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Flexible High Speed Riveting Machine

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ABSTRACT

Airbus UK was interested in a high-speed riveting machine cell that could automatically rivet over 30 different wing panels for a wide range of aircraft to fit in a limited floor space. Electroimpact was approached and proposed a Flexible, High Speed, Riveting Machine (HSRM).

The resulting flexible riveting cell is 170 feet long and contains two flexible fixtures located end to end. Two fixtures allow manual work on one fixture while the machine is riveting on the second fixture. Each fixture can be quickly reconfigured to accommodate a broad range of Airbus panels. The system went into production on January 12, 2003 and has been extremely effective, riveting the first wing panel, a lower panel 1 for the A330-300 in only 5 days. This was one of the largest panels the cell was sized to accommodate. Anticipated process improvements will reduce the riveting time to just three days per panel.

INTRODUCTION

The Flexible High Speed Riveting Machine (HSRM) system is designed to rivet pre-tacked, upper and lower wing panels from the Airbus A330/340, A319/320/321 and A300 aircraft families. One of the many benefits of this cell is the ability to maintain the wing panels in true aerodynamic form during the fastening process while only requiring a minimum of factory floor space. To justify the system for production use, the HSRM cell would need to reduce fastener rework and the amount of time a panel is needed in jig for fastening.

Rapid adaptability of panel sequencing through the cell was of paramount importance, therefore the fixture design needed to be quickly re-configurable to accommodate any of the wing panels slated for the cell.

<u>Configurations currently programmed include:</u>

A330-M10 Lower panel 1 (port & starboard)
A330-M10 Lower panel 2 (port & starboard)
A330-M10 Lower panel 3 (port & starboard)
A330-M10 Lower panel 4 (port & starboard)

A340 (Growth) Lower panel 1 (port & starboard)
A340 (Growth) Lower panel 2 (port & starboard)
A340 (Growth) Lower panel 3 (port & starboard)
A340 (Growth) Lower panel 4 (port & starboard)

A319/A320 Upper Panel 1 (port & starboard)
A319/320 Upper Panel 2 (port & starboard)

A321 Upper Panel 1 (port & starboard)
A321 Upper Panel 2 (port & starboard)

<u>Fixture sized for various other configurations:</u>

A300 Upper panel 1 (port & starboard)
A300 Upper panel 2 (port & starboard)
A300 Upper panel 3 (port & starboard)

A300 Lower panel 1 (port & starboard)
A300 Lower panel 2 (port & starboard)
A300 Lower panel 3 (port & starboard)

A340-600 Upper and lower panels 1 & 4

A319/320/321 Upper panel 1+2-Assembly

SYSTEM OVERVIEW

The HSRM cell is comprised of an E4150 traveling yoke machine and two flexible fixtures joined end to end. Wing panels are oriented vertically in the fixture with the leading edge pointed skywards. The footprint of the cell was minimized to approximately 80m long x 10m wide. A park zone at one end of the cell doubles as a buy-off and maintenance area.

"Pendulum Loading" to the cell was one technique that Airbus wanted to achieve to reduce component load/unload time. This allows panels to be craned into the fixture on the opposite end that the riveting machine is engaged in the fastening process on another panel. In order to construct the cell in the allocated physical space within the factory, the cell length has been optimized to pendulum load the most commonly completed panels of the Airbus single-aisle family.

FIXTURE LAYOUT

The Flex Fixture is a continuous structure made up of 2 distinct, symmetric zones each consisting of an inboard Endgate, 10 sliding Posts and 5 Trailing Edge Supports. The inboard end panel lug is used as the primary datum feature of the wing panel. A series of Trailing Edge Supports orient the panel about the Z-axis and serve as the secondary datum. Fixture Posts along the span of the wing serve to support the panel as well as induce the proper panel curvature at their index station. (See figure 1)

