Robotic Installation of OSI-Bolts

2015-01-2512

Published 09/15/2015

Mark W. Sydenham and Tim Brown
Electroimpact Inc.

CITATION: Sydenham, M. and Brown, T., "Robotic Installation of OSI-Bolts," SAE Technical Paper 2015-01-2512, 2015, doi:10.4271/2015-01-2512.

Copyright © 2015 SAE International

Abstract

Electroimpact has developed an automated solution for installing OSI-Bolts on the HStab for Boeing's 787-9 aircraft. This solution utilizes Electroimpact's existing accurate robotic system together with new hardware designed specifically for OSI-Bolts. In addition to automated drilling and fastener installation, this system performs numerous quality checks to insure the installed fastener meets engineering requirements. Before installing the fastener, the system measures actual stack thickness and the length of the fastener to ensure that the proper grip is installed. Torque and angle feedback are recorded during installation which can be used determine if the fastener was installed correctly. The system will also automatically shave the small protuberance on the fastener head left by the broken off fastener stem, which is inherent to the OSI-Bolt.

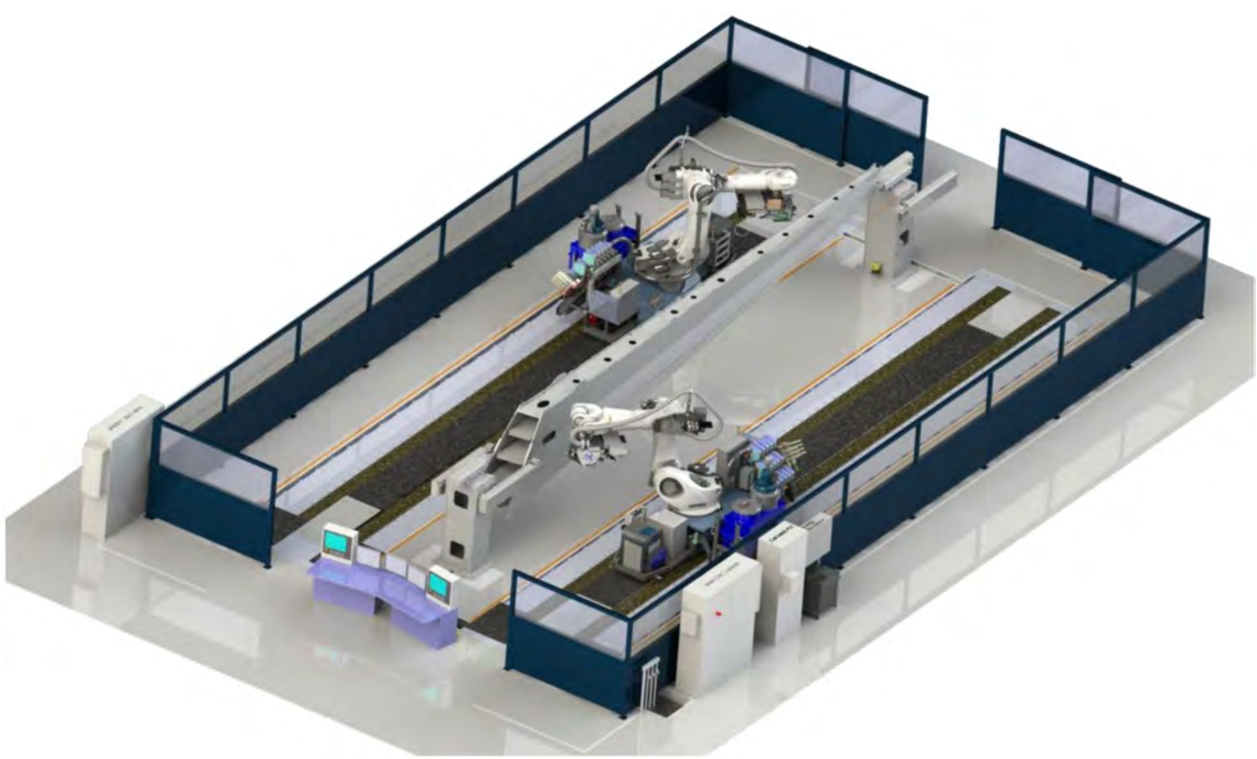

Figure 1. Cell Overview

Introduction

OSI-Bolts are a single sided fastener and can be a great solution when fastening is required in areas that have restricted access to the backside of the work piece. However, because OSI-Bolts are relatively new to the market, installation of these bolts has been performed by hand since the automation had not yet been developed. Electroimpact saw this as another application for their accurate robotic system and developed new hardware specifically designed to insert OSI-Bolts.

