

A New Robotic Vibration-Drilling Process

Sylvain Laporte
MITIS

Etienne Gueydon
Alema Automation

Alain Auffret
PRECISE France

Cosme De Castelbajac
MITIS

ABSTRACT

In today's aircraft assembly process several new features make drilling operations very challenging according to production requirements. Parts are made of thin or thick multi-material stacks with a large scope to cover and complex assembly sequences. In addition, the current ramp-up in aircraft programs involves to improve productivity while keeping process quality and reliability.

In this context robotic solution meets perfectly all these requirements as it is flexible, reconfigurable, fast and agile. Among the possible end-effectors, the Barrel Multi-Function End Effector (BMFEE) appears to be the most flexible solution to allow many different process configurations.

The latest developments have been focused on the drilling equipment of this BMFEE. In fact the drilling process efficiency can be constantly improved especially in terms of reliability, quality and productivity. Therefore vibration-assisted drilling system has been integrated into the BMFEE drilling module. This innovative drilling process allows breaking up the metallic chips in such a way that jamming is avoided. Thus peck-drilling cycles are avoided and the global process offers more reliability and productivity while fulfilling quality requirements.

This article presents the work of this integration. Benefits of this new robotic vibration-drilling process are shown on the basis of an industrial example.

CITATION: Laporte, S., Gueydon, E., Auffret, A., and De Castelbajac, C., "A New Robotic Vibration-Drilling Process," *SAE Int. J. Mater. Manf.* 8(1):2015, doi:10.4271/2014-01-2258.

INTRODUCTION

In aerospace assembly, robotic solutions are a relevant alternative to classic heavy CNC machines and ADEs. However application cases have more and more demands in terms of productivity and quality. So, robotic means of production need to be ever more reliable and accurate.

The paper presents, first the latest developments performed on a specific ALEMA's end-effector, notably concerning the stiffness and the accuracy. Among these developments one of

the most important is related to the drilling function of this end-effector. Indeed many issues are related to drilling applications which can be improved through the new Vibration Assisted Drilling process. A challenging co-design has been carried out to integrate the vibration drilling system of MITIS inside the spindle which is integrated in the end-effector. Finally the robotic end-effector equipped with the new vibration drilling module has been tested on an industrial case study. A comparison is made between original regular drilling and vibration drilling. The new process allows significantly improved reliability and quality.

KEY ISSUES OF AEROSPACE ASSEMBLY WITH ROBOTIC SOLUTIONS

ALEMA Automation implemented first 6-axis robotic applications for aerospace assembly 15 years ago.

The basic idea is to offer an alternative solution to two classic aeronautical means of production:

1. Huge heavy 5-axis machines dedicated to drilling operations, sometimes for very small diameters. The robot provides an increasing flexibility as it can move directly to the part and be integrated in a moving line very easily and without major civil engineering work. This solution is obviously very competitive.
2. Automated Drilling Equipment (ADE): for decades this kind of machines has been the best technical answer to meet the challenge. Nevertheless, their productivity cannot be compared to an automated mean. They also require much manpower, working in hard conditions (noise, dust, fumes, scaffolding...).

For many drilling/fastening applications robotic solutions appear to be very relevant. Specific functionalities have been developed in order to improve the accuracy of the robot and to compensate the lack of stiffness. These two problems have been solved by designing a specific end effector called the Barrel Multi-Function End Effector (BMFEE) which offers high configurability.

There are 6 module locations in the barrel. These locations can welcome 5 types of modules: vision, drilling, fastening, hammering and hole quality measuring module. The design is very flexible and evolutionary. Indeed the BMFEE brings five main features together:

1. A BMFEE can be exchanged for another one using quick changer;
2. Modules can be selected to combine different processes within the same BMFEE;
3. The BMFEE provides a wide range of clamping and normality including slippage compensation;
4. It is easily configurable as different modules can be loaded in order to meet process requirement;
5. It is also easily adaptable to different types of fastener.

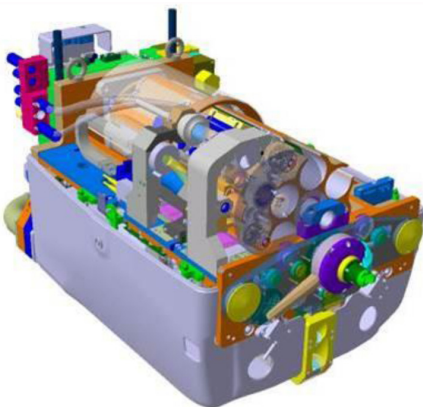


Figure 1. the Barrel Multi-Function End-Effector

The main advantage of the BMFEE is its ability to carry out all the operations without releasing the clamping force. When the BMFEE is clamped on the panel, the only movement is the barrel rotation which places the required module in the axis of the drilling point.

IMPROVING THE ACCURACY OF THE ROBOT THANKS TO THE VISION SYSTEM

The localization operation is a very important one. It allows adjusting theoretical trajectories of the robot according to the real aircraft part geometry. A specific vision system has been designed in order to align precisely the BMFEE working axis with the drilling point axis.

This vision module is composed of a COGNEX camera, a lighting system, an angle converter and a laser telemeter. The COGNEX camera is located in the static part of the BMFEE, which axis is orthogonal to the module axis (Figure 2). The angle converter allows turning the camera field direction into the same direction as the drilling axis for an optimal accuracy.

