Measurement of the State of Hole With One Exposure Using a Single Digital Camera

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Abstract: - In this paper, a novel measuring method for examining the state of a single drilled through-thickness hole in terms of exact surface roughness, precision tolerance, eccentricity is presented. The proposed method can also measure the diameter and depth of the hole with one exposure using a single digital camera. It is the aim of this paper to develop a new camera positioning control device which utilizes the forementioned measuring method to reduce expenses and process time during the measurement. We designed the apparatus according to an established frame of digital camera measurement parameters (height of optic position and width of horizontal view angle). The effectiveness of the proposed approach in measuring the diameter and depth of the through hole has been validated by using gray scale chromatic aberration of the image contour regions. This measurement system not only increases the accuracy of the measuring results but is also applicable with any kinds of digital cameras.

Key-Words: - measurement frame, through-thickness hole, digital camera.

1 Introduction

Currently, there are many kinds of measuring gauges in use for measuring the diameter as well as the depth of hole in mechanical fabrication industry. The most popular measuring gauge is Vernier Calipers [1]-[2] which requires two steps, by measuring the diameter and depth respectively. Other measuring gauges such as ultrasonic waves [3]-[4] and laser beams [5]-[7], too, can be used for this measurement purpose, however, they are claimed not being very user friendly.

Measuring gauge made with a LVDT is also available [8]-[9]; nevertheless, none of the above can provide a visual image contour region of the drilled through-thickness hole and show the measuring data of diameter and depth of through-thickness hole at one time.

As mentioned earlier, the goal of this research is to design a measuring method that allows the measurement of through-thickness hole's diameter and depth at one shot. It is worthwhile noting that the method does not require any physical contact of the two objects (drilled through-thickness hole and measuring gauge) to avoid any scratch or any other negative impacts. A digital camera with two high intensity LED lights is installed above the hole to be measured to provide a visual definition. Only the top and the bottom of the through-thickness hole are photographed which will show as in two different sized round image contour regions. The dimension of the round image contour region will equal the total pixels it takes and based on the result, the diameter and depth of the drilled through-thickness hole can then be calculated.

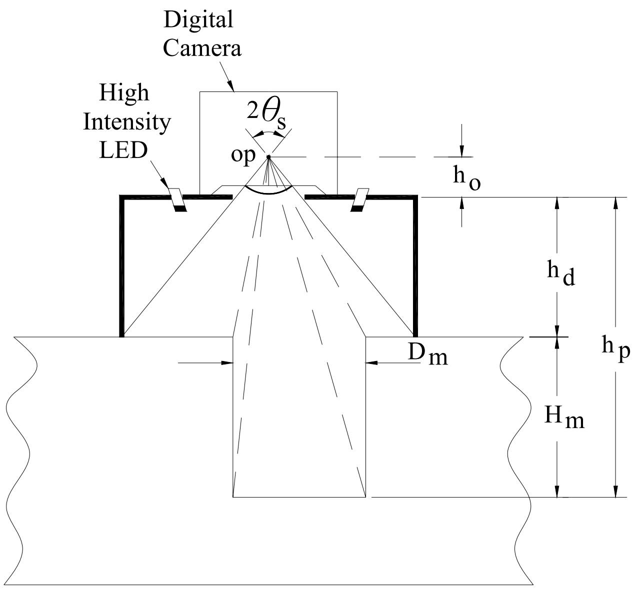
The second section will explain the reason we believe the measurement of hole's diameter and depth can be done in one shot. We continue to elaborate on the formula in the third section. In the fourth section, we will prove the adjustment frame designed is applicable to all kinds of digital camera with the correct measurement parameters. Section five and six will justify the formula and calculation process with an experiment and followed is the conclusion in section 2.3.

2 Theory of hole diameter and depth measurement

As most digital camera's effective pixels have reached to the level over 6 million [10]-[12] and equipped with lighting these days, a clear close up can be easily taken even when the illumination is minimal.

