

# EBOPULS



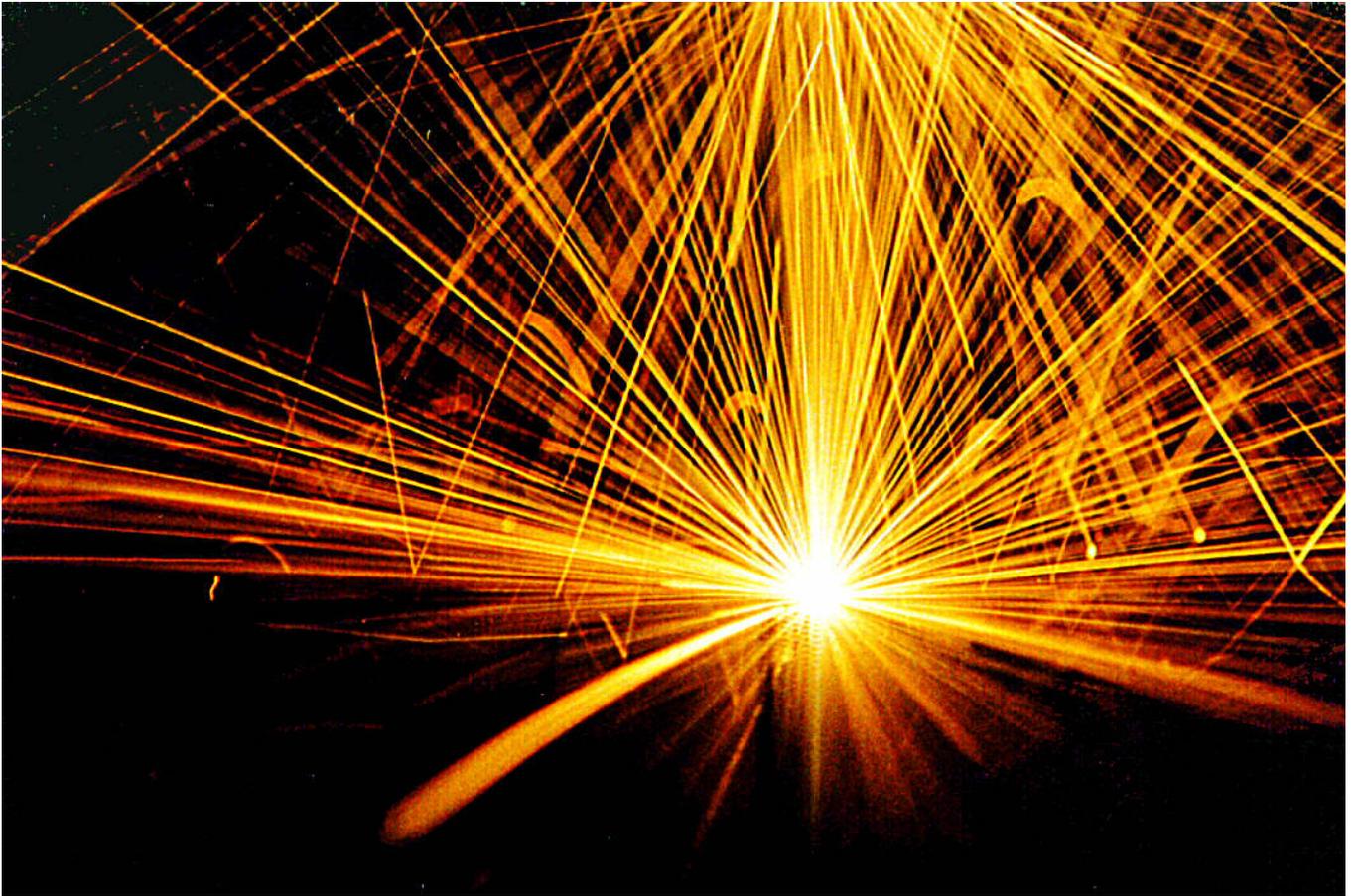
## Electron Beam Drilling

*Non-Traditional machining*



BEAM TECHNOLOGY WORLDWIDE

## *The idea - drilling without tool wear*



*EB drilling process*

47.20.01e/16

The first electron beam machine was a drilling machine which was used for drilling holes in the jewel bearings of watches. It was developed by the physicist Karl-Heinz Steigerwald at Carl Zeiss in the early "fifties".

