A breakthrough in handheld Smart Drilling Units

Material detection with advanced electrical drilling

1) Introduction

Aerospace is always struggling to achieve the right level of quality in assembly, while keeping the price at an acceptable level.

In term of quality drilling, a lot has been made in the past, using full automation in order to solve this equation. However, all drillings are not in the reach of automated systems, and the price of such systems is out of reach for a number of actors, or for small rate productions. In addition, it request to have very skilled personnel to program and run the machines.

On an other hand, the design of the aerospace structures is in constant evolution, and for optimization of strength and mass, we can see more and more complexes structures composed of heterogeneous stack-ups made of different materials such as aluminum, carbon fibers, titanium, stainless steel, etc.

This causes real challenges for the production, as the drilling parameters for each material might be very different leading to inefficiencies in term of cycle time.

Taking all this into account, AET has decided to take the challenge, and to design a new type of hand drilling machine combining the quality achieved in the automated systems, and the flexibility of the handheld drilling machines.

Let’s first establish the specifications on which we based the new Smart Driller.

2) Specifications

Before starting the development of the new drilling machines, we analyzed the market in order to maximize the ad equation of the future Smart Drilling Units with the real needs of the market. The result is a list of basic specifications:

- Electrical power for both rotation and feed
- Low voltage power for safety reasons
- Feed and rotation speed managed separately to allow any combination
- Programming capacity for each type of hole
- Speed rotation: 0 to 8000 rpm or more
- Feed from 0.001 mm/rev to 6m/mn.

- High Quality of the holes
- The production of full-depth countersinks shall be repeatable to ±0,02mm
- Must allow the achievement of drilling/reaming/countersinking up to Ø25,4 mm with only one body
- Possibilities of changing all parameters according to the thickness, during drilling
- Possibility to set parameters based on thrust forces and torque
- Detection of change of materials
- System to detect cutting tool exit during drilling
- Possibility to set peck parameters
- Split up chips capability
- Imbedded lubrication
- System for sucking up chips
- Possibility to quickly plug/unplug the drilling unit.
- Detection of tool breaks and wears; dead stop of drilling unit on event.
- Minimizing the weight of the machine (very important for overall ergonomic)
- NC fully integrated
- Real time quality monitoring for quality insurance

We will not, in this paper, go through all of them, but we want to focus on detection of the material change.

3) Technical challenge

One of the most challenging technical aspects was to determine a method permitting to accurately measure the physical parameters during the drilling process. If it seems obvious that the drill bit will react differently when it will be acting in the different materials of the stack-up, it is no so easy to get the real time information and to use it for quickly restore the optimum parameters for the qualified process.

So, we specifically worked in the sensing part of the system, with the ability of measuring the thrust and the torque on the spindle axis. The accuracy and the stability of the measurement are depending on the mass and inertia between the surface where are generated the forces (i.e. the cutting edge) and the surface where the measurement is done (i.e. sensor interface). We spent a lot of time for determining a sensor location which combines several exclusive conditions

To be close to the drill bit attachment in order to reduce the mass and inertia

To be small enough in order to be integrated

To be able to monitor the parameters, even when the spindle is operating high speed

We tested our device in a wide range of drilling conditions:

Rotation speed from 300 to 8000RPM

Drilling diameter from 2mm to 32mm

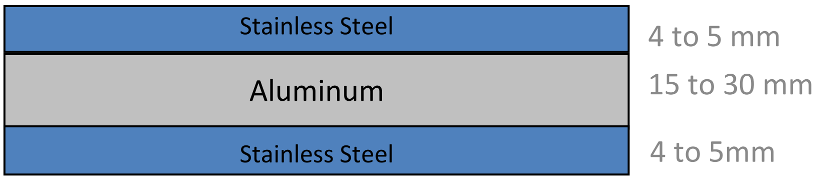
Different materials, such as aluminum alloy, Stainless steel, Titanium, Carbon fiber, Kevlar, …

The analysis of all the collected data was encouraging, as we were able to get specific values depending on the material leading us to detect the transition between 2 materials.

Our Smart Drilling Unit is operating in production on multi material sub-assemblies. We will now present some significant results in the transition detection in production environment, and the usage of such detection.

4) Operating conditions

The sub assembly is composed of 4 layers (2 aluminum plates between 2 stainless steel plates). The total thickness varies from 23 mm to 40mm; and the boring diameter varies from 6,35mm to 11,1mm.

