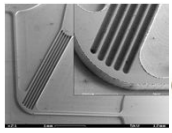
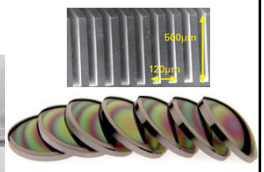
Thermal control of the µ4 machine

Paul Morantz, Paul Shore

µ4 market

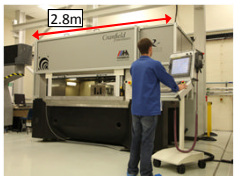
- Markets – mass production in:
  - watch components
  - inkjet printing components
  - IR and integrated optics
  - moulds
    - medical & microfluidic devices
    - optical components

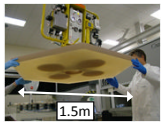




Refs: Akribos, Rochester Precision Optics, Fanuc, Sarix

Machine : component (size ratio)





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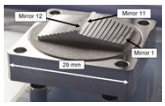
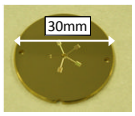




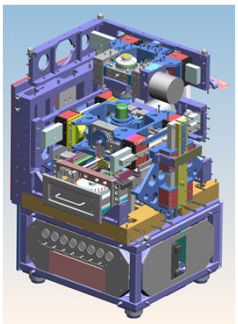
Precision milling and diamond machining centres

Kern Evo, Germany, 2000s

Moore Nanotech 500FG, USA, 2000s

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

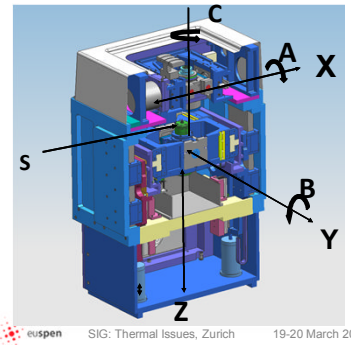


µ4 design target

- 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



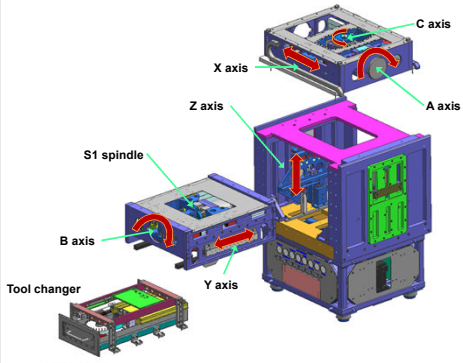
Axes - Strokes - Capacity

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

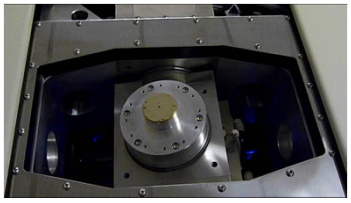
Modules

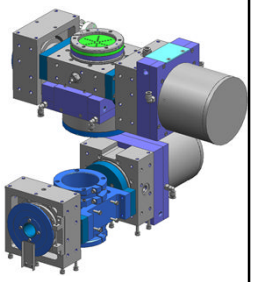


Rotary air bearings

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

150 Hz bandwidth target



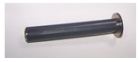


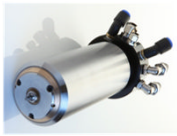
330,000+ rpm air bearing spindle for micro-machining

WESTWIND®

350,000 rpm shaft speed - higher productivity and better surface finish on components (<10 nm)

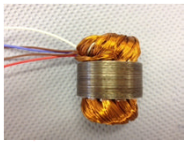
Lightweight ceramic shaft - allows faster movement of machine tool axes for higher productivity, and fixed axial tool position due to minimal shaft thermal growth

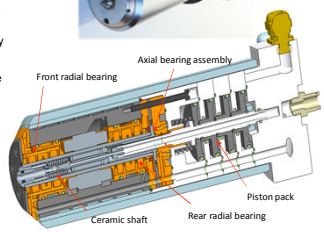




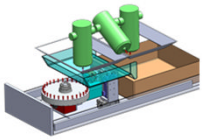
High efficiency permanent magnet DC motor - faster acceleration for improved productivity and reduced thermal impact on machine tool accuracy