The machine utilized the high kinetic energy of accelerated electrons and the facility for focussing them to a high power density. It is this property that enables materials to be melted and vaporised.

Use was also made of the advantage of deflecting the electron beam virtually inertia-free by simple means.

At that time, single drill-holes were produced per workpiece. Today, the electron beam or EB drilling process is particularly economical when it comes to drilling many holes in one workpiece. Workpieces with tens of thousands or even millions of drill-holes are no exception. And drilling frequencies of up to 3000 drill-holes per second are no dream.

# Maximum energy density and ultra-precise positioning

## Beam generation

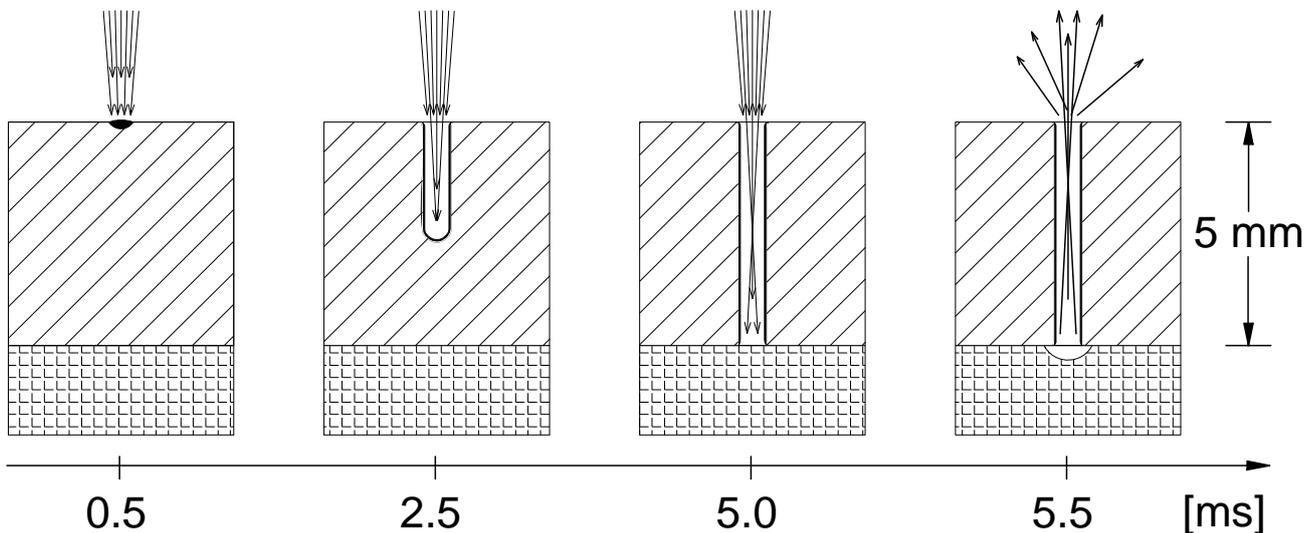
An electrically heated cathode produces electrons which are accelerated to three-fifths the speed of light by the electrical field applied between the cathode and anode at a voltage of 120 kV. A modulating electrode controls the intensity of the diverging electron beam which is focussed onto the workpiece through an electromagnetic lens to power densities of  $10^8$  W/cm<sup>2</sup> and above.

## Drilling depth effect

With almost all materials, the power density of  $10^8$  W/cm<sup>2</sup> is sufficient to produce a vapour capillary in the material which is surrounded by a cylinder of molten material. The vapour capillary constitutes the basic hole.

## Backing material

In order to ensure close diameter tolerances from one drill-hole to another, a backing material which produces a large volume of gas through the effects of the electron beam is employed on the reverse side of the workpiece to be drilled. This gas expands explosively through the capillary and ejects the cylinder of molten material surrounding the capillary.



The principle of EB drilling

## Drilling pulse

The electron beam works with a steep current pulse and sharp up-slope and down-slope edges at the drilling position. The main drilling parameters are controlled very precisely. The pulse time and the beam current level of the pulse ensure that a highly reproducible quantity of energy is made available from pulse to pulse where no variation in pulse energy is desired.

## Flying drilling

The high frequencies used for drilling with the electron beam result from an optimized combination of the deflection of the beam, the workpiece

manipulating device and a process control which fulfils all the require

ments of sophisticated EB applications. The workpiece is continuously rotated in the drilling process. During the drilling operation, the beam is simultaneously moved along the workpiece surface.

