The application of ultra-precision CNC machining to enable high-volume direct manufacture of complex geometry x-ray backlighters

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Figure 1. The MMT Development Facility CNC area.

Introduction

The millimetre wave Precision Development Facility (PDF) within the Space Science Department at RAL develops novel techniques for the manufacture of high precision micro components for departments within the laboratory, spinout companies and industry. For many years PDF has been working in increasingly close collaboration with the Target Fabrication Group of the Central Laser Facility to manufacture microtargets and micro-components for use in high power laser experiments. This collaboration has enabled a wide range of high specification, typically 3D, microtargets to be designed, developed and manufactured for a number of high profile experiments. This report describes one specific programme; the development and manufacture of x-ray backlighters for use in shocked crystal experiments.

In the first experiment of a series [1] on x-ray diffraction from shocked matter the backlighters were made of several micro-components which required complex microassembly. Consequently the number of backlighters which could be produced in the time available was a limiting factor on the number of experimental shots. By totally redesigning the backlighter for subsequent experiments it was possible to propose a design offering the same functionality but which could be mostly produced in a single CNC machining process. Purchase of a 3-axis KERN Micro mill and a 5-axis head enabled backlighters of the new design to be produced in large numbers (a few hundred at a time). Research underpinning realisation of the necessary manufacturing processes required development of novel machining techniques to enable larger production quantities while still maintaining very high accuracy.

Original backlighter design

The original backlighter assembly (fig 2) consisted of a number of micro-components which were individually (semi-manually) manufactured and then assembled by Target Fabrication staff. All stages of the production process were time consuming. A particular challenge was to glue the gold blocker foil in the correct position relative to the backlighter body, especially controlling the relative angle, to ensure effective blocking of line-of-sight laser-produced x-rays to the film packs. To facilitate sufficiently accurate assembly a 5-axis jig was designed and manufactured within PDF (fig 3). It incorporated micrometer drives to position each component prior to gluing. With the backlighter components held in place assembly was completed by gently driving the glass supporting stalk into position which had been primed with a very small amount of adhesive on the tip (fig 4). The adhesive wicked between the components and stalk tip which held the entire ensemble together when cured.

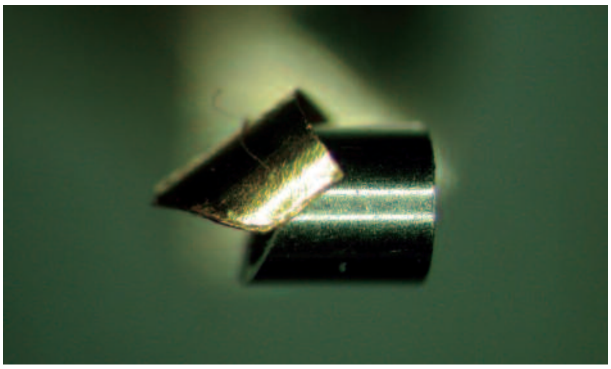


Figure 2. Original design backlighter.

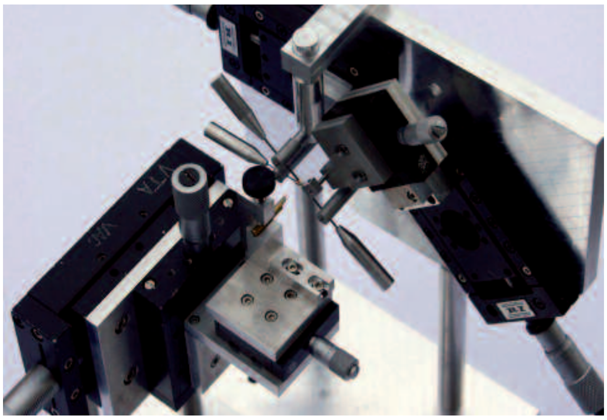


Figure 3. The 5-axis jig used to assemble backlighters.

