LASER DIGITIZER BASED STRAIN MEASUREMENT
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Abstract

Automotive sheet panel strain measurement usually involves large surface areas. For high resolution analysis, using the circle grid analysis method, several hundred elements must be measured. Existing technologies are limited to the small surface that area can be measured in one setup. As well, the (X,Y,Z) location on the part is not accurately available. This paper reports a new surface strain measurement system based on use of a laser digitizer attached to a Coordinate Measuring Machine (CMM). A Forming Limit Diagram is automatically generated. The thickness strain is calculated, and displayed as a color shaded part surface image. There is a very good agreement with a dial gauge measurement of thickness.

Keywords: metal forming, coordinate measuring machines, strain measurement, laser digitizing

2. Introduction

The sheet metal forming process is widely used in the production of automobiles and other high volume manufactured items. Although computer prediction of formability is advancing, there remains a need for experimental “try out” when dies for a new part are first used. This involves checking that the part is within dimensional tolerance, and that the sheet has not been strained beyond the Forming Limit for the material and process combination. Obtaining the strain experienced during forming is therefore an important process measurement.

The traditional approach to strain measurement begins with electrochemical etching of 0.1 inch diameter circle grid pattern onto the undeformed sheet. After forming, the circles will deform into ellipses. The strain is obtained by manually reading the ellipse major and minor axis lengths with dividers and rulers, a graduated mylar tape, or a microscope [1]. The differences in length from the undeformed circle radius are the local strain value. This process is repeated for every circle in the area of interest, and the results are typically plotted on a Forming Limit Diagram.

Because the manual approach is time consuming, tedious, error prone, and not repeatable, automation of the process has been investigated. One example is the Grid Circle analyzer [2]. This system uses a camera to obtain the image for one ellipse at a time. A least-squares fit is used to calculate the major and minor axis lengths and hence the strain. No information on the (X,Y,Z) part location, or local curvature, is available. Vogel and Lee [3] proposed a stereo video camera and frame grabber. By analyzing a square grid from two images of the same surface area, the part location can be obtained by triangulation. More recently, this approach has been improved by moving to higher resolution digital camera [4]. Existing approaches share the common deficiencies that only a limited surface area can be measured in one setup, and the (X,Y,Z) location on the part is not accurately available.

The new approach of strain measurement uses a laser digitizer that operates with a CMM. The output of laser digitizer is
(X,Y,Z) co-ordinates and the associated intensity value. Using intensity data, the location of the deformed circles can be measured precisely. The remainder of paper is organized as follows. Section 2 describes the measurement system. Section 3 describes curve detection for the grid location. Section 4 data points segmentation will explains how to group the ellipse data points. Section 6 is strain calculation. Section 7 concludes the paper.

3. Measurement System

![Fig. 1. System architecture.](image1)

Fig. 1 shows the overall system architecture. The Co-ordinate Measuring Machine employed is a DEA IOTA model 1102. The configuration has a standard bridge Z vertical axis on Y, on X and granite table. Each axis consists of a rack and pinion drive, linear scale and air bearings. The linear scales are interpolated to a 1 µm resolution. The CMM controller uses a Pentium 166 MHz based computer, and Motion Engineering Inc. (MEI) Digital Signal Processor (DSP) based motion interface card [5]. It provides scale quadrature counting, probe switch latching, digital control system interval timing, analog to digital (A/D) tacho-generator input and digital to analog (D/A) output to the Pulse Width Modulated (PWM) DC motor servo amplifiers. The laser digitizer employed is a Hymarc Hyscan 45C SC2 [6].

![Fig. 2. Camera body.](image2)

The camera body (Fig. 2) of the laser digitizer includes a Charge Coupled Device (CCD) array, two fixed mirrors, lens, oscillation mirror, and laser diode. The oscillating mirror is rotated about its center and sweeps out the scan line along the surface being scanned. The laser digitizer applies the principle of active triangulation with synchronization of projection and detection. Beginning at the laser diode, the beam travels to the bottom of the oscillating mirror, left fixed mirror, part surface, right fixed mirror, to the top of the oscillating mirror, ending at the CCD array. The Hyscan system (U,V) coordinates are determined from the orientation θ of the scanning mirror and position P that has the greatest intensity value on the CCD array. Using calibration data, the (U,V) coordinates are converted to (X,Y,Z) position. Data samples along the scan line are normally separated by 100 µm.

4. Curve Detection

The curve detection algorithm uses the local image threshold strategy. The algorithm starts by choosing a threshold value ε. This depends on the contrast of the image and gray level of the CCD camera. The next step is to establish the size of the curve detector threshold window. This
depends on the diameter of the circles. During detection, the square window will move from left to right and top to bottom on the data structure. In this case, the data points are stored in a format scan line by scan line. At the current location the curve detector takes the data points and performs intensity normalization. Let \( I(i,j) \) is the intensity value. The normalized intensity value is

\[
I_{\text{norm}}(i,j) = \frac{I(i,j)}{SI}, \quad SI = \sum_{i=1}^{m} \sum_{j=1}^{n} I(i,j)
\]

Retained curve data points satisfy the condition

\[
I_{\text{norm}} < \varepsilon
\]

For the research reported herein, \( \varepsilon = 0.016 \) and \( m = n = 7 \).

5. **Ellipse data points grouping**

For neighboring ellipses, the closest edge to edge distance is approximately 500 \( \mu \text{m} \). The closest data point neighbor within an ellipse is 100 \( \mu \text{m} \). A midpoint threshold is therefore 300 \( \mu \text{m} \). Using this relationship, the data points can be grouped into ellipses. If the point separation distance is less than 300 \( \mu \text{m} \), the data points are grouped into a single ellipse. If the distance is larger, a new ellipse group is created.

An orthogonal least squares fitting algorithm [7] is applied to compute the ellipse center and length of major and minor axis for each group of ellipse data points.

6. **Strain Computation**

Once, the ellipse centers and length of major and minor axis is available, the strain of each ellipse elements can be calculated. For each axis, the true strain is

\[
\varepsilon_s = \int_{L_0}^{L} \frac{dL}{L} = \ln \left( \frac{L}{L_0} \right)
\]

where \( L_0 \) and \( L \) are original and elongated length, respectively.

7. **Experiment Results**

[Fig. 3] shows scanned area of the part. Comparing the center with the circumference of part, the center region has the highest strain since the size of ellipse is larger. [Fig. 4] shows the result after curve detection and the extra pieces of line are erased. [Fig. 5] is a Forming Limit Diagram corresponding to scanned area. [Fig. 6] is a 3-D thickness strain color plot, and illustrates the promising results.

To evaluate the result of laser digitizer based strain measurement, manual dial-gauge strain measurement is performed. The results of the measurement are shown in [Fig. 7]. Comparing the result with the laser digitizer measurement, [Fig. 6] and [Fig. 7] shows good agreement.

8. **Conclusions**

In conclusion, this paper has presented a new laser digitizer based strain measurement system. The key procedures of the new technology consist of curve detection, ellipse data point grouping, ellipse fitting and 3-D graphical display of the results. Compared to existing CCD camera methods, the laser digitizer based strain measurement method has the advantage of high accuracy measurement of (X,Y,Z) coordinates. This information is needed so that detailed die forming geometric errors, such as spring back, can be investigated. As well, using a CMM to carry the laser digitizer permits accurate measurement of large part areas.
Fig. 3. Scanned Object.

Fig. 4. The ellipse data points.

Fig. 5. Forming Limit Diagram.

Fig. 6. 3-D thickness strain color plot from dial-gauge manual strain measurement.

Fig. 7. 3-D thickness strain color plot.

Reference