For a hole with 20mm diameter, total pixels taken in its visual image contour region will be over 2000 and the resolution of distance measurement will reach below 10μm. It is because of all the functions mentioned above installed in nowadays' digital camera, this research can then be practiced and completed.

The following section will introduce the measurement concept and structure with actual visual image contour region taken to prove its accuracy.



h_o : Height of optic position
h_d : Distance between the top of the hole and digital camera
D_m : Hole diameter of sample
H_m : Hole depth of sample
h_p : $h_d + H_m$

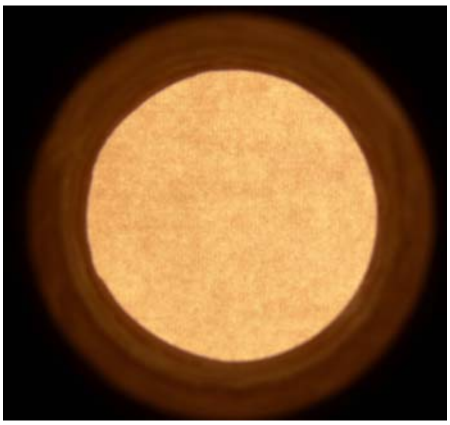
Fig. 1 Schematic diagram of system for hole diameter(D_m) and depth (H_m) measurement.

As shown in Figure 1, attach the digital camera with two high intensity LED lights (in order to provide enough illumination for a clearer image contour regions output) to the measuring frame at height h_d. Now the distance between the digital camera and the very bottom of the hole to be measured becomes h_p hence the hole-depth H_m equals to h_p- h_d. Elaboration on how to calculate the hole-depth (H_m) and hole-diameter (D_m) will be included in the later section.

When the digital camera photographs from top down, the visual result will show two round gray scale contour regions. The larger one being the top of the hole as it is closer to the camera (h_d) and the smaller one is the bottom of the hole which is more distant from the camera (h_p). The dimension of the two round gray scale contour regions can be used to determine the total pixels taken in the visual image contour region and then obtain the hole-diameter and hole-depth measurement by applying the formulas introduced next.

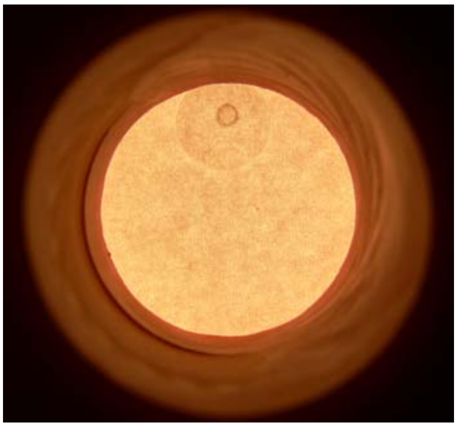
In Figure 1, h_o is the height of the optic position and $2\theta_s$ denotes the width of horizontal view angle. Both are the measurement parameters and by utilizing the adjustment structure designed in this study, different measurement parameters can then be calculated depends on which kind or brand of digital camera in use, i.e. the structure is applicable to all digital cameras. We will now look at the actual image contour region in the picture taken to explain why the dimension of image contour regions can be used to calculate the actual hole-diameter and hole-depth.

Figures 2 and 3 gives a comparison between the image contour regions of two different drilled through-thickness holes (in terms of diameter and



Hole-diameter of sample: 22mm
Hole-depth of sample: 14.9mm

Fig. 2 actual image contour region of sample I



Hole-diameter of sample: 22mm
Hole-depth of sample: 20.3mm

Fig. 3 actual image contour region of sample Ⅱ.

depth) and it is obvious that the dimensions of two round image contour regions in each visual result vary.

It is worthwhile noting that when photo-graphing the hole-contour, there is no need to focus on the center of the circle (hole). As long as the two gray scale contour regions fit into one screen, the measurement can then be done.

Both As in Figures 2 and 3 are the image contour regions of the hole-surface and Bs are the hole-bottom. In later section, we will discuss how to determine how many pixels an area of image contour region (A & B) takes.

