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# AFDE For The Next Generation 737

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## ABSTRACT

Boeing needed a process to replace hand drilling for floor panel holes and galley and lavatory mounting locator holes in the floor grid of the completed 737 fuselage. Electroimpact developed a process, and the 737 AFDE machine, that is a substantial improvement over existing technology. It provides full CNC control, quick reconfiguration of hole patterns, fast drilling of up to 3000 holes in one 8-hour shift, both titanium and aluminum drilling and fits inside the fuselage.

## INTRODUCTION

Boeing needed a process to replace hand drilling using Lexan templates and machined aluminum drill jigs for drilling both the low accuracy floor panel holes and high accuracy galley and lavatory mounting "hardpoint locator" holes in the floor grid of the completed 737 fuselage. This fuselage is shipped complete (minus the interior) by rail from Wichita, KS to Renton, WA for wing-to-body join and final assembly of the 737. Boeing Wichita's cost for Lexan templates and jigs had been in the millions of dollars for the fixed configuration older generation 737s, and the costs were expected to be much greater with the added configuration flexibility offered to Boeing customers on the new generation 737s.

1. The process had to be fully CNC controlled. In the New Generation 737 Boeing provided customers with the option of custom interior configuration with a minimum time required from definition of final configuration by the airline customer to the actual drilling of the floor structure. Custom configuration had the potential to dramatically increase Boeing's tooling costs for larger numbers of different Lexan templates and drill jigs.
2. The process or equipment had to work inside the completed fuselage, and be able to use the standard entry and exit doors and windows. Boeing Wichita intended to perform all the drilling on the new 737 in the completed fuselage.
3. The process had to support the drilling of both titanium and aluminum with the same equipment. Drill capacities were specified to be 120 in-lbs. torque at 500 RPM and 60 in-lbs. at 6000 RPM. Approximately 10% of the holes drilled in the fuselage are through titanium structure.
4. The process or equipment had to work in the final integration build station. Rate considerations dictate that other processes had to happen concurrently with the floor drilling.
5. Process accuracy had to be exceptional. Hole location accuracy had to be within 0.002" over a hardpoint locator hole pattern of up to approximately 80" x 60".
6. The process had to be fast. There are approximately 2400 holes to be drilled on a 737-700 and 3000 holes on a 737-800. Setup, marking the hole locations prior to drilling as a check for mislocated structure, and drilling the holes had to occur in a single 8-hour shift.
7. The process had to be developed quickly – the fast development timeline of the new generation 737 left little time for a major R&D effort.

## AFDE HISTORY

Boeing approached Electroimpact with their process requirements and a notion that a process implemented in the Everett plant for the 747, 767, and 777 as "AFDE", short for Automatic Floor Drilling Equipment, could meet their requirements. Electroimpact had built 3 AFDE machines for the 777 program.

The AFDEs at Boeing Everett had started with the AFDEs for the 747 upper deck. The original machines were largely a Boeing designed platform for moving four air motor/air feed drills to the correct and Y station. The machines consisted of a frame driven the length of the airplane by a chain drive on the actual seat tracks. The drills were mounted on 4 "wings", each of which moved independently in Y. The machines were loaded into the open end of a fuselage section with the controller located in a separate cabinet on the scaffolding near the loading area. The controller and air were connected to the "crawler" via "umbilical" cables.

The original machines were designed only to drill low accuracy floor panel mounting holes. Hole location accuracies in the +/-0.030" range are acceptable in the bulk of the applications in Everett AFDEs. For a variety of reasons related to the floor structure, the chain drives, low machine stiffness, poor setup procedures, etc… these accuracy's were frequently difficult to achieve with the original AFDE design.

Over time the original Everett machines had changed with Boeing specifying the addition of servo feeds, servo spindles, better ball screws, mist lubrication of the drills, better drill bits, more advanced controllers, "bridge tracks" to allow the AFDE to drill none-constant sections, etc. Accuracy of the machines improved only marginally.