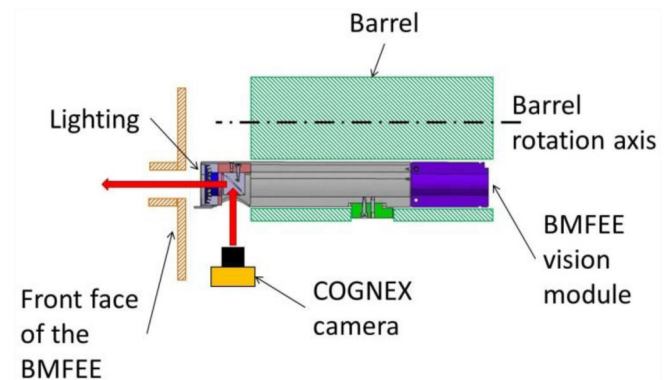


Figure 2. drawing of the BMFEE vision system

This module is used to align the robot on known targets (holes, fasteners...). The robot is allowed searching these targets through the vision module within a small reference plan (maximum 400 by 400mm). The measurement is done in three dimensions (3D) with combination of camera images (2D) and the laser telemeter which provides the third dimension.

Compensating the Lack of Robot Stiffness through the Anti-Slippage Table

As 6-axis entry-level robotic arms are not rigid enough, deflection could happen during clamping operations. In order to improve this issue and to avoid damaging the part, the BMFEE is equipped with an {X,Y} Anti-Slippage Table (AST) as shown on Figure 3. This AST automatically and precisely adjusts the axis of the end effector through a slippage compensation system which allows the robot working on its full working envelop.



Figure 3. Anti-Slippage Table

As soon as the clamping operation starts, two mechanical actuators are released. These actuators allow the blue plate slipping on rollers positioned on the front of the end effector. As the clamping operation progresses a gap could occur in the {X,Y} plan. The Anti-Slippage Table is able to measure this gap and to calculate the X-Y-position offset. Once the required clamping force has been reached, new X-Y-coordinates are sent to the robot to fix the offset. Thus the drilling axis is correctly aligned with the programmed hole axis.

These major improvements make robotic systems more and more used in aerospace industry. Meanwhile requirements are higher and higher especially in terms of drilling process. Robotic solutions have therefore to be combined with new drilling technologies to improve drilling process performances.

Drilling Process Improvement

The last improvement has dealt with the drilling module. Actually robotic solutions have to face more and more demanding applications among which many CFRP-titanium and big-diameter drilling operations. Three main issues have been identified.

First issue is linked to thrust force in drilling. Clamping force must be increased in order to counterbalance the increase of the axial force on cutters. But the lack of stiffness of the robot arm limits the acceptable global force on the BMFEE.

Second issue is the cycle time. Due to the limitation of the acceptable force on the BMFEE peck-drilling process has been implemented. But it is not very efficient regarding to the cycle time.

Last issue concerns chips evacuations. In the case of big holes, the ability to correctly collect chips is limited because of the small clearance between the BMFEE nose, the workpiece and the cutter. Therefore it is very important to get small chips to avoid jamming in the vacuum pipe.

The implementation of the MITIS technology [1] in the drilling module of the BMFEE has been identified as a relevant solution to solve all these problems. It allows drastically increasing the performances on the drilling sequence and enlarges the scope of applications for robots.

A RELEVANT INNOVATION FOR ROBOTS' END-EFFECTORS

Statements About the Regular Drilling

A previous article at a SAE conference [2] had shown the interest to question the way drilling operations are carried out, especially in multi-material stacks. This paragraph lists the most well-known stumbling points in regular drilling operations according to different points of view.

Quality Point of View

In a regular drilling operation, the classical long metallic chips getting out from the material may damage the already drilled surface. This is particularly true when drilling multi-material stacks made of different material such as Al/Ti, CFRP/Ti. The first (soft) material can be burnt or scratched by hard and hot chips from the second (hard) one. In some cases, this phenomenon can even enlarge the final diameter in the first material. The only solution consists in mastering the chip generation.

As quality aspect is the leitmotiv of the aerospace production, many solutions have been found and used to match with the high quality levels required. Here is a non-exhaustive list of solutions that allows controlling the flow of chips and therefore, mastering the quality specifications:

1. Multiple drilling operations, in which one (or several) first hole(s) is (are) achieved to limit the volume of material to extract for the final operation (that can be a reaming operation).
2. Peck drilling operations, in which the constant feed is interrupted several times in order to fragment the long chips into reasonable sized chips, easily extractible.
3. Orbital drilling operations, in which the classical cutter is replaced by a milling tool and the trajectory is composed of rotation and a plunge motion.
4. Specific cutters with chip breakers, which use (associated with suitable cutting conditions) allows generating small chips.

All of these solutions have been commonly used in aerospace for many years and proved they have been able to get through the quality issues. Yet, considering other aspects of assembly they do not always fit with productivity and/or cost aspect.

Productivity and Cost Points of View

The multiple drilling operations basically entail a great loss in terms of productivity as a final hole requires being predrilled once (or more times) till its final obtainment. In brief, the cycle time for a single hole is roughly multiplied by the total number of operations needed to get the final hole. Beside the productivity point of view, costs are also impacted by the method as predrilling cutters are put in place and need introduction of additional references.