In between drilling operations, the beam is cut off and is restarted exact at the new drilling position with the next drilling pulse.

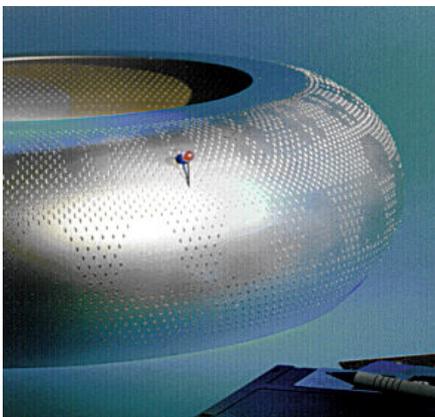
No competitive drilling process uses this so-called flying drilling technique which forms the basis of the outstanding efficiency of EB drilling technology.

Steigerwald drilling technology is an unrivalled expertise. There are numerous industrial applications for the EB drilling process - a technology that is technically mastered by Steigerwald Strahltechnik. The optimum results are obtained in terms of drill-hole shape, reproducibility of shape, roundness and diameter tolerance from hole to hole with the single pulse method in which only one pulse is used per drill-hole. This process calls for power of a magnitude which can only be provided by a new switched-mode high voltage power supply with a direct bias control and a Steigerwald drilling generator - power which no other drilling technology can match.

## EB drilling in action

### Hard material - no problem

Virtually all metallic materials as well as ceramics can be drilled with the electron beam, regardless of their hardness, reflectivity, special alloy components or high thermal conductivity. The illustrations show workpieces comprising high-temperature alloys which cannot be



Combustion chamber housing 47.45.01  
3,746 drill-holes with 0.9 mm diameter

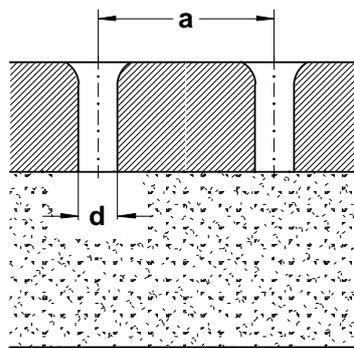


Spinner used in glass fibre production 47.45.01b/7  
25,600 drill-holes with 0.55 mm diameter

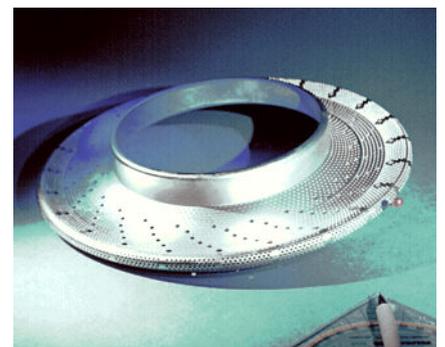
drilled at all with other drilling processes or only considerably less efficiently.

### Hole pattern, hole angle - freely selected positioning

The permissible minimum distance between drill-holes ( $a$ ) is of the order of two to three times the hole diameter ( $d$ ) and is dependent on the dimensions of the hole. For example, holes with a diameter of 0.9 mm can be made in 7 mm thick material at intervals of twice the hole diameter. In the case of extremely small drill-holes with free diameters of 0.1 mm in 0.5 mm thick sheet, the minimum distance between drill-holes is three times the hole diameter. The conical form of small drill-holes with large diameter to depth ratios (1:8 to 1:10) places restrictions on the distance between drill-holes in this example. If one uses the densest possible hole arrangement, open areas of up to 22 % can be achieved.



