The Influence of the Cutting Tools Parameters on Inconel CNC Manufacturing

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Abstract. There are several types of super alloys: Titanium, Inconel. Titanium alloys are typical for aerospace products. They are attractive because of their low specific weight, and their resistance. Inconel alloys are corrosion and oxidation resistant materials, well suited for work in extreme environments who have a good resistance at high pressure and heat. Inconel alloys retain their properties in a wide temperature range and are attractive for high temperature applications where aluminum and steel parts will not resisted. But the processing of these super alloys is complex and requires dedicate cutting tools and special cutting tools parameters. In the paper will be present solutions at this requirements: new cutting tools and new solutions to manufacturing aerospace parts from Inconel.

1. Introduction

Inconel alloy 718 can be readily machined, but its high strength and work-hardening characteristics must be considered in the selection and use of proper tool materials and design, operating speeds, and coolants.

Until today Ti 6Al 4V (Ti64) is still the most employed of all Ti-alloys both for engine and air-frame applications. Ti64 is characterized by an optimum combination of properties: Uncritical in processing, high strength at low temperatures, excellent machinability and good, weldability. Ti64 is available as forging, sheet and since about 1975 as investment casting for stator components, for example compressor casings. Ti 6242 and Ti 6246 have higher strength and temperature capabilities. At present the most advances Ti-alloy for disk applications (up to 550°C) is IMI 834. Above 450°C this alloy is superior to any other Ti-alloy. Its price, however, is about twice the price of Ti64 with respect to its complex metallurgy and the thermo mechanical processing parameters needed for optimum microstructure and mechanical properties. [2]
When machined in the age-hardened condition the alloy will have a slightly better finish; chip action on chipbreaker tools will be better. The use of annealed material, however, provides easier machining and longer tool life.

Because of its strength, INCONEL alloy 718 is more resistant than most materials to deformation during hot forming. Its relative resistance is shown by pressures developed in the roll gap at 20% reduction.

It is readily hot-worked if sufficiently powerful equipment is used.

Hot forming is performed in the 900°-1400°C temperature range. In the last operation, the metal should be worked uniformly with a gradually decreasing temperature, finishing with some light reduction in the 900°-950°C range.[3]

This procedure is necessary to ensure notch ductility in stress-rupture applications when material has been annealed and aged.

In heating for hot working, the material should be brought up to temperature, allowed to soak a short time to ensure uniformity, and withdrawn.

2. State of art
Take in consideration the new materials of the aerospace components (Fig.1) who use super alloy and the complexity of the parts, the aerospace industrial needs are: 1. Educated scientists and engineers 2. Globally sourced 3. “Clearable” for defence-related projects 4. Mathematical and analytical capability 5. Probability and statistics 6. Communications across various disciplines: Not just interdisciplinary studies, but interaction.

Industrial aerospace research directions: 1. Increased global sourcing of subcomponents and materials 2. Global sourcing of assembly 3. Networked manufacturing 4. “Materials by Design” 5. Lean manufacturing 6. “Green” materials and processes 7. Networked aircraft, satellites.[8]

Regarding the manufacturing we can conclude:
The cutting conditions are totally different when we manufacturing Inconel in comparison with general steel manufacturing. The cutting speed is lower, the depth of cutting is much more less because the wear of the cutting tool is much higher.

The cutting tool parameters in the milling process have connections between: cutting tool speed \( V/V_c \) [m/min], the feed “s” /”fz” [mm/rot], and the depth of cut “t” / “ap” [mm] with the setting parameters: rotational speed “n” [rot/min], feed by teeth ”fz” [mm], and the axial and radial depth of cut ap, ae [mm] (Fig.2).[1]

![Figure 2. Milling process with the cutting tool parameters](image)

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Take in consideration this inconveniences, the cutting tools was adapted to this hard conditions of Inconel manufacturing. Was develop new geometries of the inserts (this we can see this, we can measure it) and new thermal coatings (this procedures are not presented by the companies - are their protected patents). All this new technical solutions must be tested and after that, to be confirmed.

In the paper was tested new cutting tools with new round rotate insert K0-90 in manufacturing Inconel super alloy.

2.1. The round indexable inserts K0-90°

This have a new design with a chip breaker who assure a good stability of the cutting process.

