IOP
Precision Technology
Polishing robot

SENTER IOP

Shape and polish with abrasive jets

Subject:
Free form fluid jet polishing (FJP) with interferometric in-process monitoring (IIPM). High-precision polishing and shaping of different-sized spots with immediate feedback (there is no need to remove the object for measurements).

Purpose:
To combine two novel technologies, FJP and IIPM on a 6-axis machine bed. This allows corrective free form shaping and polishing to less than 60 nm PV (shape) and 1 nm RMS (roughness).

Market application:
Precision optics, ophthalmic, precision moulds, high-precision parts.

Potential use:
FJP: machining equipment is low in cost, no tool wear occurs, capable of polishing and shaping surfaces in places hard to reach with conventional methods.
IIPM: great improvement in process control, a major consequence of which is to decrease manufacturing time scales by order of magnitude.

Research period: January 2002 – December 2004

Total budget: EUR 603.000 of which EUR 275.000 funded by IOP

Research institute: TNO Institute of Applied Physics (TNO TPD), Delft

Project leader: Ian Saunders

Scientists and engineers at TNO Institute of Applied Physics (TNO TPD) in Delft are researching the combination of two novel technologies, fluid jet polishing and interferometric in-process measurement. While jets of abrasive slurry shape and polish a surface to a super-smooth finish, the in-process monitoring technology of material removal guarantees a significant improvement in process control.
'Without the need for grinding tools or polishing pads, even complex shapes and hard-to-reach places like inner surfaces can be smoothed', says Jacob Jan Korpershoek, head of Precision Mechanics at TNO TPD.

The current practice of polishing surfaces in the optical industry is a long and repetitive process. Polishing of high-precision lenses is done with brushes or pads combined with chemical substances. As this is a relatively uncontrolled way of working, there is the danger of disturbing the product shape. This needs to be corrected by local polishing, often by specialized companies located outside the Netherlands. Another issue is the off-line measuring of shape and smoothness, which can lead to loss of time and quality. 'Being able to measure and polish on the same machine without removing the object can significantly improve manufacturing time', explains Ian Saunders, precision mechanical engineer at TNO and project leader of the new polishing robot. ▸

Project team at TNO TPD. From left to right: Leo Ploeg, Hedser van Brug, Jacob Jan Korperskoek, Michiel Dorrepaal, Bert Dekker, Jack Idzes, Ian Saunders

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Jacob Jan Korpershoek, head of Precision Mechanics at TNO TPD, adds: 'Fluid jet polishing technology has several advantages: machining equipment is low in cost and there is no tool wear.' He also claims there is a large range of variables to optimize the process. An extensive variety of slurry materials can be used on different materials.

Proof of concept

'With a grant of the innovation-driven research program (IOP) for Precision Technology our practical research brings this combination of techniques a step closer to market application. It concerns a proof of concept: is it really possible to build a machine that can polish and measure the changes at the same time?', says Saunders.
The feasibility of interferometric measuring was proven during research carried out for a Masters degree at the Delft University of Technology. TNO TPD successfully developed the fluid jet polishing part. This research was supported by a doctoral thesis from the university.
After this engineering phase, the next logical step will be to build and test prototypes for specific applications, like lenses for wafer steppers or satellites, ophthalmic (spectacle lenses) or moulds for high-precision parts.
The IOP project at TNO started at the beginning of 2001 and should be finished by the end of 2004.