Limits for the distance between drill-holes

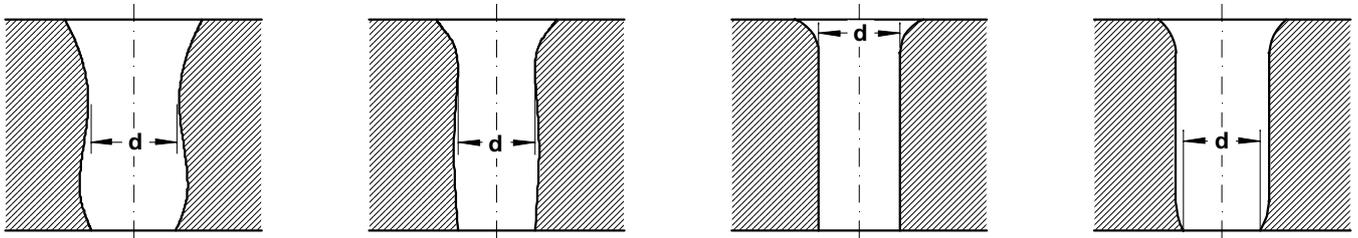


Mixer disc 47.45.01g/03  
2,340 drill-holes with 0.9 mm diameter

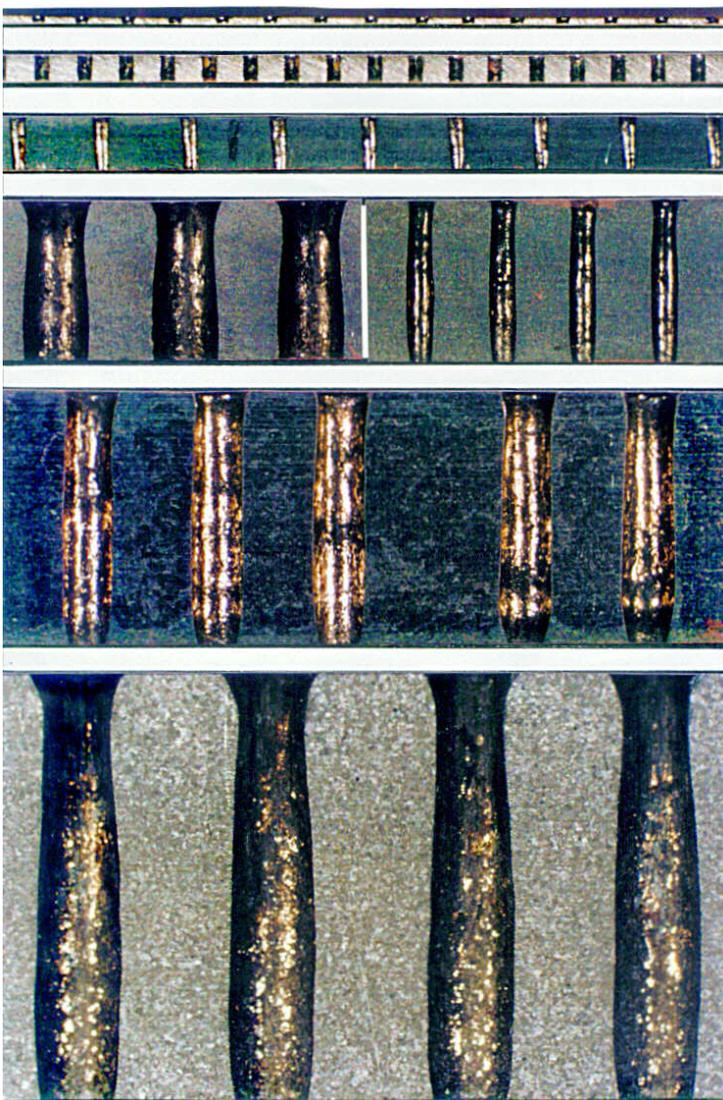
The accuracy of the drilling positions is dependent both on the workpiece dimensions and on the positioning accuracy of the manipulating equipment. For example, a positioning tolerance of  $\pm 14 \mu\text{m}$  is achieved on a sheet which is clamped on a rotation / linear-feed unit with the 630 mm drum.

The centre line of the drilled holes can be inclined at an angle to the surface of the workpiece. This is possible over a wide range whereby angles of  $25^\circ$  in relation to the workpiece surface can be achieved;  $20^\circ$  is possible in exceptional cases.

## Shapes of EB drill-holes



Typical shapes of drill-hole cross-sections



Cross-sections of EB drill-holes  
in CrNi steel

### 0.1 mm *Drill-hole shape*

0.5 mm  
1.0 mm  
3.0 mm

EB drilling can produce the drill-hole shapes shown in the diagram. Specifically required forms can be obtained by varying and optimising the work parameters over a wide range. The diameter-to-length ratio also influences the drill-hole shape.

At the beam entry point, the drill-hole normally features a slight rounding. The edge at the beam exit point is always sharp and burr-free.

