Integrated Process Chains for Enhanced Micromanufacturing Technologies

Univ.-Prof. Dr.-Ing. Jens P. Wulfsberg,
Dipl.-Ing. Sven-Eric Hilpert, Dipl.-Ing. Jörg Lehmann
University of the Federal Armed Forces Hamburg
Laboratory of Production Engineering
Hamburg, Germany

Introduction

Originally the manufacturing of integrated microsystems was based on manufacturing technologies for the production of microelectronic systems. These processes are using mainly etching and coating technologies. One other feature is the limited capability to generate 3-dimensional structures. Typically with these processes 2½-D structures can be generated with a submicron accuracy. But today there is also an increasing demand for real 3-D microsystems. Additionally due to new applications of these microsystems, e.g. in the field of medical instruments, new or already existing materials have to be processed. So it is absolutely necessary to use stainless steel or other biocompatible and chemical resistant materials for medical instruments. But as a matter of fact these are no typical materials of the classical microsystem production technology. Therefore the development of adapted manufacturing technologies for materials difficult to machine is requested for the setup of 3-D hybrid microsystems. For the manufacturing of hybrid microsystems the production of single parts is necessary. These parts are assembled in ancillary steps.

1 Process Chains in Micromanufacturing

Carefully dimensioned process chains are an absolutely necessary precondition for the production of parts and technical systems within the required quality level. Many principles for sequential or hybrid process chains are already known from the production of macroparts. Figure 1 shows the formal definition of different kinds of process chains. In this example a hybrid process is combined sequentially with a second production process. On the input and output side additionally handling, positioning and checking processes are indicated. In this contribution new approaches for the setup of process chains in micromanufacturing are introduced. The first development shows an integrated production unit for the setup of different sequential processes based on the technology of microcutting and laser machining. In the second case a new hybrid process for laser assisted microforming is introduced.

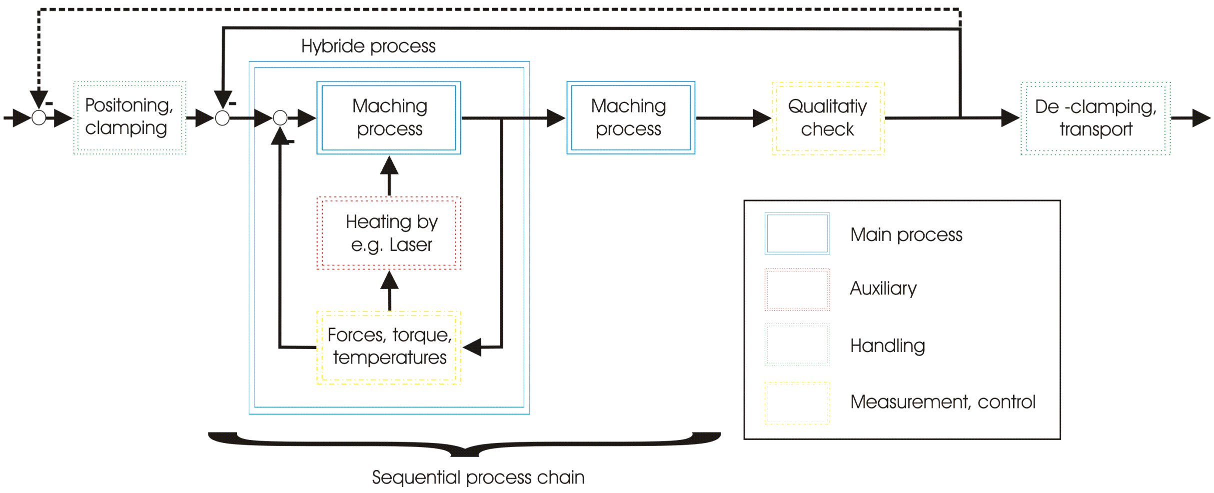

Fig. 1: *Combination of sequential and hybrid process*

2 Integrated Sequential Process Chains

In conventional manufacturing processes the workpieces are leaving the working space of the machine tools after each manufacturing step. That means they have to be released after manufacturing and newly to be clamped before the next manufacturing step. Every time the geometric reference between the workpiece and its geometric elements on the one hand and the coordinate system of the machine gets lost. So a high effort is necessary for the re-positioning and clamping of the workpiece in the following manufacturing step. For the manufacturing of 3-D microparts this is an important limiting factor to reach higher accuracies and smaller tolerances.

