

Optical Wear Inspection of Countersink Drill Bit for Drilling Operation in Aircraft Manufacturing and Assembly Industry: A Method

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Abstract. Assembling aircraft skin requires thousands of rivets in order to fasten the skin together with rib. Therefore, there will be a lot of drilling operations daily. This could lead to wastage of drill bit usage if the operation is not fully utilized or reduce the hole quality if it is overused. An inspection system is developed to monitor the condition of the countersink drill bit and put these issues under control. Currently, the existing optical wear inspection system is capable to detect and measure the percentage of wear of the drill bit. The theory and application of image processing used in the detection and measurement were already discussed in previous work. In this paper, a method is proposed to inspect the wear of countersink drill bit by using the current existing system. Several key factors that may affect the accuracy of the optical inspection such as relation between illumination and image quality, and subject positioning and alignment are discussed in this paper. An external illumination system is developed to improve the quality of image captured. The drill bit positioning and alignment are corrected using image registration method in image processing. Another relevant precaution is also added into account before finally implement the complete step of performing the inspection.

1. Introduction

Aircraft manufacturing and assembly industry involves several machining operations such as drilling, riveting, sanding and painting. Drilling and riveting are done in the sub-assembly stage while sanding and painting usually come after these process for finishing. Thousands of rivets require to fasten the skin and rib together. Countersunk or flush rivet is preferable to use for assembling this exterior aircraft parts because it is more aerodynamic. It is flush with the aircraft skin and thus reducing drag on it. Countersink drill bit is necessary to create a countersunk hole to fit the rivet in. The shape and diameter of the countersink drill bit is not consistent along its length because it has conical shape in the middle which is used to create the countersunk hole.

Drilling process in aerospace industry become more challenging as modern aircraft structures are made up of composite material. It is a material known for its high strength to weight ratio but worst machinability [1]–[4]. High strength is good for the aircraft but it would be extremely hard to drill and may reduce the life expectancy of the drill bit. Therefore, a stronger and tougher material such as



polycrystalline diamond (PCD) and carbide bit are commonly used to drill composite material in order to improve the machinability efficiency [4].

The usage of the drill bit has no indicator that can control the process. An overused of the drill bit may reduce the quality of hole while stopping the usage before the end of the tool life may cause wastage. This is where an inspection system is needed. There are a lot researches that has been done in monitoring drill bit using the optical approach. One of the earliest was already done in 1990 by T. Pfeifer and J. Elzer. They propose a vision system and measure the flank wear of drill bit by applying the knowledge of digital image processing [5]. The research on monitoring the wear continues until nowadays with different approaches, methods and objectives. J.C. Su *et al* use edge detection method to extract the boundary of the cutting lips and divided the region to multiple region in order to measure the flank wear [6]. Yu-Teng Liang and Yih-Chih Chiou proves that a real time flank wear measurement method is possible by measuring the wear on 3 drill bits with different materials [7]. Another group of researchers, Guifang Duan *et al*. developed an automatic optical inspection (AOI) for microdrill bit in PCB manufacturing application. The system is capable to perform phase identification of the drill bit condition [8]. Different approach was done by A. Volkan Atli *et al* as monitoring the tool condition from side view rather than top view. A concept of deviation from linearity (DEFROL) is used to measure the changes of the drill bit point angle [9].

From previous research, a system is developed to inspect and monitor the condition of the drill bit wear [10]. It is capable of measuring the amount of wear in term of percentage. This paper proposed a method using optical approach in inspecting wear of countersink drill bit which is used for drilling operation in aircraft manufacturing and assembly industry. The detection method and process flow will not be discussed in details as it already presented in previous work. This paper will be focused on the methodology of the inspection system which includes the system design, illumination system, inspection precaution and procedure.

2. Method approach

2.1. System design

Figure 1 shows the actual configuration of the system. The method used in the inspection system is by monitoring the cutting lips region from top. The system basically can be divided into two parts which is hardware and software. The hardware of the system consists of a digital microscope as the sensor for capturing images and it has its own lighting. However, light emitting diode (LED) strips are used for additional illumination for a better image quality. Servo motors are used on both sides to control the rotation angle of the LED strip with simple programming using Arduino. Chuck is used to lock the drill bit into position and secure its alignment with the digital microscope.

