Big effort for micro payback

Andrew Joslin of motion control specialist Delta Tau and Professor Kai Cheng of Brunel University detail progress in the Europe-funded MASMICRO nanoscale machining project

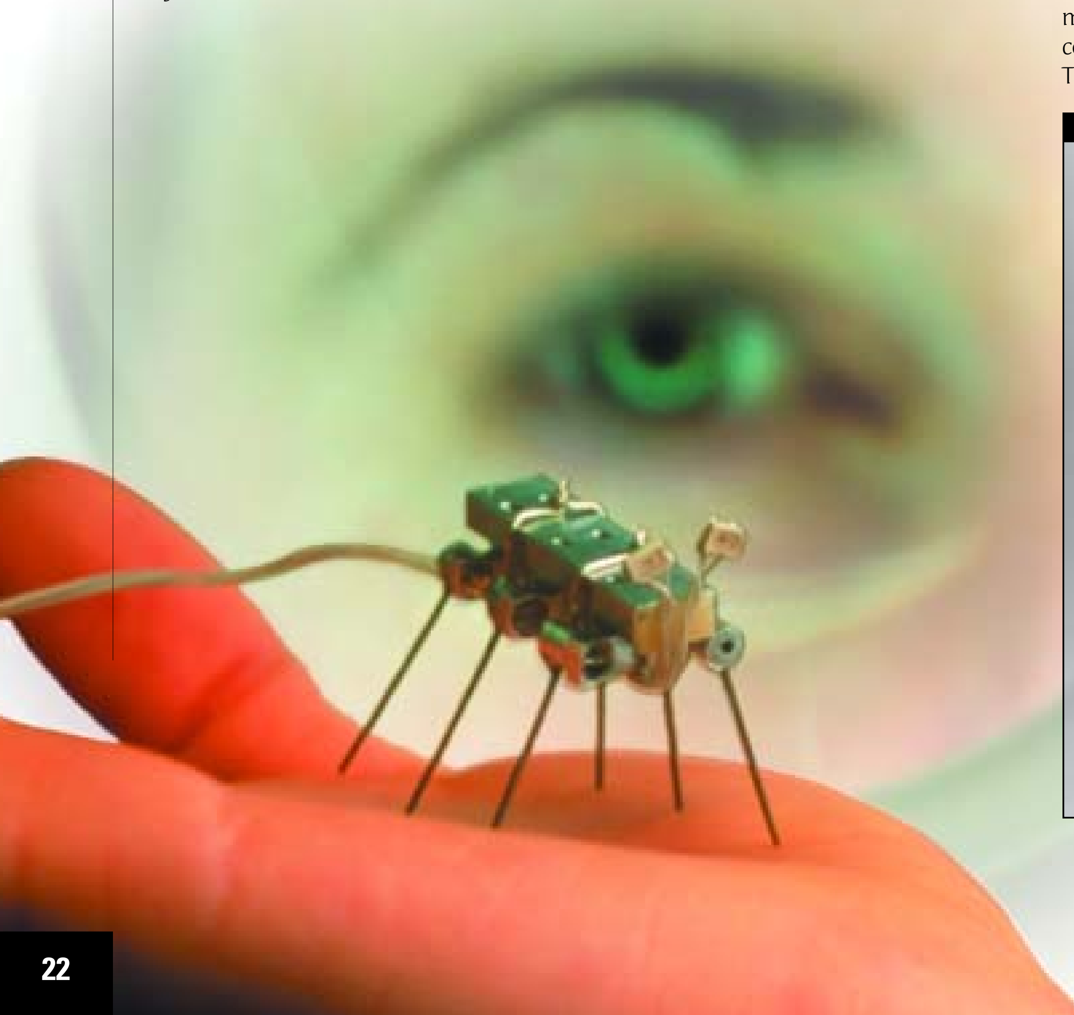
The MASMICRO Project aims to develop a machine tool capable of attaining 50 nm accuracy with staggering 5 nm repeatability. In addition, it aims to make that machine perhaps one-tenth the size of anything before, at one-tenth of the price! It must also remain suitable for mass production of micro-components within small and medium enterprises (SMEs) in the manufacturing sector.

The four-year project, which involves 36 partnering organisations from 13 countries, began in July 2004, with eight of the participants drawn from the UK; the highest number from any single country (see box item, page 24). Brunel University is focusing on developing multi-axis machine tools able to produce complex 3D geometries to nanoscale tolerances.