This round inserts will be fix on the plate support (Fig.3.b) with 7° positiv inclination (Fig.3.a) or with 0° inclination (Fig.3.c). The cutting angle is recomanded for the martensitic materials X38CrMo17, austenitic steels (316Ti), where was obtain very good rezults.[3]

![Figure 3. Position of the cutting plate in support](image)

Figure 3. Position of the cutting plate in support

The plate geometry is different for Inox (Fig 4a), general milling, (Fig 4b) and super alloy (Fig 4c).
2.2. New System

The new innovative tooling system change an old conception of the cutting process: "the insert has to be rigidly coupled to the cutter body-if it lose in its insert seat it would break soon or later ".

So this theory was unconfirmed by new research in the cutting tools manufacturing where the insert is rotating in the milling process.[4]

With this new technical solution it is not necessary to stop the machine and to make a manual re-positioning with the change the wear area of the inserts. The results is that we will minimize the set-up time and will eliminate the un-productive time of manufacturing.

More that then, we will obtain the same wear along the circumferences of the round plate, we will use 100% of the total insert periphery and we have a multiple increase of tool life.

The geometry of this rotating plate have a dedicated design for the cutting edge. (Fig. 4). The clearance angle W1 reinforces the cutting edge while the clearance angle W2 provides sufficient space to eliminate the chips and to grow up the cooling liquid in the cutting tool area.

With this geometry was stabilized the cutting edge and form the limiting feature for the wear mark.
2.3. Milling Application areas
Titanium requires specific considerations due to its high strength to weight ratio which results in higher cutting temperatures.

It is also chemically reactive which can result in adhesion, welding and smearing when machining. The combination of mechanical, thermal and chemical loads will create a typical wear pattern known as edge chipping. (Fig. 7)

![Figure 7. Wear types a) Roughing, b) Semi-finishing c) Finishing](image)

2.4. Recommendations in programming
1. Entering the component
When the cutter is programmed to enter straight into the workpiece, thick chips will be produced at the exit until the cutter is fully engaged. This will dramatically reduce tool life.

![Figure 8. a) enter straight to cut b) Roll in to cut](image)

The main way to solve this problem is:
Roll in to cut (Fig. 8 b)
Program a roll into cut in a clockwise motion. By rolling into cut, the chip thickness on exit is always zero, allowing for higher feed and longer tool life.
Keep cutter constantly engaged
Sharp changes of direction in a cut will cause the same problem as occurs when entering straight into the workpiece (Fig. 8a). Rolling around all corners should always be applied as a key step to provide a robust, optimized process. Program around interruptions and holes when possible. [3]

2.5. Programming Centre line or periphery feed
A machine is designed for either centre line feed, \( v_l \) (without radius compensation) or periphery feed, \( v_{fm} \) (with radius compensation).
If the machine requires a centre line feed, and periphery feed is programmed instead (on machines without radius compensation), the $f_z$ value will become too high, with the subsequent risk of insert breakdown.[3]

Centre line feed programming
The NC codes generated will program the centre of the cutter rather than the periphery.
For straight line cutting (G1), the feed at the wall of the component, $v_{fm}$ is the same as the programmed feed, $v_f$ while the periphery feed around a radius (G2) will be higher than the tool centre feed.
Therefore the table feed, $v_f$ needs to be reduced to maintain the feed per tooth, $f_z$ and keep constant hex.

![Figure 9 Programming centre line versus periphery feed](image)

To be successful in machining titanium, optimized tools are necessary.
However, to achieve an optimized process these must be combined with application 'know how' to deliver a robust machining process.[5]

3. Conclusions
After the test of Inconel 718 manufacturing that was made in the workshop, sing the "New System" with roud indexable inserts (the rotating round plate) versus with the " Standard-System" we can conclude:
Cutting data recommendations:
- Roughing $v_c$ 50 m/min Depth of cut : > 3mm
- Semi-finishing $v_c$ 70 m/ Depth of cut : min 2 mm
- Finishing $v_c$ 100 m/ Depth of cut : min 0.5-1 mm

![Figure 10. a) the price for the inserts "Standard -System" /" New System" b) the price for manufacturing Standard -System" / New System](image)
In the paper was presented the new trend in Inconel manufacturing, was tested and validate the "New System" - using the revolutionary solution in cutting tool construction - the round plate is rotating in the cutting process, and was manufacturing a part with establish the optimise cutting tools parameters for better quality and the time manufacturing.

Making the comparison between the "Standard -System" - the fixed round plate with the round indexable inserts (the rotating round plate)- "New System", we made one significant reduce price for the cutting plate used: with 7% and with 23% reduce the price for manufacturing the part with "New Systems".

4. References
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