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Developments in Fastener Coldworking in Next Generation Automated Production Units

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ABSTRACT

The incorporation of split mandrel coldworking into a single-station, automated wing assembly machine advances the technical quality of automated production. Coldworking innovations, including the CMX process and new puller unit development, combined with new clamp-up technology, have eliminated the need for manual dissasembly and deburring, both costly and time consuming procedures.

These advances in automation are illustrated in the development of a next-generation automated unit created for wing production of the Airbus A340-600 wide-body program. This paper describes the implementation of new fastener and coldworking technology that led to the development of this automated manufacturing system.

INTRODUCTION

Due to the part size and technological limitations of assembly equipment, traditional wing manufacturing has consisted of a three-stage process. Parts are first manually tacked together in an assembly jig. Assemblies are then removed from the jig, rotated horizontally and craned into a manual or automated fastening machine. Finally they are removed from the fastening machines and craned to a third station where the manual tacks are removed and the parts are manually prepped for final wing box assembly.

With advances in manufacturing processes, including electromagnetic riveting (EMR), fastener hole coldworking, and the traveling yoke assembly, this traditional approach has been replaced with single station processing [1]. Wing panels and spars can now be automatically tacked together under continuous clamp up in a single jig [2]. While the wing panels and spars remain rigidly held in their flying configuration by the assembly jig, they are coldworked and fastened with an articulated yoke. This eliminates the disassembly, deburring, and cleaning required with the manual process. Assembly jigs are lined end to end to allow one machine to service multiple stations and further enhance productivity.

By integrating the coldworking process into lower-wing automated manufacturing, the assembly of lower surface wing skins is now cost effective and technically feasible. This allows the lower skins to be completed in a similar overall cycle time with the upper skins, thus producing complete shipsets in pairs.

DESCRIPTION OF NEW UNIT

The focus of this paper is the second of two automated wing assembly machines Electroimpact produced for British Aerospace Plc. The new machines will manufacture wingsets for the new A340-600 wide body airframe in Broughton England. The cell began production in August 1999.

The E4100 automated wing assembly machine is designed to access the entire surface of the wing panel for drilling and coldworking holes, then installing rivets and fasteners. Figure 1 is an overall view of the new unit. The machine is capable of accurate positioning of the toolpoint, the point where the drill first touches when entering the skin. The machine is designed to locate this point within 0.20-mm over the work envelope of the machine.

The overall length of X travel of the machine is 134 meters with Y travel measuring 3.55 meters. The automated machine utilizes a solid yoke that is articulated in five axes. By rotating the solid yoke, the curvature of the airframe is accommodated while the alignment between the opposing heads is maintained. Correspondingly, the work axis of the yoke is horizontal. The unit can rotate the yoke ±15 degrees in A and B to keep the drilling axis normal to the wing panel surface. The machine has 21 servo axes, three of which are calculated. The machine is capable of full five axis programmed motion, but can also sense and trace the components where required. Rotation of the solid yoke provides precision alignment between the opposing heads. Alignment within 0.18-mm is maintained for reliable collar loading on fasteners. The

yoke is employed as the engine of alignment and clamp up.

Figure 1 – Overall View of E4100 Machine

The new cell consists of two automated machines, complete with assembly jigs for each, for upper and lower wing skin attachment. The two lines are nearly identical, with the difference being the inclusion of automated coldworking on the lower skin line, and slightly different fastener feeding configurations due to the mix of fastener diameters and grips from upper to lower panels.

The process capabilities of the machines include drilling, riveting, coldworking, and bolting. Fasteners installed include 6.5, 8.0, 9.5, and 11.0-mm (¼ to $^{7}/_{16}$ inch) lockbolts, both with collars and Hi-Lite types. Drilling and coldworking capacity is up to 13-mm (½ inch) diameter. Maximum coldwork material stackup is 7.6-cm.

