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Drill and Drive End Effector

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ABSTRACT

Electroimpact developed an end effector for Airbus UK, Ltd. for use on a Kuka KR350 robot provided by Airbus UK. The end effector is referred to as the DDEE (Drill and Drive End Effector), and incorporates four main functions. The end effector pushes up on a wing panel with programmable pressure, drills a hole with a servo-servo drill, inspects the hole with a servo ball-type hole gauge and then drives a pin-tail style lockbolt into the hole. The end effector is being used as part of a development and feasibility study for incorporating automation into the wing panel manufacture process.

INTRODUCTION

The main functions of the DDEE machine are described in this paper. The requirements and relationship of these functions to wing manufacture are discussed.

It should be stressed that the machine has a high degree of flexibility in order to examine many aspects of the feasibility of automating wing manufacturing. For example, the control selected for this machine is much more capable than would likely be needed for actual production. However, the machine as built is configured for a single diameter of LGP lockbolt for evaluation purposes.

END EFFECTOR DESCRIPTION

The DDEE consists of a baseplate with a robotic quick disconnect attached. Refer to Figure 1. Attached to the baseplate is a cage which slides to provide a push-up force to wing components. This cage incorporates a laterally moving servo-driven shuttle table with 3 tools that access the wing through a pressure foot bushing on the cage.

Figure 2 is an image of the DDEE machine connected to the KR350 robot. This figure shows how the DDEE is used to drill prototype rib feet on large wing assemblies. Figure 3 is an image of the DDEE controller. The controller photo shows the 18i CNC color interface above, and the Fanuc machine tool panel below.

The main functions of the DDEE machine include:

- Push-up of components
- Drilling with panel detection
- Hole inspection
- Bolt insertion

In addition, information about the controls, data collection and exchange, and programming interface is included. A description of the docking station or nest for storage of the machine and production of test pieces is also included.

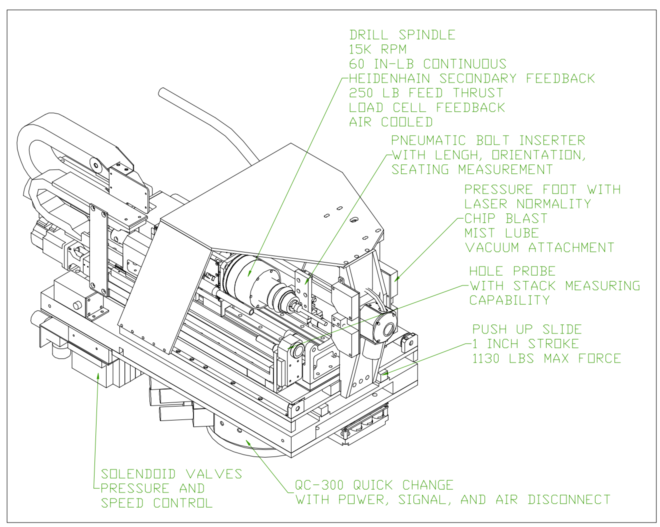

Figure 1: Drill and Drive End Effector

Figure 2: DDEE with KR350

Figure 3: DDEE Fanuc 18i Controller

BASIC CYCLE - The DDEE basic cycle consists of the following:

- Power-on of the robot and end effector
- Homing of machine axes
- Downloading of process parameters from the cell controller
- Tool changing and verification
- Production of a test piece while in the nest
- Robotic positioning of the DDEE in the programmed hole position
- Push-up of components, including normalization
- Drilling, including panel touch-off
- Hole inspection, including data transfer
- Bolt insertion
- Retracting from components

POWER-ON - The DDEE is powered from the controller cabinet. The CNC, I/O, and drives are located in the controller cabinet. Motor power and I/O signals are conveyed via the cable management system on the Kuka robot. All signals are conveyed through a robotic quick-disconnect. Axis detach functions within the Fanuc control allow the servo axes within DDEE to be disconnected electrically without causing power-down errors. This enables the end effector to be detached from the robot while the control remains operational.

HOMING - The DDEE servo axes are homed via an automatic routine. The 3 servo axes (spindle feed, hole probe feed, and tool shuttle axis) are first attached to the control electronically, and then homed in sequence to avoid collisions. The robot has absolute encoders and so maintains home through power-up.