The Electroimpact build 777 AFDEs were the last in this progression of machines in the original line, with the addition of spindles capable of drilling titanium and carbon fiber, a titanium space frame, an operator console on the crawler and an up-to-date control. The 777 AFDE program left Electroimpact with the experience to recognize the strengths and weaknesses of the original designs, and with some very strong ideas on how to dramatically improve future AFDE machines.

## 737 AFDE IMPLEMENTATION

When Boeing Wichita approached Electroimpact they were barely familiar with the AFDEs. The original specification for the 737 AFDE called for another AFDE in the original line. After Electroimpact and Boeing Wichita discussed the shortfalls of the existing AFDEs and got a clearer understanding of Wichita's goals it was clear that a very different approach had to be taken.

The first thing to happen was to change the AFDE thinking from one of a machine as a replacement for 4 hand drills to one of a machine tool on the move. Meetings and communications over the course of 2 months refined and clarified the actual process requirements.

Since the machine operates inside the 737 fuselage and is heavily dependent on Boeing tooling and setup for it's accuracy, Boeing's responsibilities in ensuring overall process accuracy were defined. The original specification to Electroimpact was re-written. In this process, the design of the tooling associated with the original AFDEs was scrapped entirely and a new design agreed on. The entire setup procedure was revamped. Each source of inaccuracy was analyzed and in some of the most important cases, ways to compensate for them conceived.

The end result was an entirely new AFDE with exactly one thumb sized machined part in common with the 777 AFDEs Electroimpact had build previously. The differences between the two machines are dramatic.

## THE X DRIVE SYSTEM

The original AFDEs rode on airplane seat track and engaged the 0.78" holes in the track with a chain drive. The system typically had about 1/8" of lash and a high sensitivity to floor levelness.

The new AFDE drives on an AGMA 12 quality 6-pitch gear rack mounted to supporting c-channels which tool directly to the airplane floor grid. A ground rail at the pitch line height of the rail runs directly next two the rack. These are installed in the fuselage before drilling.

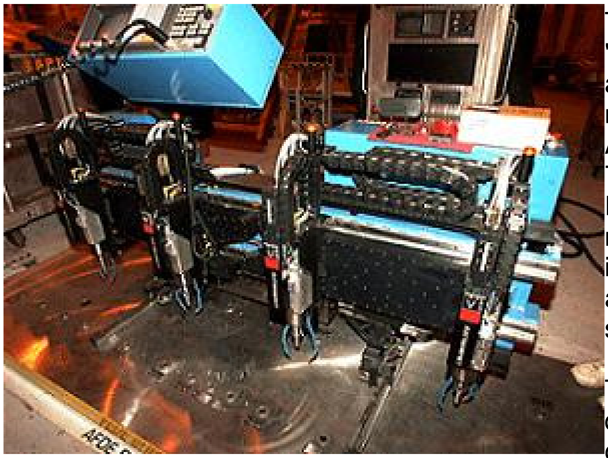
The X drive on the new AFDE consists of belt driven high-speed shaft connecting to a pair of ultra-low backlash planetary gearboxes. The output of the planetary gearboxes connects directly to an inspection gear equivalent to AGMA 15-quality gear and a ground hub at the diameter of the pitch diameter. The hub rides on the rail to set the correct engagement of the gear into the rack.

The rack and rail mounted to the airplane floor grid act as the machine bed for the AFDE. However due to airplane build tolerances Boeing could not guarantee the levelness of the floor to better than 0.100". These level variations are a major cause of inaccuracy on the original AFDEs as the chain drive under engages in the seat track.

To minimize the inaccuracies due to levelness, or waterline deviations, Boeing and Electroimpact agreed that the X drive gear had to maintain full engagement in the rack. Leveling the rails in each airplane was deemed impractical, so Electroimpact agreed to design a mechanism for forcing the hub down to the rail. A spring mechanism guarantees that the gear remains fully engaged. On level tracks the springs are compressed to a stop. On out of level tracks both front wheels remain down and one of the planetaries is pushed down relative to the crawler frame to meet the rail while the other remains on its stop.

