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Method of Accurate Countersinking and Rivet Shaving

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ABSTRACT

Wing skin riveting and bolting requires the surface to be flush to +/-.025mm(.001") to produce an acceptable finish. Using the method described in this paper, automated wing riveting technology and panel assembly techniques can achieve better shave height and countersink accuracies than have previously been possible in production.

INTRODUCTION

Wing panels are assembled by clamping the wing skin to the stringers or ribs. A countersunk hole is then drilled and a rivet or bolt installed. In riveting applications, the rivet is subsequently shaved flush with the skin. In many instances the automated fastening equipment is set to leave shaves high, rather than risk deep shaves. A manual operator removes the rest of the material. In bolting applications, bolt-head height variation is often larger than desired. These and other factors motivated us to investigate why variations occur. This paper contains our findings and the methods we used to overcome these variations.

The process for achieving high tolerance countersink and shave heights involves taking advantage of the parallel axis clamp-drill arrangement, which has become the standard on C-frame fastening equipment. It is our opinion that this process can be used on any parallel axis clamp-drill arrangement. This includes post mills, c-frames and most importantly robotic drilling/fastening equipment. Several 5-axis machine tools are currently using this process to meet stringent production tolerances (see ref 1). This process allows lightweight machines, which may deflect while clamping, to achieve the required tolerances. An end effecter mounted on a KUKA robot uses this process and achieves extremely tight +/-.018mm(.0007") countersink tolerances (see reference 2).

MAIN SECTION

DESCRIPTION OF THE PROCESS

In the typical arrangement, cutting operations are performed by servo controlled spindles, which stroke normal to the skin and cut as they feed toward the skin. (See figure 1) The pressure foot is pressed up against the skin. The spindles stroke relative to the pressure foot and toward the skin. Typical RPM is 6000-20000 RPM and the typical feed rate of the spindles when cutting is between .100mm(.004") per revolution and .250mm(.010") per revolution. Typical of most clamp-drilling machines used in aircraft manufacture, this method requires that the part is stabilized by clamping and that the pressure foot face and skin share the same plane. The apex of the stroke of the spindle determines the depth of cut. Using linear scales on the spindle feed axis to close the position feedback loop increases accuracy. Along with temperature compensation and the above assumption that the pressure foot face and skin share the same plane, theoretically all drilling equipment should be able to achieve this +/-.013mm(.0005") countersink and shave tolerance. In practice however, we see much larger variations during the manufacture of wing panels.

CAUSES OF INACCURACY

Thermal growth of the spindle is a major source of inaccuracy. For practical reasons temperature is measured on the non-rotating spindle body rather than the tool holder (see figure 2). This allows us to compensate for most of the thermal growth. We noticed that the tool holder temperature (in our case an HSK-40) did not follow the temperature of the spindle body precisely. The tool holder is cooled while spinning and when stopped it grows as the spindle shaft transfer's heat into it. While the tool holder is warming up and growing, the spindle body where temperature is being measured is actually cooling. In practice, the nonlinear aspect of this temperature variation causes a .038mm(.0015") spread across the median temperature compensation curve. It is undesirable to leave the spindle running because of the long time to reach steady state after changing tools and the danger if an operator must work around a spinning tool.

On the A340-600 wing panels, stacks vary from 6.35mm(.25") to 25mm(1.00") and larger. Because of the stiffness of the panel, the part will not conform to the pressure foot surface if there are normality errors. Normality of the tool is usually driven by sensors. In some areas, where normality sensors can't be used, we rely on the programmed angles of the machine tool. A normality error of 20' with a pressure foot 25mm(1") in diameter produces an error at the center of 12.5mm(.5") X sin (20') = .073mm(.003"). This exceeds our desired tolerance.

Chips or contamination between the clamp pad and the panel will place the panel further from the drill apex, resulting in high fasteners. (See figure 3)

The pressure foot will often press on the panel with a force exceeding 9000N(2000lbs.) to eliminate gaps between the pieces being fastened. Variations in this force will cause the clamp pad to deflect different amounts. This changes the relationship between the spindle and the clamp pad causing errors in fastener height.

