the bent plate will be calculated.

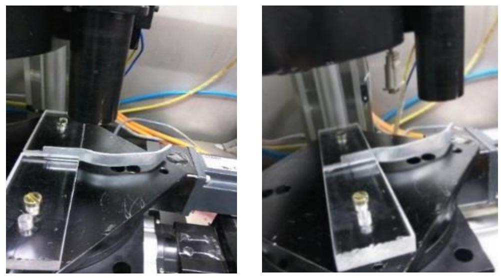
$$tan\theta = \frac{AD}{CD} \quad (8)$$

$$\theta = tan^{-1}\left(\frac{23.054}{13.416}\right) = 59.803° \quad (9)$$

$$Required\ angle = 180 - 59.803 = 120.197 \quad (10)$$

$$Error = \frac{120.197-120}{120} = 0.1642\% \quad (11)$$

2.2 Calculation of Bent Radius



(a) **(b)**

Fig. 9: (a) Initial position of confocal while measuring bending radius (b) Final position of confocal while measuring bending radius

The measurement procedure of bent radius has been delineated in Fig 11. The steps to measure the bent radius is as follows:
1. To measure the bent radius of a plate, confocal sensor point is focused on starting point of bend. The workpiece is kept in such a way that while moving from point A to B, the initial and final position is sensed and taken as input. The initial and final position of confocal sensor is shown in fig. 9(a) & 9(b). Now, the distance between A and B is known which is denoted as W.

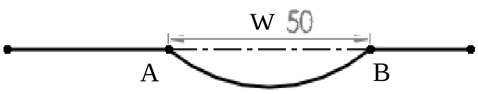


Fig 10: Schematic diagram of measurement of Width, W

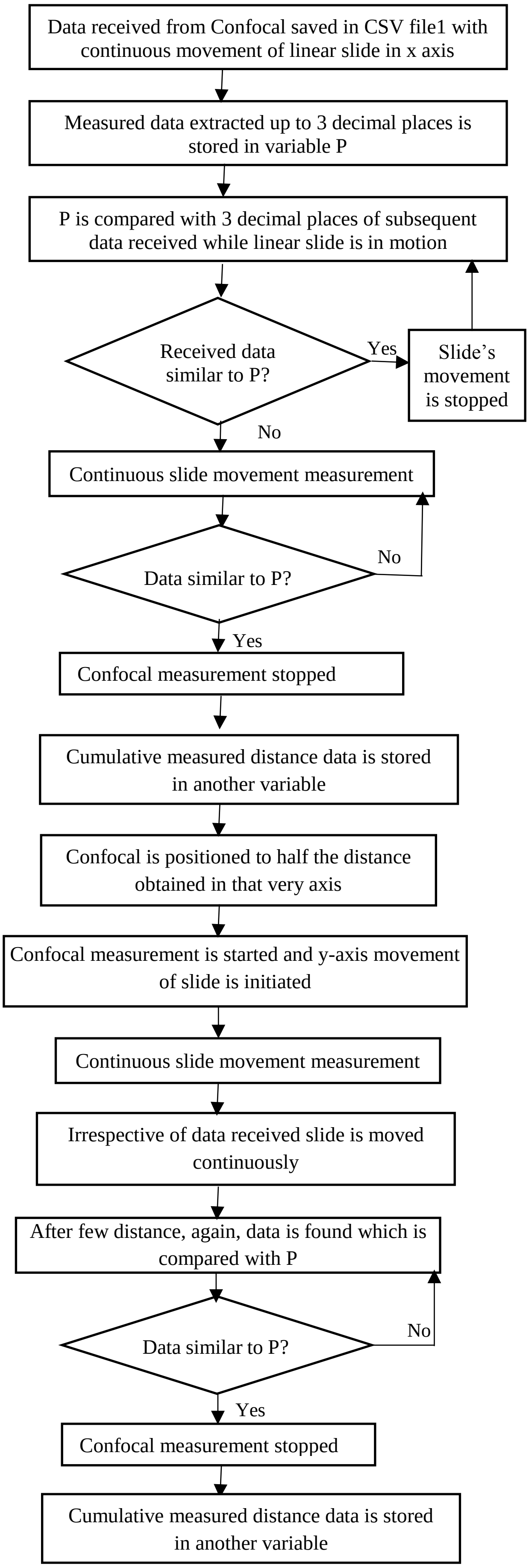


Fig 11: Flowchart for Calculation of bent radius

2. Through the movement of linear slide in x-axis up to half of the distance between A and B, confocal point is focused at midpoint. Now confocal point is moved vertically using y-axis slide until it touches the curvature which when measured is marked H.

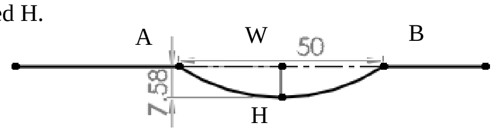


Fig 12: Schematic of measurement of Width, W and Height, H

3. Using the relation between radius R, width W and height H, the bending radius of plate is found out, as shown in equations:

$$R = \frac{H}{2} + \frac{W^2}{8H} \qquad (12)$$

$$R = \frac{7.583}{2} + \frac{50.054^2}{8 * 7.583} = 45.087 \qquad (13)$$

$$Original\ Radius = 45mm \qquad (14)$$

$$Error = \frac{45.087 - 45}{45} = 0.020\% \qquad (15)$$

3. CONCLUSIONS

In this paper, a new automatic method of measurement of bending angle and radius of bent was introduced. The experiments were performed and result were obtained which were found to be in close proximity when compared with the measurements of bevel protractor. The error obtained for measurement of bending angle was 0.1642% and of bending radius was 0.02%.

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