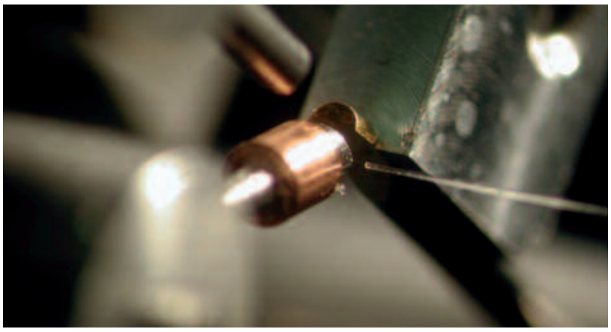


Figure 4. Attaching glue-tipped glass stalk to facilitate final assembly.

Although successful the procedure was time-consuming and manually challenging (but the yield was high). However, only a limited number of targets could be produced in the available time.

Design Innovation to Enable High Number Production

After the first experiment it became evident that in order to fully support future experiments in the series an alternative backlighter production method would be required to enable the production of far larger numbers. After an iterative consultation process between the experimental, PDF and Target Fabrication groups a new design was produced for the backlighter (fig 5). This radically reduced the amount of micro-component production and microassembly compared to the earlier design. Although different in appearance the new design had identical functional characteristics to the original, particularly with regard to film pack shielding. Specifically, the modified design enabled the backlighter body to be produced from a single piece without demounting using the PDF's KERN Computer Numerical Control (CNC) machine using minimal tooling.

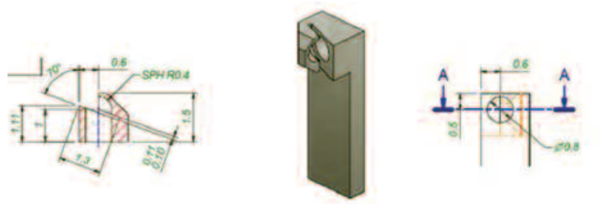


Figure 5. New design of backlighter body.

The KERN Micro milling machine (figure 8) was the ideal choice for the production of these targets. This machine is designed specifically for the production of micron-accurate components by being capable of running at 40,000 rpm with a spindle cooling system to reduce thermal expansion at high speed. It has an automatic tool changer with a 20 tool capacity eliminating the need for human interaction during the machining cycle.

All the tools within the machine are set using a laser tool setting system (fig 6) which uses a 30µm diameter beam and permits non-contact measuring of tools down to 0.1 mm in diameter setting length, radius and concentric accuracy relative to the datum position, even at the highest speeds. The measured data is then automatically transferred to the control unit and the cutter compensation is automatically updated to take into account any cutter run out which minimises errors due to the tool set up. The machine needs to remain stable and free from vibration when running at high speed and high feed rates in order to maintain the accuracy and surface finish of the components. To achieve this the KERN Micro has a polymer concrete base to ensure stability during the most extreme machining cycles and this is a major consideration when machining high accuracy components. Other features of the machine include an oil mist lubrication system to clear particles of swarf from the component which keeps the cutting surface clear and thereby maximises the life of the tooling and enables the manufacture of miniature components to the highest standards.

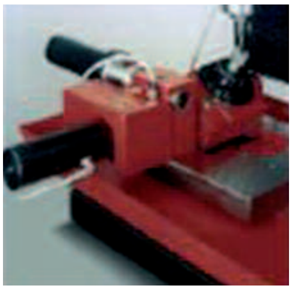


Figure 6. The two-axis table.

Figure 7. The laser tool setter.

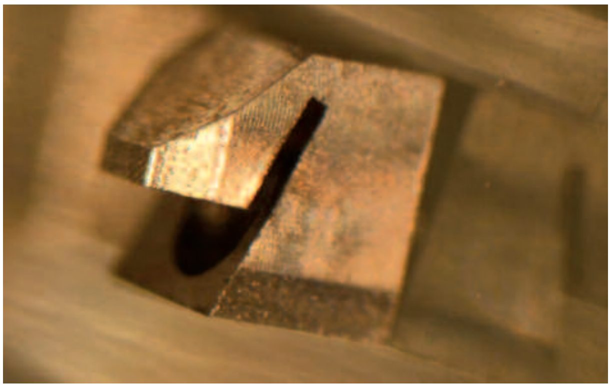
Figure 8. KERN Micro CNC milling machine.

