

Efficient precision machining of the smallest bores 0.015 to 4 mm in diameter

Product miniaturisation is continuing not only in the electronics, analytical, automotive, telecommunications and medical sectors, but also in machine building. The market for and the overall economic importance of micro technology are developing dynamically and will continue to grow substantially in the future. This can be seen at all levels where value is added in the micro technology industry [1]. To 'miniaturise' successfully, often it is not enough simply to make everything smaller. For example, the choice of materials has to be reassessed, because in micro technology the chip-removal machining of ductile materials is extremely critical, since for most applications even the smallest burrs and plastic deformation cannot be tolerated [2]. This is also why the use of tungsten carbide, ceramic, silicon and polycrystalline diamond (PCD) is becoming increasingly more important. Also, it is not always possible to scale down conventional machining methods with the accompanying machines and tools to the micrometer range, which in many cases means that the machining system has to be changed. Brittle-hard materials are machined predominantly by grinding and polishing, using diamond as the abrasive. In micro technology, the machining of a bore presents a particular challenge. This is mainly due to the fact that access to the machining surface is difficult and also what are often large aspect ratios (the length of the bore in relation to the diameter).

Small bores

Conventional boring with cutting tools, laser drilling, punching, EDM or PIM – to name just a few examples – are economic methods that have already become established for microengineering applications. As such, producing microbores efficiently is not a problem in itself, provided that the demands made on precision (shape, dimensional stability, etc.), surface finish and reproducibility are not too great. While bores with a diameter of more than 2 mm can be ground or honed, methods such as this reach their limits below diameters of 1.2 mm and at this point cannot really be miniaturised any further.

This article by **P. Mikhail** describes the universal and modular machines, tools and customised solutions that are available for the machining of small bores from 0.015 to 4 mm in diameter.

Micro Bore Sizing

Swiss company, Microcut has addressed this situation and with Micro Bore Sizing (MBS) offers economic solutions for the machining of bores down to a minimum diameter of 15 µm, particularly for hard materials as well [3,4]. Easy to use machining solutions enable the geometry (diameter, roundness, cylindricity) to be brought into narrow tolerance bands and also improve surface roughness. Micro Bore Sizing (Fig 1) is a customer-friendly system consisting of machines, tools and services.

In the Micro Bore Sizing method, chips are removed with accurate tools. Due to the (cold) machining process the structure of the material does not weaken the surface layers. Two different processes are available, each adapted to the material that is to be machined or the requirements (Fig 2):

- a) with loose abrasive (a lapping process), preferably brittle-hard materials such as ceramic, sapphire or tungsten carbide are machined efficiently. This process is also suitable for meeting the highest requirements in terms of surface finish. With this process the tool consists of a carrier rod/carrier wire, carrier fluid and abrasive (typically micron diamond). The rod, which acts as a carrier for the abrasive, is wetted with this and is introduced into the existing bore. With the conical part of the carrier rod the rough bore is increased in size and with the cylindrical section a uniform final diameter of the bore is achieved, also with large numbers of components. Because of the defined accuracy of the carrier rod and the stable machining conditions, the user does not have the tedious task of seeking to achieve the required bore diameter and geometry.

