

# Hole Drilling by Means of an Electron Beam

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Using a high-resolution electron microscope, Mr. Steigerwald discovered in 1949 by accident, that he drilled a hole in an orifice of his microscope. He developed the micro-drilling process at Carl Zeiss to the first industrial use of drilling holes in jewel bearings of watches (Fig. 3a). Today's state of the art are two different processes: the single pulse mode or perforation and the multi pulse drilling with again two different techniques: percussion and trepanning. In practice, perforation is used nearly exclusively due to the high productivity compared to laser beam drilling, electro discharge machining or electro chemical machining.



Fig. 1: Electron Beam Drilling Machine

## Perforation

The highly accelerated electrons are focused to or near to the work piece surface. At the spot of impact, they release their kinetic energy, melt and vaporize the material. At the reverse side of the work piece, a backing material is applied, which produces a high vapor pressure as soon as the beam penetrates through the work piece. This pressure of up to 100 bars blows the liquid material out of the borehole

and leaves only little heat and a very thin (approx. 5  $\mu\text{m}$ ) recast layer at the wall of the hole. The main process parameters with a typically constant acceleration voltage of 120 kV are: beam current to vary the hole diameter; pulse time for penetration depth; the focus position relative to the work piece surface influences the shape (taper) of the hole.

In order to achieve a high drilling rate and to overcome shrinkage problems, the sheet metals are rolled to a drum and then continuously rotated and shifted on a mandrel below the beam. An incremental encoder triggers the pulses when the position of a hole is under the beam. During the time of impact (typically 10  $\mu\text{s}$  to 10 ms depending on depth) the beam follows the circumferential speed of the work piece surface (drilling on the fly). Drilling speeds between 10 holes per second for the largest possible holes and 150.000 holes per second (Fig. 2 b,c) for tiny little holes can be achieved today.

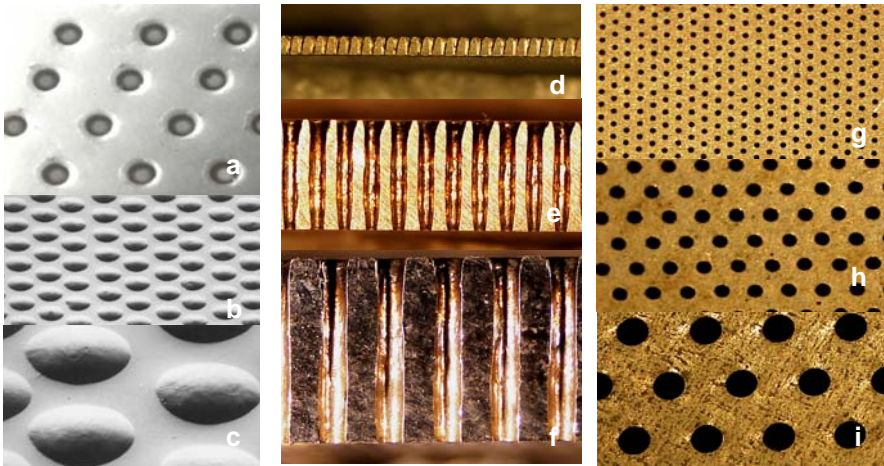


Fig.2: Single Pulse Perforation: d)hole dia 0.1mm in 0.5mm thick stainless steel for tofu production. e)screen for pulp and paper centrifuges, 3mm thick with hole dia 0.2mm. f) fiberizer for glass wool production in high alloyed steel,6mm thick, 0.8mm hole dia. Right side: top view of d,e,f

Examples for applications are blind holes with varying diameters and depths in copper foils for rotogravure printing cylinders with about 100 Mio dots / $\text{m}^2$ (Fig. 2b-c), screens with about 10 Mio holes/ $\text{m}^2$ , through which soya beans are squeezed to produce tofu (Fig.2 d+g), screens for pulp- and paper centrifuges with about 3 Mio. holes/ $\text{m}^2$  in stainless steel (Fig. 2e+h) or fiberizers for glass wool production with about 50.000 holes in high temperature alloys (Fig.2f+i). Another typical example are straight or inclined holes in nickel alloys for film cooling of

aircraft engines. Due to the need of vacuum, only applications with many holes on the work piece are of economic interest. Therefore EB-perforation is applied when many (thousands to millions) small (0,05 – 1,2mm) holes in thick (0,1 – 6 mm), tough or hard material under various angles are required. The aspect ratio can be 2 to 20. Limiting factors are to maintain the vacuum of 1 Pascal with the gas producing process, the pulse power and the speed of computers, sometimes also the temperature increase of the work piece is critical.

