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Adaptations of mechanical machining processes for laser target manufacturing

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Abstract
In order to produce laser targets for laser plasma experiments, the target department of CEA / Valduc operates different fields of mechanical machining techniques and develops methods able to be consistent with the target requirements in terms of quality, delay and cost.
Combining these aims involve taking up several challenges. For one side, laser experiments need a wide range of target geometries with common points: reduced dimensions (millimetric range) and wall thickness (micrometric range), as well as very strict dimensional and geometric specifications. According to these requirements, target specifications demand to machine different kinds of material from metal (aluminum, copper, gold) to polymer and low density foam. For the other side, complexity of targets is in constant growth to answer to the experiments requirements on OMEGA (USA) since most than a decade, and on the Laser MégaJoule (LMJ, France) at present.
In this context, versatility of the machining process is the key word. This presentation is focused on the mechanical machining (diamond turning and milling, µ-EDM) aspect and the way of coupling it with mechanical design optimization to use the full potential of these technics.

Keywords : Laser target, Diamond cutting

1. Introduction

The target department of CEA / Valduc produce laser target needed for laser plasma experiments and used in different experimental facilities over the world : in the past for the "Ligne d'Intégration Laser" (LIL, France) and OMEGA (USA) and now, for the Laser MegaJoule (LMJ, France). Laser experiments need a wide range of target geometries with common points: reduced dimensions (millimetric range) and thin wall thicknesses (micrometric range), as well as very strict dimensional and geometric specifications. According to these requirements, target specifications demand to machine different kinds of materials from metals (aluminum, copper, gold) to polymers and low density foams.

Most of the time, a single target requires advanced material synthesis (low density foam, aerogel), complex shape machining and high accuracy in assembling and metrology process. In the same time, the rise of experimental configurations and the adaption for varied experimental facilities need a production process able to a quick and accurate response over a wide range of geometries and target scale. To match these aims, three main fields are investigated for machining operations: adaptations of machine tools, development of original process and parametric optimizations. These three items are presented and illustrated.

2. Machine tool adaptation

Several technologies are developed in order to meet different shapes on wide range of materials with the high required accuracy. As related [1] [3], [4]; the micro target application requires specific adaptation of these technics (customized machining setting, parameters) as well as combining them to obtain a final part, from the rough machining step to the finished part. Since a decade, ultraprecision technology has become the heart of the machining process due to the very low tolerance (< 3 µm) and roughness (Ra < 10 nm) which can be obtained as well as the machining capability of low density material. Several developments have been done to adapt the machine setting to micro-machining and target application.

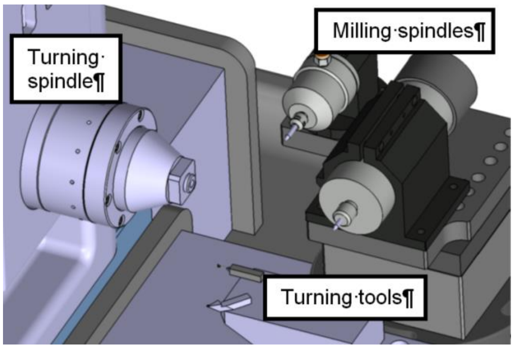

Figure 1. Example of combined turning/milling setting on 4 axis Moore Nanotech® 350FG.

Figure 1 shows a combined turning/milling setting developed on 4 axis Moore Nanotech® 350FG. In this example, 2 radial milling spindles (60 000 RPM and 160 000 RPM) and 2 turning tools (for outer and bore machining) are disposed on the lathe. This kind of configuration offers several advantages. For one side, for complex parts, the number of process steps (turning and milling) can be reduced. Consequently, geometrical and dimensional variations between milled and turned surfaces can be optimized (and, hopefully, reduced) as well as the global process time can be reduced. For other side, this setting allows new machining optimization possibilities. Programming complex combined turning / milling operations using 4 axis motion (X, Y, Z, C), without dedicated software, is an issue. A specific post-processor have been developed and, now, permits to use C.A.M. software for most applications.