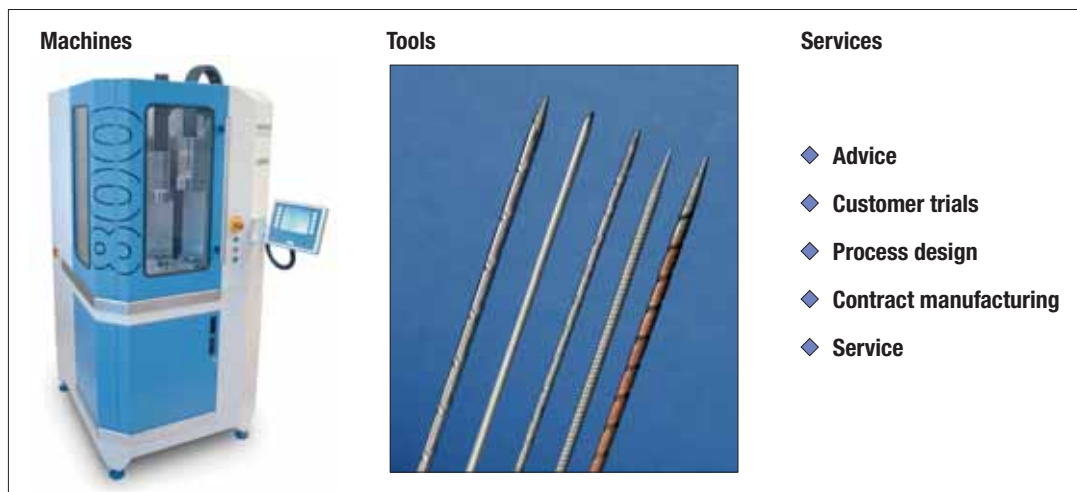


Fig 1 Micro Bore Sizing system

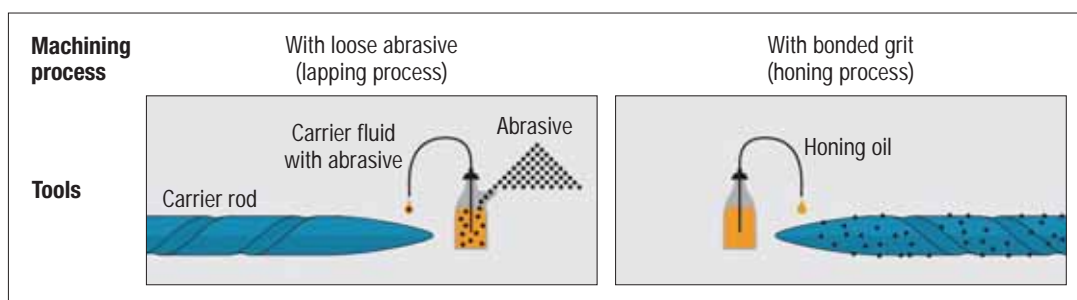


Fig 2 Graphic representation of the Micro Bore Sizing machining processes and tools

b) With Micro Bore Sizing, the process involved is that of honing, with machining being carried out with a tool with bonded abrasive. This process is used above all for softer materials such as steel. Here the geometry of the tool is the same as that of the carrier rod in process a, but here the diamond abrasive is fixed to the carrier and is not fed into the workpiece using a fluid.

The MBS machine range includes application-specific and universal, modular machine types. Criteria for machine selection are the diameter of the workpiece bore, the symmetry of the workpiece (rotationally symmetrical/non-rotationally symmetrical), the material, the material removal and the geometry of the bore that is to be achieved and also the number of bores that are to be machined. The machining tools form an important part of the Micro Bore Sizing system, since it is above all through the accuracy of the tools that the precision of the diameter is achieved. Also, surface roughness and material removal can be controlled by the choice of tool. The tools are made in one piece with a conical and a cylindrical part, and are made as standard tools or are made to the required accuracy for a particular application. Important criteria with the tool are, among other things, the geometry, a chip groove, the diamond grain size or a specific coating, which depends above all on the material of the workpiece. With certain production machines the carrier wire on the machine is removed from a roll,

and as such continuously replaces the worn tool. The range of services includes advice, customer trials, process design, contract manufacturing and service, and as such completes the MBS system.

Criteria in the machining of a bore

Dimensions, shape and surface are known to be interconnected. So if a tolerance on the diameter of the bore is to be, for example, $3\ \mu\text{m}$, a roundness more accurate than $1\ \mu\text{m}$ must be guaranteed. Surface roughness also has to be in a certain relationship to dimensional accuracy and shape. The possibilities offered by Micro Bore Sizing are shown based on a number of machining examples. The criteria are discussed that can be substantially improved by MBS.

Shape

With the MBS method dimensional accuracy is determined by the tool and then improved even more by the overlaying movements (rotation and translation) so that the roundness of the machined bore typically ends up as being more accurate than that of the tool itself. The nozzle bore in Fig 3 was made by conventional machining with a twist drill and with this has a roundness of $5\ \mu\text{m}$. Finishing with MBS results in a roundness of $0.65\ \mu\text{m}$. With the MBS method it is even possible to achieve a roundness of $0.2\ \mu\text{m}$. Cylindricity of $< 1\ \mu\text{m}$ can be obtained.

