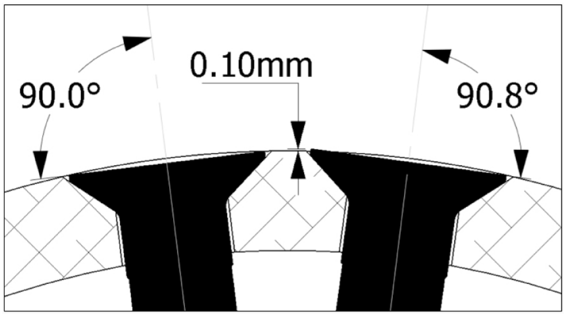

Figure 5. Fastener head protrusion caused by off-normal drilling and countersinking. Shown are 3/16″ flat head fasteners on a curved panel with 45mm bend radius.

Four Point Lander

A compliant contact pad with a widely-spaced four point lander as opposed to a flat contact surface allows for a wide base of contact with a highly curved part. The four point lander, as shown in Figure 6, prevents wobbling or cocking of the compliant lander and allows normalization even on curved surfaces. While the four point lander solves one issue it also creates a significant problem. When the four point lander is clamped up to surfaces of various different radii of curvature, the contact pad does not have a consistent gage length relative to the part surface. In this case a lengthy panel touch-off procedure is required to establish panel position, which must be known in order to drill countersinks to an accurate depth.

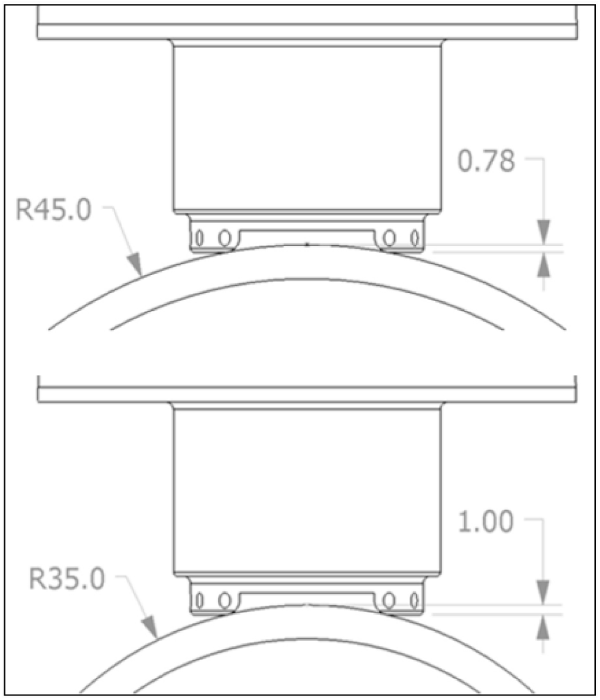

Figure 6. A four point lander prevents wobbling of compliant lander but induces uncertainty in panel position. Dimensions in mm.

Actuated Four Point Lander

To solve the problem of unknown panel position presented by a four point lander, an actuated four point lander was developed. The actuated lander has four spherical pads and enshrouds a rigid base contact surface. Compressed air is used to extend the actuated lander so the spherical pads are proud of the base contact surface.

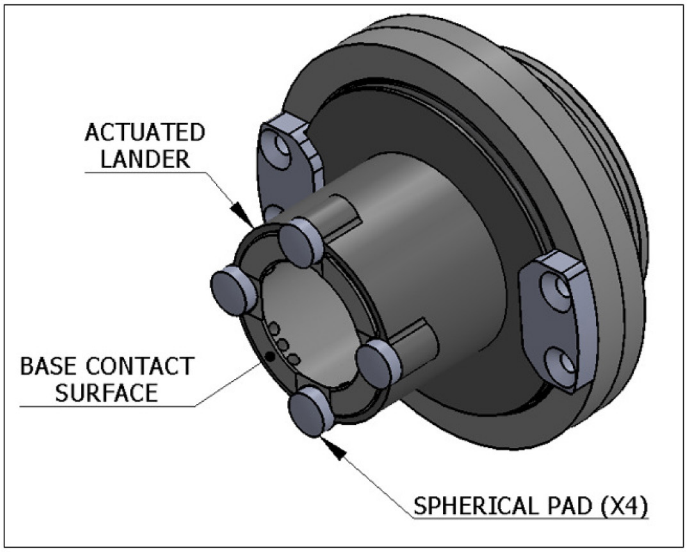

Figure 7. Actuated four point lander.