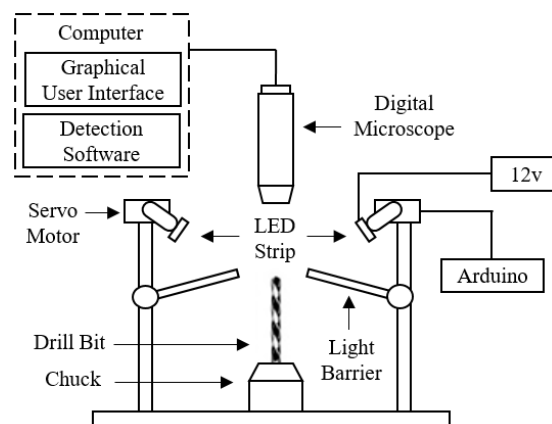


Figure 1. Schematic of the actual inspection system.

The software consists of a graphical user interface which is developed along with the system using MATLAB. The software is capable of capturing the sample for the inspection with a special guideline which will be explained in the next section. It also includes a detection system to detect and measure the wear in term of percentage. This hardware and software is integrated together to become a complete inspection system

2.2. System illumination

The inspection process is focused on monitoring the cutting lips area of the drill bit. A very good light source required to obtain a high quality and clear image of the cutting lips region. The existing light from the digital microscope is not satisfying the requirement of the inspection. The light basically lightens the entire region of the drill bit which could make the detection process more difficult. Additional light source using LED strip is added on both side and projected to the drill bit with help of the law of reflection. The idea is to project the light at certain angle directly to the cutting lips so that the light enters the lens perfectly and the image captured will only focused or highlighted at the cutting lips only.

The law of reflection defines that when light falls into a smooth surface, the angle of the reflection is equal to the angle of incident and the incident ray, reflected ray and the normal line all lies in the same plane. Figure 2 illustrate the definition of the reflection law where, i is the incident angle of the incident ray and r is the reflection angle of the reflected ray.

The additional illustration is projected at certain angle which denotes as β , angle of the light projection which remains unknown at the moment. The only information available is the drill bit point angle, α , used 130° . The relation between these two angles is defined with help of the diagram shown in figure 3. Therefore, the angle of the light projection, β is can be calculated for any different drill bit point angle, α .

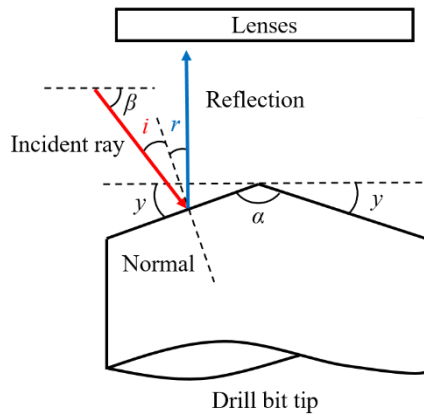


Figure 2. Law of reflection concept used for the additional illumination to ensure light rays enters to the lenses perfectly.

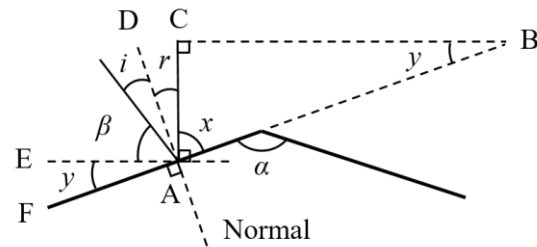


Figure 3. Diagram used to define the relationship between angle α and β .

From figure 2, it is clear that,

$$y = \frac{180^\circ - \alpha}{2} \quad (1)$$

From the perpendicular angle $\angle CAE$ in figure 3,

$$\beta = 90^\circ - i - r \quad (2)$$

Using the law of reflection, $i = r$. Therefore, equation (2) become,

$$\beta = 90^\circ - 2r \quad (3)$$

From right triangle $\triangle ACB$, the total angle of a triangle is 180° , therefore:

$$\begin{aligned} 180^\circ &= 90^\circ + x + y \\ x &= 90^\circ - y \end{aligned} \quad (4)$$

From perpendicular angle $\angle DAB$,

$$\begin{aligned} 90^\circ &= x + r \\ r &= 90^\circ - x \end{aligned} \quad (5)$$