DOWNLOADING - The DDEE CNC has 2 modes of operation: Operator Mode and Remote Mode. Operator Mode allows the user to select the end effector's operations via the button panel. Remote mode allows a PC to select machine operations using the HSSB (High Speed Serial Bus) fibre optic link. The PC uses two bits to communicate with the Fanuc: transfer requested and transfer complete. Once the PC has established communications with the CNC the PC has the ability to set the following variables: push-up force, spindle speed, chip load, break through distance, and programmed stack thickness. The PC also uses communication bits to set up the end effector's cycle. The following options are available: hole probe mode, drill only mode, drill and countersink mode, lockbolt mode, bolt mode. For example, a cycle can be set to drill and countersink, no probing, and do lockbolt insertion. Lockbolt mode differentiates between pintail and stump-type lockbolts. The end effector cycle is controlled with the Remote cycle start bit, and in-cycle errors are indicated to the PC with an error bit. To prevent robot movement when the end effector is locked in the nest, a bit is used to indicate the status to the cell controller PC.

TOOLCHANGE – The tooling is changed with operator assistance. Generally the end effector is docked in the nest during toolchange. The operator may change the spindle toolholder and/or bit via a manual drawbar. The operator may also change the hole probe tip, in case of need for cleaning. The operator may also change the bolt inserter fingers or bolt hammer if they are worn or damaged. The DDEE then executes a routine to verify the tooling. The drill is shuttled to a verification position and the drill tip is measured against a button. The bolt inserter hammer is measured against a button as well. The hole probe is calibrated against its proving ring.

TEST PIECE PRODUCTION – A test piece coupon is loaded into the holder integral with the end effector nest. The programmed process parameters are verified on the coupon. The test piece can be removed for examination and replaced for subsequent holes. Adjustments to countersink depth, feeds, speeds, etc. can be made by the operator via either the DDEE control or the cell controller.

POSITIONING– When the machine is correctly set up, the Kuka moves the end effector out of the nest and into position on the panel. The robot positions the end effector at the fastener location and then normalizes to the panel. The end effector can be used in the orientation shown in figure 1, called underhand. It can also be deployed in an inverted position known as overhand. Normalizing hardware on the DDEE feeds panel normality information to the cell controller, which then directs the robot position interactively. The normalizing hardware and software were customer supplied. Reference Auto Wing Box Assembly Phase II by Rajesh Mistry, Airbus UK., for more information.

PUSH-UP– Once the end effector is in position, the DDEE controller receives a handshake bit from the cell controller. The DDEE control then rescans the process parameters before executing the fastener cycle. The programmed push-up force is converted to air pressure via a servopneumatic regulator. The push-up force is modified to compensate for the gravity effect of angle of the end effector. The angle is determined via an on-board inclinometer. The air pressure is supplied to a large-bore air cylinder that extends the inner cage of the machine relative to the robot. A pressure bushing contacts the wing component, applying the force radially around the hole location. There is 1 inch of push-up stroke available. Pressure feedback is used for error detection; if the end effector strokes out before contacting the panel, a limit switch indicates an error to the controller. Push-up force is programmable between 500 and 1200 lbs. To limit overshoot, the push-up force is applied in stages. Velocity of push-up is controlled via inline throttle, manually adjusted. Push-up force should be enough to close the gap between the panel and the rib foot underneath, with geometry typical of wing final assembly. Excessive push-up force may distort the structure and so this is a parameter of interest in research. In all cases push-up force must be greater than the applied drill thrust to ensure system stability and good hole quality.

DRILLING- Developed for use in end effector applications, the Model 14 drill spindle has been designed to achieve small volume, low weight, and high output. See figure 4. The model 14 is required to produce precision countersunk ϕ5/16" holes in aluminum with a countersink depth accuracy of +/-0.0005" (technique patent applied for- see Reference 2). Material stacks can range anywhere from 1/8" to 2.5" thick. Although aluminum was the sole material intended to be drilled in the DDEE application, the spindle is capable of drilling a broad range of hole sizes (up to ϕ3/8") in titanium and composites.