SOLUTION

A method of measuring these variations and compensating for them is as follows. Measure the location of the panel after clamp-up using a touch probe. The best probe we can use is the drill bit for the following reasons; it is accurately positioned by a linear scale; it is the first tool used in any fastening process; and the error from the tool holder temperature change will be measured at the same time. The measured panel position is then compared to a stored position that is found during setup and calibration.

The cycle works like this:

1. As the clamp table comes forward drive the drill bit out proud of the pressure foot plane.

2. Before contact is made with the panel, reduce torque to nearly zero on the spindle feed axis.

3. Clamp as normal. The panel pushes the drill back.

4. Measure the drill position and subtract from it the known position of the pressure foot plane. We will call this δP.

5. Subtract the temperature comp (δT) from δP to get the change in length due to the above variations (δL). $\delta L = \delta P - \delta T$

6. To the known position of the pressure foot plane, add δT and δL to achieve the correct apex of the drill spindle.

7. Back up the drill and start spindle.

8. Return drill feed torque to full.

9. Drill the hole as normal using the apex calculated with the measured errors above to achieve the correct countersink depth. (See figure 4)

For bolting applications, the bolt is then driven into the hole and countersink depth sets the head height as shown in figure 4.

For riveting applications, the rivet is shaved flush after the rivet is formed. (See figure 5) This is done with a separate spindle that also must be compensated. The shaving bit cannot measure the panel position because the rivet is now in the panel. We can however use the panel location found by the drill to calculate the shave depth. The only difficulty is that the two spindles will typically run at different temperatures so using just the position measured by the drill would cause an error equal to the difference in thermal growth of the spindles. To compensate for the thermal growth we add the temperature compensation for the shave spindle to δL, which already has the drill temperature compensation subtracted as shown in step 5 to obtain the correct position. Both spindles have the same duty cycle and so any nonlinearities in the growth of the tool holder will be similar. The two spindles have unique temperature compensations this way and can still take advantage of the measured panel position. Using this method on the A340-600 panel assembly line, we achieve .025mm(.001") total shave height variation.

CONCLUSION

Using the method described in this paper, the accuracy of automated fastening machines can be increased to a level that allows fasteners to be installed flush with the surface within required tolerances. This technology will enable machine tools to be built lighter while maintaining high accuracy.

REFERENCES

1. Hartmann, John and Meeker, Chris, "Automated Wing Panel Assembly for the A340-600" SAE Aerospace Automated Fastening Conference and Exposition, New Orleans, Louisiana September 20-22, 2000.
2. "The Art of Wing Assembly", Aerospace Engineering, July 2001.