2.1 Formula for measurement

In order to give a clear explanation, we will enlarge the graphic and go through the formula assuming the camera photographs at the center of the contour region (hole).

Diameter(D_m) will remain the same regardless of anything and according to our previous investigation [13]-[16]. Since the scan time and horizontal distance are in direct proportion, hence the total pixel taken will also grow when the horizontal distance extends when using a digital camera for measurement.

$$D(h_d) = \frac{N_s(\max)}{N(h_d)} \times D_m \quad \text{.............. (1)}$$

$D(h_d)$ is the maximum horizontal distance when the height is at h_d and the horizontal angle is at $2\theta_s$. In the case of visual image contour region, the maximum amount of pixel taken for every horizontal line scanned is denoted as N_s (max) and with the hole diameter (surface of the hole) being D_m, $N(h_d)$ represents the number of total pixel taken for D_m. When using the triangular theorem to determine the relationship between the horizontal distance and height:

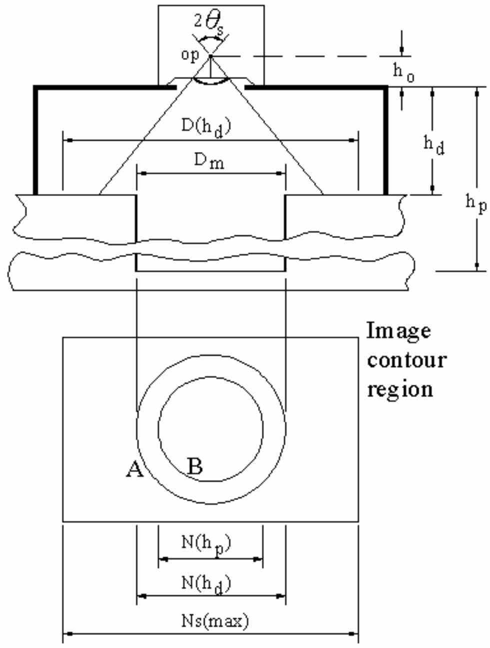


Fig. 4 Schematic diagram of measurement frame.

$$h_d = \frac{1}{2} D(h_d) \cot\theta_s - h_o \quad \text{........... (2)}$$

From (1) and (2) we then derive the following formula

$$D_m = \frac{2N(h_d) \times (h_o + h_d)}{N_s(\max) \times \cot\theta_s} \quad \text{........ (3)}$$

Since N_S (max) has been determined, we will then explain how to utilize the adjustment structure to obtain the measurement parameters for the digital camera. Assuming h_O and $\cot\theta_S$ are also known and h_d being the height that the user can decide, this leaves $N(h_d)$ to be the only variable in the formula. Therefore, once $N(h_d)$ is determined, the hole diameter D_m can then be calculated.

From Figures 2 and 3, there will be 3 different gray scales contour regions. In the center, the visual contour region is the hole-bottom, the next contour region is the vertical inner side of the hole and followed by the surrounding of the hole-surface. When comparing the output in terms of gray scale chromatic aberration, the difference between Figures 5 and 6 can be easily distinguished. $N(h_d)$ and $N(h_p)$ denote the diameter of the two circles (top and bottom of the drilled through-thickness hole respectively) shown below:

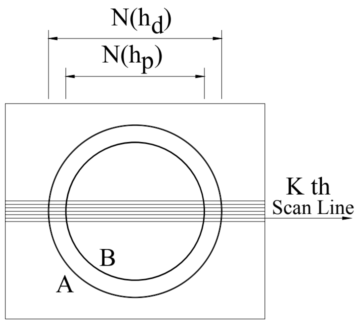


Fig. 5 differentiation of image contour region Ⅰ.

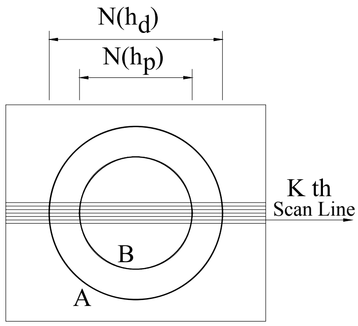


Fig. 6 differentiation of image contour region Ⅱ.