3. Developments of original processes

In addition to the machine tool adaptations, specific process is developed to realize millimetric parts with micrometric (≈ 30 µm) wall thickness. The process is illustrated in Figure 2 and consists in realizing the part from a mandrel (with the inner shape of the part). Then, the mandrel is gold plated and machined again to the final outer shape of the part. Finally, the brass mandrel is removed by selective dissolution in the acid bath.

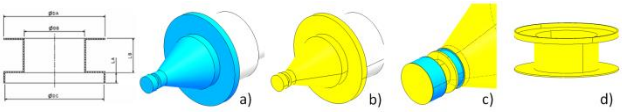

Figure 2. Machining of a gold "thin wall" part, a) Turning of brass mandrel, b) Gold plating, c) gold machining, d) selective dissolution of brass mandrel.

From this process, several adaptations have been developed to meet target design requirements and to obtain polymer, gold/polymer and gold/aluminum part.

For each kind of parts, the main problematic is the chemical compatibility between mandrel material, part material(s) and the type of selective dissolution used to remove the mandrel.

3. Low density foam machining optimization

Aerogel (SiO_2 or Ta_2O_5) fabrication matter has to be considered for target application ([1], [2], [5]). This kind of material is brittle and sensitive to surface propagation of cracks introduced by machining stress. The main issue is the surface finish optimization to limit cracks and reduce the roughness.

As shows Figure 3 – a, inappropriate machining parameters induce cracks issue. Several parametric tests were done, with ultraprecision lathe, by diamond turning mean (Figure 3 – b) and milling mean (Figure 3 – c). The main aim is to determine the optimal parameters for rough and half-finishing by turning method and for surface finishing by milling method.

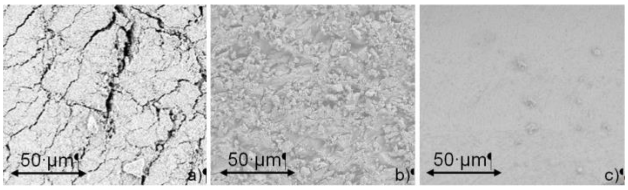

Figure 3. Comparison of surface finish (SEM), a) diamond turning – rough machining, b) diamond turning – finishing, c) milling.

In terms of surface finish (Table 1.), the arithmetic roughness is significantly improved from more than 2 µm (rough diamond turning) down to 100 – 500 nm range (milling).

Table 1. Comparison of roughness (arithmetic roughness), a) diamond turning – rough machining, b) diamond turning – finishing, c) milling.

Process	Arithmetic roughness
Diamond turning rough machining	> 2 µm
Diamond turning finishing	700 – 1000 nm
Milling	100 – 500 nm

4. Conclusion

In a context of constant growth of target complexity, these examples highlight the development problematic to meet physical requirement as well as to improve fabrication efficiency. Firstly, machine tool adaptations are required to cross limitations in terms of dimensional and geometrical accuracy and to be compatible with low dimensions of target parts. As well, the development of new process synoptic (mixing machining, assembling, chemistry process) is needed to open new possibilities in terms of geometries. Finally, most of the time, parametric optimization dedicated to a specific application (shape, material) is necessary to match dimensional, geometric or roughness specifications.

In any case, creativity and originality are the key to adapt standard process and machine tool to answer to specific requirement needed to build a laser target. As well, operator skill and knowledge of the target problematic are essential: handling and machining exotic material efficiently is an issue and require background in this field.

Metrology methods have also to be improved. The increase of process complexity needs accurate absolute measurement from common reference of the part to guarantee repositioning along the manufacturing process. For that, specific methods as well as in-situ measurement are under development. Foam and aerogel characterizations need to take up other challenges: transparent or diffusive surface combined with poor mechanical characteristics require to develop optical mean measurement able to detect the surface.

In addition to traditional technologies, others technics are explored (3D printing and MEMS technologies) for future integration in the manufacturing process. With some developments and adaptations, these technics could cross technologic limitations and open to new shape possibilities and material manufacturing.

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