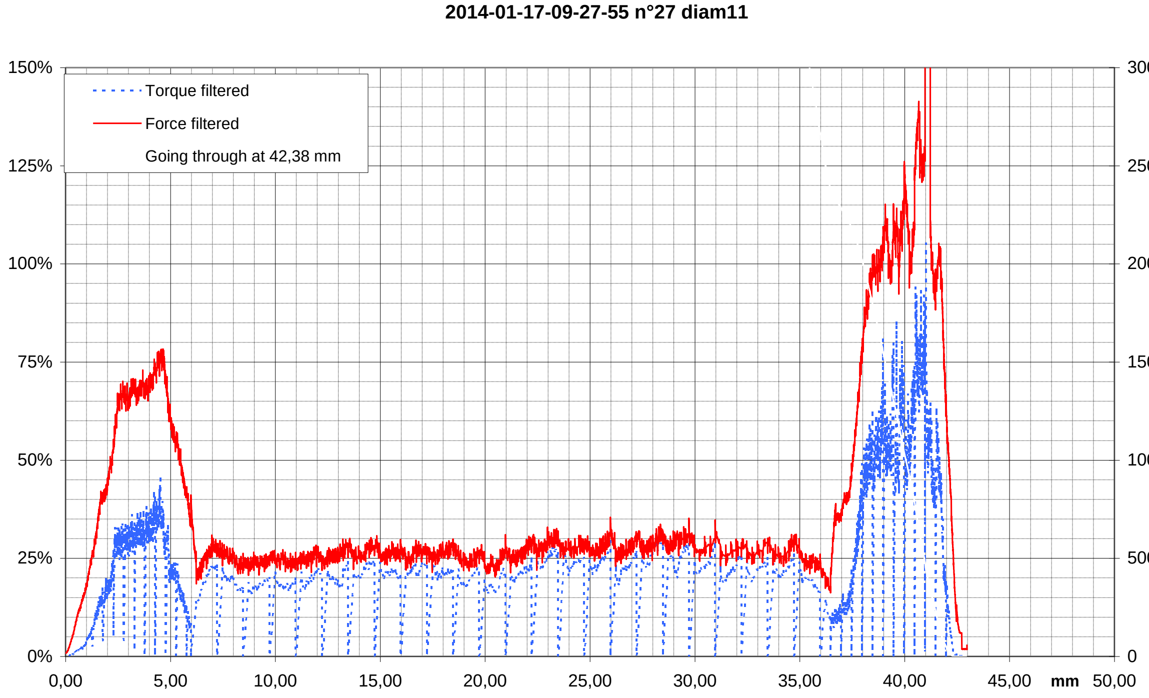


Here below is an example of the results. We can see the real time monitoring of the data collected during a one shot drilling process with 11mm cutting tool operating on a 40mm stack up.

The X axis is representing the position of the drill bit with a zero reference when the tip of the drill bit is touching the external surface.

The upper curve (in red) is representing a global contribution of the forces generated on the drill bit. These data are filtered with a real time optimized filter improving the position accuracy.

The lower curve (in blue) is representing the torque generated by the drill bit during the process. This value is filtered on a time basis.



Step 1 : Contact detection. Cycle parameters (speed and feed) are set to start the process. As the drill bit has no contact with material force and torque are staying at the zero level up to the surface touching. At that moment, force and torque are quickly increasing. The sensor detects this contact in a few milliseconds and changes the parameters for the 1rst material.

Step 2 : 1rst material entry. The drill bit qualified for this production has a conical tool tip. So the cutting diameter is growing from 0 up to the final diameter when the drill bit is moving forward. So we can see on the curve that force and torque are also increasing up to a stable value which is reached when the largest diameter is engaged.

Step 3 : 1rst material drilling. During this sequence, force and torque are staying at a rather stable value which is depending on the current operating conditions. The monitoring of this value permits to detect abnormal process condition such as dull or broken drill bit.

Step 4 : Transition 1. During this sequence, the tool tip is going through the 1rst material and is entering in the second material. As in this case, 1rst material is stainless steel and 2nd material is Aluminum, force and torque are decreasing up to a stable value which is reached when the final diameter of the drill bit is fully engaged in the 2nd material. When the programmed transition conditions are fulfilled, the Smart Drilling Unit automatically loads the process parameters qualified for the 2nd material.

Step 5 : 2nd material drilling. This sequence is equivalent to step3. The system is monitoring the value to detect abnormal process conditions.

