Fully Automated Off-Line Cartridge Filling Station

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Abstract

A fully automated off-line cartridge filling station has been commissioned to support the new Boeing SAL production cell. The filing station uses automated fastener feed technology that is typically found on the machines themselves. Incorporating this technology off-line in place of the traditional manual handling processes extends the benefits of automation beyond the main manufacturing cell. A single operator is able to keep up with the demand of eight production fastening machines while maintaining the highest levels of accuracy and quality. Additional benefits to this application of automation include reduction of the operators exposure to risks associated with manual handling and repetitive tasks.

Introduction

Boeing's new 737 SAL (Spar Assembly Line) entered production in 2016. The machines drill and automatically install nuts, collars, and 115 different bolt types and grips across four diameters in front and rear spars for five different aircraft wing variants. The fasteners are stored on the machines in plate cartridges. As with all cartridge type feed systems, an off-line loading station was required to fill the cartridges.

With eight of these SAL machines in production at the same time, each one twice as fast as the ASAT3 machine they replaced, the off-line cartridge loading station would be required to reload cartridges at a rate of over 18,000 bolts per day at peak production. With the high fastener type variability, this would be an impossible fill rate for a traditional single or even multiple vibratory bowl based cartridge loading station.

In addition to the high fill rate, the spec also required the same kind of accuracy levels usually found on the machines. To meet this requirement, each fastener would have to be verified prior to loading into the cartridge so as not to slow the machines down by sending the wrong fastener to the tool point.

Figure 1. Plate Cartridges

Concept

The concept for the fully automated off-line cartridge filling station came from asking two questions: The first question was how to physically get the fasteners into the new plate cartridges quickly and accurately. The second question was how to do this with as little operator interaction as possible.

The first question was answered with the design of the cradle. The complete description follows in a later section but in short; the cradle is an assembly that the cartridges are placed in where they are scanned, checked for fill status, and loaded with the correct fasteners as required. No matter what additional hardware is selected to send fasteners to the cradle, this assembly is necessary for automatically filling plate cartridges.

The answer to the second question was to build a fastener "vending machine". In other words, every fastener used in the system needs to be available for loading into the cartridges at all times. This realization was arrived at after conducting a rate study based on traditional off-line filling stations using vibratory bowls.

Figure 2. Off-Line Cartridge Filling Station

Rate Study

Looking at bolts only; the loading station would need to fill approximately 80 plate cartridges per day to cover all 18,000 bolts needed. Many scenarios were considered but here are some highlights:

If just one vibratory bowl is used, with interchangeable tooling to accommodate the different bolt types and diameters, it would take 110 hours to load, one at a time, the cartridges needed to support the next day's production. It is easy to see that this would not work at all.

If four bowls are used, one for each fastener diameter, along with three or four cradles (5/16 and 3/8 could be combined, due to their smaller percentage of the overall fastener mix), much of the loading can be done in parallel and be completed more quickly. In this scenario, still filling cartridges one at a time (per diameter) it would take approximately 28 hours to load the cartridges. It would also require constant interaction and monitoring by two or three operators to achieve that rate.

Ultimately it became obvious that the bottleneck was constantly filling and emptying the vibratory bowls each time the fastener type/grip changed. The only solution was to have all 115 different bolts ready at all times.

This realization led to a system that uses hoppers for the fasteners used in high quantity, hangers for the fasteners used in low quantity, and dedicated bowls for the eight different nuts and collars.

Using this vending machine concept, along with four cradle assemblies that can hold at least 10 cartridges each, allows all 80 cartridges to be loaded in approximately 8 hours by just one operator. The operator is not required to tend to the machine during the majority of the run time and so is free to carry out other tasks and activities nearby.

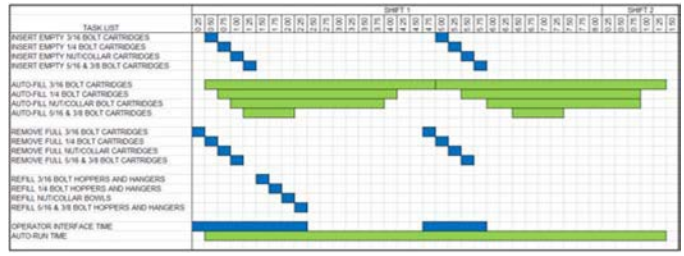

Figure 3. Rate Study

Description

What follows in this section is a description of each of the subcomponents that make up the entire off-line cartridge filling station.