Two types of machines are being developed – a 5-axis machine (essentially like a conventional machining centre); and a 3-axis test bench (in principle, a turning centre). Development is driven by the increasing miniaturisation of systems and also by the new features, functions and benefits that micro-surfaces can deliver. These include anything from sophisticated lubrication designs in which oil can be retained and directed to the surfaces needing it using highly accurate micro-grooves, to the manufacture of miniature filters for portable blood testing apparatus in which the micropores are laser machined to incredible accuracies.

Recently, new demands in the fabrication of miniature/micro-products have appeared, such as the manufacture of microstructures and components with 3D complex shapes or free-form surfaces. These microstructures possess some special properties including light guiding, anti-reflecting and self-cleaning, among others, and are useful in microlenses, micromoulds, laser targets and so forth.

Take, for example, the matrix of tiny prismatic lenses that reflect light within a mobile telephone's screen; while this functionality exists before finishing the part at a nanoscale, the efficiency is increased by nanomachining which in turn reduces the number of LEDs required to light the screen and so lowers power consumption accordingly.



MULTI-FUNCTIONALITY

Fabrication of real 3D miniaturised structures and free-form surfaces are also driven by the integration of multiple functions in one product, for example adding light guides to existing mechanical components or aiding lubrication methods by using micromachined surface geometries. As one example, the smoothness of lenses in a camera or telescope increases the accuracy, effectiveness and quality of the resultant image. Glass lenses are traditionally produced by a tedious manual process of machining (lapping), grinding and polishing. In ultra-precision machining, using a single-point diamond cutting tool, a surface roughness of less than 10 nm can be achieved. This is especially important today in producing optical microstructures such as DVD and camera lenses, lenses for photonics and optical fibre for telecommunications. Many of these lenses can now be moulded from plastics materials as a result of the ultra-smooth finish that can be achieved within the mould tools.

Currently, design advances in Micro Electro Mechanical Systems (MEMS) devices, together with their increasing acceptance by industry, is one of the major driving forces for making micro-components. Silicon is the traditional material for making MEMS or microsystems, but many other materials, including a range of polymers and even some metals, have emerged for the increasing number of applications that are becoming relevant for micro-products. While early MEMS relied primarily on laser micromachining, the silicon surfaces (largely a 2.5D application –interpolated geometry in the horizontal plane, but with a fixed depth of cut), more recently complex 3D geometries have been

MASMICRO aims to deliver machine tool designs suited to small parts production

NC axis stiffness explained

For nano-level machining, mechanical stiffness is of overriding importance so not only must a control system react to NC commands but also respond to external influences, both in very short time. To deliver a stiff (responsive) NC axis, the speed at which current can be injected into a motor in order to provide torque or force is critical. Torque figures in excess of 30 N/micron are not untypical for directly driven systems using linear motors.

In an NC system there are three feedback control loops which must be closed before action can be taken: position (axis), velocity (motor speed), and current (motor torque). An error in position calls for more or less speed, and an error in speed calls for more or less torque (current).

Delta Tau has for a long time maintained that the best control philosophy is to incorporate as many of the control loops in one processor as is practically possible. This approach has seen the company migrate the velocity loop into the position control with the current loop similarly integrated.

The net effect of this, together with the introduction of some very high resolution laser interferometers and interpolation, is to produce positioning control systems that are potentially capable of resolving to just a few picometres (10^{-12}); to achieve any level of positional accuracy, it is necessary to resolve at least an order of magnitude lower.

The speed with which information about any loop is transmitted is clearly relevant, too. Delta Tau has eliminated one of the biggest sources of delay in processing feedback data – digital to analogue (DAC) and analogue to digital (ADC) conversions at the amplifier/position control interface. This is achieved by employing direct pulse width modulation (PWM) in the servo-amplifier. By doing this, and deploying high-accuracy, stable-current sensing devices to control the current loop, Delta Tau has attained exceptionally high loop gains that increase stiffness or the speed with which the system reacts to feedback signal errors.

Another important factor in positional error control is how often the position loop is closed and errors recalculated. Delta Tau can achieve loop closure frequencies measured in just a few micro-seconds.These are all features of the company's Geo PMAC PWM amplifier incorporated into the MASMICRO 3-axis turning machine design.

