The design and development of a novel 'Twin Turret' machining platform

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1. Introduction

Cranfield Precision has developed a novel concept for high precision machining. Recent ideas such as the Hexapod and the Tetraform [1] have demonstrated significant process benefits. The concept described here leverages the extrordinary capabilities intrinsc to modern control systems in order to coordinate two rotary axes and a linear axis in a novel 'Twin Turret' (TT) design.

1.1. Machine design concept

Cranfield Precision was challenged to find a radical machine configuration which would act as a common platform for multiple applications and could deliver a highly stiff, thermally stable foundation for a wide range of machine systems. Initial designs were targeted the optics industry for grinding spheric, aspheric and free-form surfaces on a wide variety of components. Cranfield Precision's experience in the optic industry over many years shows that ductile regime grinding [2] delivers considerable process advantages over conventional glass grinding. This mode of operation is difficult to support unless the machine system is of the highest quality.

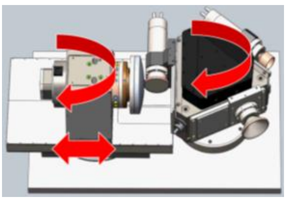

Figure 1: Machine axes concept.

The machine uses a unique combination of rotary and linear axes to produce relative motion (both position and angle) between tool and workpiece over a swept working area. Critically, the two rotary axes are rigidly mounted a fixed centre distance apart from each other. In order to traverse the tool across components of 400mm diameter, the rotary axes need only to rotate by around 20° each. It is possible to align the 'best' segment of the rotary encoders to the critical 20° of motion. It has thus been demonstrated that by using rotary encoders specified with 1 arc sec accuracy over 360° it is possible to reduce the effective error over the 20° working range to 0.1 – 0.2 arc sec, resulting in an uncorrected traverse position error between tool and component of around 0.6µm. The linear axis is used to control the depth of cut and profile shape of the component being machined. It is a simple procedure during machine build to error correct the linear infeed axis such that the correct profile is followed. It is only necessary to carry out the error correction in one location between the two rotary axes (see fig 2). This is because the centre distance between the turrets is fixed. The correction data is thus valid for any position of the linear axis. Fig 2 shows how a Zerodur straight edge can be used to error correct the interpolated straight line motion between tool (here the probe) and component (here the straight edge). The intrinsic error before correction was in this case 50µm (largely a product of the error between the nominal and the actual turret centre distance). After error correction, the straight line motion error was reduced to 0.3µm.

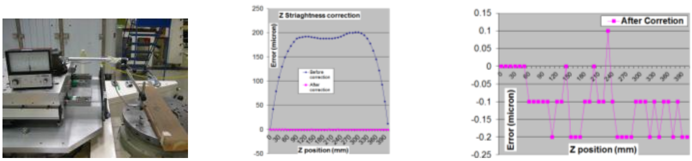

Figure 2: Linear axis error correction procedure and results

The time taken to grind optical quality surfaces rises exponentially as the specifications for form error, surface finish and sub-surface damage become more challenging. The traditional machine design suffers from a constantly changing coolant return path as the grinding wheel carriage moves along the linear axis, resulting in constantly varying machine distortions. The twin turret design enables a very simple non-contacting and frictionless labyrinth seal, making the machine base almost immune to such distortions.

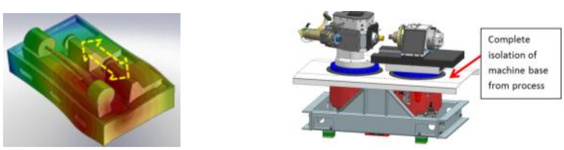

Figure 3: Conventional machine thermal distortion and TT machine base isolation

In the optics industry, a common requirement is to achieve ‘tool normal’ operation of the grinding wheel. Achieving tool normal operation is conventionally achieved by mounting the grinding spindle upon a rotary axis that in turn is mounted upon one or more stacked linear axes. Each interface reduces the stiffness of the machine. The new machine base is effectively two highly stiff (>10 000 N/µm radial and axial) rotary hydrostatic bearings. Conventional machines use linear axes to provide the primary motion between tool and component, the machine base thus has to resist machining forces in bending. The TT machine’s turrets are bolted together via a solid base plate resisting the machining forces in tension, inherently far stiffer.