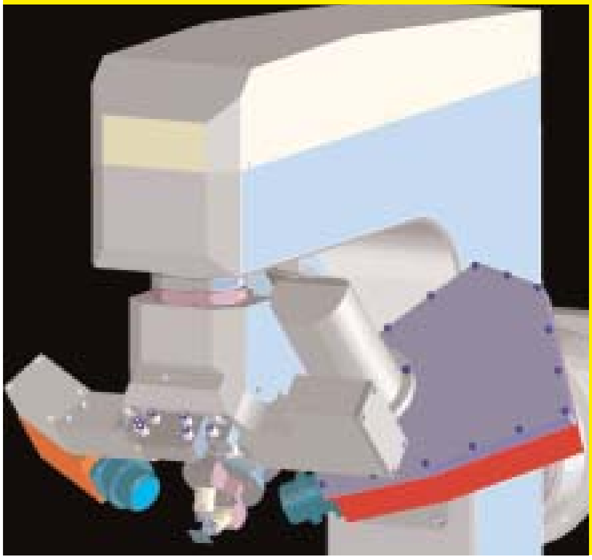
Abrasive fluid

Fluid jet polishing is a new technology developed at TNO TPD. It exploits the properties of an abrasive fluid for the fine finishing of surfaces, for example glass optics. Slurry (a fluid mixed with particles such as aluminium oxide or silicon carbide, depending on the surface to be polished) is directed with a pressure of 1 to 10 bar through a nozzle with a speed of 10 to 20 m/sec. Depending on the impact with which the jet hits the surface it can change the shape of the object and/or polish the surface. It can even retain or lower the surface roughness while changing its shape, which is not possible with more conventional production methods.
The exact removal rate and surface finish depend on the slurry composition, jet pressure and nozzle design.

Closed loop

The idea to measure the changes in shape and roughness with light is a spin-off from research at the Delft University of Technology and has resulted in a prototype. Two beams of laser light are reflected on the surface of the object on two different places and recorded by a camera. One beam is aimed at the place where the fluid jet is doing its work, the other at a spot of reference, where no changes are made in the roughness or shape of the surface. By measuring the modulation patterns of these two light beams the decrease in material can be computed. This enables feedback to the robot and correction of the positioning of the fluid jet stream.
The new interferometer is based on shearing and uses a single spot – a significant improvement.

Changing spot size during the polishing process



Detail of the Zeeko robot arm with nozzle and interferometer

The robot

The polishing robot which combines both technologies is based on a machine developed by UK-based Zeeko Ltd. It will become part of their range of ultra-precise optical lens polishing machines. Built onto a 6-axis machine bed, fluid jet polishing allows corrective free form shaping and polishing to less than 60 nm PV (shape) and 1 nm RMS (roughness). The interferometer will be attached to the robot arm which also houses the nozzle.
The machine is able to load work pieces up to 150 kg with a diameter of 600 mm. The company is interested in further adapting the robot to specific application areas.

Experiments

Results of the research program are expected in the fields of both fluid jet polishing and interferometric in-process monitoring. 'After the installation of the Zeeko FJP600 robot we will start testing the effects of various slurries and slurry concentrations', Saunders explains. Other major macroscopic parameters, like

nozzle angle or shape and jet velocity, and their relation to material removal will also be studied. Various specimen materials, like silicon, polycarbonate, steel or ruby will be tested for their response to this novel way of shaping and polishing.
The first 18 months of the project ended with the delivery and installation of the machine. A successful proof of concept was done by means of stationary measurements with the interferometer and 4 patents are already pending which relate to this research and to fluid jet polishing.
In the second half of the project various design configurations will be tested, measuring in different experimental settings will be done and the most promising markets will be chosen.

The Zeeko machine bed

Telescope lenses

Three fields of market application are currently under investigation. Korpershoek: 'High-end optics seems the most promising and interesting at the moment.' Here, not only the shape of a lens needs extremely high accuracy, but its roughness also needs to be very low. 'The FJP600 robot will make very precise corrections to shape possible without altering the surface roughness.' He mentions the manufacturing of telescopes, lenses for satellites, wafer steppers and astronomic applications as the most interesting areas.
A second potential market is the ophthalmic market, which requires less accuracy but shorter process time.
The third possibility is using fluid jets on metal to polish very small spots with high precision in places which are difficult to reach with current tools. 'Without the need for grinding tools or polishing pads, even complex shapes and hard-to-reach places like inner surfaces of moulds can be smoothed', says Korpershoek.
With a background in mechanics and engineering, Saunders enjoys the process of bringing scientific findings into proven technology under lab circumstances. 'This project is a challenge for me because of its size and duration.' He is very curious which market will prove to be the most interesting for this combination of technologies: 'The prospects are good; several companies have shown strong interest in our work.'
According to Korpershoek, that interest is based on the combination of properties such as shaping and polishing very small spots, if necessary in hard-to-reach places, and getting feedback on what is done without removing the object from the machine.