The skin-side of the yoke uses a linear motor to rapidly and accurately shuttle several tools to the tool point. The shuttle table includes the following tools:

“Smart” bolt inserter – an air cylinder that has a linear encoder grating etched directly on its rod controls the axial position of the pneumatic bolt inserter. This powerful feature allows continual monitoring and verification of the bolt insertion process. Bolt length, orientation, diameter, installation speed, and interference levels all can be checked in real time with this feedback device.

Sealant inserter – The sealant inserter employs a peristaltic pump for positive displacement of sealant. The inserter deposits a uniform amount of sealant in a ring inside the countersink prior to the bolt being installed. A twisting action ensures that the sealant dispersed from small holes in the applicator tip gives complete coverage. The inserter uses standard 6-oz. Cartridges and is adjustable for changes in viscosity of the sealant.

Clampup tooling – Servo clampup achieves and maintains a programmed clamp force on the wing components, local to the hole being drilled and coldworked, or the fastener being installed, of between 500 and 2,500-pounds. This is achieved through load cell feedback on the ballscrew drive system of the shuttle table. The actual force may be programmed to correspond with fastener type or diameter, and as a function of the tooling used.

Servo EMR – Servo control of the EMR forming dies’ axial position by the CNC sets a constant protrusion for each rivet diameter on the skin side. This guarantees countersink fill. This feature provides more repeatable and higher quality fastener installation results.

Drill spindle – The 20,000-RPM servo controlled drill spindle is provided with water-cooling for increased heat dissipation required at higher power levels. The spindle is configured with an Ott-Jacob powered drawbar that allows for quick change of the appropriate cutters. Cutters can be preset with their set-up parameters stored in the CNC to reduce downtime during tool changes.

Shave spindle - During the coldwork cycle, the shave spindle is loaded with a combined ream and countersink cutter using HSK 50 tooling with a hydraulic drawbar. The servo-servo all-electric spindles have 120 in-lbs, available from 500 to 20,000 RPM. The RPM is programmable to ± 1-RPM. The countersinking and shaving depth control is repeatable to ± 0.01-mm, and utilizes temperature compensation for spindle growth. The spindles use an Ott-Jakob hydraulic drawbar to retain the tool holders. Tool offsets are stored in the machine, allowing drills to be preset off-line.

Hole probe – A servo driven hole probe based on precision ball gages is used to validate hole diameter in process and prior to fastener installation. Hole diameter is one parameter that cannot be measured after the fastener installation cycle is completed. A record of the hole diameter is critical to the long-term goal of reduction or elimination of test coupons.

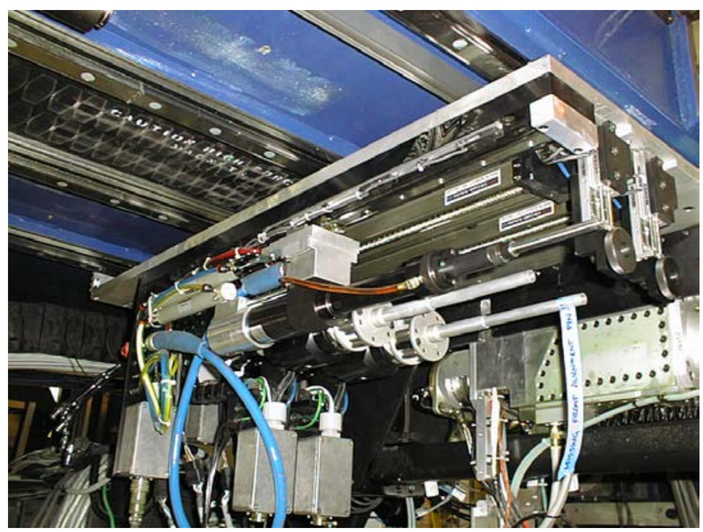

Figure 2 – Shuttle table and tooling

Resynchronization camera – The resynchronization camera is used to reference the machine to the appropriate fixture. In addition, it is used to verify the location of parts that were manually installed in the initial tacking stage. This tool thereby allows the machine to function as a very large CMM for verification of part and fastener locations.