FIXTURE INDEX STRUCTURE

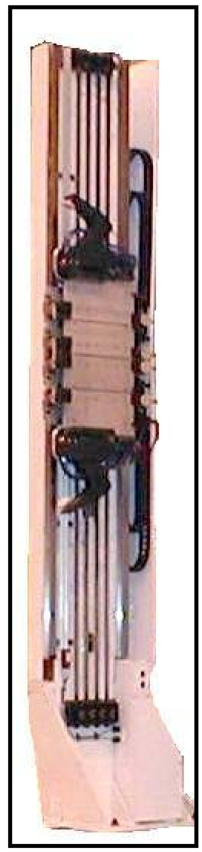
Flexibility of the fixture to accommodate the vast array of wing panel sets was accomplished by a variable index structure on the fixture posts. Each post has 4 adjustable index mechanisms that induce the proper panel curvature. Trailing Edge Supports along the aft edge of the panel have telescoping post indexes that support the vertical position of the panel.

The technology used on the Flex Fixture is a unique hybrid of modern tooling techniques and logic control hardware. To maximize the adaptability of the fixture design it was decided to avoid the use of hard index positions for every wing panel configuration. Instead of using traditional slides and dedicated pin-off plates, indexes are mounted on linear ball rails and use acme screw drive mechanisms to move and maintain index positions. To define the panel index locations, every critical index axis uses electronic positional feedback. In total there are over 186 distinct axes used throughout the fixture to correctly control the wing contours.

With a typical control system this would have been a monumental task to integrate. Electroimpact took a different approach with the Flex HSRM system, combining the best properties of a logic control system with none of the complexity of a computer motion controller. This system uses feedback devices solely to aid an operator in manually configuring the panel index mechanisms. A portable pneumatic tool and a dedicated screw drive system for each axis, give the operator the ability to quickly set the index positions. A handheld display unit shows the operator real-time positional information as adjustments are being made. In the background is a central PLC, which stores all of the extensive data table information for every individual panel configuration. The PLC compares the current axis position to the required index position and sends, to the handheld display, a simple "distance-to-go" readout. Once a panel has been selected, the display system communicates to the operator the exact distance every index needs to be moved to bring it into precise alignment. The operator simply rotates a specific axis screw drive until the display reads "0.000"mm for that axis.

POSTS

The backbone of the fixture system is the Fixture Post assembly and it's adaptable index structure. The 4 Index Actuators on each post can be positioned vertically (in Y) and horizontally (in Z) along linear bearing rail sets. Individual screw drive systems are used for each axis to move and maintain index position. Positional feedback for each Index Actuator is provided through the use of draw wire sensors for the Z-axis and a magneto-restrictive sensor common to all 4 actuators with individual magnets for each Y-axis position. These sensors communicate with a central Fixture PLC through a ProfiBUS data network.



The operator undertakes all motion control to move an index to position. A pneumatic Hex Drive Tool for rapid coarse adjustment is provided with a built-in hand wheel for efficient fine adjustment of the screw drives. Real-time readout of the axis position is shown on a handheld display unit.

In an attempt to reduce maintenance complexity and increase operational simplicity a limited amount of intertwined ladder logic is used on the fixture post. Only basic position input from the axis sensors is fed to the PLC. Output is centered about the Fixture Handheld Display, which is the functional front end of the Flex Fixture feedback system.

FIXTURE HANDHELD DISPLAY

The Fixture Handheld Display is a network node point device using the ProfiBUS data transmission protocol. Its primary function is to provide operator prompts and display positional information about each of the jig's 186 axes. The display cable is plugged into the control box of a post to be displayed. Each of the post sockets is a discrete node on the fixture network. Once plugged in, the display automatically knows which node and therefore which post it is at and will display specific information related to that post.

Working through an ordered set of display screens the operator configures each actuator under power with the Hex Drive Tool for a specific axis. All nominal panel configuration data is stored in data tables at the central fixture PLC. The display communicates the difference between the programmed nominal index position and the current position. The operator is always simply adjusting an actuator to its zero position within the pre-specified tolerance. This procedure is repeated for the Y and Z-axis of each of the four actuators on a post for as many posts as are affected by the current wing panel configuration. In addition, the height of the Trailing Edge Index is read and adjusted in a similar manner.