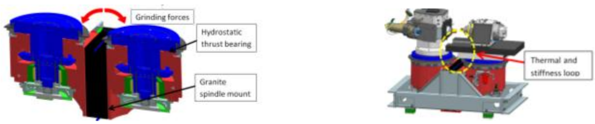

Fig 4: Rotary turret cross section (left). Thermal/stiffness loop of TT design (right)

Using rotary axes as the primary machine axes enables complex geometrical traverse grinding as well as tool normal grinding without the need for an additional rotary axis. Multiple tools can be mounted upon a common and highly rigid turret. The turret shafts are precision ground and the very large diameter (440mm) bearing provides excellent averaging producing radial and axial spindle error motions of around 100nm

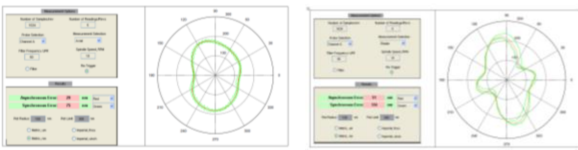

Fig 5: Axial turret error motion (left). Radial turret error motion (right)

It is these rotary axes that provide the primary motion control for the machine, replacing conventional linear axes. They are very highly stiff, axisymmetrically.

Peripheral wheels are mounted with the grinding wheel aligned to the turret axis, thus wheel imbalance and process forces are directly resisted by the bearing stiffness, not the axis servo. For cup wheel grinding the grinding wheel to component interface is maintained at tool normal, thus any imbalance force induced axis oscillation produces only a 2nd order motion between wheel and component.

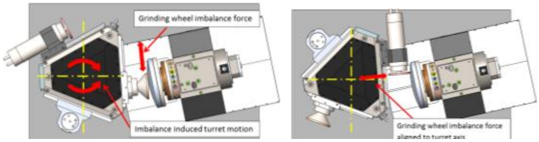

Figure 6: Wheel imbalance forces for peripheral (left). Cup wheel grinding (right).

The grinding results presented here are for the optical components using both cup and peripheral wheel grinding.

2.1 Plunge ground spherical surfaces

Spherical plunge grinding of concave and convex spheres using 14µ diamond in a resin bond wheels.

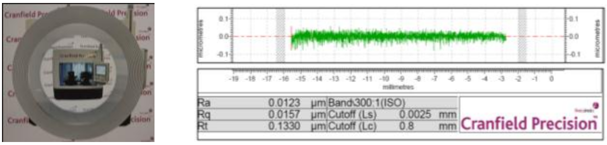

Figure 7: View through a plunge ground BK7 lens and Measured texture, <13nm Ra.

2.2 Traverse ground aspheric surface

This result is for uncorrected ‘tool normal’ grinding of a silicon aspheric surface. The traverse grind time using a metal bond wheel, Ø60mm, 6µm grit was 30 minutes. The form error of the ground surface is 0.6µm P-V. The machine can use measurement data to produce corrective grind passes, however this plot shows the 1st pass, uncorrected and is thus effectively a measurement of the intrinsic machine accuracy, including thermal stability over 30 minutes.

Type	Concave
Radius of curvature (mm)	261.250
Conic constant	-27.060916
A4	3.76263×10^{-8}
A6	-5.47353×10^{-11}
A8	2.97755×10^{-15}
A10	$-4.51446e \times 10^{-19}$

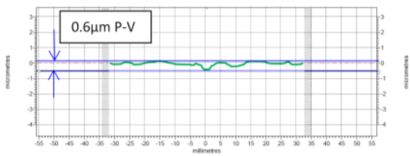

Figure 8: Ground asphere specification (left). Ground asphere form error (right).

3. Conclusions

A novel machining platform has designed and developed compatible with a wide range of machining processes. Grinding results demonstrate that the design objectives of ultra-high stiffness and thermal stability have been achieved.

References:

[1] Novel Machine Tool Concepts: Structures and Bearings. Corbett J; Stephenson D J. *International Seminar on Precision Engineering and Micro Technology. euspen 2000 p13*
[2] Ultraprecision, high stiffness CNC grinding machines for ductile mode grinding of brittle materials. Patrick A. McKeown; Keith Carlisle; Paul Shore; R. F. Read. Proc. *SPIE 1320, Infrared Technology and Applications, 301 (October 1, 1990).*