Cradle

The cradle is the part of the system where the plate cartridges are placed to be loaded. There are four cradles, each capable of holding 12 plate cartridges. One cradle is dedicated to 3/16 bolts, one for 1/4 bolts, one for 5/16 & 3/8 bolts, and one for 3/16-3/8 nuts and collars.

Each cradle consists of a box with indexed slots, raised off of the floor to an ergonomic level, for holding the cartridges. There is a hinged lid attached to the box that is raised to allow the cartridges to be installed and removed, and lowered to allow filling.

When the cartridges are placed in the cradle and the lid is closed, the operator presses a button which initiates the filling process. First a Balluff RFID reader scans the cartridges in the rack to determine which slots contain cartridges as well as what fasteners are required for each. The filling then commences through a buffer assembly. A cradle full of cartridges is pictured in Figure 4a.

The buffer is guided over each column in the cartridges by a servo driven X-Y table mounted to the lid. Knowing which fastener is required for each column, a laser sensor determines if the column is full. If not, a fastener is sent from the feed system and stopped in a measurement chamber. A second more accurate laser sensor measures the length of the fastener. This is to ensure that each column is loaded accurately - that is, each column contains only the fastener diameter/type/grip it is supposed to. If it passes the length check, the fastener drops into the cartridge and its fill level is checked again. This process is repeated until the column is full and the buffer is moved over the next column. If a fastener ever measures out of range, it is automatically purged from the system and a replacement fastener is sent. The buffer and X-Y table can be seen on Figure 4b working over a set of cartridges.

Once all columns of all cartridges are filled, the system displays its fill status on the HMI and awaits the operator to remove the full cartridges and replace them with empties.

Figure 4a. Cradle Assembly - Front

Each bolt buffer can verify and load approximately 20 fasteners per minute. The nut and collar buffers can load approximately 60 fasteners per minute since they do not need to conduct a length verification.

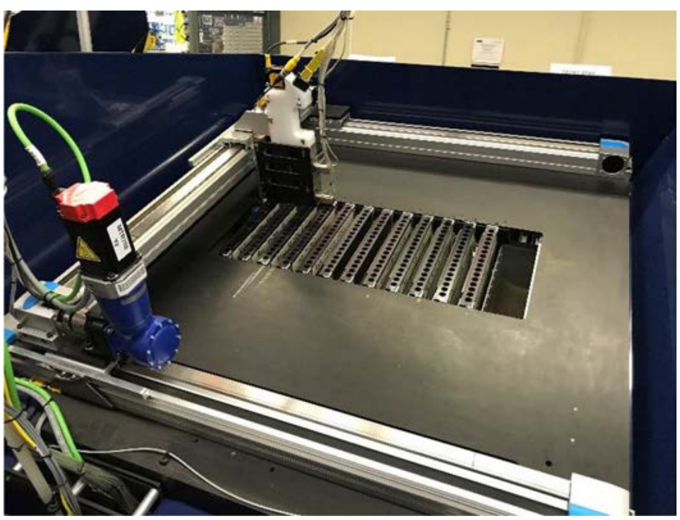

Figure 4b. Cradle Assembly - Top

Hoppers

The hoppers are grouped in three racks. One for 3/16 bolts, one for 1/4 bolts, and one for 5/16 and 3/8 bolts. There are 88 dedicated hopper assemblies, one for each fastener used in quantities higher than 20 per day.

Figure 5a. Hoppers and Hangers

Each hopper has a bin that holds hundreds of fasteners. A blade rises through the bin orienting and transferring some of the fasteners to a buffer. The buffer holds the fasteners at the ready until called for by the cradle assembly. Then they are escaped one at a time into a feed tube.

The hopper blows the fastener down the feed tube and past a manifold called a selector. The selector has a servo driven head which aligns the outgoing feed tube with the incoming hopper or hanger. Once the fastener passes the selector it is blown up to the buffer on the head of the cradle to be verified and loaded into the cartridge.