The development of the new microproduction machine followed the targets which are shown in figure 2. Some targets are already reached in the production setups of the microsystems or mainly the microelectronics production, e.g. the LIGA processes. These are:

- machining of workpieces in one clamping (on one wafer or substrate) during all manufacturing steps
- keeping the reference between workpiece and production unit
- integrated sequential process chains
- machining with an extreme high accuracy and resolution

Further more there are other necessary targets for the production of hybrid microcomponents which are already implemented in the typical procedure of precision engineering and fine mechanics:

- the capability of machining real 3-D geometries
- the setup and joining technology for hybrid systems
- the machining of free-form surfaces
- the machining of arbitrary materials
- the generation of complex NC-programs via CAD/CAM

These advantages derived from the precision engineering on the one hand and the microsystem technology on the other hand are combined in the newly developed micromachining centre. The development was carried out in a cooperation between the Laboratory for Production Engineering (LaFT) at the University of the Federal Armed Forces Hamburg, Kugler GmbH Salem and Lasag Thun [1].

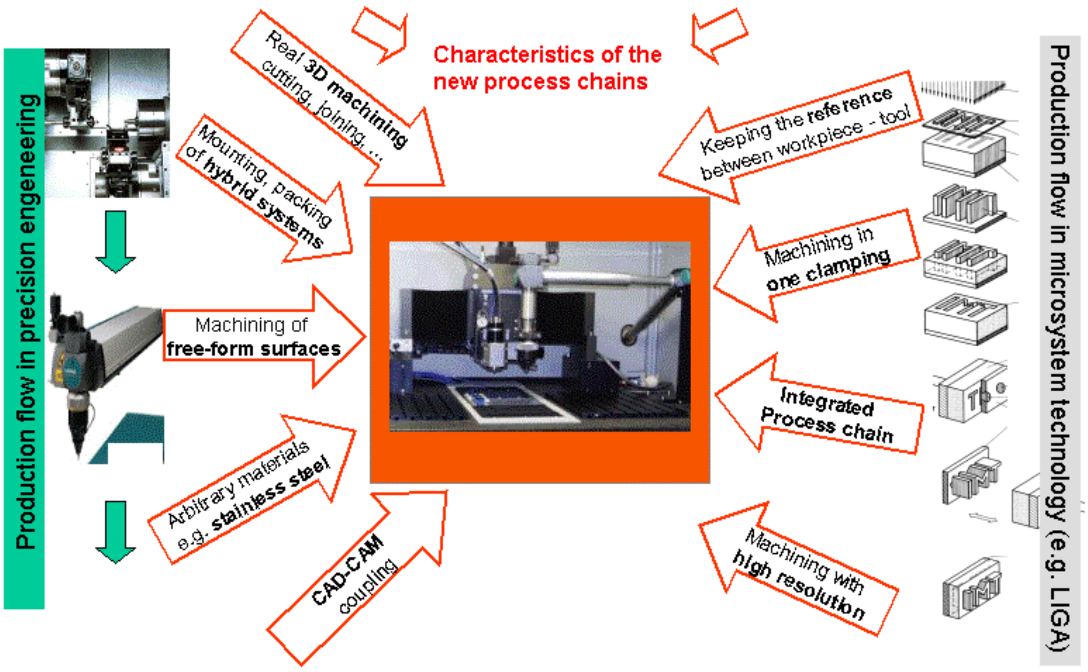