Figure 2. OSI-Bolt

To achieve the full benefit of an automated solution, this system performs numerous quality checks during the installation process. After drilling, the actual stack thickness is measured and is compared to the fastener length to ensure that the correct fastener will be installed. The system monitors and records torque and angle feedback during fastener installation. This data can be used to verify correction installation and possibly eliminating the need for post process inspection.

Inherent to the OSI-Bolt is a small protuberance that remains after the fastener installed. This protuberance is shaved off by the robotic system making installation of the OSI-Bolt completely automated.

Machine Overview

The machine consists of various systems centered around the accurate robot. Below is a breakdown of the systems and a description of their function.

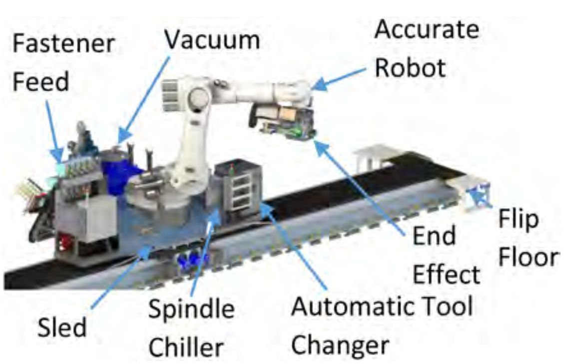

Figure 3. Machine Overview

The accurate robot[1] is a 6 axis industrial robotic arm to which Electroimpact adds their patented[2] technology to increase positional accuracy from ± 0.025″ to better than ± 0.010″. This increase in accuracy is achieved by using an enhanced kinematic model together with the use of secondary positional feedback, known as external scales, on each axis, shown by the arrows in Figure 4. By doing this, the flexibility of a robotic arm can be utilized in the demanding environment of the aerospace industry.

The Accurate Robot

Figure 4. Accurate Robot with Arrows Pointing to External Scales on Each Axis

End Effector

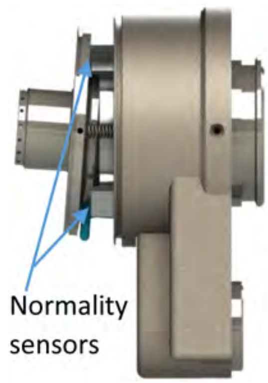

Figure 5. Swiveling Nosepiece

Attached to the end of the accurate robot is the end effector. On to the front of the end effector is the nosepiece, which contacts the work piece during the drilling and fastening process. The nosepiece contains normality sensors placed behind a swiveling tip, as shown in Figure 5, which allows the machine to adjust the end effector to be normal to the work piece surface.

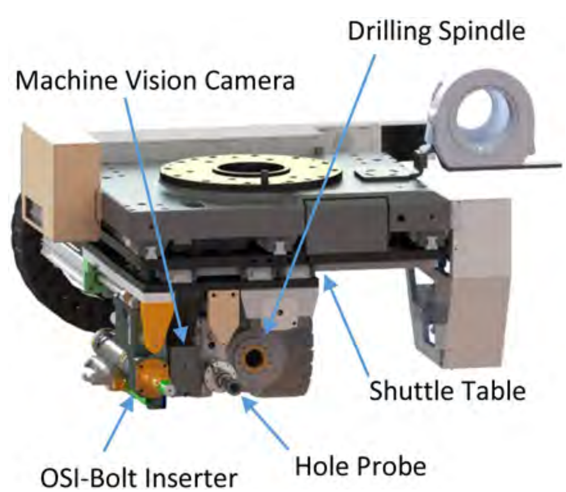

Figure 6. Process Tools Attached to Shuttle Table

Located behind the nosepiece is load cell that is used to ensure the end effort is being pushed up to the work piece at the pre-defined load. The end effector also contains all of the process tools, such as the drilling spindle, hole probe, machine vision camera and the OSI-Bolt inserter. These process tools are all mounted to a shuttle table, as shown in Figure 6, so that the entire process can be performed without having to reposition the end effector.