Step 6 : Transition 2. During this sequence, the tool tip is going out of the 2nd material and is entering in the 3rd material. As in this case, 2nd material is Aluminum and 3rd material is stainless steel, force and torque are now increasing up to a stable value which is reached when the final diameter is fully engaged in the 3rd material. When the programmed transition conditions are fulfilled, the Smart Drilling Unit is able to automatically load the qualified process parameters for the 3rd material.

Step 7 : Going through. The last sequence is starting when the tool tip goes out of the 3rd material layer and is completed when the outside diameter of the drill bit is out. During this sequence, force and torque are decreasing up zero value. When the going through condition is fulfilled, the Smart Drilling Unit automatically loads the end of cycle parameters and reset the controller for the next drilling cycle.

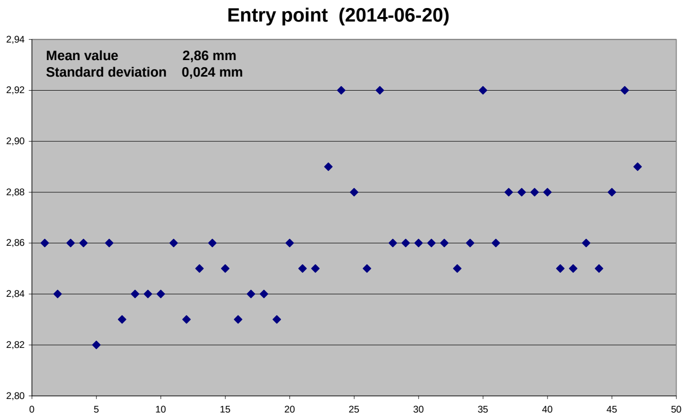
This way, the next hole does not need to be accurately programmed, as the Smart Drilling Unit will adapt to the new conditions of thickness

5) Process control performance

We showed in the previous chapter that the real time monitoring is replicating quite accurately the physical constraints of the process. However, this is not sufficient for an industrial process which must be repeatable and robust. Our Smart Drilling Unit has been running on a lot of different process conditions for several years. We are managing a quickly growing collection of data on which we are performing statistical analysis; some results dated 2014, June 6th are described below. About 50 consecutive drillings were realized at different location on a production part and performed with the same parameters set.

a. Contact detection

The contact detection values are determined in real time by the system and referenced within the Smart Drilling Unit coordinate system.



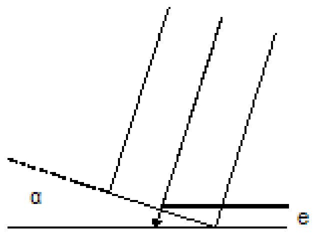
The standard deviation of this collection is

e = 0,024mm

It integrates the deviation due to the equipment itself (mechanical, electrical and numerical control aspects), but also the deviation due to the part and the tooling.

For the purpose, the tooling was designed for locking the Smart Drilling Unit with a quick turn attachment and a contact of the nose piece tip to the part surface. These allow a good reduction of the deviation due to the tooling; but some variation in the normality of the machine to the surface is still remaining and this is included in the global standard deviation value.

For example, considering that the angle between the axis of the machine and the normal to the surface is α, the variation in the contact detection will be affected as follows:



e = R sin α (where R is radius of the nose piece contact plate)

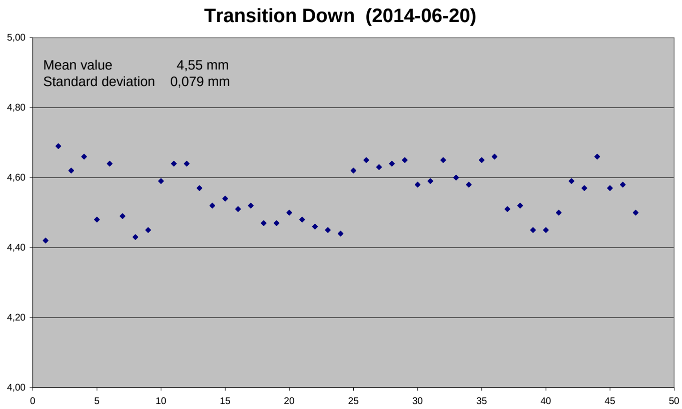
for R = 10mm et α = 0,1°:

e = 0,017 mm

This simple calculation shows that the current standard deviation in production is of the same order of magnitude than the deviation given by a misalignment of 0,1°.

b. Transition

The transition values are determined in real time by the system and are referenced relative to the contact detection position. Two collections of data were analyzed.