Second hole probe – The second hole probe is identical to the first probe. It can be fitted with a different diameter probe tip for use as a gage after coldworking the hole. Using both probes, the pre-coldwork hole diameter and the post-ream diameter prior to bolt installation can be recorded.

Coldwork tooling – This application required standard powerpak and expendable tooling (e.g., mandrels, pilots, drills, and reamers). WCI developed a new puller unit specifically designed for the range of holes for this application. See "New Tooling Development" section for more information.

COLDWORKING ON E4100 MACHINE

The split mandrel coldworking process was chosen for inclusion in the E4100 machine due to its ease of automation and superb life enhancement benefit. As in any next-generation program, new challenges were presented.

This application minimized manual interaction, becoming as close to fully automated as conventionally possible in airframe production. In order to achieve this maximum automation, the coldworking process must not generate any volcanoing at the faying surfaces, thereby eliminating the need to manually disassemble, deburr, and clean the wingsets. In addition, since this a single step manufacturing process, a layer of sealant is placed between the faying surfaces. The coldworking process is conducted through a plane of “wet” sealant, a first for coldworking applications. It is important that the coldworking rate be rapid as possible, thus not allowing the sealant time to seep and create internal voids.

The final challenge involved the best choice of puller unit for this application. The range of hole sizes to be coldworked falls nicely between the specification for two different WCI standard puller units. The smaller unit is capable of coldworking 90% of the holes, while the larger puller unit could coldwork all the holes in the desired range but at a slower rate, thereby possibly invoking more concerns involving the sealant.

A specially designed new puller that accommodated the desired hole sizes while maintaining a rapid pull rate overcame these challenges

SPLIT MANDREL SOLUTIONS

MATERIAL UPSET ACCEPTANCE TESTS

As mentioned previously, it was critical there be no volcanoing at the faying surface. The authors developed a series of acceptance tests to investigate the effect of clamp up force on the formation of volcanoes at the faying surface of coldworked holes. Testing was conducted on 6.5-mm thick rectangular 2024-T6 aluminum plate specimens (30.2-cm long by 49.5-cm wide) that were secured together at their ends. Seven holes were drilled in each test specimen. The edge margin and hole spacing were consistent to nominal coldworking standards. The holes to be coldworked corresponded to final hole diameters of 11.0-mm. Three applied expansion levels were examined (5.0, 3.2 and 2.0%). Coldworking was conducted on a test bench that was created to simulate the clamp up available on the new machine. Clamping force was applied via an Acme screw tightened to a load read via a load cell inline with the test piece. Three clamp up forces were investigated (800, 1,200, and 2,000 psi). Some of the specimens had sealant applied to the faying surface while the remaining specimens had bare faying surfaces. The authors tested for separation several times during specimen coldworking attempting to place feeler gages (0.05-mm and larger) between the faying surface of the stackup. After coldworking was complete, the specimens were separated and the bottom plate volcanoes were measured in profile with a CMM unit.

The testing indicated that applied expansion levels and clamping forces do make a difference in the height of material upset of coldworked holes. As expected, the largest material upset was seen at holes coldworked with the highest applied expansion level and lower clampup force. As seen in figure 3, specimens coldworked at 5.0% applied expansion had material upset heights averaging 0.15-mm at the edge of the hole, while upset heights averaged 0.13-mm for the 3.2% applied expansion specimens and 0.08-mm for the 2.0% applied expansion specimens.

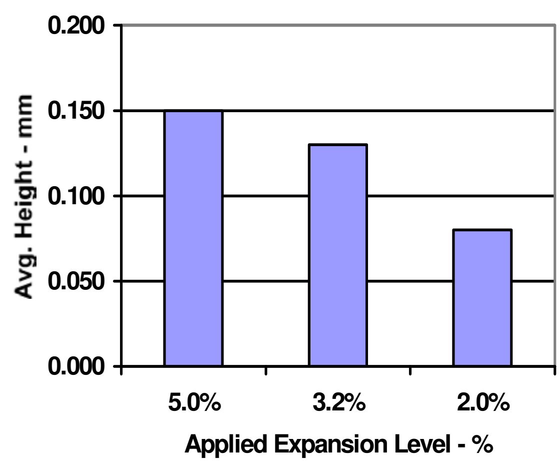

Figure 3 – Height of volcano as a function of applied expansion

Stackup separation varied inversely to clampup force applied. As can be seen in figure 4, average separation varied from 0.08mm for clampup forces of 800 lbs. to no separation with 2,000 lbs. clampup.