Business participation

In order to stimulate knowledge transfer between research institutes and companies, Senter, with its innovation-driven research programs (IOP), provides several options. One of the possibilities for interested companies is to join an industrial user group. As the most direct means of knowledge transfer, this means close involvement in one or more projects. 'My interest is in precision measurement of a-spherical lens surfaces such as in cd or dvd players', says Marco van As from Philips Research. As a member of the industrial user group he is kept updated twice a year on the progress of the project and has the possibility to profit early from the project's findings. Rob Bergmans from NMi Van Swinden Laboratorium mentions the two-way involvement between the business community and the research institute: 'As a member I can use my own expertise and background to further assist the project in case of difficulties.' It also gives the user group the opportunity to steer the project back onto a perhaps more practical track.
Other ways of involvement with IOP projects include taking over patents or licenses, contributing towards the costs of a project and providing work experience placements for researchers.

Members of the industrial user group

Anteryon
NMi Van Swinden Laboratorium B.V.
Philips Research
Philips Centre for Manufacturing Technology (CFT)
Philips ETG
Polgron
Stichting Astronomisch Onderzoek in Nederland (ASTRON)
Delft University of Technology
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IOP Precision Technology

Precision technology is needed when products are to be built with high demands on the accuracy of their shape or size, and also when products or parts need to be positioned with high precision. Examples are laptop computers (especially data storage), cd players, dvd recorders, optical and medical instruments, space engineering and mobile phones. Further miniaturizing makes it impossible to build these functions in a purely mechanical way; a multidisciplinary systems approach is needed.

The IOP program in this field of technology started in 1999. Currently 16 projects have received grants for research on one of three central themes.

- In the field of systems-oriented design, subjects for research include design topics such as piezo actuators, precision movements in vacuum and high algorithmic mechanics. These topics all have movements with great speed and/or high precision.
- The second theme covers the constant raising of the precision of production processes by improving process control or using new production techniques. Not only conventional methods like precision machining are included but also new technologies such as lithographic etching, the use of laser or X-ray bundles and chemical vapour deposition.
- Micro system technology is the third area in this IOP program. Sensors and actuators coupled with a control system are of interest here. Examples are wet chemical etching and packaging of MST devices like an optical chip to a glass fibre.

Further questions on IOP Precision Technology

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IOP

An innovation-driven research program (IOP) awards grants to innovative technological research projects at universities and other non-profit research organizations. Through this approach, the Dutch government wants to make the research world more accessible to the business community and improve and intensify contacts between the two. A precondition is that projects must fit in with the long-term research needs of the business community. The program stimulates interaction between the research world and business community through the latter's involvement in research projects, knowledge transfer and network activities. Major efforts are made to ensure that each completed program leads to lasting co-operation between the Dutch research institutes and business community with a view to fulfilling technological developments.

Business participation

In order to build a bridge between research and industry, an IOP provides opportunities for companies to take part in innovative research. The possibilities are as follows:

- Joining an industrial user group.
  As the most direct means of knowledge transfer, joining an industrial user group means close involvement in one or more projects. The business is kept up to date on the latest research developments, and, in some cases, can contribute practical experience that steers the course of the research work.
- Taking over patents or licenses that have resulted from IOP projects at universities and non-profit research institutes.
- Providing work experience placements for researchers, so that new know-how is passed on to the business quickly and can be tested in and adapted to practical conditions.

Colofon

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Senter is an agency of the Ministry of Economic Affairs

TNO Institute of Applied Physics (TNO TPD) is one of the 15 institutes of the Netherlands Organization for Applied Scientific Research TNO. TNO TPD aims to strengthen the competitiveness of its clients through innovative applications of technology.
Technologies are: applied physics, informatics, optics, acoustics, mechanics, electronics, materials and process technology.

Ministry of Economic Affairs