Fig. 2: *Characteristics of process chains in the new micromachining centre*

3 Technical Specification of the Micromachining Centre

The basic design of the micromachining centre is shown in figure 3. It is a four axis CNC machine with a feed resolution of 10 nm. In the working space a spindle for milling, drilling and grinding operations is mounted. The maximum speed is 160.000 rpm [2]. Next to the spindle the optics for laser machining is mounted. The laser beam can be alternatively coupled in via a mirror system for ablating and cutting or via a fibre for welding. The laser source is a Nd-YAG laser with a wavelength of 1064 nm and a mean power of 150 W. The minimum focus diameter is 60 microns. In the working space additionally components like handling, cleaning or storage devices for parts can be mounted if they are necessary elements of the process chains.

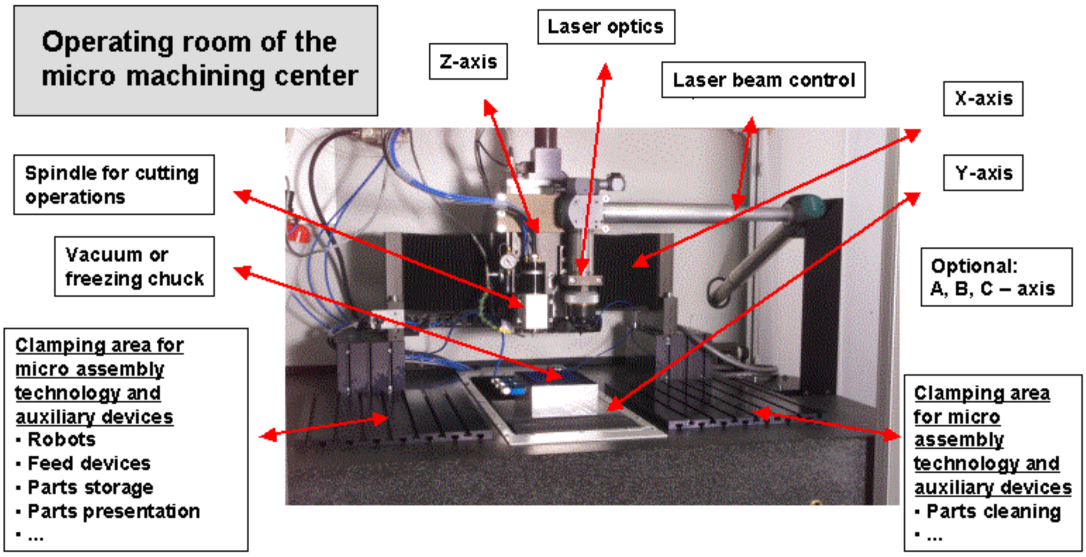

Fig. 3: *Setup of the working space*

With the described setup many process chains which are based on microcutting and laser technology can be realized for the parts as well as assembly production with high accuracy and resolution. The most important basic elements are shown in figure 4. All elements displayed in figure 4 are only consisting of two steps, one is laser machining, the other is microcutting.