### 5.0 mm *Metallurgy - minimum thermal influence*

The EB drilling process is a thermal process. The material to be removed is locally heated, melted and partly vaporised. Although the major part of the molten material around the vapour capillary is ejected, a thin, 5 - 10  $\mu\text{m}$  thick, resolidified layer is left behind on the wall of the drill-hole.

8.0 mm

No oxidation is likely in these layers as the drilling process is carried out under vacuum.

# EB drilling technology - hole sizes and drilling frequencies

## Application range for EB drilling

The green marked area of the diagram shows the range of applications for drilling ferrous materials covered by the standard generator G 96 PM.

For drilling very small holes as for example with a diameter of only 50  $\mu\text{m}$  in 0.3 mm thick stainless steel sheets the special generator G 33 PM is available. Contradictory to this the high power generator G 120 PMS extends the drilling range to hole diameters up to 1.1 mm and 7 mm in length. The application boundaries can vary with other base metals.

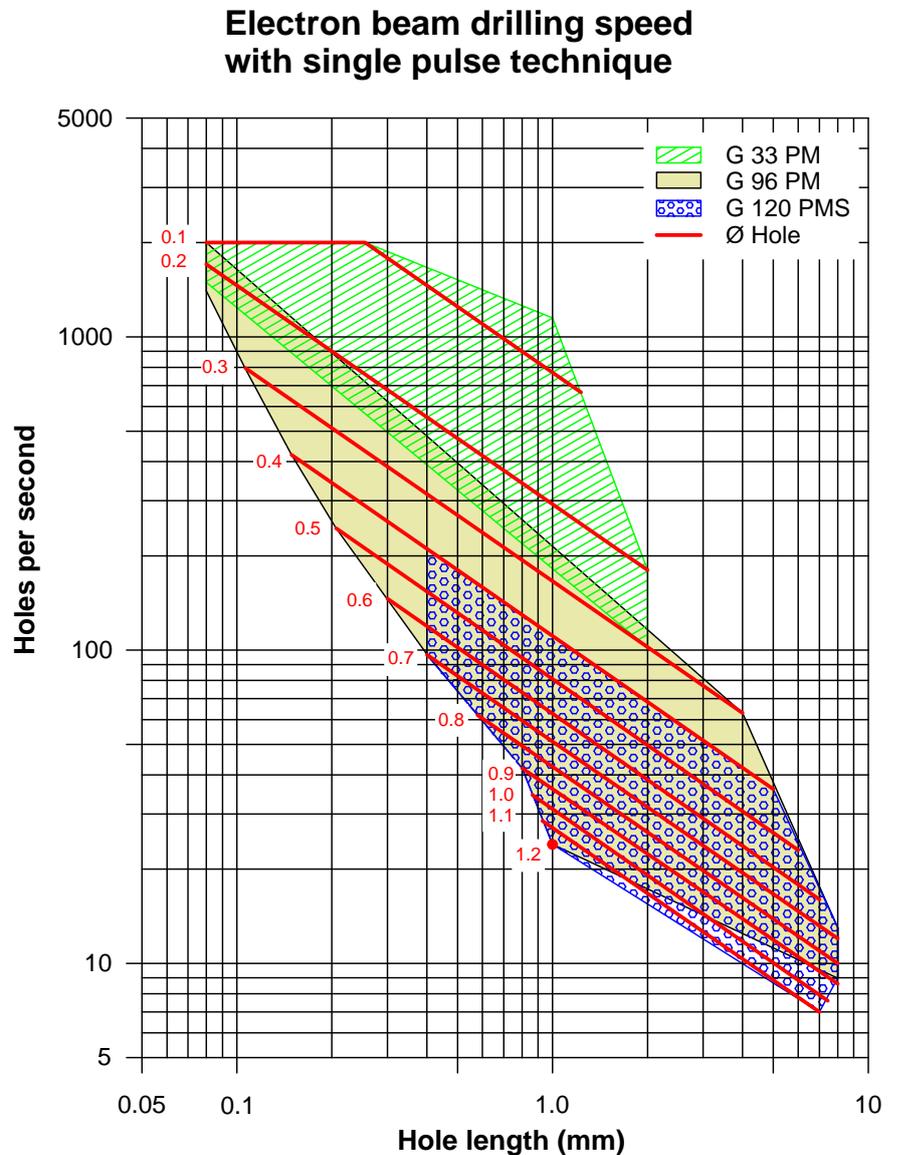
## Fast - up to 2000 drill-holes per second

An important advantage of electron beam drilling lies in the high drilling frequencies which no other process can match. The diagram shows the relationship between the drilling frequency and the length of the drill-hole.