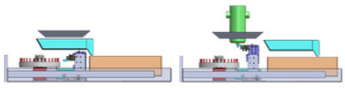
New low voltage motor – valuable reduction in amplifier size and dissipation for inclusion in base

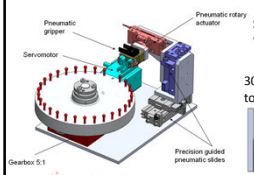


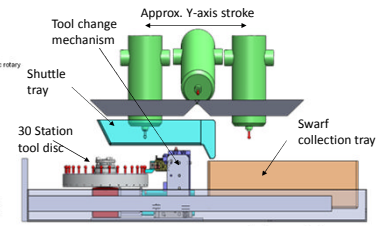


Automation



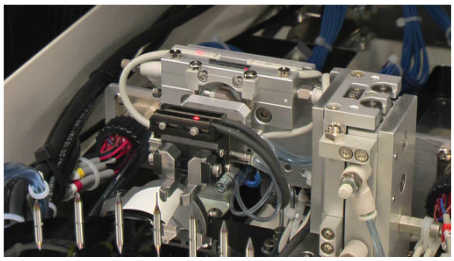






Tool change mechanism

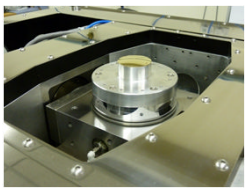
- Tool spindle collet or holder (not shown) sits above tool change mechanism



Ease of access to workpiece from above

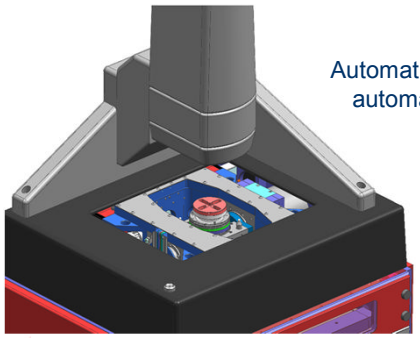
LOXHAM PRECISION

Machine designed from the outset for automatic loading and automatic metrology



In-situ Metrology system

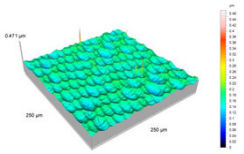
LOXHAM PRECISION



Automatic loading and automatic metrology

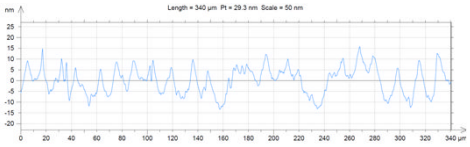
Initial testing – diamond turning results

LOXHAM PRECISION



Tests in brass

Roughness:
3nm Ra
(~ 6 nm Sa)



Initial testing diamond milling results

LOXHAM PRECISION

Parameters calculated on the profile SWATCH MILLED STAR -00002
Extracted profile

* Parameters calculated on the full length of the profile.
* A microroughness filtering is used, with a ratio of 2.5 µm.

Roughness Parameters, Gaussian filter, 80 µm

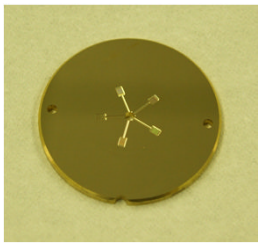
Rms = 19.3 nm
Rms: Root-Mean-Square (RMS) Deviation of the roughness profile.
Rt = 129 nm
Rt: Total Height of roughness profile.

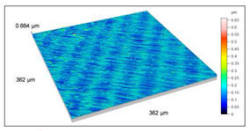
Roughness Parameters, Gaussian filter, 25 µm

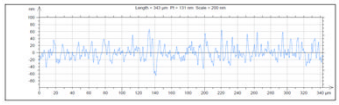
Ra = 13.7 nm
Ra: Arithmetic Mean Deviation of the roughness profile.

Roughness Parameters, Gaussian filter, 102 µm

Rz = 130 nm
Rz: Maximum Height of roughness profile.