We calculate the total pixels taken for the sum of all round image contour regions instead of using the one with the biggest quantity of pixels for diameter calculation. $AN(h_d)$ and $AN(h_p)$ represent the sum of pixels for the two round image contour regions (surface and bottom of the hole with $N(h_d)$ and $N(h_p)$ being the diameters of each) and from the formulas used to calculate the dimension of a circle, we derive the followings:

$$N(h_d)=2\times\sqrt{\frac{AN(h_d)}{\pi}},\quad N(h_p)=2\times\sqrt{\frac{AN(h_p)}{\pi}}\ \ldots(4)$$

We choose the above way to determine $N(h_d)$ and $N(h_p)$ is because it is based on the same concept of using the method of mean (average). This is to avoid misjudgment and ultimately to increase the measurement accuracy.

For the part of hole-bottom, the height to where the camera is remains to be h_p and the diameter of which also stays still (D_m). At height h_p, the digital camera should have the maximum horizontal distance which is:

$$D(h_p)=\frac{N_s(\max)}{N(h_p)}\times D_m\ \cdots\cdots\cdots\ (5)$$

h_p then becomes

$$h_p=\frac{1}{2}D(h_p)\cot\theta_s-h_o$$

$$=\frac{1}{2}\left(\frac{N_s(\max)}{N(h_p)}\right)\times D_m\times\cot\theta_s-h_o\ \cdots\cdots\ (6)$$

The unknown depth $H_m=h_p-h_d$

$$H_m=\frac{1}{2}D_m\times\cot\theta_s\times\left[\frac{N_s(\max)}{N(h_p)}-\frac{N_s(\max)}{N(h_d)}\right]\cdots\ (7)$$

From Formula 3, the diameter of the hole has been calculated and from Formula 7, the depth of the drilled through-thickness hole is also determined. This truly achieves what we had proposed earlier, to have the measurement result of the diameter and depth at one time through the hole's visual image contour region output.

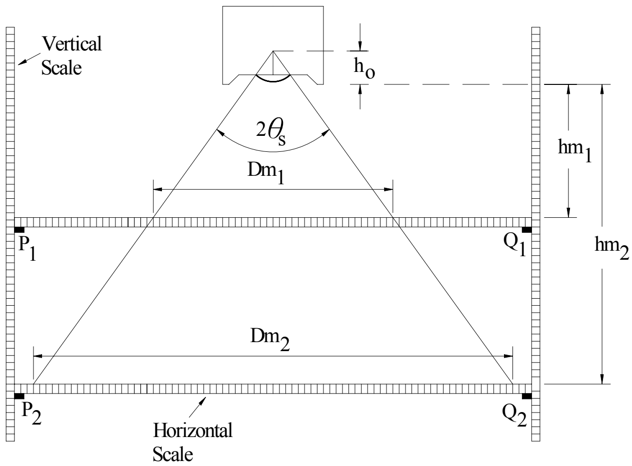


Fig. 7 Adjustment Structure.

2.2 Establishing the measurement parameters

When placing the horizontal measurement gauge between P_1 and Q_1, the distance obtained is h_{m_1} and same applies when measuring the distance (h_{m_2}) between P_2 and Q_2. The horizontal distance for both cases is D_{m_2}.

$$h_{m_1}=\frac{1}{2}D_{m_1}\times\cot\theta_s-h_o\ \cdots\cdots\cdots\ (8)$$

$$h_{m_2}=\frac{1}{2}D_{m_2}\times\cot\theta_s-h_o\ \cdots\cdots\cdots\ (9)$$

From (8) and (9) we get

$$h_o=\frac{h_{m2}\times D_{m1}-h_{m1}\times D_{m2}}{D_{m2}-D_{m1}}\ \cdots\cdots\ (10)$$

$$\cot\theta_s=2\frac{h_{m2}-h_{m1}}{D_{m2}-D_{m1}}\ \cdots\cdots\cdots\ (11)$$

Apply the measurement parameters h_o and $\cot\theta_s$ into formula 3 and 7, we will be able to get D_m and H_m respectively.