Display Screen Before and After Actuator Adjustment:

POST NORTH 01
DIST TO Z4
184.120mm
POSITION NOT OKAY
A330 PORT BOT P1

POST NORTH 01
DIST TO Z4
0000.000mm
POSITION OKAY
A330 PORT BOT P1

INDEXING DETAILS

To set the major Z position of the posts, a coarse indexing system is designed to allow 600mm of travel at the post base in 50mm increments along a bearing rail set. Further index positioning is done at the Index Actuators.

To accommodate the continuously variable panel curvature, a unique sphere-in-socket design is used on all the Index Actuators for the point of contact with the wing panel components. This design uses a semi-sphere that rotates about the center point of its planar face. This design produces a spherical index foot that regardless of angle will provide a true index position with no other additional positional compensation required. Additionally the sphere was sized so that it could be replaced with a standard 1.500” SMR target during laser tracker alignment to quickly measure the true index center position.

To fixate the panels at the post station, the upper and lower Index Actuators incorporate a Skin Clamp assembly. This is a similar design used on previous Electroimpact wing panel fixtures. It uses a compact air motor coupled through a gearbox to a screw drive for its power source. A proprietary cam slot is used to open the clamp arm approximately 135 degrees to allow the arm to retract to within the shadow of the clamp body. Clamp loads in excess of 3500lbf throughout a long stroke length are attainable with this design.

During the fastening cycle it is necessary to move the post away from the index station to provide the riveting machine access to all areas of the panel. The fixture uses a pair of X-axis bearing rails along the entire length of the fixture, common to all posts. This allows the posts to be easily and accurately moved and re-indexed whenever required during the fastening cycle. Operator prompts on the machine CNC display tell the operator when to move a post. Discrete shot-pin locations are provided at a *clear* and *build* position with limit switches that communicate to the PLC where the post resides. A green status light on the affected post flashes when a move is required during the program cycle. The operator manually unlocks and moves the post between positions and re-locks it.

ENDGATE

The Endgate assembly is similar to the Fixture Posts in that the Actuator axes and Z positioning are nearly identical. The most significant difference of the Endgate is the ability to accommodate various root end angles. The Endgate was designed such that the post can rotate through a range of 0 degrees (vertical) to 30 degrees inclined. For the currently programmed panels there are 3 distinct index angle pin-off positions and a screw drive mechanism used to move between them.

TRAILING EDGE INDEX

The Trailing Edge Index supports and maintains the orientation of the panel assembly. The vertical index position is adjustable through a jackscrew assembly and the Y-position is measured with a draw wire sensor. The height adjustment is done with the Hex Drive Tool and the position is read from the Fixture Handheld Display.

MACHINE STRUCTURE

The machine is an E4100 5-axis dual trunnion traveling yoke machine optimized for riveting. The solid yoke structure allows five-axis capability within the panel envelope while maintaining precision alignment between the stringer and skin side heads. The yoke assembly is mounted on a pair of gimbaled trunnions that are supported by four Y-axis sleds. Four monolithic towers support each of the Y-axis sleds. The towers move in unison to form the X-axis. Tower pairs are rigidly coupled on both the skin side and the stringer side of the machine. These two tower pairs can be offset in X from one another to form the yoke B-axis rotation. The Y-axis sleds on the skin side can be offset from the Y-axis sleds on the stringer side to produce the A-axis rotation. The entire machine straddles the fixture on two parallel 170 ft. long machine beds.

KEY SYSTEM BENEFITS

SIMPLE FLEXIBILITY: The Flex Fixture uses a combination of linear feedback on all critical fixture axes and a simple easy to use handheld display. Panel configuration is all controlled by a central PLC that allows for easy data access and straightforward updates. Having the operator perform all motion control significantly reduces the system complexity and cost.

CHANGEOVER SPEED: “Pendulum loading” allows panels to be loaded and unloaded while the machine is running on the opposite end of the fixture. Reconfiguration of the fixture indexes for a different panel can be completed in less than an hour. These 2 features provide an efficient solution to last minute changes in panel sequencing and better accommodate the day-to-day variability in factory production scheduling.