Sled

The base of the accurate robot is mounted to the sled and is surrounded by the rest of the systems of the machine. The sled is the 7th axis of the machine and is moved side-to-side on a track that is mounted sub flush to the factory floor.

Mounting the track sub flush increases the overall safety for operator and maintenance personnel as it eliminates the need to climb over the track to get around the machine. As the sled moves, it lifts flip floors to expose the rails that it rides on, then lowers the floors as it passes by, leaving a level floor behind it. All of the cable routing and the cable track are neatly hidden below the flip floors so that only the sled is visible.

Fastener Feed System

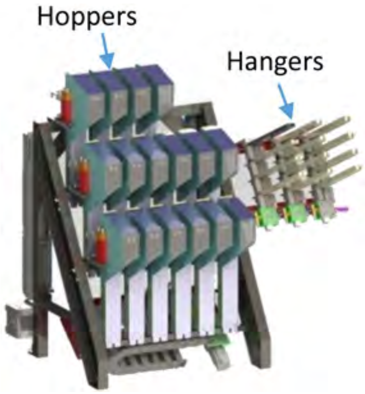

Figure 7. Fastener Feed System

Another system mounted to the sled is the fastener feed system, as shown in Figure 7. This system is responsible for sending fasteners to the end effector. The fasteners can be loaded into one of two storage containers: hoppers or hangers.

The hoppers are designed for easy loading of high quantity fasteners. A bag of fasteners is dumped into the hopper and the hopper handles orienting and sending the fastener when requested.

Hangers are a more compact design, but since loading the fasteners must be done one at a time, hangers are recommended for low quantity fasteners.

The hoppers and hangers are diameter specific but they are not grip specific, meaning that a hopper or hanger is able to send any grip fastener of a certain diameter.

Nut Runner Module

Just to the side of the fastener feed system is the nut runner module. This module controls the tightening of the OSI-Bolt using predefined parameter sets, or PSets. Each PSet specifies a fastener tightening process and allows for limits to be set on angular rotation and torque. During installation, the angular rotation and torque are monitored and recorded allowing for immediate comparison to the predefined limits. If the installation stays within the limits, the installation was successful. In this way, it is possible to eliminate the need for backside inspection to confirm that a fastener was installed correctly.

Automatic Tool Changer

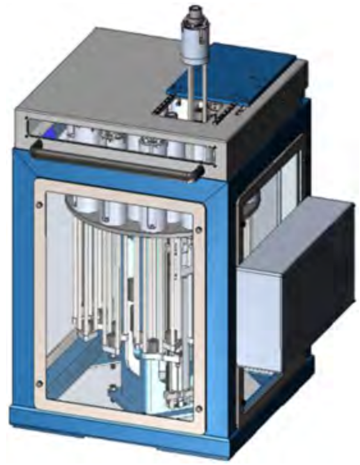

Figure 8. Automatic Tool Changer

On the other side of the sled is the automatic tool changer, shown in Figure 8. Operators can load drills and probes into tool holder pockets located inside of the tool changer. These tools are then available for the robot to pick up automatically.

All drill holders are fitted with RFID tags that contain information about the drill. This information is scanned by read heads inside of the tool changer so the machine knows where each tool is located and which pockets are empty. Another read head is located on the end effector and is used to confirm which tool is in the drilling spindle and writes tool usage information to the tag for drill life monitoring.

Spindle Chiller

Located next to the automatic tool changer is the spindle chiller. This unit cools and circulates chiller fluid through the spindle. Not only does this unit keep the drilling spindle within its operating temperature range, but it also helps to maintain the spindle at a constant temperature which in turn helps to maintain a consistent countersink depth.

Vacuum

Mounted behind the accurate robot is the vacuum. In addition to collecting the swarf created during drilling, the vacuum also collects the stems from the OSI-Bolt that are broken off during the installation process. The vacuum is suspended just above the flip floors and can be rolled off the sled for easy cleaning.