### Pulse modulation

In order to expand the range of hole sizes and shapes, the beam pulse may be modulated during pulse time. For example, by modifying the beam intensity into a series of sub-pulses for deeper penetration, or by oscillating the focus length during the pulse time for better cylindricity or a smoother surface, or by oscillating the beam spot position to achieve not round holes like slots, ovals or triangles (Fig. 3c). The high flexibility of the process results from the free programmable modulation of the beam in 3 dimensional spot position and its power.

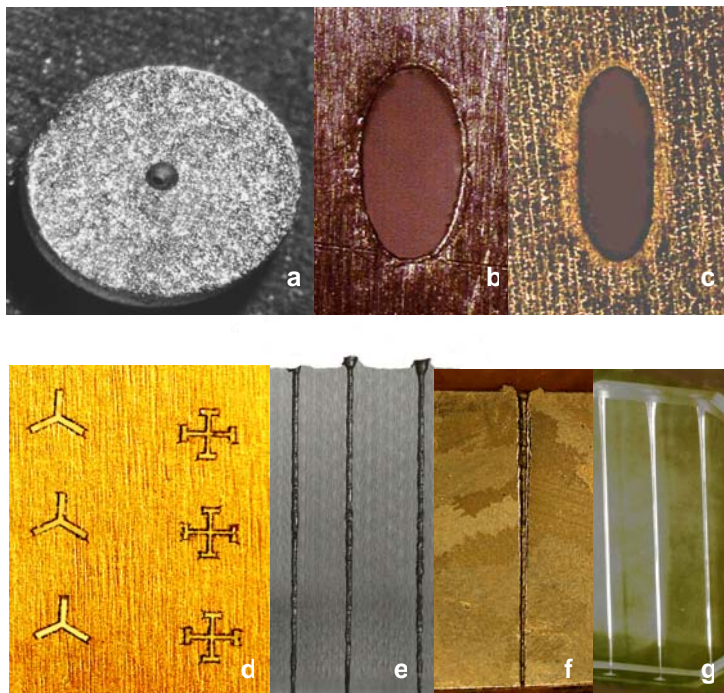


Fig.3 Multi pulse drilling: a) Rubin Bearing of watches, hole dia 0.08mm, 0.3mm thick. b) trepanning of an ellipse 3mm long, 1.5mm thick. c) slotted hole with 0.6 x 0.25mm. d) trepanning of spinnerets, slot width 0.06mm wide. e) 60mm deep hole with dia 0.8mm in steel. f) tapered hole 12mm deep, exit dia 0.12mm. g) Quartz 15mm thick, hole dia 0,1mm.

### Multi pulse drilling

There are also two different processes for multi pulse drilling. If several or many pulses are performed at the same location, with or without changing the focus, we talk of percussion drilling. If the beam is displaced from pulse to pulse on any contour, we talk of trepanning. An increased number of pulses within the same hole improves the surface quality, whereas the thickness of the recast layer grows. As multi pulse drilling is as slow as laser beam drilling, it has no economic importance.

### Economic and future aspects.

Due to the very high productivity of this drilling process, there are only about 25 eb-drilling machines worldwide. Half of them are doing sub-contracting work to meet the requirements of those who cannot fully occupy such an equipment. The markets for drilling non-metallic materials and screen- or rotogravure-printing are still to develop. Only with the last generation of computer development the high speed, inherent in the drilling process, can be controlled accordingly. If technologies like laminar flow control on aircraft wings would come into operation, the number of machines would grow considerably. There is also a big potential for micro drilling of holes in the range down to 10  $\mu\text{m}$  diameter. Today's machines are not capable of drilling these holes, however the eb-process can be developed to perform such applications.