Thermal control of the µ4 machine
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µ4 market
• Markets – mass production in:
  – watch components
  – inkjet printing components
  – IR and integrated optics
  – moulds
    • medical & microfluidic devices
    • optical components

Ref: Akribos, Rochester Precision Optics, Fanuc, Sarix

µ4 design target
• Operation
  – 4 axes diamond turning
  – 5 axes diamond milling
  – Fully automated & integrated:
    • Metrology
    • Tool loading
    • Workpiece loading
• Machine size and supply
  – 0.6m x 0.6m x 1.0m, portable
  – Fully integrated control electronics
  – single-phase supply “plug-and-play”
  – chilled water and compressed air

Precision milling and diamond machining centres

Kern Evo, Germany, 2000s
Moore Nanotech 500FG, USA, 2000s

µ4 design target
• Capability
  – 150mm Ø, 50mm thick component
  – 3000rpm turning
  – 300,000rpm milling
  – 150 Hz positioning dynamic ability
  – 30 tool cassette, < 2sec tool change

• Machined quality
  – Roughness 1nm Sa
  – Form 100nm rms
  – Feature tolerance < 1µm
  (Dimensional tool point stability demand < 1 um/30mins)
μ4 Concept

Axes - Strokes - Capacity

Strokes:
X = 190 mm
Y = 190 mm
Z = 100 mm
A = 180 deg
B = 180 deg

'C' = 0-3,000 rpm
'S' = 0-330,000 rpm

Max work capacity
150 x 150 x 50 mm

A = 180 deg
B = 180 deg

Modules

C axis

A axis

S1 spindle

Tool changer

Y axis

X axis

Z axis

330,000+ rpm air bearing spindle for micro-machining

330,000 rpm shaft speed - higher productivity and better surface finish on components (<10 nm)

Lightweight ceramic shaft - allows faster movement of machine tool axis for higher productivity and reduced axial tool position due to minimal shaft thermal growth

High efficiency permanent magnet DC motor - faster acceleration for improved productivity and reduced thermal impact on machine tool accuracy

New low voltage motor - valuable reduction in amplifier size and dissipation for inclusion in base

Rotary air bearings

A/C and B/S1 axes assemblies of same design

150 Hz bandwidth target

Automation

Tool change mechanism

• Tool spindle collet or holder (not shown) sits above tool change mechanism
Ease of access to workpiece from above

Machine designed from the outset for automatic loading and automatic metrology

In-situ Metrology system

Automatic loading and automatic metrology

Initial testing – diamond turning results

Tests in brass

Roughness:
3nm Ra
(~ 6 nm Sa)

Initial testing diamond milling results

Control system in base stand
- 6 axes CNC
- 7 drive amplifiers
- + 1 for tool indexing
- PLC
- Power supplies
- Optical tool setting
- Pneumatics
- Mass compensators

Control Integration

Athermalisation

2 plane symmetry of structure and motion system
### Heat Loss Analysis

**Upper Operational Region of Machine**

- **Peak Heat**: ~500W

**Lower Control-Services Region of Machine**

- **Peak Heat**: ~580W

### Athermalisation

**Temperature Control of the Machine**

1. Water cooled heat shield
2. Direct water cooling of amplifiers
3. Air purge convection cooling

### Ultra Precision Temperature Controllers

**Thermal Control**

Loxham Precision's Ultra Precision Temperature Controllers are based on the most advanced thermal management technologies offering:

- Sub milli-Kelvin resolution control
- Multiple channels
- Matched performance temperature sensors
- High performance cooling technology
- Advanced fluid heater technology
- Remote heater and sensor positioning
- Advanced control functions

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**µ4**

- Machined Quality
  - Roughness 1nm Sa
  - Turned form 100nm RMS
  - Milled feature tolerance < 1µm
μ4

- 6 axes ultra precision machine
  - Fully integrated
  - Single phase
  - 2kW power supply needed
  - 1kW heat loss
  - Domestic appliance size