2.3 Pixel calculation based on the gray scale contour regions output

Figures 2 and 3 are the visuals output we obtained when measuring the hole and Figures 5 and 6 denote the borders of the circles which are done based on the difference of gray scale chromatic aberration. This will allow us to know to which extent the pixels are to be calculated. There are four chromatic aberrations on the scanning-line of image contour region.

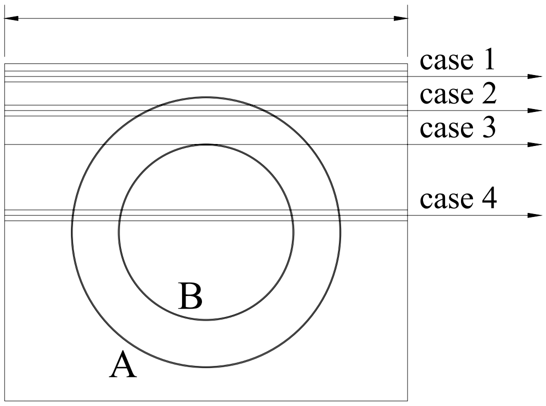


Fig. 8 Judgment rule of pixel calculation.

From Figure 8, we are able to know that pixels taken for each line scanned. Therefore, every time when Figures 5 and 6 are scanned, the sum of the total pixels for the two image contour regions will be known simultaneously [$AN(h_d)$ and $AN(h_p)$] which can then be utilized for $N(h_d)$ and $N(h_p)$ calculation by adopting formula 4.

Regarding the pixel calculation, there are different applications available. However, we have taken the difference in terms of measurement parameters for different digital cameras into consideration and concluded with an easiest judgment rule and calculation method. An experiment is conducted to prove that the method is practical to serve the measurement purpose and more details will be provided in the next section.

3 Experiment results

A. Scheme of experiment

(1) The digital camera is PANASONIC Electric Industrial Co., Ltd. Lumix DMC-FZ30 Type.

(2) N_S (max)= 1024 pixels.

(3) Measurement parameters suggested by measurement frame $h_o + h_d$ = 48.99 mm , $\cot\theta_S$= 2.11 .

(4) Details of the hole of sample to be measured as Table 1

We drilled several through-holes from various steel plates with different thicknesses. With the depths of each hole being known (each steel plate's thickness), we then measure every hole-diameter by using a measuring gauge and label them individually.

Table 1 contains the measurement results of the diameter and depth of each hole produced in the sample

No of sample	1	2	3	4	5	6
Actual hole diameter (mm)	15	15	15	19	22	22
Actual hole depth (mm)	10.2	14.9	20.3	14.9	14.9	20.3
$N(h_d)$ (pixels)	276.3	256.5	235.1	311.5	356.6	325.1
$N(h_p)$ (pixels)	338.1	339.6	339.0	412.8	472.1	471.3
Value of hole diameter measurement (mm)	15.33	15.4	15.37	18.72	21.41	21.37
Value of hole depth measurement (mm)	10.96	15.87	21.65	15.93	15.87	22.03
Error value of hole diameter measurement %	2.21	2.68	2.49	-1.48	-2.69	-2.85
Error value of hole depth measurement %	7.43	6.88	6.92	7.28	6.85	8.80

4 Conclusion

In this paper The method of measurement for measure diameter and depth of hole by using only one digital camera.

We design an apparatus of measurement system that applies to any kind of digital camera which allows two dimensional measured to be achieved based on the image contour regions output as long as the measurement parameters suggested by the system are correctly being adopted. The error of measurement value is within the acceptance range and it also helps in checking the state of hole-surface through image contour regions output.

This system of measurement will be economical and portable for hole-drilling fabrication.

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