

A Global Improvement in Drilling and Countersinking of Multi-Material Stacks with Vibration Assisted Drilling

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ABSTRACT

Over the last few years, many aircraft production lines have seen their production rate increase. In some cases, to avoid bottlenecks in the assembly lines, the productivity of processes needs to be improved while keeping existing machine-tools.

In this context, the case of drilling machine-tools tends to require particular attention, especially when multi-material parts are drilled. In such instances, the Vibration Assisted Drilling (VAD) process can be a way to improve productivity and reliability while keeping quality standards.

This article presents a case of a drilling/countersinking process for stainless steel and titanium stack parts. Firstly, the article assesses the feasibility and benefits of using Vibration Assisted Drilling and Countersinking with the current cutting-tools. Secondly, it studies the consequences of introducing a new tool holder in the process, which combines the V.A.D. function, a new declutching function and the ability to control countersink depth. Thirdly, a process study is undertaken on these last developments in order to design more efficient cutting tool geometries. New drilling and countersinking combined tools are developed. Their performances when used with the V.A.D. process are highlighted, in terms of productivity, reliability and quality.

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INTRODUCTION

As world air traffic is constantly growing, airplanes global demand makes manufacturers ramp up their production. For existing aircraft programs increasing production rates needs improving the productivity of assembly lines. Two solutions can be explored: either new means of production are bought or the current ones are retrofitted and their processes optimized in order to be more efficient.

This article deals with this last way of optimizing production rates in the global context of airplane assembly lines. A particular example is detailed which concerns a special machine-tool dedicated to drilling and countersinking operations on engine pylons. Four different aircraft programs are affected by this machine. The parts in question are mainly made of Stainless Steel (15-5 ph) and Titanium (Ti-6Al-4V), diameters go from 3/16" to 1/2" (4.78 to 12.7 mm).

Firstly, the case study is presented and the original process is detailed and main issues are highlighted. Secondly, a global retrofit solution is proposed which consists in applying a Vibration Assisted Drilling (VAD) process combined with a dedicated tool holder. The expected benefits of this solution are described; a focus is made on the countersinking operation, which has to be taken into account in the

design of an innovative Vibration Assisted Drilling and Countersinking (VADC) tool holder. Thirdly, specifications, design and functioning of this new VADC tool holder are explained. Fourthly, the drilling and countersinking process is optimized: the initial regular drilling and countersinking process is replaced by a new one and specific cutting tools are designed in order to suit with the VADC process. Finally, both processes - initial and final - are compared and the VADC process is proved to be more efficient in terms of reliability and productivity.

CASE STUDY AND MAIN ISSUES

This article deals with a drilling and countersinking machine-tool for engine pylons. This machine is used for four different aircraft program, so it can drill and countersink four different types of pylons, which are mainly composed of Stainless Steel and Titanium alloys. Whatever the type of pylon cutting tools must be suitable for all the materials or stacks to be drilled. In other words, for a given diameter, the cutter must be able to drill a Stainless Steel part of pylon A (aircraft program A), a Titanium part of pylon B or a Stainless Steel and Titanium stack part of pylon C.



The pylon is clamped on its tooling system at the center of the machine-tool which is composed of two 5-axis machining heads on both sides of the workpiece. For each diameter the machining plan of procedure includes three different operations: one regular drilling operation with a drilling cutter (Figure 1), one rough countersinking operation with a countersink tool and one finishing countersinking operation with a second countersink tool (Figure 2).

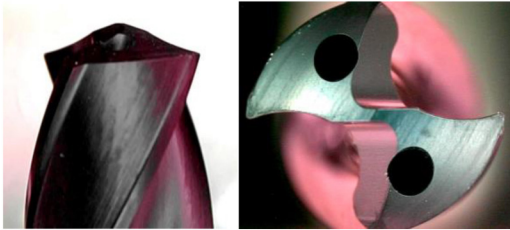


Figure 1. original drilling cutting tool (Kennametal)



Figure 2. original countersinking tool - one for rough operation, another one for finishing operation

Countersinking operations are realized with a specific tool holder which includes a depth control system. Indeed, given the tolerances for assembling and clamping such large parts, the machine-tool must be able to compensate positioning errors in order to guarantee the right countersink depth. This system rests on two main ideas. On the one hand, a distance equal to the maximal positioning error is added to the theoretical countersinking tool path. On the other hand, the tool holder integrates a depth control system which allows absorbing the overstroke of the machine axis from the moment its tripod nose has got in touch with the surface of the pylon. Implementing this process needs adjusting the height of the tripod nose in relation to the geometry of the countersinking cutter.