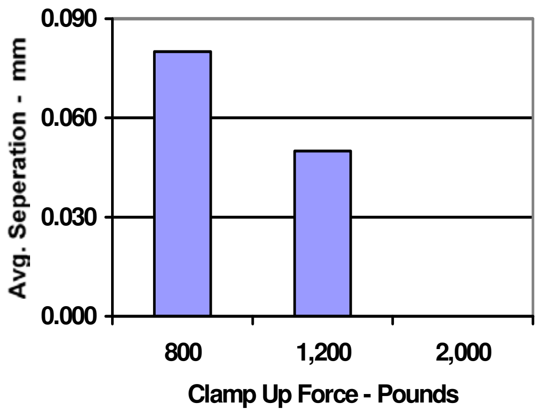

Figure 4 - Stackup separation vs. clampup forces

CMX SPLIT MANDREL PROCESS

The CMX Split Mandrel process was developed three years ago by West Coast Industries to provide a complete solution for customer coldworking applications. Previous coldworking processes produced nominal applied expansion values that fluctuated between successive hole diameters. This fluctuation is illustrated in figure 5. Additionally, these coldworking processes did not provide adequate ream allowance for all final hole sizes. Thus not all holes could be completely "cleaned up" (e.g. completely remove the axial ridges and volcano immediately around the hole) after coldworking.

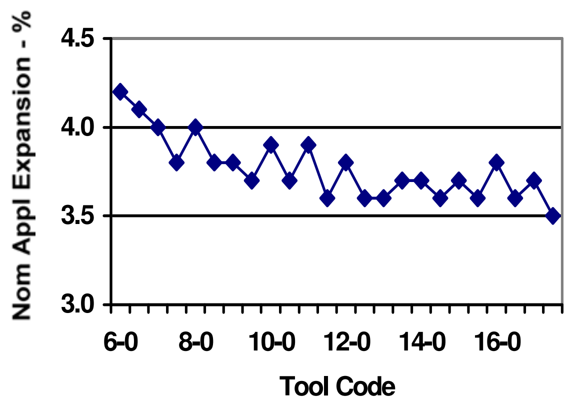

Figure 5 - Nominal Applied Expansion Levels for Split Sleeve Process.

The development of the CMX process was inverted from most process development. This was due to the use of previous coldworking specifications [3-5] that had already established applied expansion levels. It was important to retain the same final hole diameter range for a given tool code size as found in previous processes, so that existing fasteners could be used.

The first step was to review the final hole diameter ranges of the established coldworking procedures. One quarter of a millimeter (0.25-mm) was subtracted from the minimum hole diameters per tool code to produce an adequate ream allowance for all final hole diameters.

The next step in development was an analysis of existing applied expansion levels. The applied expansion levels in existing processes varied due to several reasons, including a start hole range of 0.13-mm, and the thinning of the split sleeve during the coldworking process. The split mandrel procedure calls for a tighter 0.08-mm start hole range. The tighter start hole range, along with the elimination of the sleeve, provides for more uniform applied expansion levels, as illustrated in figure 6.