PANELS IN-FORM: The benefits of fastening panels in form have long been proven on previous panel machines. In order to safely navigate machine tooling (consisting of clamping forks, rivet dies, tracers, etc) into and out of stringers, the positional relationship between machine and fixture must be well defined. Since the fixture indices hold the panels to proper form and the relationship between the machine and fixture is precisely aligned during fixture build, the HSRM can operate in full CNC mode. A re-synch camera (coincident with the tool point on the machine process head) is positioned at a re-synch target on the fixture to establish the initial panel program datum. CNC part programs then control all of the machine motions to navigate the stringers and other areas without manual intervention. Additionally the machine can avoid or drill out manually installed bolts and temporary fasteners. And holes for determinant assembly may also be possible since an accurate relationship between the machine and formed panel is established. HSRM accuracy requirements are .008” in X, .004” in Y and .005” in Z, at all A-B rotation angles measured at the inboard end of the panels where most critical datum holes are drilled.

QUALITY: Fastening quality has been significantly improved for the panels completed in the Flex cell. Secondary operations and re-work have been reduced by carefully controlling shave height variations, maintaining head alignment, and through precise tool point positioning accuracy.

Rivet shave height variations are a major cause of fastener concessions on wing panels. Factors such as debris between the clamp pads and panel, temperature variations of drill tooling, and even slight normality errors affect the height on the milled rivet head. Touch-off technology is used to control the relationship between drill countersinks and shave heights to achieve +/- 0.0005” rivet head accuracy on the panel eliminating the need for hand milling the shaved rivets. During the Touch-Off routine the drill bit lightly contacts the skin as the machine clamps-up on the wing panel. The drill is pushed backwards and stops once full clamp-up is achieved. The new drill position is recalculated using the touch-off offset to control the countersink depth for that particular fastener location.

The riveting machine yoke structure supports the skin and stringer side heads to maintain the critical tool point alignment. Secondary scale feedback devices are used on all major machine axes to place fasteners within reduced tolerance zones. With this level of accuracy part programs can utilize nominal wing CAD data to determine the fastener positions as opposed to manually placing fasteners with only rivet pitch data.

RIVETING RATE: The machine process tool positions have been optimized for the riveting cycle so that it can complete 8 clamp-drill-rivet-shave cycles per minute. Drill-only cycles can be performed at a rate of 12 per minute.

POTENTIAL IMPROVEMENTS

Future versions of the HSRM cell could be designed around a multitude of different aircraft panel arrangements. Besides increased height and length possibilities, the Flex cell could incorporate additional tooling to fixture supplemental components such as reinforcing plates, do panel splices or provide secondary operations like panel trimming and lug removal.

Riveting machine upgrades could include bolt cycle routines and touch probe hardware that would allow for inspection routines and reverse engineering capabilities.

CONCLUSION

The Flex HSRM panel-riveting cell provides a significant upgrade for panel assembly facilities. Utilizing proven E4000 riveting machine technology in conjunction with versatile flexible panel fixturing the HSRM cell will provide improved fastener quality and maximum throughput while still offering significant variability options for day-to-day factory sequencing.

The ability to accommodate a broad range of wing panel designs and future variants through basic part programming changes provides significant value to this fixturing and fastening system. Future wing panel additions to the Flex HSRM library will only require simple PLC data table updates for the fixture and current fastener programs for the machine, without the need for further fixture alignment time or extensive tape try-out routines.

It is believed that the Flex HSRM cell fits in well with the industry's greater interest in flexible tooling systems and adaptable factory flow methods.