After this automated drilling and countersinking process, the pylon is taken out from the machine-tool and final manual operations take place before riveting. Two types of manual operations are realized: reaming and, if necessary, fixing. Fixing operations are necessary when surfaces are scratched by long drilling or countersinking chips or when the countersink depth is too short. This last problem frequently occurs when long chips are caught between the tool holder tripod and the piece. All these manual fixing operations are an obstacle to the global productivity of the pylon assembly line.

In a context of production ramp up, a global productivity issue has been identified. Two ways of optimization may be explored. The first way deals with the drilling and countersinking automated process. Using three different cutting tools for each diameter make the machine-tool multiply tool paths between each hole to be drilled. The second way deals with the reliability of the cutting process. Indeed, many defects are due to the long chips that are generated during

regular drilling and countersinking operations. This lack of reliability leads to decrease the productivity of the global line because of the several manual fixing stations.

In order to answer this double issue, Vibration Assisted Drilling has been identified as a potential solution which could allow avoiding long chips and increasing productivity.

VIBRATION ASSISTED DRILLING AND COUNTERSINKING (VADC) SOLUTION

Main principle of VAD consists in generating a controlled oscillation that is added to the regular feed of the cutter in order to guarantee an optimal fragmentation of chips. As a consequence of this oscillating feed motion, the thermo-mechanical performance is better than in regular drilling and authorizes increasing cutting conditions, notably the cutting speed [1].

Indeed, scientific and technical literature shows that VAD process is an interesting way to improve both reliability and productivity. Moreover, another way to improve productivity consists in reducing the amount of “useless” machining tool paths, i.e. when the machine moves from a hole to the next one between each operation (drilling, rough countersinking and finishing). An obvious solution is to replace the three-cutter machining process by a single cutting operation achieved by a Drilling-and-Countersinking (D/C) combined cutting tool.

Actually in this case, the use of a D/C combined cutter plus VAD process appears to be relevant and requires two joint developments. The first development consists in defining a new combined cutter for Stainless Steel and Titanium alloys, and the second one focuses on designing a specific tool holder for the Vibration Assisted Drilling and Countersinking (VADC) process.

Among all the features of this new solution, a particular attention must be paid to the Vibration Assisted Countersinking (VAC) operation. Given the VAD functioning principle, the final countersink surface might be wavy as the last circular path of countersinking edges leaves the trace of the VAD oscillating feed before exiting. Two main ideas can be explored in order to solve this problem.

First idea consists in adding a time out in the CNC program at the end of the countersinking stroke; in that case feed is stopped at the final programmed axial position while cutting edges rotate several times before exiting in order to glaze the countersink surface. Figure 3 is a model simulation showing the influence of the number of spindle turns on the countersink form error. When the spindle turns five times in the same axial position at the end of countersinking operation, the form error is 13µm high; for ten rotations the form error is only 2.5µm.

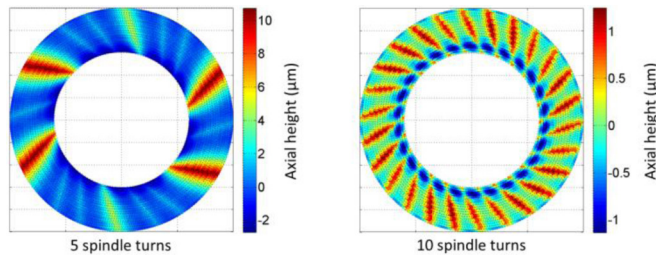


Figure 3. influence of the number of spindle revolutions on the countersink form error when countersinking with vibration assistance

This principle can work if the VAD frequency is not an integer multiple of the spindle rotation frequency - otherwise each circular path of cutting edges superimpose to the previous one and the surface remains wavy whatever the amount of revolutions. But this solution makes the productivity decrease because of the time out phase.