For example, 100  $\mu\text{m}$  diameter drill-holes can be drilled in 0.3 mm filter sheet at frequencies of 1500 to 2000 holes per second. In this example, each individual hole has a volume of around 0.004  $\text{mm}^3$ . With larger drill-holes of, for instance, 0.7 mm diameter and 5 mm length, frequencies up to nearly 20 Hz are possible. Here, the drill-hole volume is approximately 2  $\text{mm}^3$ .

The diagram assumes that the holes are drilled in a suitable drill-hole arrangement on a cylindrical workpiece which permits the use of flying drilling.

Even at high drilling speeds, it is possible to vary the process parameters from hole to hole as all parameters are outputted as electrical quantities.



Application range for EB drilling

Laboratory tests have also been carried out at Steigerwald Strahltechnik with multiple pulse drilling. This technique is used only in isolated industrial applications.

In the percussion process for producing deep holes by multiple pulses, the focal point of the electron beam is controlled right inside the drill-hole.

In high-frequency trepanning, the pulses are positioned along given contours by means of a computer control.

The drilling of oval holes or slots in thin sheets is particularly straight-forward.

## The electron beam drilling gun

The EB-generator, the work chamber with the workpiece manipulating unit, the vacuum installation and the CNC control are the main assemblies of a drilling machine.

### The generator

On standard machines, the EB generator is mounted vertically on the work chamber. It consists of several sections.

The top section contains the beam generating system comprising the thermally operated cathode, the Wehnelt cylinder and the anode. An accelerating voltage of 120 kV is applied between the cathode and anode. The vacuum system of the generator, consisting of the turbomolecular pump, the backing pump, gauge heads and valves, is connected to the second section. When the work chamber is vented for changing the workpieces, a valve protects the beam generating section from the work chamber with a vacuum-tight seal.

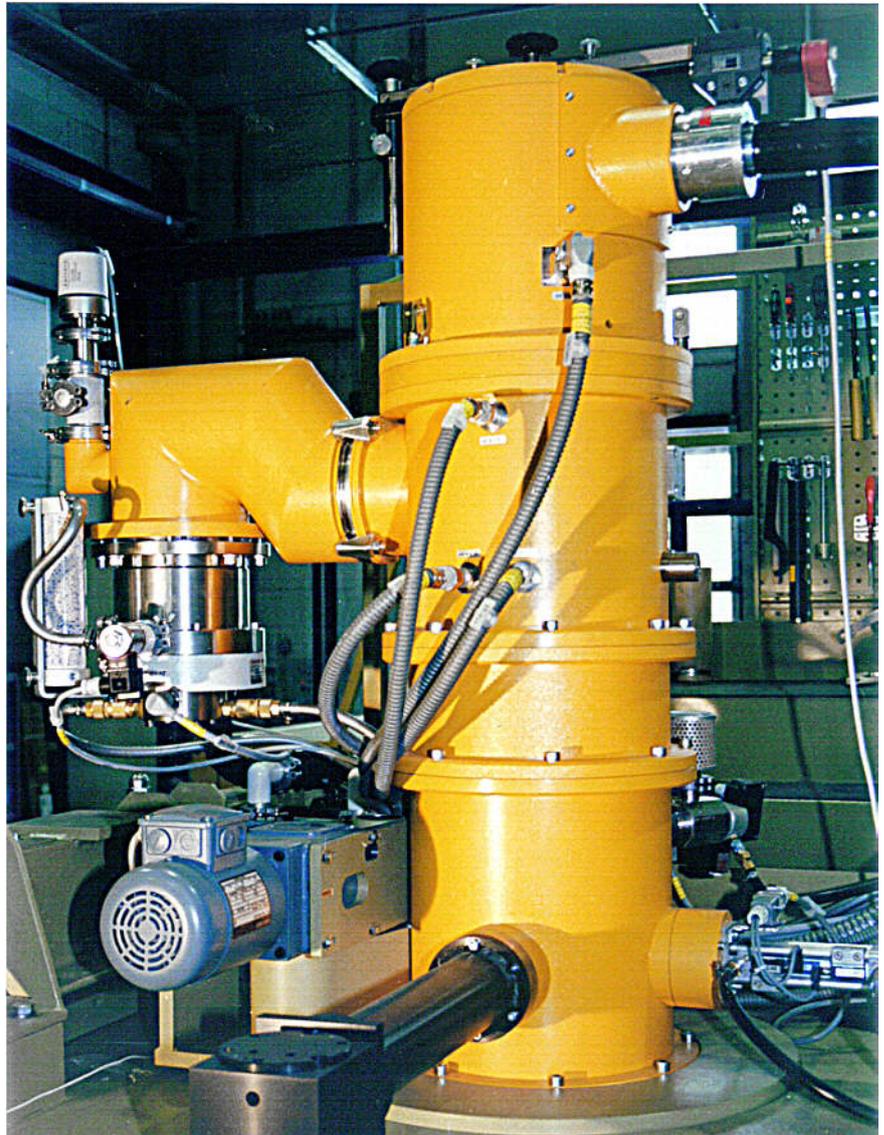
The third section is an intermediate control tube which is added due to electron-optical reasons.