Substituting equation (4) into (5),

$$r = y \quad (6)$$

Rearranging equation (1) and (6) into (3), therefore the relationship between α , drill bit point angle and β , angle of the light projection can be defined as follow:

$$\begin{aligned} \beta &= 90^\circ - 2 \left(\frac{180^\circ - \alpha}{2} \right) \\ \beta &= \alpha - 90^\circ \end{aligned} \quad (7)$$

The LED projection angle is controlled using motor servo on each side. Both servo motors are programmed through Arduino to hold the LED and projected the lights at angle β calculated using equation (7). The brightness of the light source is also an important factor of capturing a clear image. Too much or not enough light could remove an important information from the image. Therefore, dimmer is added to the system in order to control the brightness of the LED in the illumination system.

2.3. Subject Positioning

The detection is done by comparing the image of brand new and worn drill bit and measuring the difference of both images as wear. This comparison requires the image taken each time to be exactly at the same position and size. Therefore, a software is developed to capture the image and included with reference line as a guide as shown in figure 4. This will maintain the size and position of the subject each time the inspection is done. However, the subject positioning is difficult to maintain along the inspection process because there is still a slightly small difference between images taken. This small difference can affect the accuracy of the detection as it increases or decreases the amount of wear detected.

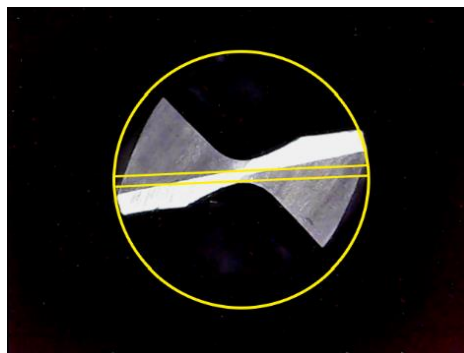


Figure 4. Reference line used to guide and maintain the size, position and orientation of the drill bit during inspection process

3. Result and discussion

3.1. Illumination result

3.1.1. Application of light barrier. Monitoring a countersink drill bit has its own challenge. As mentioned before, countersink drill bit has a conical shape in the middle and this conical region is visible from top view. The region is unwanted as the inspection system is only focused on the cutting lips region to monitor the wear. This is because the conical region is least affected compare to the cutting lips area. The presence of the unwanted region is affecting the inspection result. Therefore, the light barrier as shown in figure 1 is added on both side to eliminate the conical region by blocking lights to the region. It helps the system to focus only to the cutting lips area. Figure 5 proves that the application of the light barrier improves the image acquisition of the inspection system.

Basically, the conical region around the drill bit in figure 5(a) distract the detection algorithm from detecting the region of interest. This image resulted as shown in figure 5(b) which cause error to the detection. A very good example of sample image and its result can be seen as in figure 5(c) and (d) respectively. The detection system clearly detects the region of interest and able to filters all unwanted information. The application of the light barrier to the system has enhanced the inspection result by avoiding the possibility of error in the detection. This enable the system to apply the automatic detection of the cutting lips region which replaced polygon crop, a user defined cropping method to select the region of interest in previous research [10].

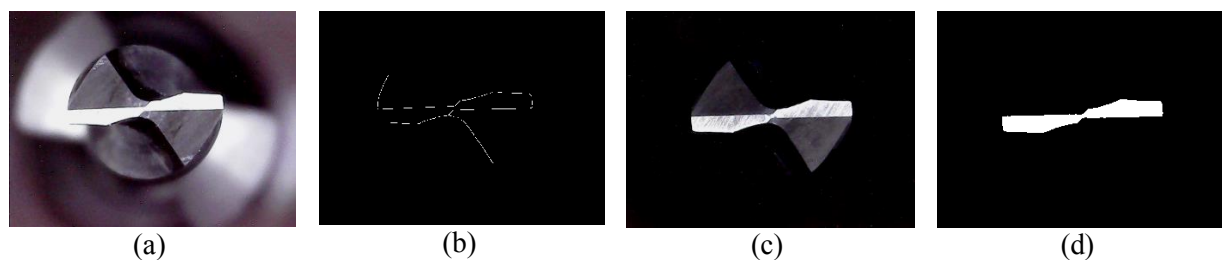


Figure 5. Comparison of images capture with and without application of light barrier and its results (a) Images captured without using light barrier (b) detection result of image without using light barrier (c) image capture with light barrier (d) detection result of image with light barrier

3.1.2. Angle of light projection. In this research, the illumination is important as it affects the accuracy of the inspection system. The additional LED lighting system is included with servo motors on both side to control the projection angle of both LED. A set of data is calculated for various drill bit point angle, α from 125.0° to 140.0° based on the equation (7) derived in previous part and tabulated in Table 1. The current countersink drill bit used has a drill bit point angle of 130° . Therefore, from Table 1 the best angle of light projection, β for the current system is 40.0° . The value is programmed through Arduino to control the servo motors at the calculated angle. This will ensure that the projection is accurate and fixed along the inspection process.