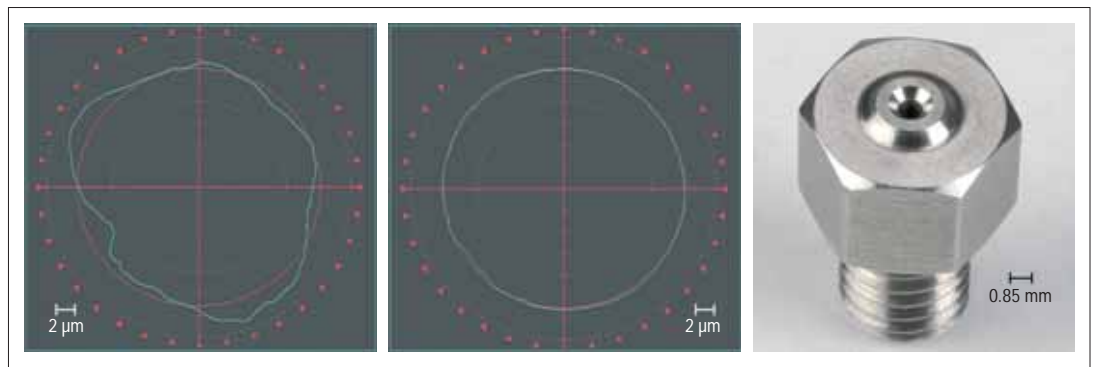


Fig 3 Roundness measurement of a nozzle with a 0.85 mm bore before and after machining by MBS

Diameter and dimensional stability

With the MBS process, **a)** a bore can be brought from the starting diameter to the required final diameter, and **b)** a narrow tolerance band can be adhered to. Fig 5 shows a watch gearwheel of unhardened steel that has been produced by turning. In order to be able to keep to a tolerance on diameter of 2 μm and also a surface finish of $R_z = 0.2 \mu\text{m}$, the bore has to be finished with the MBS process. With the ferrule (a main component made of zirconium oxide ceramic in a lightwave connector), the requirement concerning diameter with a bore length of about 10 mm is given as follows:

$$\varnothing = 125 \mu\text{m} +1/-0 \mu\text{m}$$

Other typical workpieces are all kinds of nozzles. With the steel nozzle in Fig 3, the diameter tolerance of the rough bore could be reduced from $\pm 5 \mu\text{m}$ to $\pm 1 \mu\text{m}$.

Surface roughness

The Physikalisch-Technische Bundesanstalt in Braunschweig (the national metrology institute) is pursuing the aim of reducing the uncertainties of measurements with the optotactile sensor. Microbores with diameters of 0.2 mm determine the function of components in many areas of industry. Examples are fuel injection nozzles and drawing nozzles in the wire and textile industry. With tolerances down into the sub-micron range, very great demands are made on the measuring of these microbores. To carry out these measurements tactilely, at present this can only be done with the optotactile sensor. However, the effects on measuring uncertainty are not yet fully understood. When measuring in deep microbores (a bore depth of $> 0.2 \text{ mm}$), systematic deviations occur, among other things due to optical shadowing. In order to be able to determine these deviations, a microbore normal has been developed with a high aspect ratio and a patent has been applied for [5]. As the surface finish and roundness values needed for this bore normal could not be achieved by EDM, these criteria have been considerably improved by Micro Bore Sizing. Fig 5 shows, above, a finely eroded surface



Fig 4 Watch gearwheel

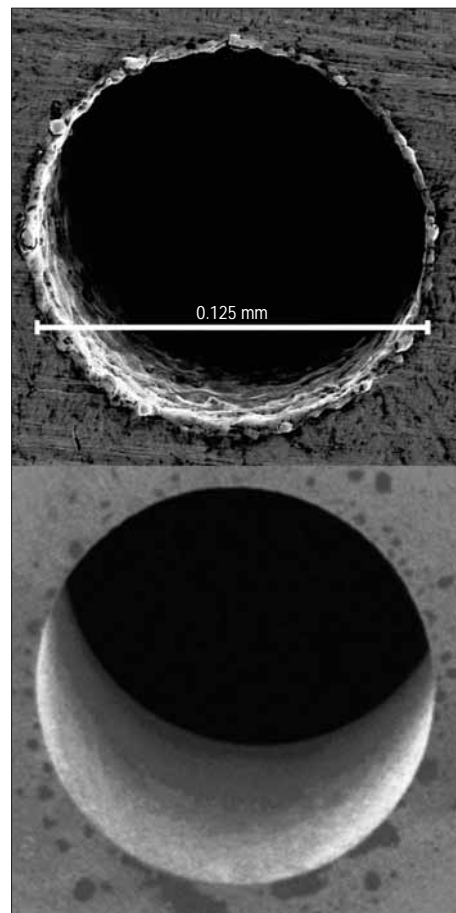


Fig 5 Bore normal: eroded surface (top), after MBS machining (bottom)