Second idea is to integrate a declutching function in the VADC tool holder, which allows cancelling oscillations at the end of the countersinking stroke. This principle is taken on for the specific tool holder design.

On the basis of these concepts, next paragraphs detail the new product and process solution. Firstly, the VADC tool holder is described in terms of design and functioning characteristics. Secondly, developments on new combined cutting tools are presented.

INNOVATIVE VADC TOOL HOLDER

The design of the VADC tool holder must take into account several specifications in order to fit with the different diameters to be drilled (from 3/16 to 1/2 inch).

Specifications

Indeed, each diameter configuration corresponds to a maximal thrust force, a rotating speed and oscillation amplitude.

Maximal speed is set to 5000rpm considering the smallest diameter, and available VAD oscillation amplitudes must go from 0.10mm (0.004") for smallest diameters to 0.30mm (0.012") for biggest ones. The tool holder must integrate a countersink depth control system, which features have to be similar to the system of the original tool holder (see "Case study and main issues" previous paragraph): the VADC tool holder must be able to absorb an overstroke of 5mm (0.20") and guarantee a countersink depth tolerance of 0.3mm (0.012"). Another specification concerns the quality of the countersinking surface, which must not be damaged by the oscillation traces. As it is explained in the last paragraph the most appropriate principle consists in deactivating the vibration assistance at the end of the countersinking stroke; the VADC tool holder has to integrate this function.

Operating Protocol

As material to be drilled and countersunk is not perfectly located (depth) and its rigidity is not infinite (possible deflection due to the thrust while drilling and countersinking), the travel of the cutter is computed with an overstroke motion.

Concretely, this means the cutter goes further than the theoretical point where it should retract. The excess of travel is offset by the tool holder planned compression (5mm, 0.2").

The Mitis tool holder PF5532 uses this overstroke travel to ensure the declutching of the vibratory system, the countersinking depth and the glazing of the countersunk surface.

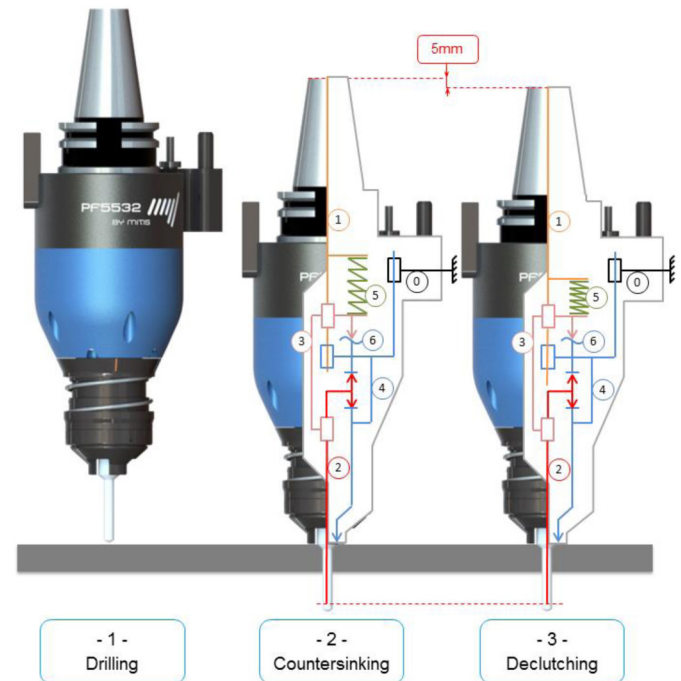


Figure 4. kinematic schema and functioning concept of the VADC tool holder (MITIS PF5532)

Drilling Phase (-1-)

The spindle attachment of the tool holder (1) is rotated and moved at the desired rotation speed and feed rate (machine). A sliding joint transmits the torque to the cutter through the tool shank (2). The Mitis bearing (6) generates an oscillating axial motion thanks to the relative rotation speed between the rotating parts (1 + 2 + 3) and stator (4). The stator is blocked in rotation by the mean of the stop-block (0) linked to the machine. Oscillations coming from the bearing (6) are transmitted to the tool shank (2) and the stator (4).

The use of this kinematic modifies the feed of the cutter as it is the addition of the constant feed motion (machine) and an axial alternative motion (Mitis bearing). Therefore the drilling operation is turned into a VAD operation.