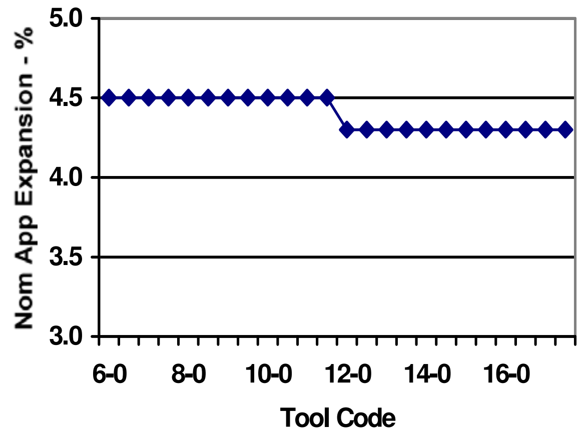

Figure 6 - Nominal Applied Expansion Levels for CMX Process.

Since the applied expansion levels and the final hole range were known, the final process parameters to be determined were start hole and mandrel major diameters. The main author developed a computer model that uses basic material properties (e.g., tensile and shear stress, elastic modulus, Poisson's ratio, etc.) along with variations in published closed form elastic/plastic zone analysis [6-9] to estimate the post-coldwork hole diameter for a given start hole/mandrel major diameter/applied expansion level. The goal was to discover the start hole/mandrel major diameter/applied expansion level combination that produced a post-coldworked hole that closely approximated the desired post-coldworked diameters discussed earlier. Actual post-coldworked hole diameters were within 0.05-mm of the computer-predicted values. When the start hole and mandrel major diameter were determined, the CMX process was introduced and shortly thereafter implemented at a number of customer installations.

When British Aerospace approached WCI regarding automating the coldworking process for this application, they felt major modification might be required for any coldwork process. The fact that the CMX process anticipated their concerns led British Aerospace to implement the process without modification.

NEW TOOLING DEVELOPMENT

WCI developed a new WCI-350 puller unit to coldwork the range of holes in this application. The new unit is a modification of the standard WCI-300 split mandrel puller unit. The standard barrels, nosecaps, mandrels, and pilots are interchangeable for the -300 and -350 units. The cylinder size of the new unit was increased to produce the pull force needed for the larger diameter holes in British Aerospace's desired final hole range.

Automating the coldworking process required several slight modifications to a standard manual puller unit. The handle was replaced with a ported manifold, while a quick-change barrel was developed to allow simultaneous change of the nosepiece, mandrel, and pilot.

FINAL QUALIFICATION TESTING

The qualification test plan was created to ensure that the pull-force feedback system would detect failure to properly coldwork the hole. The machine design utilizes a pressure transducer in the puller unit line for this purpose. The output from this transducer is read by the CMC. A software algorithm then detects the peak pressure during the coldwork cycle. If the peak pressure does not reach a minimum threshold, the machine concludes that the coldworking process is out of tolerance, due to a variety of problems (e.g., improper or worn tooling, start hole oout of tolerance, etc.) The test plan incorporates a matrix of specially manufactured mandrels that simulate medium and advanced mandrel wear conditions along with a selection of reamers which will represent in and out of tolerance holes. The results from these static coldworking tests will be used to determine the minimum threshold pressures for each hole diameter. Separately prepared high-load-transfer fatigue and fuel leak test coupons were dynamically tested to verify the design fatigue life of the coldworked joints. The machine was used to produce fatigue dogbones with coldworked holes, fully fastened with interference bolts. In addition, coupons of the lower skin materials were produced containing examples of each diameter fastener at maximum and minimum grips. Testing is ongoing in the program with the goal to certify the process prior to production start of the lower wing line in October of 1999.

OVERALL RESULTS

The overall results of the new automated wing assembly machine will be the production of high-quality wingsets with minimal manual operations. The machine will run 24-hours/day and require six (6) operators for a standard continental 12-hour shift. Therefore 12 operators per shift will produce an estimated five (5) wingsets per month. This is a considerable reduction of man-hours when compared to semi-automated and completely manual production.

Advances in fastener coldworking were an important aspect in the success of this next generation assembly unit. Innovations such as the CMX procedure and new puller unit development combined with the technology of servo-clampup, eliminates the costly and time consuming manual disassembly and deburring of coldworked holes, thereby allowing "One-up" assembly to include all drilling, coldworking, and fastener operations for the total wingset.

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