The fourth section contains a movable Faraday cup and the beam diagnosis system which monitors the intensity of the beam.

The fourth section is followed by the electromagnetic system containing the focussing lens, stigmators and the beam spot following system which makes flying drilling possible.

A screening device below the generator ensures that the material which is ejected during the drilling process cannot enter the generator and cause malfunctions.

An EB drilling generator has no wearing parts - unlike a solid-state laser.



Drilling generator G 120 PMS

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The only replacement part is the inexpensive filament of the cathode.

### Beam quality - the key to drill-hole quality

Excellent beam properties are a vital prerequisite for good drilling results. The roundness of the beam, the constancy of its diameter and the symmetry of the energy distribution in the beam are the most important features here. Therefore, the requirements that must be fulfilled by an electron beam

for drilling are much more stringent than for welding. The beam current, the pulse duration, the current of the focussing lens and the working distance are the main parameters in the drilling process.

# Sophisticated manipulator systems

## The chamber

The size of the work chamber is determined by the size of the workpieces and by the drilling application. Various workpiece manipulating units are available to suit different workpiece types and drilling duties.

Rotation/feed units (PDS) for flat workpieces (sheets) and 4 or 5-axis manipulators for symmetrical and asymmetrical shaped workpieces have proved successful as standard manipulating units. The PDS unit, with adjustment in the z-axis, accepts sheets which are loaded in cylinder form on a drum or other cylindrical workpieces. The backing material is pressed on from inside either mechanically or pneumatically or is poured on so that it adheres to the reverse side of the sheet. During the drilling process, the drum is rotated continuously beneath the beam. When one row of holes is finished, the x axis adjustment facility pushes the drum into position for the next row. The mechanical height adjustment of the drum shaft allows the optimum working distance to be set for the drum or workpiece diameter concerned.

Workpieces of other shapes can be positioned by means of multi-axis manipulators. Two or three linear axes and two rotational axes offset by 90° permit virtually any drilling position in relation to the beam axis, including for applications involving holes to be drilled at an angle to the workpiece surface.

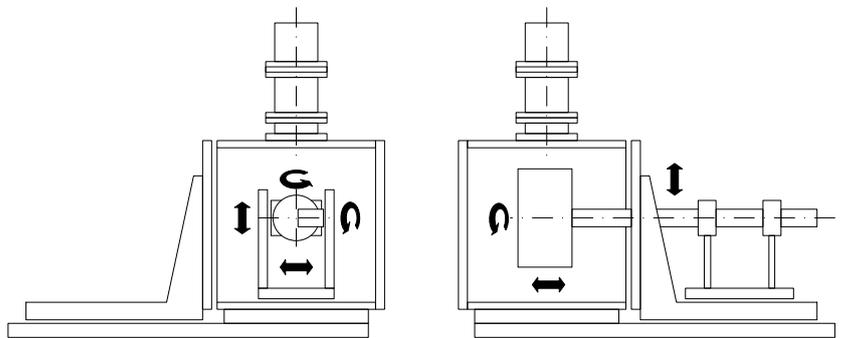
A rotation/feed unit and a 4-axis manipulator can also be combined on a single chamber. In this case, the 4-axis manipulator is arranged on a mobile slide with its own chamber door on the left-hand side of the chamber, while the rotation/feed unit is arranged - likewise with its own chamber door - on the right.

Custom-designed machine concepts can be realized for drilling duties which cannot be fulfilled with standard equipment.