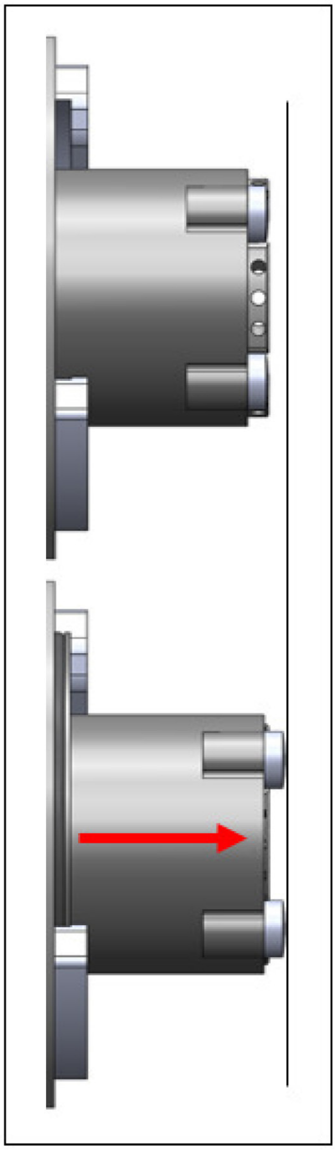

Figure 7. Compressed air is used to extend the spherical pads forward of the base contact surface. The actuated lander is shown in the retracted position, upper, and extended position, lower.

High Curvature Clamping Routine

One of the key benefits of Electroimpact's solution to the high curve clamping problem is that cycle time is not impacted by the new hardware. The routine for high curve clamping is nearly identical to low curve clamping. The only difference is that the spherical pads are actuated forward at the beginning of the routine, then disabled at the end of clamping. The full routine is detailed below, to better explain how the tip works.

1. The robot head is oriented so that the 4 points on the lander will straddle the axis of curvature. Offline programmers have 4 possible head orientations to choose from
2. Clamping routine begins. The high curve lander is actuated forward and the clamp axis servo begins driving the head towards the panel
3. The four spherical pads of the lander make contact with the panel
4. Once 20 kg force is seen by the load cell on the MFEE, the robot begins responding to normality sensor feedback. 20 kg is the minimum force required to swivel the robots nosepiece and indicates that the normality sensor readings are accurate to the real world
5. Normality correction is injected as the robot continues to clamp. The force of the actuated lander (~25 kg) is soon overcome by the clamp force, and the 4 points of contact are pushed backwards
6. The base of the contact pad makes contact with the panel. This forms two line contacts bringing the total number of contact points up to six.
7. Final normality corrections are made as the clamp load approaches the target
8. Target clamp load is reached, normality corrections are complete. Pressure to the pneumatic lander is disabled and the clamp routine finishes.

Since the base contact surface still makes contact with the part, panel position is known implicitly. This is because the base contact surface is part of the rigid structure of the head. The four point lander actuates forward to assist in normality, but does not interfere with the rigid base's final line contact with the panel. Where other systems require a panel touchoff before drilling and countersinking, this solution does not. The robot is able to continue onto drilling and countersinking immediately after clamping, meaning that cycle time is not impacted by the use of the high curve lander.

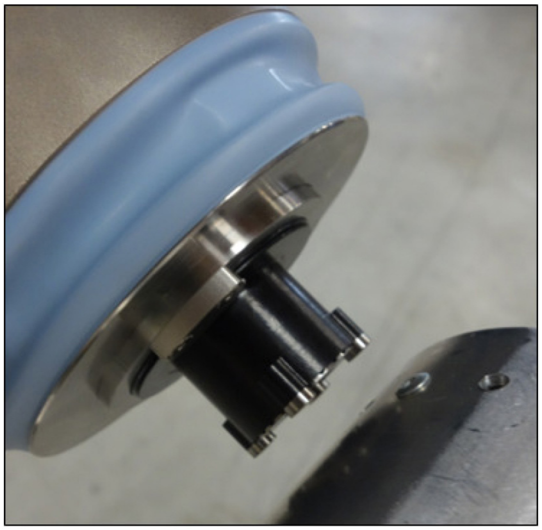

Figure 8. Photograph of the production version of a compliant contact pad and actuated lander.

Conclusion/Summary

Drilling and countersinking on highly curved surfaces has remained largely a manually performed task even as automated drilling system have become commonplace in aerospace manufacturing. The actuated four point lander was designed to overcome the technical challenges preventing robotic drilling systems from working on highly curved surfaces. This technology is production ready and has proven effective for drilling and countersinking quality holes on highly curved surfaces without any negative impact to cycle time. The expansion of drilling capabilities to include both flat and curved surfaces greatly increase the value of *Accurate* Robots for use in aerospace manufacturing.

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Definitions/Abbreviations

NC - Numeric Control

MFEE - Multi-Function End Effector

The Engineering Meetings Board has approved this paper for publication. It has successfully completed SAE’s peer review process under the supervision of the session organizer. The process requires a minimum of three (3) reviews by industry experts.

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