CONTACT

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FIGURES

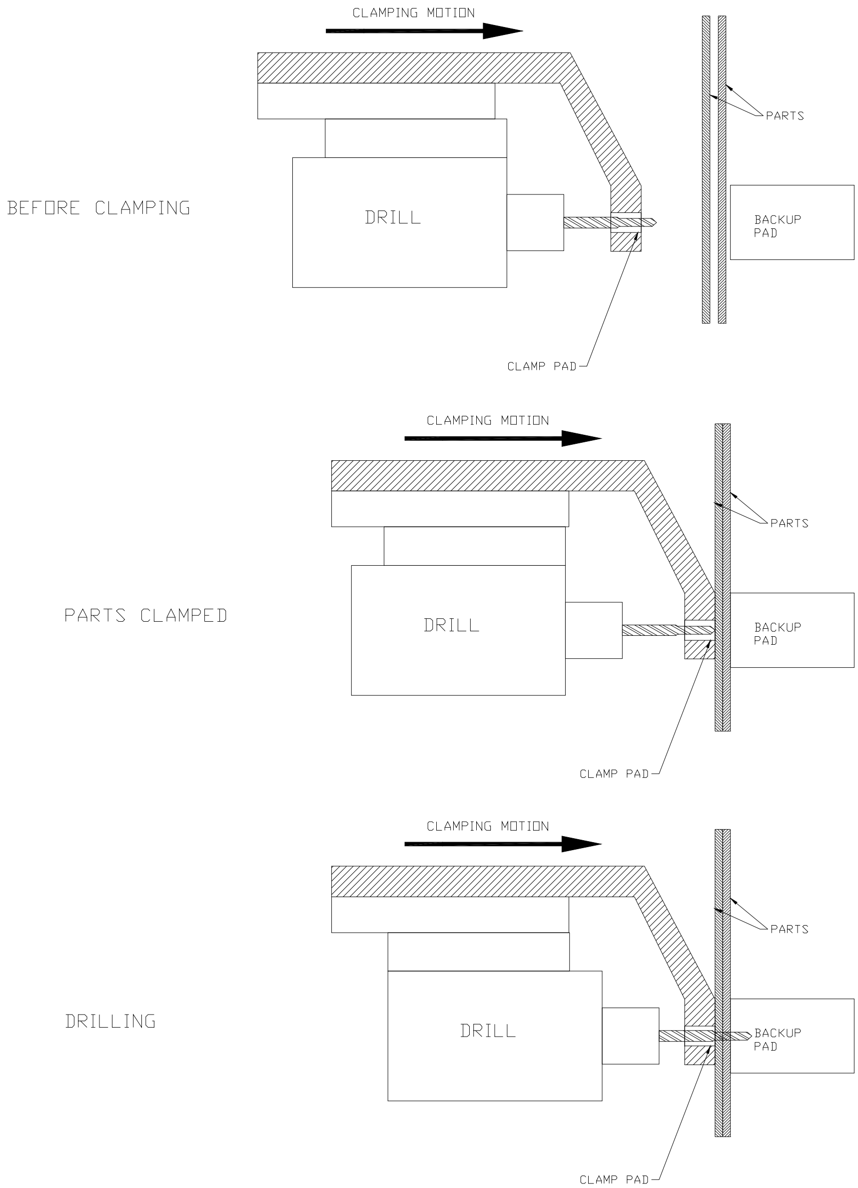