Table 1. Angle of light projection, β calculated for various drill bit point angle, α using equation (7).

α	y	i	r	β
125.0°	27.5°	27.5°	27.5°	35.0°
130.0°	25.0°	25.0°	25.0°	40.0°
135.0°	22.5°	22.5°	22.5°	45.0°
140.0°	20.0°	20.0°	20.0°	50.0°

3.1.3. Lighting and brightness. The illumination system is tested with several different lighting sources and conditions. Three lighting sources are from ambient light, digital microscope light and the additional LED light with projection angle of 40.0° . Figure 6 shows the difference of the results from different lighting sources and conditions. Figure 6(a) is the result taken using ambient light only without digital microscope light and LED light. This condition is inconsistent as the ambient light may vary in brightness and direction of light source in different situation. Capturing the image with digital microscope light resulting a very clear image as shown in figure 6(b) but it does not meet the requirement for the inspection. As explained earlier, the inspection system focuses on monitoring the wear on the cutting lips area only. However, the digital microscope light lightens all the entire region of the drill bit which makes the detection become harder and resulting the similar result as in figure 5(b). Applying the light barrier to this situation does not make any difference as the light from the digital microscope is projected directly to the top of the drill bit.

Projecting the LED lights at 40.0° from both sides resulting a clear image that focuses at the cutting lips region as shown in figure 6(c) and (d). The difference between the two images is the brightness of the LED light. Figure 6(c) shows the result of image captured using the LED light with high brightness at 1100 lux while figure 6(d) with low brightness at 400 lux. These two images are in the acceptable range of the brightness used in the inspection. This limit is necessary as it will be a guidance to control the LED brightness. Over brightness will affect the accuracy of the inspection as the boundary of the cutting lips is extra glowing and cause the system to detect a larger area of the cutting lips. Low brightness is good in differentiating the boundary of the cutting lips but if the brightness is too low, it may cause the detection system harder to detect the boundary itself and resulting a similar result as in figure 5(b). The light barrier enhanced the quality of the image acquisition by removing the unwanted region from the image. This setup combination is the best at acquiring an image that is required by the inspection system compared with image taken using ambient light and digital microscope light.

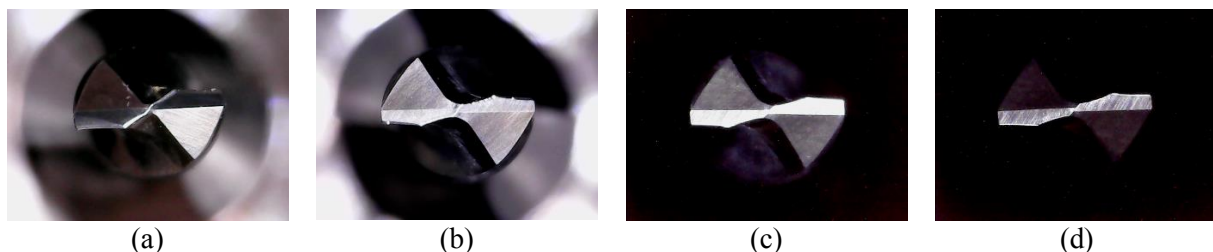


Figure 6. Images captured from various illumination brightness and light sources (a) ambient light (b) digital microscope light (c) high brightness LED strip (d) low brightness LED strip

3.2. Positioning correction

Besides the illumination of the system, the positioning of the drill bit is also important. The inspection is a repetitive process and the consistency in image acquisition is very important because this will affect the output results. As described before, there is still a small difference between images taken although the reference line is used as a guide in maintaining the position, orientation and size of the subject. The problem is solved by using image registration method in image processing. It is used to align the images based on a reference image. This method is included in the detection system in order to eliminate the small difference aforementioned. It is used to perform the correction to the position, orientation and size of the drill bit based on the reference image. Figure 7(a) shows a detection result without using image registration method. The orientation of the drill bits (brand new and worn) are intentionally misaligned to show the effectiveness of this method. This is proven in figure 7(b) as both images are aligned according to the reference image (brand new drill bit). This will make the images to be comparable and enabling the system to monitor and accurately measure the changes of the cutting lips region as wear.