The total measured backlash of the X drive system as measured on the actual machine was less than 0.0004" (4 tenths of a thousandth of an inch). Repeatability in the airplane has been demonstrated to be within this number. Total system accuracy is a function of the gear rack.

## MACHINE STIFFNESS & DIMENSIONAL STABILITY



The machine frame and the drill carrying "wings" were 100% re-designed for stiffness and long term dimensional stability while reducing the front-to-back dimension of the AFDE to allow it to be loaded in through the 737 passenger doors. In addition, Electroimpact explained and Boeing recognized that some of the weight constraints imposed on the older AFDEs were somewhat artificial and that a heavier AFDE could be a stiffer, more accurate AFDE.

The machine frame was re-analyzed. It was quickly recognized that of the four parallel sets of bearing rails for the four "wings", two were heavily loaded and two were not. On the older AFDEs, each rail had its own structural member. On the newer AFDEs the rails and drives were re-arranged to have a lightly loaded rail and a heavily loaded rail share a common, larger, structural member. As borne out by FEA modeling, the immediate result was a 16 fold increase in stiffness of the rail carrying structural member over the old design without an increase in weight and only a 20% increase in peak loading. Adding some of the allowed additional weight to the frame increased the stiffness by a factor of about 25 times in some relevant load cases. The stiffer frame members were able to support larger bearing rails and cars for further increased stiffness.

Greater attention was paid to long-term dimensional stability of critical parts, especially the wings and frame. Our experience on the 777 AFDEs suggested that a welded "wing" structure on the machines resulted in some long-term stability problems, even with proper stress relieving of Aluminum. The wings on the new 737 AFDE were hogged from solid billet, stress relieved and bolted to maintain a closed box structure. The same philosophy was applied to other critical components including the X-drive mounts. The frame, while still welded, was made from heavier material and thermally stress relieved twice: after welding and after machining to within 0.03" of final machining.

The result of the increased stiffness was that the all four drills move within a 0.0025" (+/- 0.00125") wide line over 128" in the Y direction. Stiffness as measured by the deflection of the drill heads under load increased by a factor of about 30 over the older AFDEs to about 0.005"/200 lbs. applied load.

## MACHINE SETUP

Since the AFDE drills relative to the tracks installed in the airplane, not relative to some probed point in the airplane, machine setup is critical. The accuracy of the X and the four Y-axes home positions determines the accuracy of the machine. Older AFDEs used an aluminum "test plate" bolted to the scaffolding structure. The accuracy of the test plates was at best 0.03". Electroimpact convinced Boeing Wichita that an accurate machine needed an accurate reference from which to set axis positions. The result is a ground steel test plate 6" thick resting on 3 feet. Reference bushings are located within 0.002" on the test plate. Their actual locations were measured to within 0.0002" with a calibration laser and recorded directly on the test plate. Indicators in the spindles are used to measure actual spindle locations relative to the reference.

## DRILLS

The Electroimpact designed and manufactured servo-feed/servo spindle drills for the 737 AFDE were optimized for the 737 AFDE application, including a long nose to allow drilling closely next to upstanding floor structures. The drills are 4" wide and 50 lbs. complete including feed and ISO 30 tool holder with 100mm extension. They deliver 30 in-lbs. at 7000 RPM and 60 in-lbs. at 500 RPM continuous duty with no external cooling for one of the highest power to weight or power to size ratios of any unit on the market. Maximum continuous thrust is 250 lbs. Total runout of the drill 1" past the collet of the 100mm extension toolholder is less than 0.0005". The units drill up to 0.277" diameter holes in titanium and aluminum.

To minimize total drill time all four drills on the AFDE can be drilling at the same time, each with it’s own independent drilling parameters including feed rate and chip load. Drilling parameters are controlled with a unique mode of part programming designed to provide Boeing with maximum flexibility and simple, compact part programs. Boeing has rationalized the hole locations in the floor grid to make maximum use of the spindles at each X station. The result is that in actual drilling the AFDE drills about 1200 holes per hour, including mandatory operator interventions.

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