FIGURE 1 – DRILLING PROCESS

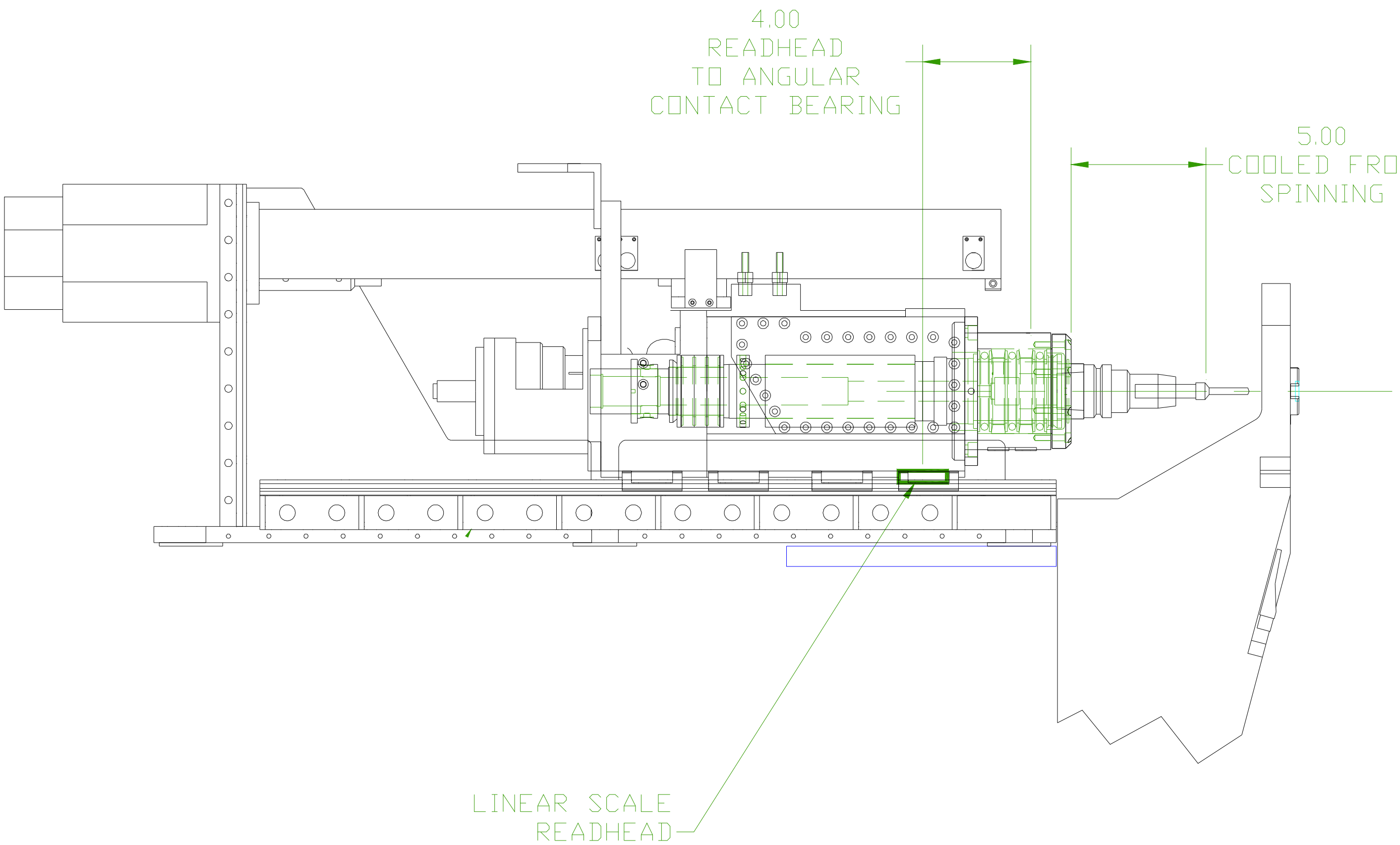

FIGURE 2 – TYPICAL SPINDLE