ACKNOWLEDGMENTS

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DEFINITIONS, ACRONYMS, ABBREVIATIONS

HSRM: High Speed Riveting Machine

PLC: Programmable Logic Controller

SMR: Spherically Mounted Retro-reflector

ProfiBUS: a high-speed data transmission protocol (see: www.us.profibus.com)

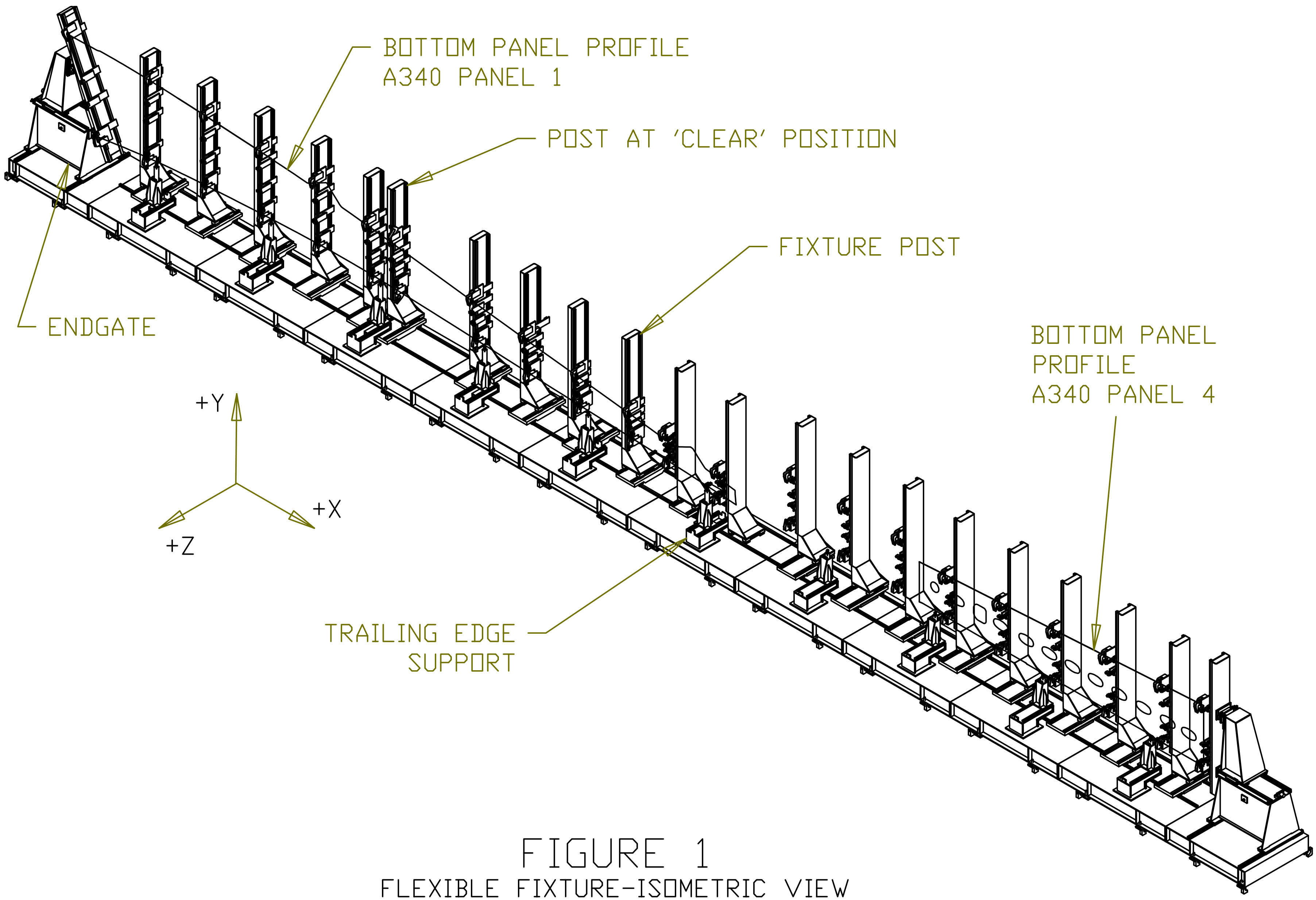


FIGURE 1

FLEXIBLE FIXTURE-ISOMETRIC VIEW