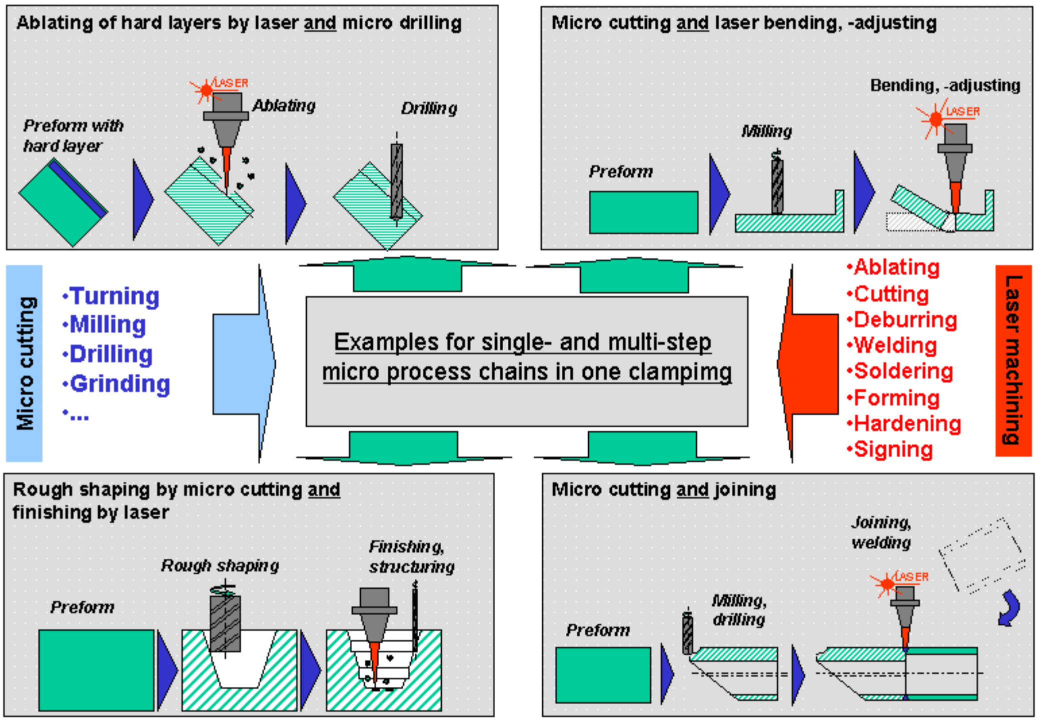

Fig. 4: *Examples for basic process chain elements*

It is easily possible to combine both technologies (cutting and laser) to execute shaping operations for one single workpiece and/or assembly treatment for subassemblies in the microrange. So a complete machining as it is known in the conventional production is also possible in microproduction. This is a necessary technology to keep the accuracy in process chains for microproduction, because as long as the workpiece is clamped in one working space of one machine tool the geometric reference between the tool and the kinematics of the machine will not get lost. Besides the technological advantages there are also economic reasons for the introduction of this new setup. With these new process chains it is possible to have a positive influence on the stock, especially the work in process will decrease. Besides this the production time will become shorter. Practical machining experiments have been carried out to combine e.g. milling operations with laser cutting and laser bending for the production of complex microparts.

4 Hybrid Process Chains for Microforming

Industrial realization of microproducts and their further breakthrough require suitable production technologies with respect to accuracy, productivity, efficiency, reliability and ecological considerations. Despite the advances in the above mentioned technologies from cutting to laser machining this factor is still a significant limitation. Metal forming technologies offer the advantages of high production rates, minimal or zero material loss, excellent mechanical properties of the product and close tolerances making it suitable for mass production and near net shape technology. But the application of metal forming to the production of microparts is still limited as a series of problems arise in scaling down this technology to the microscale.

Here microforming is understood as metal forming of parts or structures with at least two dimensions in the sub-millimeter range. In this range “size effects” occur, which lead to a different frictional and material behaviour compared to conventional dimensions. This results from the fact that some factors like the microstructure of the material or the surface topology and roughness are nearly independent of the dimension of the part to be produced and thus cannot be scaled down in the same way as the geometry. With decreasing size the influence of single grains and their orientation has to be taken into account, especially when only few grains are present in one dimension [3,4]. Anisotropy and texture of the material are further parameters to be considered. An increasing variation in the material behaviour has been observed, leading to reduced process stability and reliability.

An approach to overcome these problems concerning the material behaviour is to influence the microstructure during the process. This can be accomplished by heating the workpiece. At high temperature an increased formability is achieved and process forces are reduced as more slip systems are activated. This reduces the anisotropic behaviour resulting in a more homogeneous forming with a reduced scatter of results.

Warm forming combines these advantages with those of cold forming like good mechanical properties and surface quality. A step further, in hot forming (at a temperature above recrystallization temperature), dynamic recrystallization is induced during the deformation process. This allows the newly formed microstructure to “grow” into the given structures of the die.