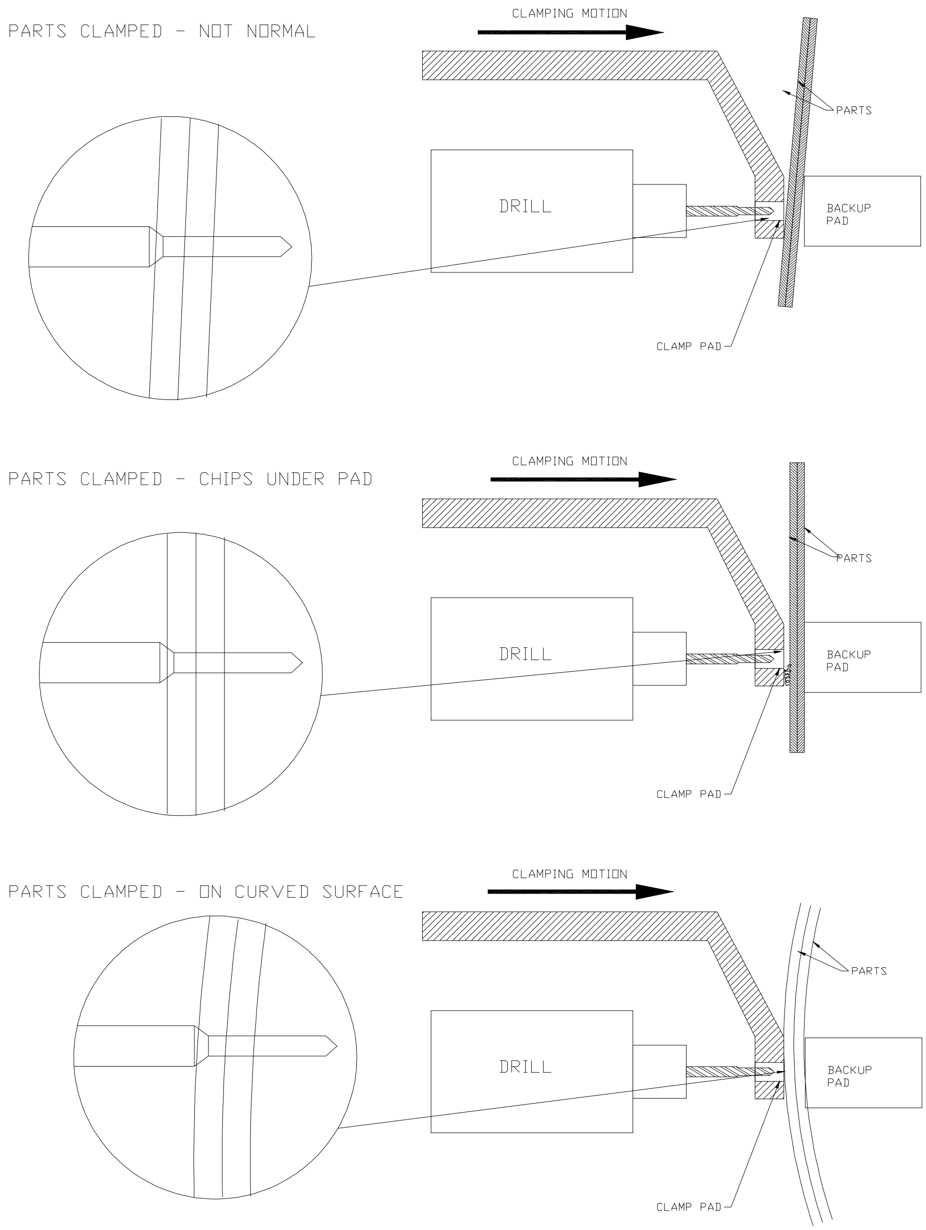

FIGURE 3 – CAUSES OF DEPTH ERROR

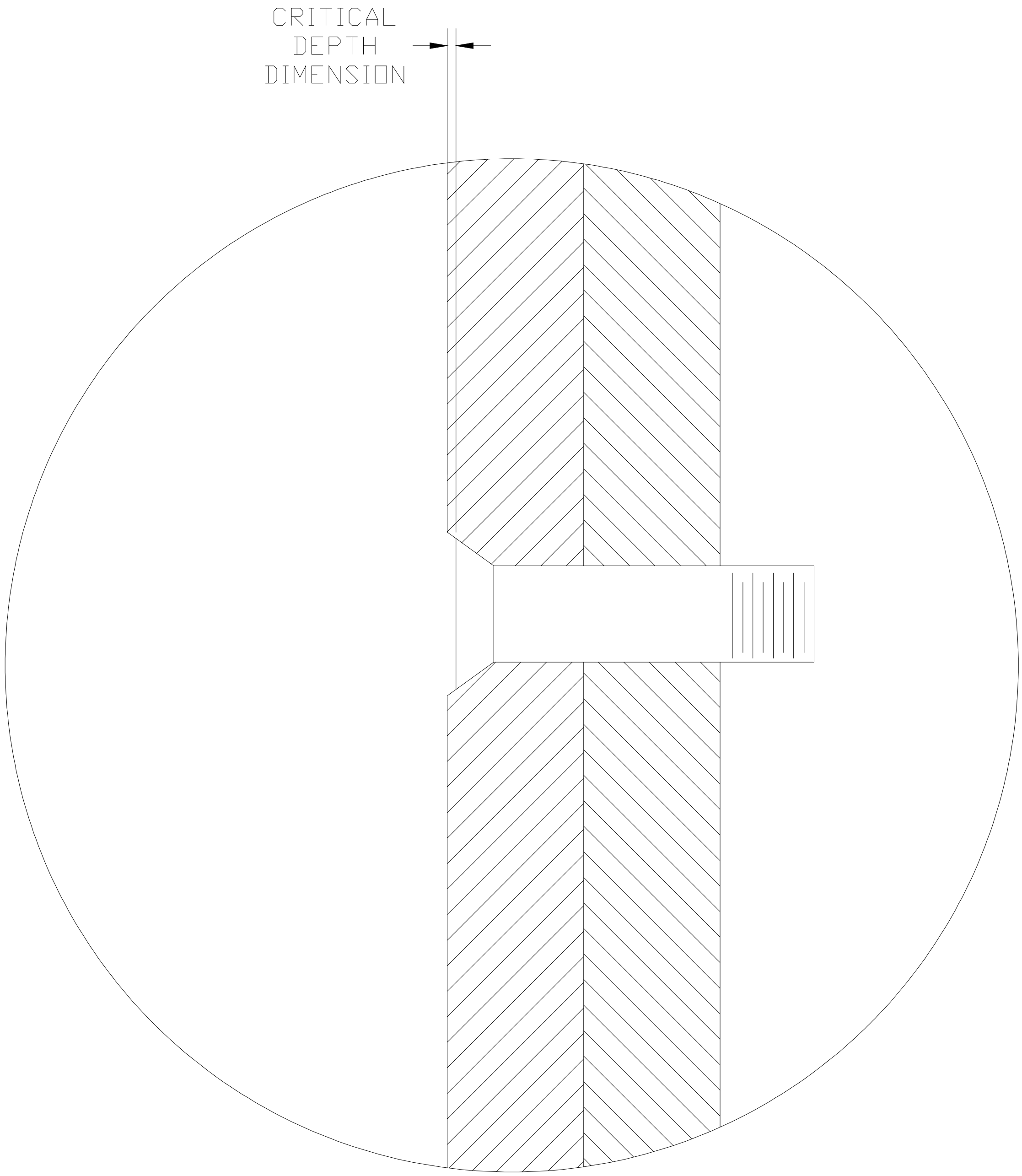