Process Overview

The full process of the machine is made up of four main steps: push up, drilling, hole inspection and fastener installation. Figure 17 is a flow chart of the process and shows how the steps are interconnected.

Push Up

Once the accurate robot has positioned the end effector, the push up axis of the end effector is extended. After the nosepiece makes contact with the work piece, the robot uses the normality sensors in the nosepiece to reposition the end effector until it is normal to the work piece. Once this is complete and the end effector has reached its predefined push up load, all of the robot axes and the push up axis will be held in place for the remainder of the process.

Drilling

While the accurate robot is positioning the end effector, the shuttle table positions the drilling spindle in line with the nosepiece and then extends the spindle until the drill tip is just behind the nosepiece. The spindle is also spun up to speed so that drilling can begin as soon as the previous step is complete.

Before drilling is allowed to start, vacuum sensors confirm that the vacuum is on. During drilling, the push up load is continuously monitored to measure drilling thrust and is used to catch certain error conditions, such as a broken drill bit. Once the drilling process is complete, the drilling spindle retracts to allow for hole inspection.

Hole Inspection

Figure 9. Hole Probe

Hole inspection is performed with a mechanical hole probe, shown in Figure 9, attached to a servo feed axis. The hole probe is recalibrated using gauge rings located on the end effector. These gauge rings are positioned such that the hole probe can recalibrate at the same time the hole is being drilled.

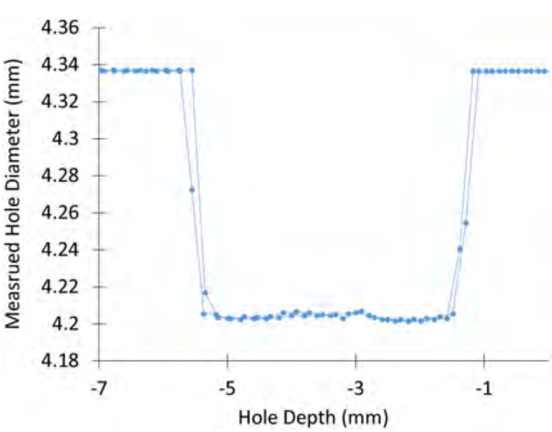

Figure 10. Hole Probe Data

After the hole has been drilled, the shuttle table positions the hole probe to be in line with the hole. During inspection, the hole probe enters the hole and records diameter measurements at numerous depths. Once the probe has traveled all the way through the hole, the base of the probe is pushed up against the work piece to measure the countersink. The hole probe is then rotated 90° as it is being retracted and continues to take diameter measurements on the way out. These two sets of measurements, offset by 90°, as shown in Figure 10, are analyzed by the machine to check for oval holes.

When the probe has finished measuring the hole, the machine reviews the diameter measurements to calculate the actual stack thickness of the work piece. This actual stack thickness is compared to the allowable stack thickness range of the preselected fastener. If the stack thickness is out of range, the operator can select to have a different fastener installed or just leave the hole open.

Once the machine has the correct fastener for the measured stack thickness, fastener installation can begin.

Fastener Installation

While the hole is being drilled, a preselected fastener is sent to the end effector and prepared for installation. The preparation includes seating the fastener in the bolt inserter and then measuring the overall fastener length to ensure that the correct grip fastener was received.

After the hole probe has finished inspecting the hole, the shuttle table positions the bolt inserter in line with the hole. The bolt inserter is then extended, pushing the OSI-Bolt into the hole and seating the countersink. The machine then triggers the nut runner to execute a PSet which installs the fastener. Once the PSet completes, the bolt inserter is retracted, pushing the broken off fastener stem into the vacuum line.

This is a brief overview of the fastener installation process. This process will be detailed in the next section.

Fastener Installation Detailed

There are four main steps in the fastener installation process: feed, inject, install and shave. Each of these steps are detailed below.

Feed

The installation process begins by feeding a fastener to the end effector. As described earlier, fasteners are loaded into either hoppers or hangers and each storage location is assigned a specific fastener. When the part program requests a specific fastener, the machine locates where the fastener is stored and then attempts to send a fastener from that location.