For the purpose of heating the material during the microforming process, laser radiation seems the most suitable choice as it offers two main advantages with respect to other methods: (i) Local heating of selected areas of the workpiece is possible. (ii) The energy input and thus the resulting temperature in the workpiece can easily be controlled via the current of a diode laser. This allows to selectively influence the forming process.

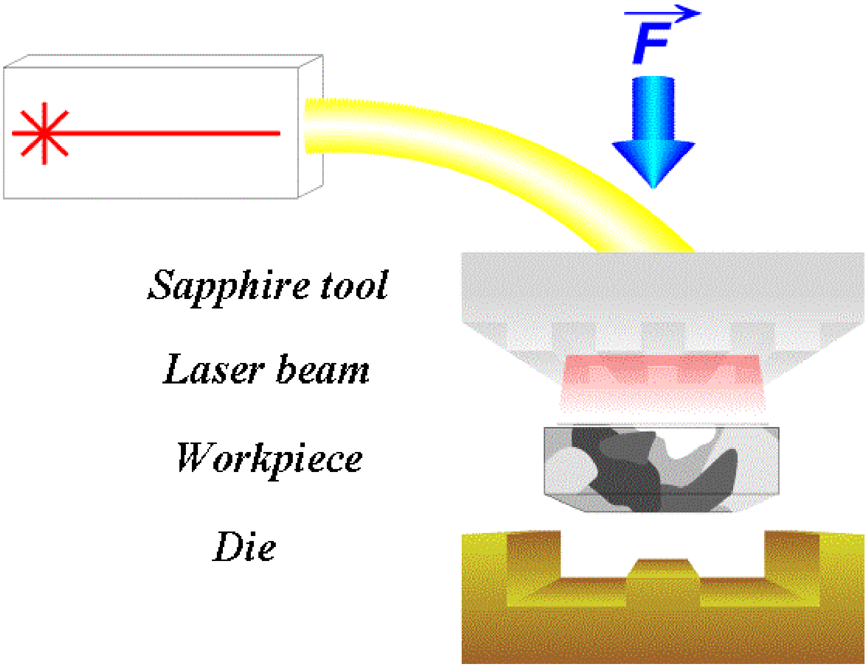

Fig. 5: *Principle of laser-assisted microforming*

The proposed method (figure 5) requires transparent tools in order to allow the transmittance of the laser light to the forming region. Sapphire combines the required transparency to laser radiation with excellent mechanical properties like high hardness, compressive strength and Young’s Modulus, making it suitable for metal forming.

In order to realize complex 3-D geometries with this technology it is necessary to structure the sapphire tools. This can be done by laser ablating processes. Due to the high transmission of sapphire over a wide wavelength range a UV laser has to be used for this purpose. For the experiments described here an excimer laser (wavelength λ = 248 nm) generated the test geometries.

5 Application of Sapphire Tools in Microforming

The usage of sapphire tools in microforming was verified in pressing and embossing experiments. First the general applicability of sapphire tools for forming purposes was tested in pressing experiments. Cylindrical punches of diameters 1,06 mm and 2,78 mm were pressed into workpieces of aluminium, an aluminium alloy and steel. The best result (figure 6) was achieved for aluminium where the punch penetrated the material to the defined depth of 1 mm with a good accuracy of the imprint.

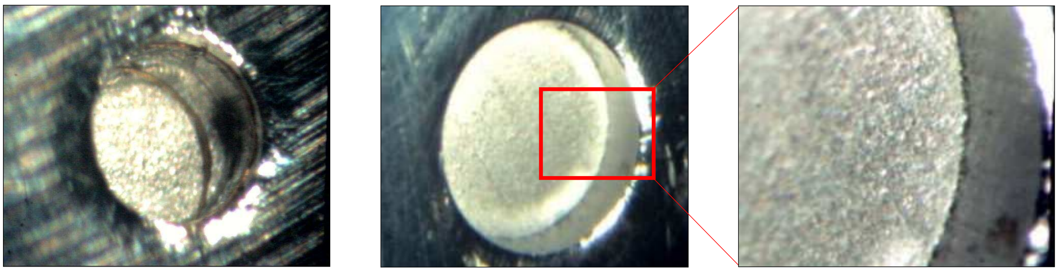

Fig. 6: *Results of pressing experiments in aluminium (punch diameter d = 1,06mm / 2,78mm)*