FIGURE 4 – TYPICAL INSTALLED BOLT

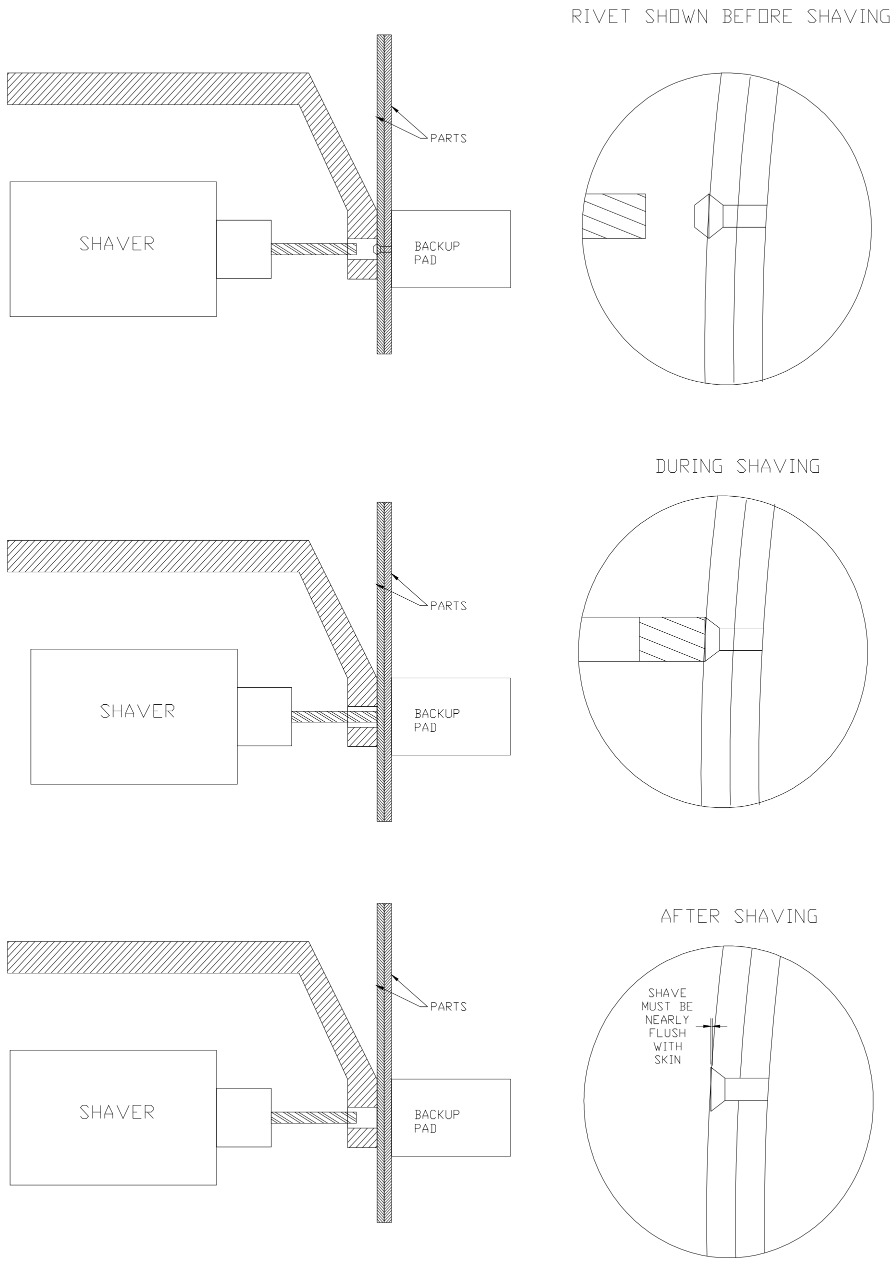

FIGURE 5 – RIVET SHAVING PROCESS