Micromachining Center based on the Integration of various Technologies in one coordinate System

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Abstract
The strong growth of the microsystem market and the trend towards the production of hybrid microsystems (in general the use of various materials in one system) boosts the demand of microsystems made of the materials used in conventional engineering. High-alloyed steal is one example for those materials, which are to date rarely used in microsystems. Various technologies are involved during the production process for such systems. The use of those technologies currently demands the workpiece transportation between several machines, since no current machining system provides the use of several microproduction processes in one workspace. The Laboratory of Production Engineering, Helmut-Schmidt-University / University of the Federal Armed Forces Hamburg, developed a micromachining center, which is based on the integration of various technologies in one workspace. This concept allows the use of serial and/or parallel process chains in one coordinate system. The workpiece transportation, going hand in hand with a geometric reference loss, is not any more necessary. The system will be completed with the integration of a manipulation system which is inevitable for the production. It's been planned to use an robot-based manipulation system with increased accuracy. The building of serial process chains is currently being improved, whereby parallel process chains are investigated on the basis of laser-assisted microforming.

Micromachining Center for serial Process Chains

To be able to perform real three-dimensional processing of common engineering materials as for example high-alloyed steals unlike the 2½-dimensional processing of silicon used in microelectronics, an ultraprecision-milling-machine 'Microgantry GU' manufactured by the *Kugler GmbH Salem, Germany* was chosen as a basis for the micromachining center. This machining center allows real three-dimensional processing whereby the tool guiding system is equipped with position sensors which have a resolution of 10 nanometers. As result the repeatability of the machine is 0,5 microns. The high-speed spindle allows the use of microtools with extreme small diameters by providing rotational speeds up to 160.000 rounds per minute(1).

If the processed workpieces are dismantled from the machine workspace, their geometric reference will get lost. This problem can be overcome with the use of laborious measurement procedures, since those workpieces feature structures in the size of several microns.

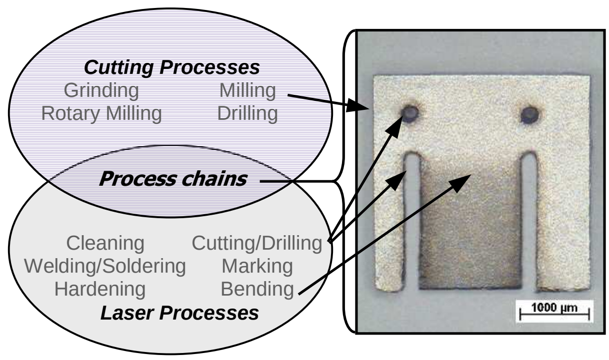

Fig. 1: Workpiece manufactured using integrated process-chains. On the left possible process-combinations for the developed machining center are shown.

Using integrated process chains, the problem of reference loss doesn't have to be taken into account: Separation, orientating, positioning as well as rechucking is unneeded. The installation of a 220W Nd:YAG-Laser (provided by *LASAG AG Thun, Switzerland*) permits the realization of cutting processes and laser based processes in one coordinate system by using only one clamping. The change of the processing technology doesn't result in a machine change including workpiece transportation, only a moving operation using the machine-own kinematics is necessary(1).

Serial process chains have been investigated in experiments with following processes: Face milling, peripheral milling, laser drilling, laser cutting and laser bending. Experimental investigations regarding laser welding and laser marking as well as milling processes show the potential of application of these technologies in the microrange. The focus of current investigations lies on the determination of suitable process parameters to improve the process stability. Fig. 1 shows a workpiece, which demonstrates the use of process chains, in this case combining milling, laser bending and laser cutting operations(2). Furthermore a prototype of a simplified but working coupling (Scharfenberg coupling) has been developed and manufactured at the Laboratory of Production Engineering (size 5*5*2mm). A further example of serial process chains being investigated at date is the production of a microguide, which is used as a centering device for tubes of small diameters and is comparable to snap-in-joints. A main problem arose from the lack of adequate clamping technology which could be compensated by the development of new clamping concepts for workpieces of small dimensions(3).

A standard Industrial Robot as Manipulation System

The present concept makes the high precision machining of single microparts possible using various technologies in one coordinate system. Considering the whole manufacturing process until getting the assembled microsystem, the same problem concerning the mentioned reference loss arises when the micropart production is finished and the assembly process is started: For the final assembly, the microparts have to be taken out of the micromachining centers. They have to be exactly re-orientated and re-positioned before being assembled. By additionally integrating a manipulation system (see fig. 2) into the existing micromachining center and thus it's coordinate system, every system connected to a superior control is able to determine the workpiece's current orientation and position as well as the status of the other integrated systems(3). The superior control allows both the coordination of all connected systems and the monitoring of the process including collision avoidance regarding movements of the robot and the micromachining center. Using such a highly integrated system economically demands high flexibility concerning the machining of different kinds of microparts and materials. State of the art manipulation systems used for microassembly turn out to be limiting regarding the wanted flexibility. For this reason it is investigated to what extent a *Staeubli AG Horgen, Switzerland* 'RX60b' standard