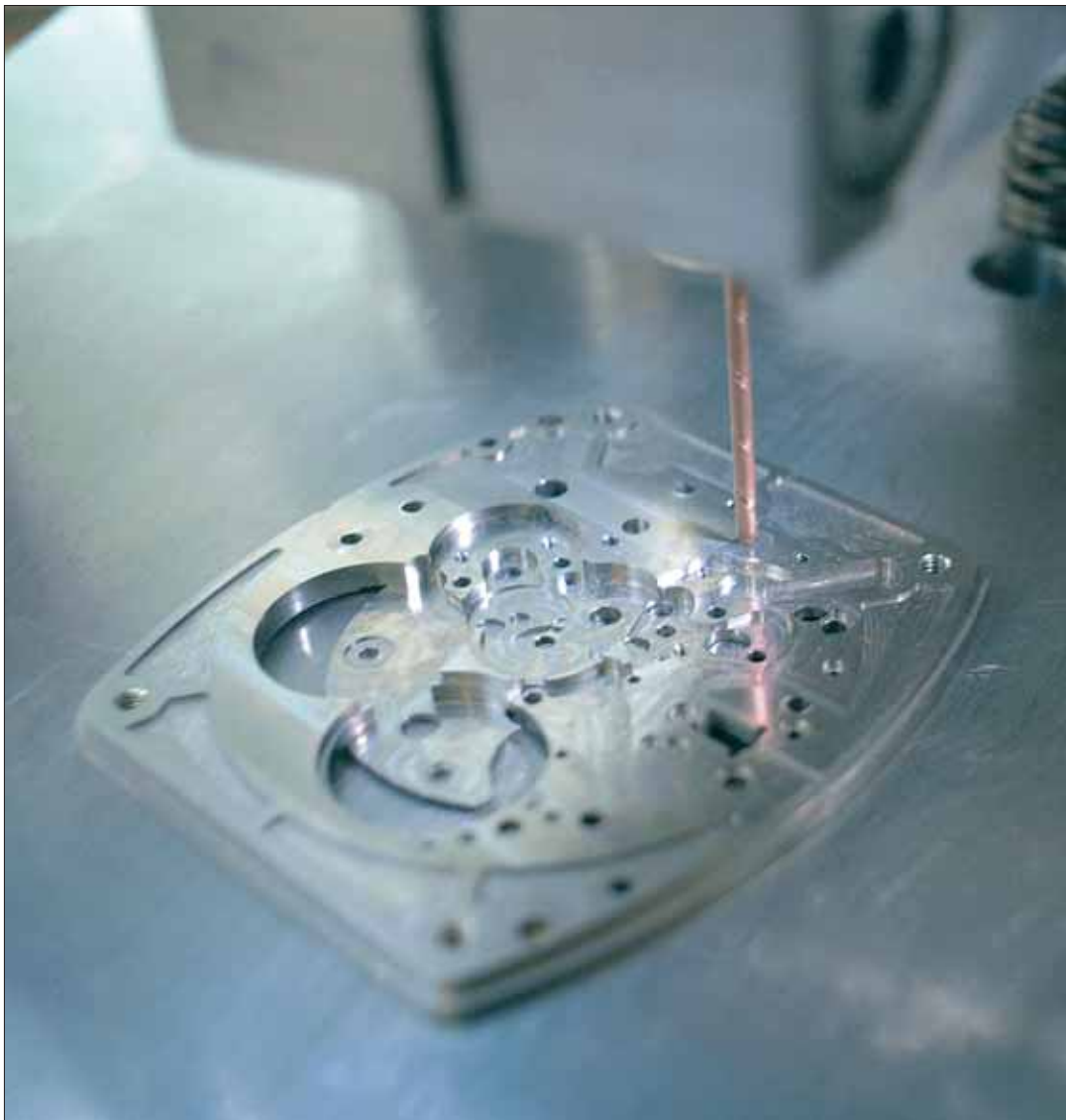


Fig 6 Machining a watch blank on the UniBore 800

and, below, the surface after MBS machining. With the EDMing of bores, typically roughness values R_z of 10 μm (rough eroded) and 1.5 μm (fine eroded) can be achieved. With the MBS method, R_z values of 0.1 - 0.2 μm can be achieved.

Material and workpieces

Typical workpieces that can benefit from the advantages of MBS are nozzles, tubes and bushes. With the UniBore 800, small bores can now also be machined in large non-rotationally symmetrical workpieces (Fig 6) such as are typically used in the die making and injection moulding tool construction industry. Electrical conductivity is not relevant, so non-conducting materials can also be machined. Preferably, hard materials such as ceramic or tungsten carbide, but also softer materials such as steel or glass, are machined. The application areas range from fibre-optics, through the medical equipment and semiconductor industry through to the automotive industry and machine building. ♦

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