First, the collection of **"transition down"** determines the transition from the hard material to the soft material (stainless steel vs. Aluminum in that case).

The standard deviation of this collection is

e = 0,079mm

This variation is specifically affected by the noise on the force signal in the hard material. As the force is decreasing from a high level to a lower level, it is quite difficult to separate in real time the reduced force due to the noise on the force signal and the reduced force due to the material reaction.

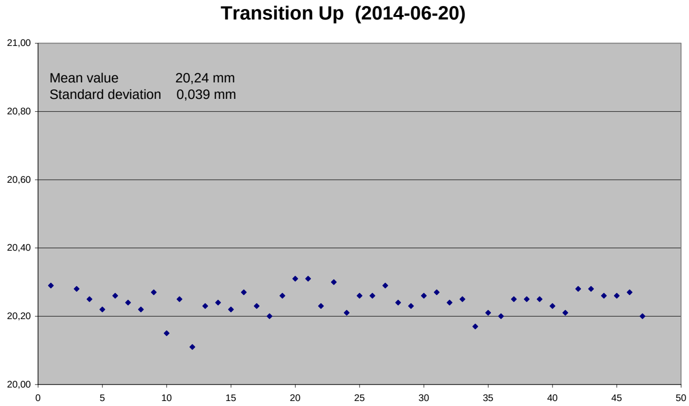
Depending on the effect we are looking for, we can adapt the strategy;

If we change the transition detection parameters, we are able to reduce the standard deviation. For example, if we increase the time in which the force must stay at a low level before transitioning, the deviation will be much lower. With such conditions, the result is a deeper location of the transition edge.

The accuracy of the transition is not really important in production conditions as it is only used to automatically change the drilling parameters in order to reduce the global cycle time. If the system delays the detection, it will continue to operate in the soft material at the same parameters than in the hard material. The quality of the hole will not be affected if the system detects the transition a few millimeters later; only the cycle time will be increased.

However, if for some reasons we need to know the place of the transition, for example to detect the hard material thickness, we can utilize the post analysis of the same data.

We can perform the analysis when the cycle is completed and we can use the 'future' data collected later in the soft material. In such a case, the standard deviation can be cut by 3 to 4.



The collection of **"transition up"** determines the transition from the soft material to the harder material (Aluminum vs. stainless steel in that case).

The standard deviation of this collection is

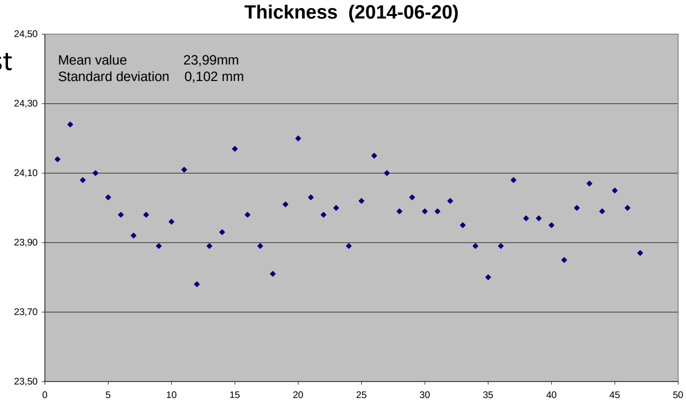
e = 0,039mm

This variation is less affected by the noise on the force signal in the soft material. As the force is growing from a low level to a high level, it is much easier to separate in real time an increased force due to the material reaction from the noise on the signal.

This is quite important as this information is used for changing parameter from high speed drilling to low speed drilling. The Smart Drilling Unit has the ability to detect accurately this transition and can optimize the drilling cycle even in the case of a titanium plate behind a carbon fiber (or aluminum) plate which is from our opinion one of the worst case. Drilling Titanium with Aluminum high speed conditions could generate a safety issue with a high risk of fire.

Our Smart Drilling Unit was designed to automatically detect the transitions between different materials reliably and in real time. The results collected over a long period of production are confirming the multiple capabilities of transition detection. However, the conditions of use have to be determined with the final user based on its own expectations.

c. Going through.



The collection of **"going through"** data determines the transition between the last material (stainless steel in that case) and the air.

The standard deviation of this collection is

e = 0,102mm

This variation is specifically affected by the noise at the end of the cycle. This noise is due to the friction of the chips inside the hole. When the drill bit exits the material, this changes the force on the chips as there is no more reaction at the front. Even if the cutting conditions are always the same, the chips generation is varying, and the variation is much more important if the material is hard, so if the initial force is high.