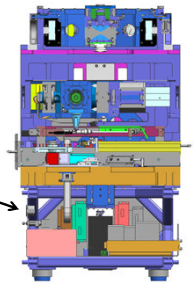


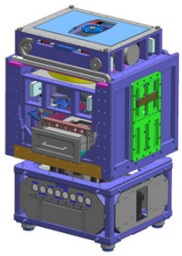
Control Integration

LOXHAM PRECISION

Control system in base stand

6 axes CNC
7 drive amplifiers
+ 1 for tool indexing
PLC
Power supplies
Optical tool setting
Pneumatics
Mass compensators

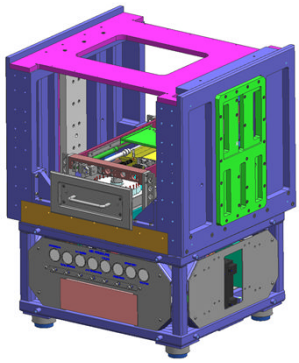




Athermalisation

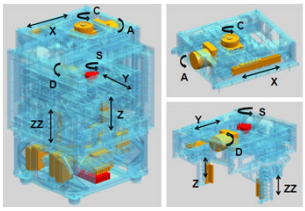
LOXHAM PRECISION

2 plane symmetry of structure and motion system



Heat loss analysis

upper operational region of machine

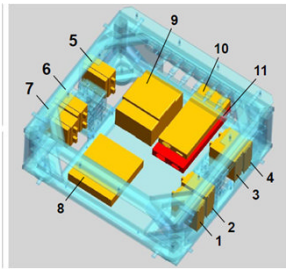


Symbol	Function	Cooling type	Heat loss [W]
X	Linear motor	Forced air-cooled	40
Y	Linear motor	Forced air-cooled	40
Z	Linear motor	Forced air-cooled	40
ZZ	Linear motor	Forced air-cooled	40
A	Rotary motor	Liquid-cooled	36
C	Rotary motor	Liquid-cooled	18
D	Rotary motor	Liquid-cooled	36
S	Spindle	Liquid-cooled	300

Peak heat ~500W

Heat loss analysis

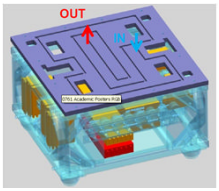
lower control-services region of machine



Symbol	Function	Cooling type	Heat loss [W]
1	X-axis amplifier	Liquid-cooled	44
2	Y-axis amplifier	Liquid-cooled	44
3	Z-axis amplifier	Liquid-cooled	44
4	ZZ-axis amplifier	Liquid-cooled	44
5	A-axis amplifier	Liquid-cooled	40
6	C-axis amplifier	Liquid-cooled	22
7	D-axis amplifier	Liquid-cooled	40
8	Control system CNC	Forced air-cooled	20
9	Optical tool setting	Natural air-cooled	10
10	Power supply A	Forced air-cooled	225
11	Power supply B	Forced air-cooled	66

Peak heat ~580W

Athermalisation

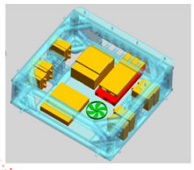


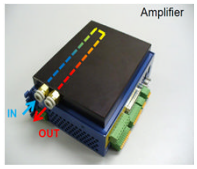
Temperature control of the machine

1) Water cooled heat shield

2) Direct water cooling of amplifiers

3) Air purge convection cooling



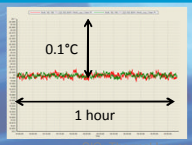


Ultra Precision Temperature Controllers

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 response cooling technology
- Advanced fluid heater technology
- Remote heater and sensor positioning
- Advanced control functions



Ultra Precision Temperature Controllers

UPTC

Modular multi-channel configurable approach
Specific miniaturised electronic and fluid control hardware development
Sub milli-Kelvin operating resolution
Specially encapsulated ultra-stable sensors
Remote (wireless) sensor capability
Numerous control options:
Cascade, gain scheduling, adaptive control, alarms etc.

Controllable:
Pumping power
Cooling power
Heating power

µ4

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

μ4

LOXHAM PRECISION

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