The fastener feed system is responsible for ensuring that only a single fastener is sent at a time and that the fastener is sent in the correct orientation. This is very simple for hangers as the fasteners are loaded by hand in the correct orientation. When a fastener is requested from a hanger, one fastener is separated from the rest and is dropped into the fastener feed tube.

Hoppers are loaded by simply pouring in a bag of fasteners. From there, the hopper handles correctly orienting the fastener. This is done with a specially designed blade and staging chamber. The blade is pushed up from the bottom of the hopper, picks up a few fasteners and extends to the staging chamber. If a fastener is oriented correctly, the fastener will slide into the staging chamber. If no fastener is sensed in the chamber, the blade will automatically retract and try again. When a fastener is requested, the staging chamber pushes the prepared fastener and drops it into the fastener feed tube. This process is depicted in Figure 11.

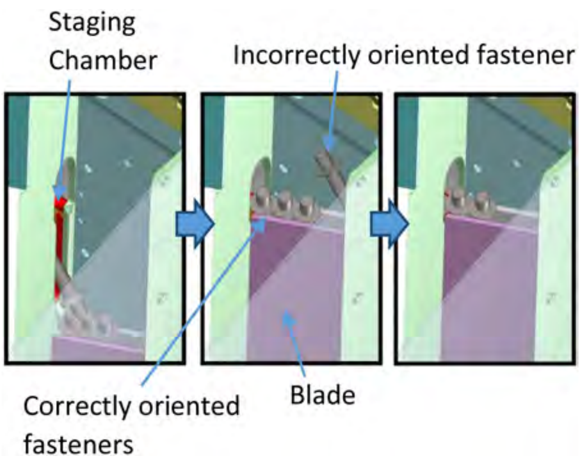

Figure 11. Hopper Staging Fastener

Once the fastener is in the fastener feed tube, an air blast pushes the fastener all the way to the end effector, at which point the fastener is ready to be injected.

Inject

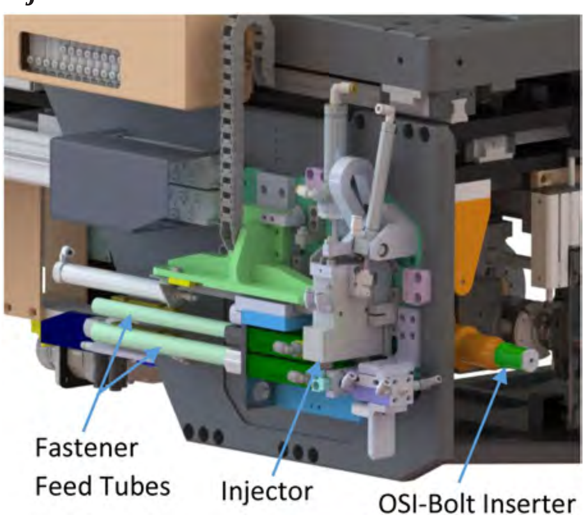

Figure 12. Fastener Injector on Side of End Effector

Fastener inject is the process of moving the fastener from the fastener feed tube to the bolt inserter. When the fastener reaches the end of the feed tube at the end effector, it is picked up by the injector, shown in Figure 12, and is removed from the feed tube. The injector then pivots to present the fastener to the inserter.

An engagement PSet is run while the inserter is extended forward by a pneumatic cylinder to pick up the fastener. Running the PSet helps to securely seat the OSI-Bolt in the inserter.

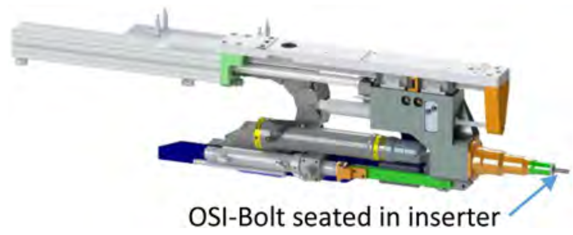

Figure 13. OSI-Bolt Inserter

A successful completion of the engagement PSet signals to the machine that the inserter has successfully picked up the fastener. At this point, the fastener length is measured using the position of the bolt inserter cylinder. The grip of the fastener is then inferred from the fastener length. If the measured length does not match a predefined tolerance or if the grip doesn't match the actual measured stack, the operator can chose to reject this fastener and send a new one.