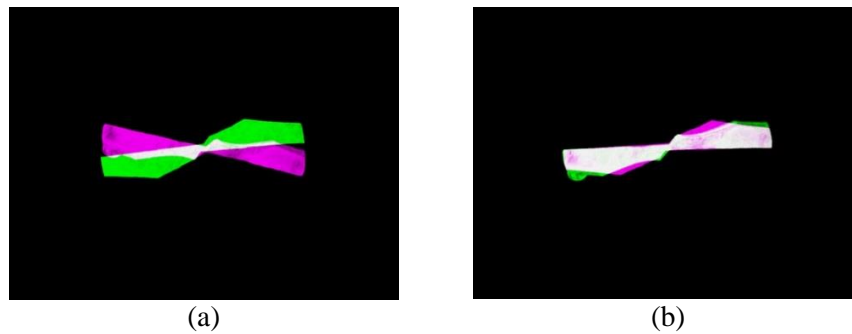


Figure 7. The comparison of the detection (a) without image registration (b) with image registration

3.3. Inspection precaution and procedure

The material of the workpiece drilled is a combination of composite layers and aluminium, since this system is applied in the drilling process of aircraft manufacturing and assembly. The composite material will produce dust when drilling while the aluminium will produce swarf as a result from the machining operation. During the drilling process, the adhesion of the swarf is possible due to the heat produce by the friction between the drill bit and the workpiece. This adhesion may distract the important information of the image which is the region of the cutting lips. The presence of dust also will prevent the lights from reflecting well to the lenses causing the image taken is not clear enough as shown in figure 8. Figure 9 shows the detection result of an inspection using the same image in figure 8. It can be clearly seen that this precaution is a compulsory step for the inspection. Therefore, it is important to clean the drill bit tip with wire brush before performing the inspection to remove the dust and adhesion of swarf around the cutting lips. This precaution is crucial for this inspection to ensure the images taken is clear and qualified to be used for wear detection.

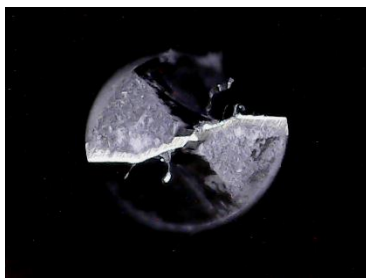


Figure 8. An example of unclean drill bit image

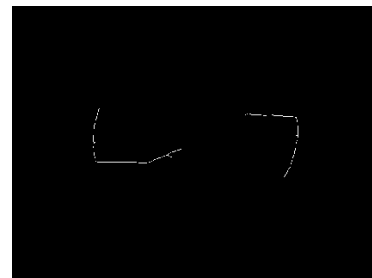


Figure 9. Detection result from the unclean drill bit image

The inspection process is done by following a standard procedure based on the output of the studies.

It starts with preparing the setup of the full system as the configuration shown in figure 1. The digital microscope is connected to the software in computer via USB cable. Then, the tip of the drill bit is cleaned with wire brush to remove dust and swarf before clamp into the chuck. The servo motors is started and the LED lights is on. The servo motors are ensured to be in the correct angle. The drill bit is adjusted into the correct position and orientation with help of the reference line built in the software. The LED brightness is adjusted into the acceptable range. The final step before capturing the image is adjusting the light barrier until the conical region of the countersink drill bit is not visible in the image. After the image is captured, it is ready to be fed to the detection system for wear measurement. The taken steps and precaution are proposed for the other similar monitoring system.

4. Conclusion

This paper proposed a method of performing the wear inspection on a countersink drill bit using an optical approach. The illumination system used is able to capture a good and clear images that is required for the inspection system. A range of brightness is set up to 400 lux to 1100 lux based on the effectiveness of the detection. Image registration method is added to the detection system to ensure the position and alignment of the drill bit for every images captured. Finally, a complete inspection procedure and precaution taken is proposed.

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