The Delta Tau UMAC system provides motion control with interface for six axes of direct PWM. There is also a 6-axis interpolator card that offers 4,096 times multiplication or interpolation of the incoming feedback signal to deliver high accuracy at high speed.

By using the internal interpolation calculations, as opposed to an interpolator built into the feed back device, the system avoids errors caused by corruption of the high-frequency positional data feedback from the encoder (1 nm resolution easily gives 1,000s MHz frequency for position feedback).

deployed in devices. For example, life sciences are an emerging application area for MEMS requiring the manufacture from glass, ceramics, metal and plastics – rather than just silicon – of micro-components for disposable blood testing cartridges.

SMALL PROBLEM IS…

But at the nanoscale, current high-accuracy machines cannot produce 3D components with sufficiently reliable repetition – which leads to high scrap levels and expensive parts. The issues to be tackled include both the behaviour of materials under machining and the structure and motion control system of a machine tool.

On the material side, Brunel University has observed hard ceramic materials that exhibit ductility at the machining face when removing material at nanoscale which is likened to machining jelly. Further work is required to model material behaviour at the nano-level.

On the machine side, no single element can be treated in isolation: feedback impinges on gain, gain on stability, inertia on dynamics, friction on stiffness and so on. The machine currently most advanced in its development is a preliminary 3-axis turning machine. The current construction is mounted on a high-density granite platform and uses a direct drive rotary servo for the c-axis, a linear motor for the cross slide (y-axis) and then a piezo electric actuator to give fine motion in the x-axis.

A Delta Tau UMAC controller will provide motion control, also factor in environmental conditions (temperature, humidity, dust) and communicate according to MASMICRO framework protocols. Tool handling and inspection, component handling, inspection and placement, lubrication and so forth must all be integrated into this holistic platform.

A new motor has been designed for the spindle (developed by Loadpoint), while the use of an air-bearing and Anorad linear motor has been adopted to obtain the level of stiffness required for nanoscale machining (see box item on control system stiffness). In parallel, the MASMICRO team at Brunel University has provided extensive FE analysis of the machine design and critical parts in order to come up with a final design.

Cutting tool production makes use of existing methods of laser machining diamond tool tips to sub-micron accuracy, with MASMICRO project partner Contour Fine Tooling providing these – the company already manufactures single-point diamond tooling for use in optical, defence and aerospace applications. Tools can now be made with tip radii measured in nanometres, but a reliable method of measurement is still to be developed.

If the MASMICRO project achieves its objectives then Europe will be at a distinct advantage in the nanotechnology field, and the UK potentially a major player.☐

A sense of proportion

A full stop on the page you are reading could cover an area of 600 microns, while a typical human hair is about 200 microns in diameter. A red blood cell is about 8 microns. A nanometre is nine orders of magnitude smaller than a metre (10^{-9} m) which approaches atomic measurements – a single atom of gold, for instance, is 0.1441 nm. The naked eye cannot detect particles below 10^{-5}, so the human eye loses its efficacy four orders of magnitude above the units proposed as manufacturing tolerances.

MASMICRO UK contingent

❒ University of Birmingham – development of micro-mechanics modelling techniques to evaluate material flow. Texture evolution and failure mechanisms in forming micro-components
❒ Contour Fine Tooling – micro/nano-cutting tools fabrication and support for development of the bench-type micro/nano-machine tool
❒ Pascoe Engineering Ltd – meets the precision machining requirements of the project (machine elements, tools, mechanical structural parts of measurement, testing and handling devices)
❒ National Metal Technology Centre – develops training programmes and supports co-ordination of innovation, demonstration, training and project management activities
❒ Brunel University – research and development of bench-type micro-machining machine tools and nano-micro manufacturing techniques on 3D micro and miniature components
❒ Loadpoint, Swindon – building a bench-top sized machine tool for machining microscale features on precision engineering components using conventional milling and grinding processes
❒ University of Strathclyde, Glasgow – acts as MASMICRO project manager and project co-ordinator and will play a key role in developing product design methodology and the system; developing intelligent tools and flexible forming-machine systems, and participating in manufacturing systems integration, as well as carrying out tasks for modelling and analysis, dissemination and exploitation of the project results, and developing training programmes
❒ TECAN, Weymouth – manufacture of precision micro-parts by photochemical techniques