A collection of data coming from a soft material drilling (Carbon fiber or Aluminum) will generate a better stability and lower standard deviation.

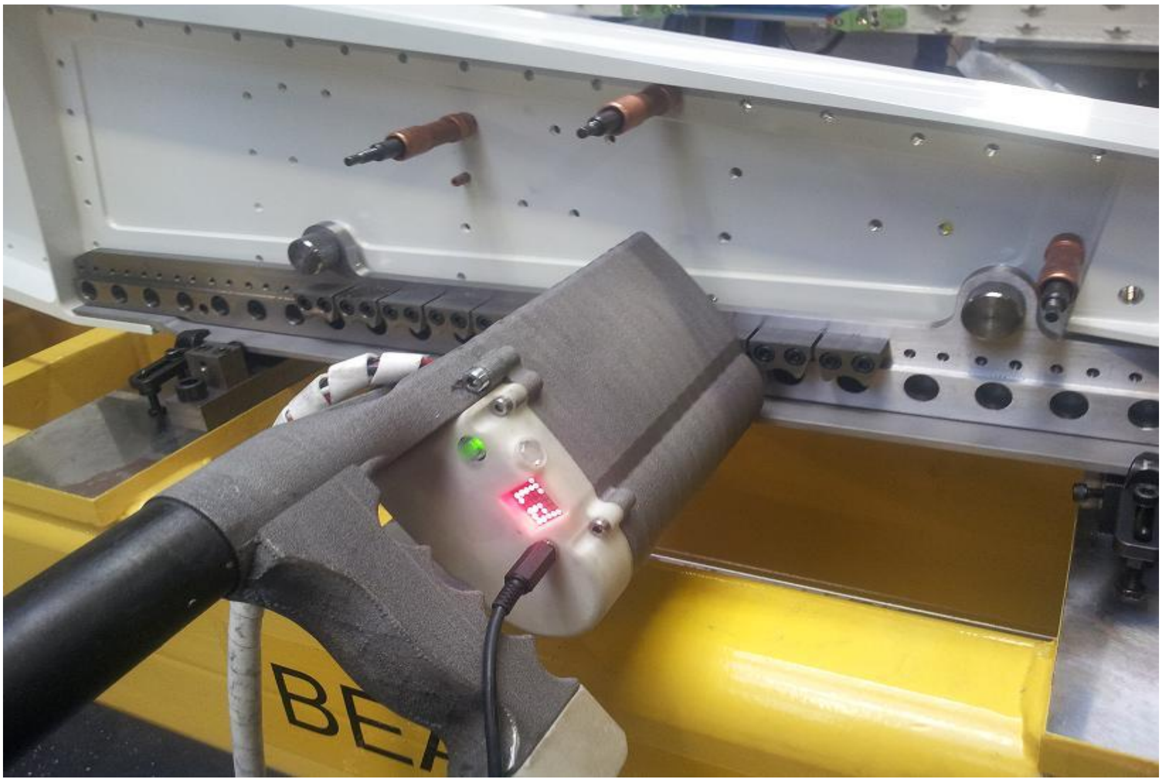
For production purpose, this information will be use to optimize the cycle time as the equipment can enter in fast return immediately and end the cycle.

It can also be used for determining the thickness of the assembly and/or for automatically making the choice of the fastener length.

6) The Smart Drilling Unit

Starting from scratch, AET has designed a new Smart Drilling Unit family which is meeting the specifications that were defined upfront, and in some cases, even exceed them.

This equipment has been proved in production environment and the reliability of the process control has been demonstrated.



The performances are the consequences of the technological choices during design phase. We succeeded with an advanced technology mix such as:

i. **Mechanics** : low weight, high rigidity

ii. **Electronics**: Very low voltage, on board cards.

iii. **Software**: optimized data analysis.

This equipment is autonomous and easy to use. And with its wireless communication device, it may stay connected to the production network whatever the conditions and transmit the required data when defined.

7) Conclusion

The case presented in this paper demonstrates some of the possibilities introduced with the Smart Drilling Unit.

However, the most important is the quality we can achieve with a single shot drilling in a complex stack-up. The Smart Drilling Unit reaches the same quality and performances than the most advanced drilling units on heavy automated machines at a small portion of weight and cost.

This very advanced Smart Drilling Unit will offer the aerospace manufacturing solutions capable to offer cycle time reduction, productivity increase, high quality achievement in a quality assurance environment, all this with a low investment. This is what we consider a real breakthrough.