Ejecting a fastener is essentially the reverse of the feed process up to this point. The bolt inserter pushes the fastener back to the injector which pivots back to the feed tubes. The fastener is then passed back to the feed tubes where an air blast pushes the fastener back to the feed system. It is then routed to an eject box. At this point, the feed system is ready to send a new fastener.

Once a fastener has been successfully seated in the bolt inserter and has passed the grip length check, it is ready to be installed in the work piece.

Install

Installation of the fastener begins by the shuttle table positioning the bolt inserter in front of the hole. The bolt inserter is then extended forward to insert the fastener. Once the bolt inserter is fully extended, the position of the inserter is analyzed to determine if the fastener was fully inserted into the hole. If the machine determines that the fastener is not fully inserted, the installation PSet will not be executed as doing so could damage the work piece.

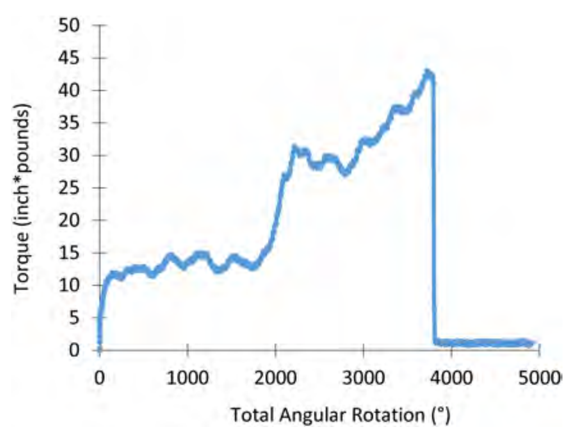

Figure 14. PSet Graph

If the fastener is fully inserted, the machine triggers the nut runner to execute the installation PSet. While the PSet is executing, the nut runner monitors the torque and angle feedback. Figure 14 is a graph showing the torque and angle feedback. As the OSI-Bolt is tightened, the torque will begin to increase as the backside of the fastener is deformed. The torque eventually peaks and then falls as the OSI-Bolt has been fully deformed and the stem breaks off, signaling a complete installation.

Figure 15. Installed OSI-Bolt

The nut runner will analyze the torque and angle measurements taken during installation and report back to the machine whether the cycle completed successfully. Figure 15 shows successfully installed OSI-Bolts.

Shave

As mentioned in the previous section, the stem of the OSI-Bolt is broken off during normal installation. The broken off stem leaves a small protuberance on the head of the fastener, shown in Figure 16. The removal of this protuberance is called shaving.

Figure 16. Protuberance Left by Stem

Shaving is performed by a shaver tool loaded in the drilling spindle. Because this requires an automatic tool change, the shave process is usually performed after all of the fasteners have been installed to save cycle time.

During the shave cycle, the machine automatically loads the shaving tool into the drilling spindle. The machine then returns to each installed fastener and shaves the protuberances leaving a completely installed OSI-Bolt that is flush with the rest of the work piece.

Summary

Single sided fasteners, such as the OSI-Bolt, provide a solution to installing fasteners where access to the backside of the work piece is limited. Electroimpact has fully automated the installation of OSI-Bolts, utilizing their accurate robot. This system monitors the installation of the fastener and reports if the fastener is installed correctly. This information can be used to eliminate the need for post process inspection. This system also shaves the protuberance left by the OSI-Bolt after installation.

References

1. Devlieg, R. and Szallay, T., “Applied Accurate Robotic Drilling for Aircraft Fuselage,” *SAE Int. J. Aerosp.* 3(1):180-186, 2010, doi:10.4271/2010-01-1836.
2. DeVlieg, Russell C. Robotic Manufacturing System with Accurate Control. Electroimpact, Inc., assignee. Patent 8,989,898. 24 Mar. 2015. Print.