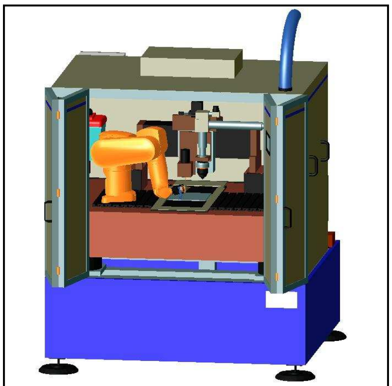

Fig. 2: Simulated micromaching center with high precision robot.

industrial robot is useful for microassembly operations. This robot features a high repeatability of less than ±20 microns. The application of high-resolution lenses and cameras allows to build direct control loops improving the robots accuracy. This can be done at the speed of the robots control interpolation timing, which is in the range of a few milliseconds. To overcome the problem of thermal heating going hand in hand with thermal expansion, the use of calibration system is recommended. The calibration could be called in the idle time between to processes or parallel to some machining processes assuring that the position and orientation of the integrated systems are exactly known during all processes. An adequate collision avoidance feature can be easily based on that data. Currently the superior control, allowing the connection to the robot as well as to the micromachining center is in development. Additionally a gripper prototype based on cryo (freezing) technique was built. That gripping principle offers the ability to pick variedly shaped workpieces made of various materials, which is necessary to assure the needed flexibility. The whole system guarantees the aimed flexibility required for industrial use. As add-on the robot can be used not only for simple assembly but also for material processing in six degrees of freedom by using the robots kinematics as workpiece guidance system.

Laser-assisted Microforming as an example for parallel Process Chains

While in the above described micromachining center serial process chains are already being carried out without reference loss to the workpiece laser-assisted microforming is separately being investigated as an example for parallel process chains for the production of metallic microparts. By parallel laser heating of the material before and during the forming process (fig. 3) advantages concerning the material behavior can be achieved: The anisotropy of the material and the process forces are reduced while the formability is increased(4). Further the microstructure, an important factor to consider in the sub-millimeter range, can be influenced by recrystallization at high temperatures. Laser radiation offers two main advantages with respect to other heating methods: (i) Local heating of selected areas of the workpiece is possible, enabling to influence the forming process selectively. (ii) The absorption of laser radiation allows short process times which cannot be accomplished with heat transfer from pre-heated tools. Sapphire tools meet the requirements for transparency to laser light and excellent mechanical properties. The machining of these tools has been carried out by laser ablation with excimer lasers(5).

The suitability of the proposed method has been verified in forming experiments. Structures as small as 100 microns have been reproduced in aluminium. Equivalent experiments with harder materials like steel are a current object of research. The results show the limitations of cold forming for these applications. In embossing of stainless steel the quality of the result is unsatisfactory and the process forces required lead to high stresses in the tool. This bears the risk of a fracture if the tool, specially in the case of tensile stresses(6). An approach to overcome these problems is seen in warm and hot forming, e.g. by the proposed method of laser-assisted forming. An imprint in stainless steel 1.4301 (AISI 304) obtained with the laser-assistance of the forming process is shown in fig. 4, demonstrating the potential of this approach.

The optimization of the technique and its application to microforming is currently being investigated. Further research aims at modelling the material behavior and size effects in microforming processes and the integration of these models into FE simulations in order to extend the application of this technique to the simulation of microproduction processes.

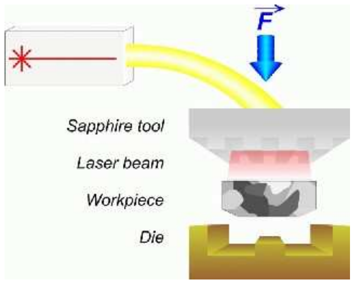

Fig. 3: Principle of laser-assisted microforming

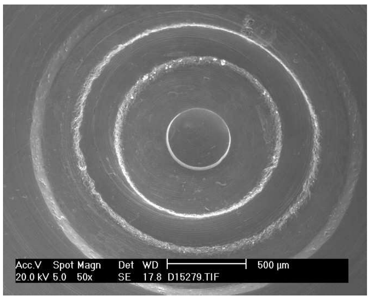

Fig. 4: Laser-assisted embossing: imprint in stainless steel

Conclusions

The market development concerning microsystems is asking for a flexible machining center, allowing high precision machining with low costs. The presented micromachining center concept features high potential in fulfilling these demands. Present experiences showed the successful use of integrated process chains as described above. The currently pushed manipulation system integration in the existing micromachining center allows to carry out the whole production process chain in one micromachining center. The biggest problem at the time is the clamping and gripping technique. The small structures in the range of several microns are highly sensitive on loads. Solutions for this problem based on freezing-techniques are currently investigated at the Laboratory of Production Engineering and have been successfully implemented.

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