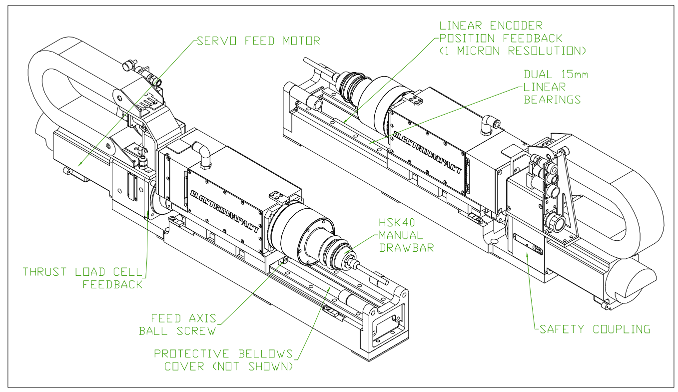

Figure 4: Model 14 Spindle

The spindle has an overall width of four (4) inches and weighs approximately 70 lbs. The spindle servo motor can be configured to deliver 60 to 150 in-lbs. (6.8-17 Nm) continuous torque at rotational speeds from 300 to 15,000 rpm. The linear feed mechanism is constrained by six high precision linear bearings in a double rail configuration (3 runner blocks per rail). Axis actuation is achieved by an inline servo motor and ball screw assembly, with linear encoder feedback. All rails, screws, and encoders are protected under integrated bellows. A safety coupling is employed to protect the drive components and drill bits from damage due to axial overload. The spindle motor stator is housed in an aluminum body with cooling fins, with forced-air cooling. The rotor uses a hybrid-ceramic triplex thrust bearing set in the front of the spindle. There is temperature monitoring of the bearings. The rear bearings are allowed to "float" axially to allow for spindle growth from varying temperatures. The spindle bearings are permanently lubricated. The Model 14 spindle is self-contained and modular for ease in installation/removal.

The Model 14 drill used on the DDEE head is equipped with the optional thrust load cell. Monitoring of the thrust load and feed position can be used to analyze a number of conditions, including drill wear, entry and breakout, load variation between differing materials, etc. Figure 5 shows a common drilling and countersinking cycle in a single material application.

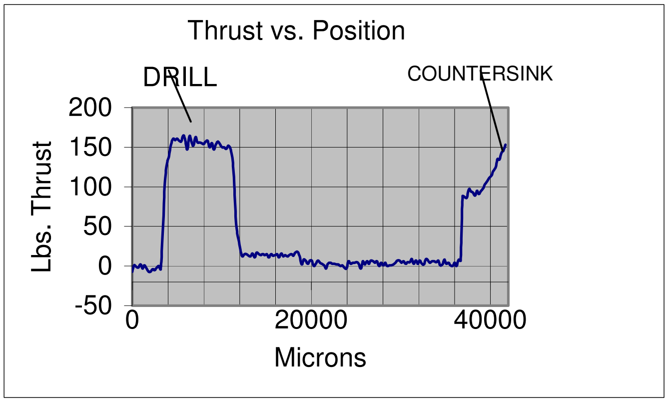

Figure 5: Thrust Graph

HOLE INSPECTION– A ball gage probe is inserted to measure hole dimensions. See figure 6. The probe is servo-actuated, and can be programmed to sample diameter and roundness at any depth in the hole, or multiple depths. There is a spring-loaded slide with a prox switch to detect a collision and prevent damage to the panel or the probe tip. Hole data is transferred to the cell controller so that out-of-tolerance conditions can be identified. An error flag can be set to immediately interrupt the cycle. The probe tool is 2" wide and weighs about 15 lbs.