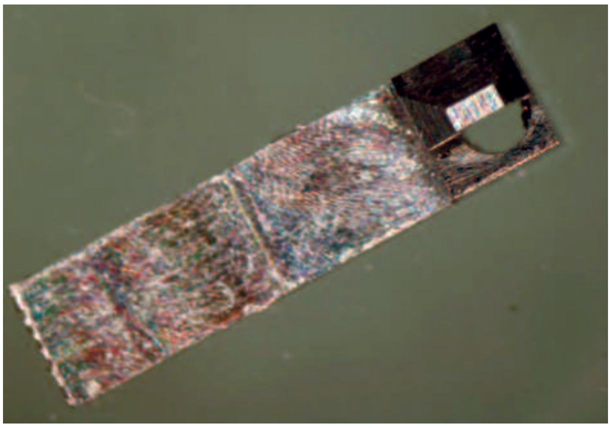
The KERN Micro in PDF has an additional two-axis table (fig 6) enabling full five axis machining. The extra two axes are a major advance in machining technology, especially for miniature components which cannot be handled easily for secondary operations. It gives the ability to machine components without the need to remove and reset using jigs and fixtures thereby increasing component accuracy and decreasing the possibility of errors during the production process.

The machine is programmed using iTNC 530 control. This system has the latest look-ahead technology allowing the control to simultaneously follow the program whilst reading machining steps that are ahead. For example, if a sharp directional change or stop is imminent the control will automatically override the programmed feed rate to slow down on the approach and accelerate on the exit of the feature and consequently avoid dwell marks on the component. Look ahead also has the advantage of increasing tool life. The tool table is set within the control system informing the machine which tools are in the carousel and their positions thereby ensuring the right tools are called at the tool change cycle. The position for the laser to measure the tool is also set in the control system and is critical when using form cutters, specifically for the backlighters a 0.1 mm wide slitting saw.

The backlighter bodies were made from pure silver supplied in 5 mm diameter rod cut into 100 mm lengths. Silver is a material requiring tooling with a very sharp edge in order to eliminate burring (which cannot be tolerated on miniature components). For this reason solid carbide tooling was used as it maintains its cutting edge longer than conventional tools. Carbide tooling together with constant tool monitoring allows more components to be produced before tool replacement is required.

Careful attention needed to be paid during machining to avoid vibration of the workpiece which would have caused poor surface finish and component inaccuracy. The presence of vibration was largely ameliorated by designing the production process steps to ensure that the workpiece had maximum support during the machining cycle. Initially, a square-ended flat was machined across the top end and then the bore created using a 0.8 mm diameter ball-nosed milling cutter. Making the bore at this point in the process stream ensured there was maximum support and consequently avoiding material deflection and burring. Next the outside profile was machined and then a long-axis slot was cut using a 0.1 mm wide, 15 mm diameter slitting saw (held in a specially designed holder to ensure rigidity). The component was then rotated and a second slot cut forming the 70° angled (foil mounting) slot (see fig 5). When this was complete the remaining surplus material was removed. Finally the component was rotated vertically and machined off to length, again using the 0.1 mm slitting saw. After demounting another piece of stock material was inserted and the next backlighter started.





Figures 9 and 10. The final micromachined backlighter body (1.5mm wide).

Conclusions

Due to the modified backlighter design new manufacturing methods have been developed which enable the production of complete backlighter bodies in 30 minutes without the need for assembly operations. It is a simple and quick (although non-trivial) process to insert the backlighter foil on its holder to complete the backlighter. The large reduction in production time has enabled far greater numbers of backlighters to be manufactured for shocked crystal experiments and, consequently, increased the amount of scientific data produced.

With the introduction of high repetition rate high power lasers over the next few years, for example the Astra-Gemini laser in CLF, high volume production of microtargets is probably going to be an enabling technology for the maximisation of scientific output from such facilities. Generic lessons learned during the development programme for the redesigned backlighters could well have significant applicability for high volume microtarget production.

References

1. J. Hawreliak *et al.*, CLF Annual Report 2003/2004 pp49-50.