Contact Information

Mark Sydenham
MarkS@electroimpact.com

Tim Brown
TimB@electroimpact.com

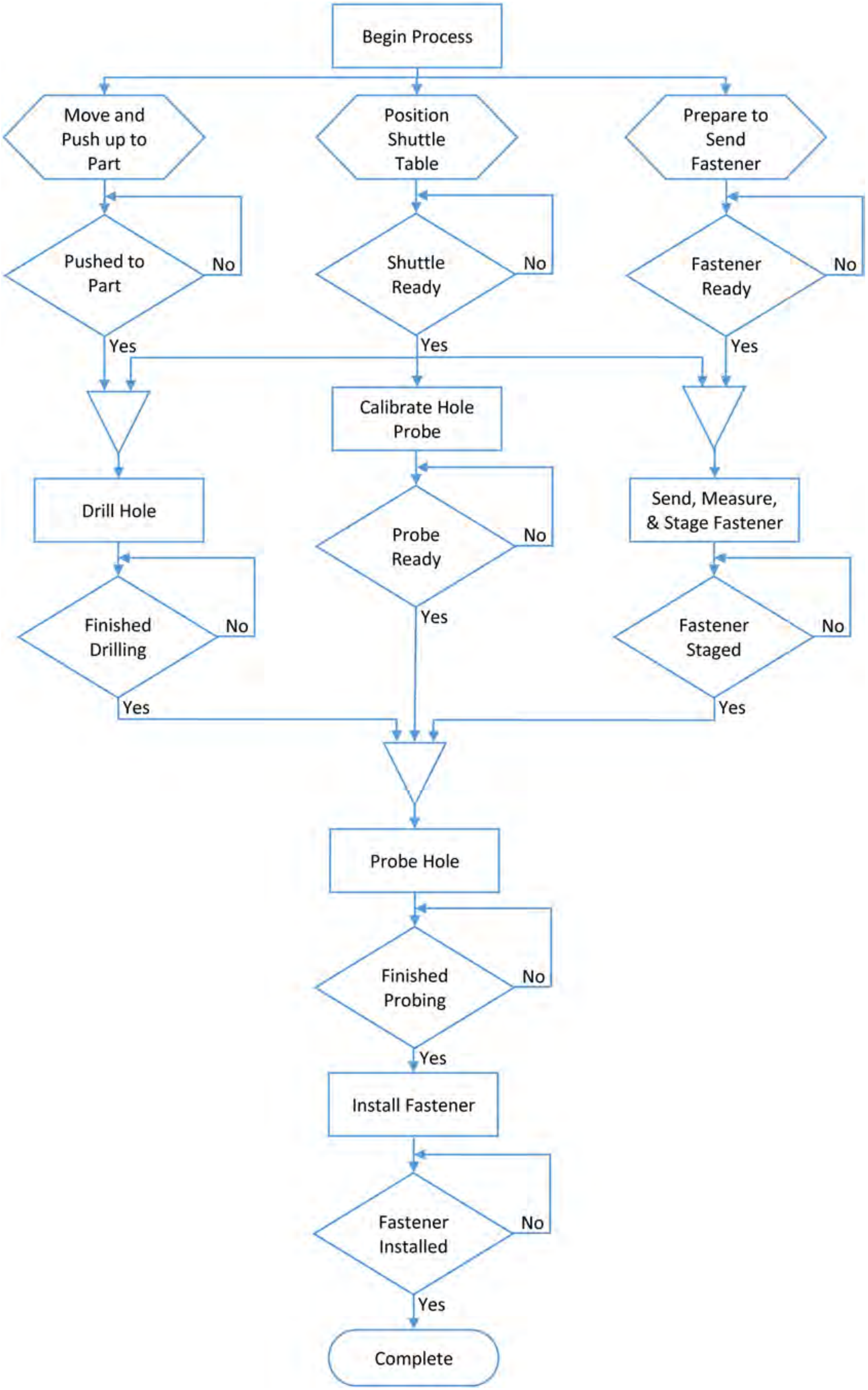

Figure 17. Process Overview

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.

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording, or otherwise, without the prior written permission of SAE International.

Positions and opinions advanced in this paper are those of the author(s) and not necessarily those of SAE International. The author is solely responsible for the content of the paper.

ISSN 0148-7191

http://papers.sae.org/2015-01-2512