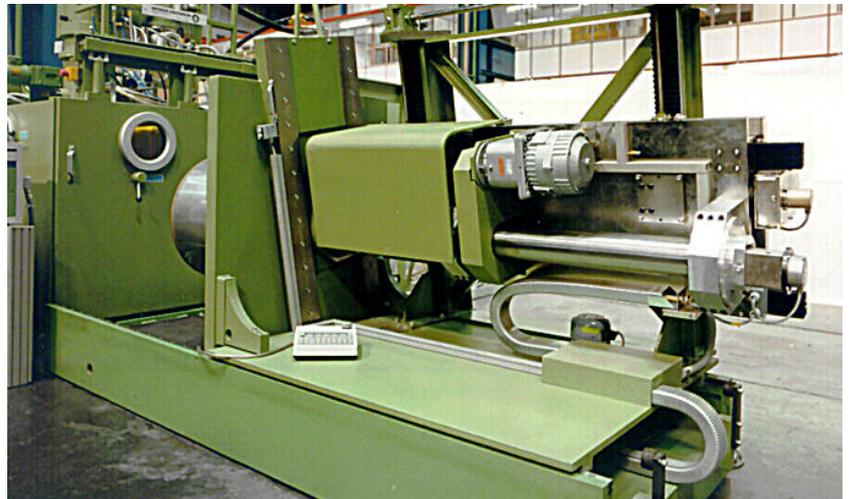


4-axes manipulator 'oszillant'

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Schemes of the manipulator systems



## The control console

Two control systems which communicate with each other form the command centre of a drilling machine - a freely programmable control (PLC) for the logic sequences of the machine and a process control (CNC) which controls the drilling process.

The process control and the PLC are linked via a data and signal transfer line to enable the EB drilling machine to be operated with automatic work sequences. Apart from observing the machine, all what the operators have to do is change the workpieces and start the automatic process.

The control console of a drilling machine consists of:

- the integrated CNC/PLC monitor
- the CNC keyboard
- a control panel
- optionally a video monitor

### The CNC process control

The EBCON® 6 CNC control has been specially developed for EB drilling applications. It is the sole key to the

efficient use of EB technology, the precision of the process and the flexibility of the drilling systems for different drilling applications.

The CNC is extremely simple to operate. Programs can be entered either directly through the keyboard of the control or generated at an external programming station.

Internal computing programs simplify programming considerably. For instance, in order to program a row of holes along the circumference of a workpiece, it is only necessary to enter the number of drill-holes required. From this, the CNC calculates the positions of the individual holes.



Control console of an EB drilling machine

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If a malfunction should occur during the drilling process which could lead to undrilled holes, the CNC memorizes the position of the last completed drill-hole and, when the fault has been remedied, resumes drilling at the next drilling pulse with pinpoint accuracy.

All the main parameters of the drilling process are controlled by the CNC. These are the pulse current and the duration, the drilling frequency and the frequency-related beam spot following as well as the current of the focussing lens.

The CNC is also responsible for the commands for controlling the axes of motion, this means in particular the positions and the speed of the axes.

### The control monitor

The monitor screen shows in free selectable function displays all information and data which are necessary to operate the machine. Different program menus and submenus are available and enable an orderly and user-friendly operation. For instance the monitor displays the start-up and switch-off routine, a pump status diagram, the set-up and adjustment of the generator, all electrical and mechanical actual values of the generator parameters and manipulating units as well as error and maintenance messages and at last the CNC programs themselves or their status during a program run.

## Technical data

Generator		Type		
		G 33 PM	G 96 PM	G 120 PMS
Accelerating voltage	kV	120		
Beam current at workpiece	mA	1 – 28	1 – 80	1 – 100
Maximum pulse power at workpiece	kW	3.3	9.6	12.0
Working distance	mm	35 – 100	35 – 150	35 – 150
Pulse length	µs	50 - 30,000		
Maximum frequency of spot following	Hz	3,000		

Chamber		Type				
		K 6	K 12	K 16	K 19	K 24
Chamber volume	m <sup>3</sup>	0.63	1.28	1.63	1.91	2.54
Maximum processable workpiece dimensions						
Diameter	mm	320	637	1,000	1,000	637
Length	mm	400	600	500	500	950

Manipulating units		Type	
		Rotation/linear feed unit PDS	4-axes manipulator Oszillant

EBOPULS-E

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