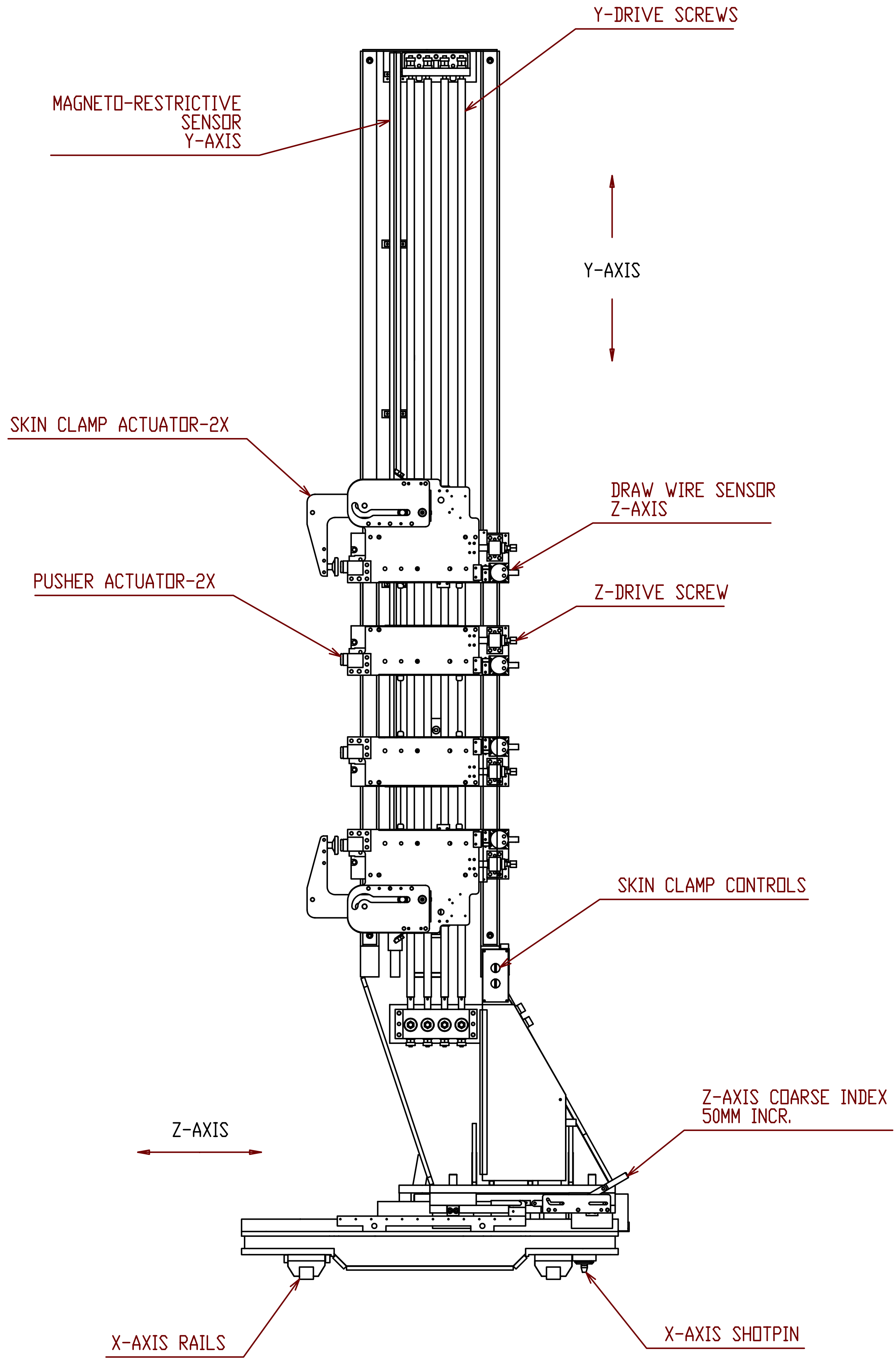
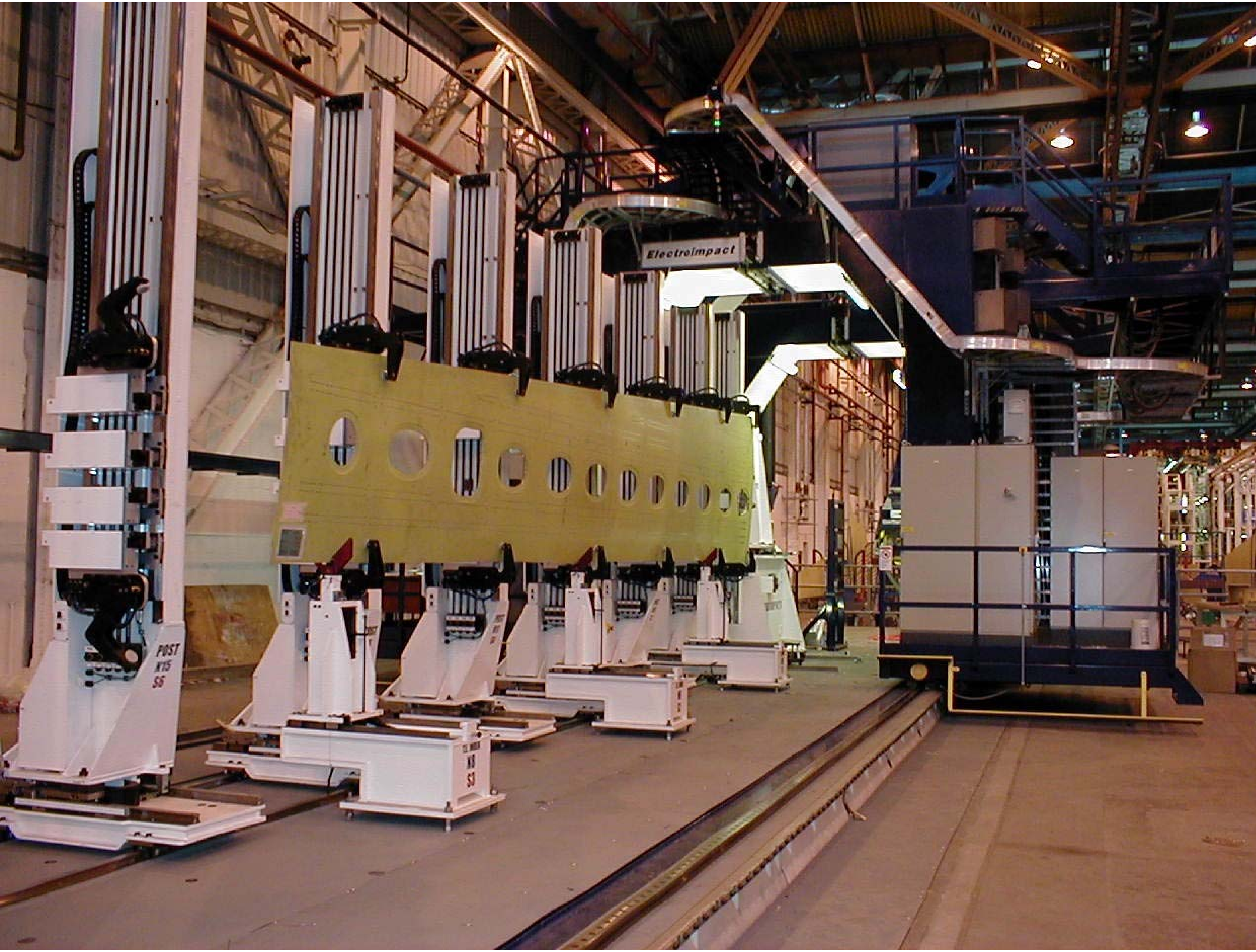


FIGURE 2

FLEX FIXTURE POST ASSEMBLY


Electroimpact
Electroimpact
POST
N12
S9
N6
S5


Electroimpact
POST
N15
S6


ENDGATE
N
LECTROIMPACT