Generally it is also possible to carry out forming processes in harder materials with tools made of sapphire. In this case it is of major importance to limit the maximum forces during the forming process by parallel heating of the workpiece with the laser. So the sapphire is protected from cracking because a critical tensile strength is not exceeded.

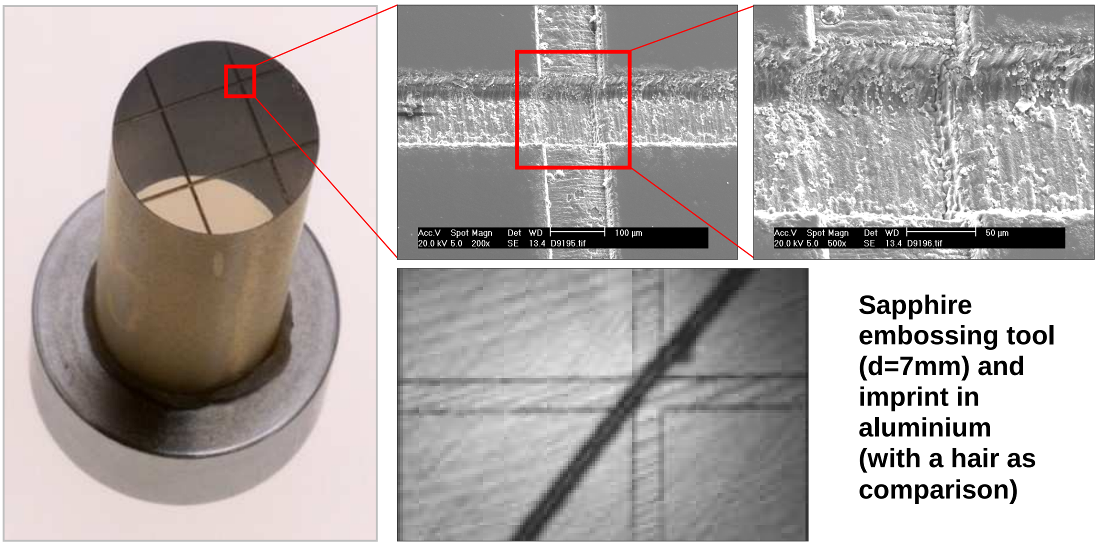

Fig. 7: *Embossing of microstructures with sapphire stamps*

Further experiments investigated the behaviour of structured sapphire tools. The tool in figure 7 was used for embossing of a structure with rectangular shapes of 100 µm width and of different depths between 10 µm and 50 µm. The figure shows details of the structure as well as its contamination with particles which adhered during the embossing experiments. An imprint of good quality was achieved in aluminium showing the suitability of the proposed technique and that structures with dimension around 100 µm can be reproduced.

6 Summary

Process chains are an adequate method in the field of macromanufacturing to reach the required quality level and to lower production costs e.g. by using methods of complete machining. In the field of micromanufacturing process chains are not yet widely used. Besides economic reasons, for micromanufacturing process chain technologies are an absolutely precondition to reach a higher quality level of microparts or to enable the manufacturing of even smaller parts or assemblies. One outstanding advantage of process chains is the conservation of the geometric reference between workpiece and machine tool over several production steps.

In this contribution two examples are explained in which different kinds of process chains are used to exceed the potential of micromanufacturing. The combination of microcutting and laser maching in the working space of one micromachining centre offers new possibilities for the complete machining of single microparts or the joining of parts in one setup. The second example describes a hybrid process chain consisting of laser heating and microforming in order to overcome size effects in microforming to reach smaller geometric elements and structures.

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