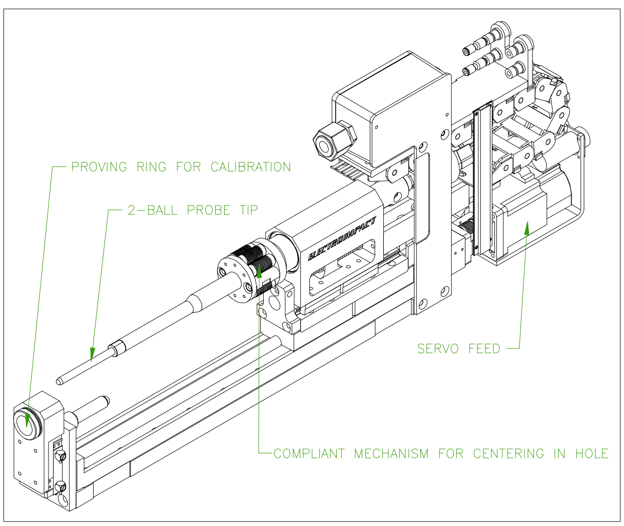

Figure 6: Hole Probe

BOLT INSERTION–The bolt inserter function is to measure the length of the bolt fed and then vibratory insert and seat interference fit countersunk titanium lockbolts (LGPL4SCV10-X). See figure 7. There are (3) main components to the bolt inserter: the feednose, the driving hammer, and the encoder cylinder. The feednose is designed to accommodate 5/16 diameter countersink pull type lockbolts from -12 to –40 grip length. The bolt hammer is a modified E5-AJ Cleco pneumatic chipping hammer. The encoder cylinder is an air cylinder with an integral linear encoder to provide cylinder rod position feedback. The rod position feedback is used to measure the length of the bolt before insertion and again to tell the CNC when the bolt is seated. See Reference 1 for more information about the bolt inserter technology.

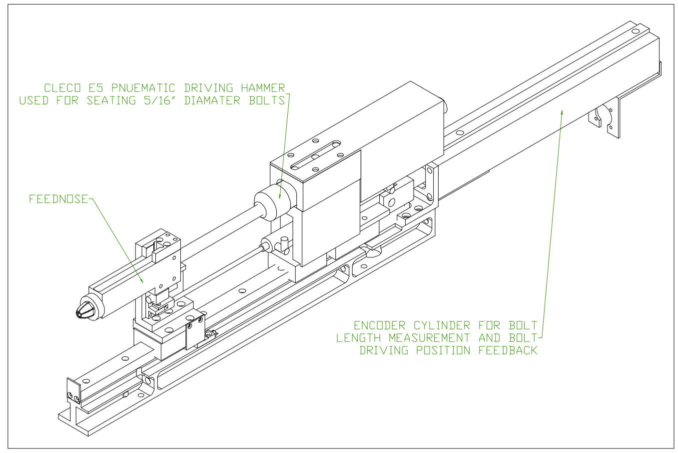

Figure 7: Bolt Inserter

UNCLAMPING– The clamping cylinder is reversed and the end effector is repositioned by the Kuka for the next fastener location. During the move to the next position, the cycle parameters such as programmed stack thickness, bolt grip length, and drilling parameter, among others, may be changed.

CONTROLS/OPERATOR STATION– The control cabinet is a free-standing console with displays as shown in figure 3. The CNC display is used to input parameters manually and also includes a RS232 dataport for downloading from a laptop. The MDI (Manual Data Input) panel buttons are customized to suit the functional inputs for the DDEE. The front, or operator side, of the cabinet opens for access to the I/O and CNC. The back side opens to give access to the drives and line-voltage connections. On the right side of the cabinet is a single-station drop tube system. This system allows the operator to drop a single bolt at a time, or to drop in a small stack of bolts. Connections to the cabinet include mains wiring, fibre optic cable for the CNC to PC data connection (Fanuc HSSB), servo and I/O wiring to the end effector, and a fastener feed tube connection to the end effector.

DOCKING STATION/NEST– When the end effector is not being used on a panel in can be stored in a nest which is rigidly bolted to the floor. The end effector can be latched into the nest and the robot disconnect, to ease access for service. The nest also includes a coupon holder, which is used in the setup routine. The nest includes forklift brackets so that it can be used to transport the end effector separately from the robot. Prox switches in the nest feed back to the CNC to indicate the presence of the end effector.

CONCLUSION

The high level of control, feedback, and measurement capabilities of the Drill and Drive End Effector are intended to enable use of the machine as a research tool. This end effector is not intended for production use, but instead for development of a large-scale automated system. The several precision process adjustments and measurements that can be made are useful in exploring the field of wing automation. The outcome of research in the area is useful for specifying and designing a production tool.

ACKNOWLEDGMENTS

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REFERENCES

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