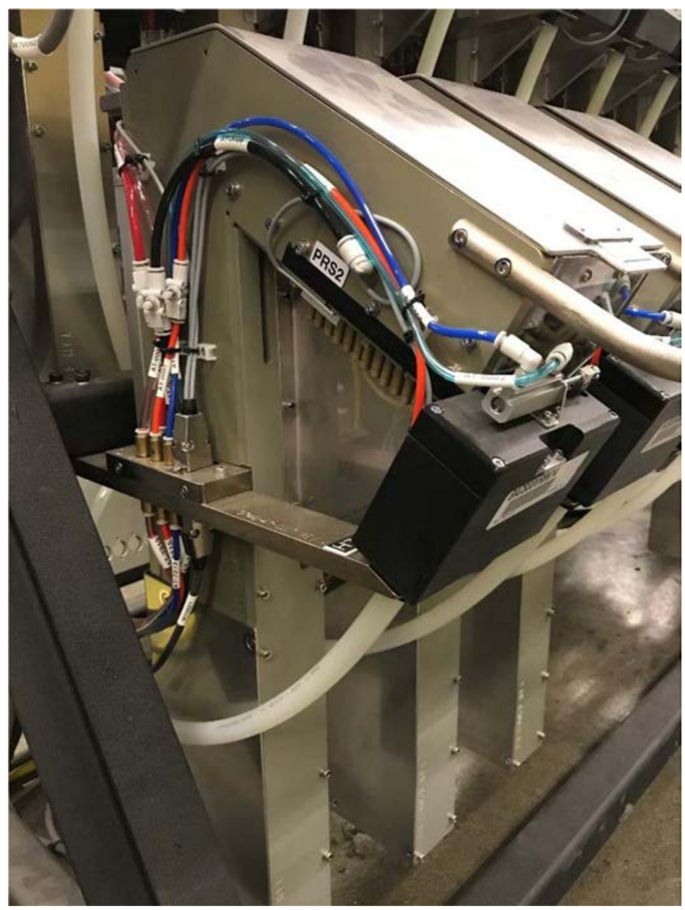

Figure 5b. Hopper Assembly

Operators can visually inspect the fill level of the hoppers at any time and add additional fasteners, even while the system is running. If they neglect to perform this task, and a hopper runs out of fasteners during a cartridge load, a message will be displayed on the HMI and the cradle will continue loading the next fastener type.

Hangers

At the end of each hopper rack is a hanger assembly used to hold and feed fasteners used in quantities of 20 or less per day. The system required a minimum of 27 hangers across the four bolt diameters but additional were included to enable future expansion.

A hanger is very similar to the buffer in one of the hopper assemblies. Fasteners hang on a track by their heads and are gravity fed toward an escapement which transfers one fastener at a time into the feed tube when called upon. The difference is that the fasteners are oriented and loaded into the hangers by hand, rather than automatically in the hopper.

The fasteners in the hangers are fully visible to the operators at all times and as with the hoppers, they can be refilled even while the system is running. If they neglect to perform this task, and a hanger runs out of fasteners during a cartridge load, a message will be displayed on the HMI and the cradle will continue to load the next fastener type.

Figure 6. Hangers

Bowls

Nuts and collars are stored and fed using traditional vibratory bowls. There are eight bowls, one for each diameter of nut and collar required. Each bowl has a dedicated feed tube leading up to a buffer on the lid of the nut and collar cartridge cradle. The bowls are pictured in Figure 7.

When a cartridge is being filled, nuts or collars are escaped from the corresponding buffer above. As the buffer runs low, it is refilled without interruption by sending a block of fasteners staged in the feed tube below the associated vibratory bowl. Once the fasteners have been sent, the bowl turns on and counts out 10-20 new fasteners to replenish the staging area in the feed tube. This process continues until all the cartridges in the cradle are full.

The operator has clear visual sight of the fill level of the vibratory bowls and may fill them at any time without interrupting the filling process. If a bowl ever runs out of fasteners before a cartridge is full, the cradle will proceed with loading the next cartridge and display a message on the HMI.

Figure 7. Vibratory Bowls

HMI

As mentioned in the sections above, the fully automated offline cartridge filling station is provided with an HMI. Although the HMI is not required for the basic operation of filling cartridges, it does provide the operators with live status information as the cartridges are being filled. It also provides information and tools for the maintenance staff along with an interface for programming the Balluff RFID chips on the cartridges.

The HMI displays real-time status of the hoppers, hangers, and bowls, as well as the status of each cradle assembly. The cradle assembly status’s are:

1. Running
2. Running With Errors
3. Completed
4. Completed With Errors

If all the cartridges are completely filled, the “Completed” message is displayed. The operator then only needs to remove the fully filled cartridges from the cradle, reload it with the next set of cartridges, and start the loading process again.

If any of the cartridges are not completely filled, the “Completed With Errors” message is displayed. If any hoppers, hangers, or bowls are listed as empty, the operator can refill the appropriate hardware and re-start the filling cycle. The system will go back to the unfilled cartridge columns and complete the filling process. Other errors may require maintenance or perhaps emptying and re-filling a hopper if it was found to be loaded with the wrong fastener.

Other messages may be displayed for individual system components if additional errors were encountered during the loading process due to problem with the hardware. Maintenance tools are also available through the HMI.

Figure 8. HMI

The system was designed such that the four cradles and their associated feed systems can operate independently. That way, if maintenance or repairs are required on one of the four systems, the other three may continue to fill cartridges - thus minimizing the effective downtime for the system.

Performance

In practice, the system is working exactly as envisioned. Empty cartridges are transported from the machines to the off line loading station via carts. An operator removes cartridges from the carts, places them in the cradles, lowers the lids and presses start. Then they check the fill levels of the hoppers, hangers, and bowls and add fasteners when required. Once that is done, they leave the system to run automatically as they perform jobs elsewhere in the factory.

The operator returns as schedule allows a few hours later, places the full cartridges on the carts and more empty cartridges in the loader to repeat the morning process.

Minimal operator training is required so with quick instructions, a large number of staff are able to run the system effectively which has decreased the reliance on any one “specialist” for this critical task.

The mechanical geometry of the systems along with the laser measuring verification hardware for the bolts has ensured that the cartridge columns are correctly loaded more than 99.99% of the time. That means that the machines using the cartridges are never slowed down by incorrect fastener supply.

Safety

Assuring operator safety was a primary goal during the design of this system. This goal was achieved by adhering to best ergonomic practices for the manual handling operations and by minimizing risks and exposure to hazards by operators and maintenance personnel. The largely automated nature of the design accomplishes both of those points by effectively limiting the required interactions with the equipment compared to more traditional cartridge loading stations. This drastically reduces the operator’s exposure to noise for instance.

Where operator interaction is required, however, care was taken to minimize risk by for instance, placing the cartridges in the cradle at a height such that no bending is required when moving the cartridges between the cradles and the carts. Hoppers, hangers, and bowls are also able to be refilled with minimal bending or reach. And the cradle lids are raised pneumatically so the operator does not need to strain.

Safety is achieved by placing fixed guards around moving components and light curtains on the face of the cradles to keep staff from accidentally coming in contact with moving components. The entire system is surrounded by a lockable safety fence so that only trained staff may enter the maintenance aisle between the cradles and the hopper racks.

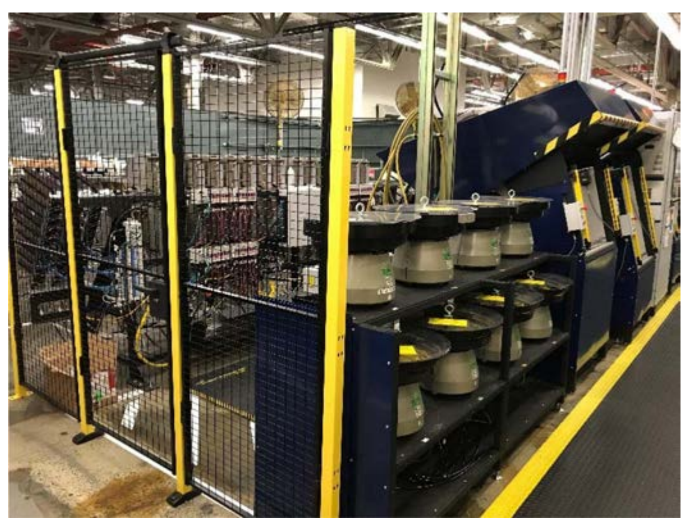

Figure 9. Safety Fence

Further safety measures include lock-out/tag-out isolation for air and electrical supply and CNC selectable maintenance modes which stop power to the servo drives to allow troubleshooting tasks without risk of components moving unintentionally.

Summary

By using technology usually reserved for fully automated fastening machines, an off-line cartridge loading station was designed, built, and put into production which is able to keep up with the demand of an entire manufacturing cell. Each cartridge is filled to the highest accuracy level possible, eliminating downtime on the machines. A single staff member is able to operate the loading station part time in a safe, low risk atmosphere. The successful application of automation in this system begs the question; what other secondary factory operations would benefit from primary factory automation techniques?

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Definitions/Abbreviations

SAL - Spar Assembly Line.

RFID - Radio Frequency Identification.

CNC - Computer Numerical Control.

On-line - Directly attached to an assembly or riveting machine.

Off-line - Located away from the assembly machine, in some cases in a different building.

HMI - Human Machine Interface.

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