The actual EB application spectrum and its prospects beside welding

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Since the industrial use of the electron beam as a reliable high power precision tool for challenging welding tasks, its properties have been applied to a wide application spectrum in manufacturing and scientific environment. The continuing demand on increase in productivity leads the development to enhance e.g. deflection speed, beam power and pulse rates as well as the software functional range, therefore new prospects beside the established welding process come apparent.

Реален спектър на електроннолъчевите приложения и техните перспективи извън заваряването (Бьорн Хансен, Торстен Льоуер). *От началото на промишленото използване на електронния лъч като надежден и с висока мощност прецизен инструмент за решаване на различни задачи за заваряване, неговите свойства са били приложени към широк спектър приложения в производството и в научните изследвания. Продължаващото търсене на по-висока производителност на заваръчния процес води към развитието на нарастващи скорост ти на отклонение на снопа, мощност на лъча и честотата на импулсите, както и софтуер за функционалния обхват, следователно стават ясни нови перспективи, освен установените режими на заваряване.*

Introduction

The technological progress on the EB technology offers a wide field of application. Nowadays industrial EB machines are custom-tailored but in general provide the opportunity to be used as a multipurpose tool. However, the technical specifications limit their usability as followed.

Systems engineering

A. High Voltage

The high voltage supply for industrial machines has been modified lately to provide a more stable processing. Therefore high voltage ripple can be reduced from 15 to less than 3% by the use of pulse width modulated power supply instead of a frequency modulated which causes a less distorted electron optical monitoring and provides a stable energy source for all processes (fig. 1).

For pulse processing, the beam current close-loop-control uses a look-ahead routine to fasten the response characteristics. Slew rates for pulses can be reduced to about 3 µs (for EB drilling processes). Furthermore arc-management algorithms can be adjusted to instantly interpret the high voltage level to improve process monitoring and just detect arcs which influence the process.

Fig. 1 Frequency modulated- (left) vs. pulse width modulated (right) high voltage source

B. EB generator and periphery

Currently used deflectors are optimized to their processing application. For high speed processing, a standard 60 kV industrial beam deflection unit runs about 1000 times faster than a comparable laser deflection system (4 kW) and is fairly independent on the beam current. Additionally there is the option to use a high dynamic z axis too, which offers the opportunity to 3d scan in high frequencies. However the maximum deflection angle and speed decreases with the increase of the high voltage level. Regarding the course of beam, it can be stated that beam parameter products down to 0,5 mm*mrad (low power tasks) are within reach on industrial systems. Referring to this, fine engravings can be done and the resolution for electron optical monitoring can be raised. Moreover process monitoring utilities such as CCD cameras, x-ray detectors, pyrometers or interferometry can observe in situ the beam-workpiece interaction.

C. Software and function generator

Depending on the system which is used, there are many possibilities to use digital image processing. To prepare the process, the beam can be automatically aligned (centering, stigmatism and calibrating the deflectors) and the workpiece can be scanned by the beam in order to get the correct start coordinates (contour tracking). Moreover it is possible to scan a workpiece with the electron optics before the process in order to compensate slight magnetic fields which would deflect the beam from its programmed path. Due to the fast electrical axis, it is also feasible to observe the process by switching alternatingly from the processing mode to the electron optics mode.

Furthermore new generation of function generators let the user intuitively generate multi beam patterns in order to solve complex beam guidance.

Process overlook

A. State of the art processing

Mostly common tasks for the EB are located in the direct industry manufacturing. For steel with carbon content < 0,18 mass%, the EB can be used for a solid state self-quenching process. Depending on the workpiece (e.g. camshafts, piston rods, vent seats and extruder screws), the scan method has to be chosen (line hardening, field hardening or flash hardening) and parameters have to be determined. Hardening depths can reach up to 1.7mm depending on the mass of the workpiece, the material compounding and the beam parameters. Available cam hardening- machines are quite effective and reach a daily capacity of about 4000 pieces which makes them cost-effective for large-scale production. Workpieces in most cases do not have to be reworked for surface quality. The process has a typical steep hardening gradient as shown in fig. 2.

The hardness reaches up to 800 HV and can be assumed to be fluctuating in a range of about +/- 50 HV over the effective hardening depth until it decreases rapidly to the base material characteristics.

The main advantage is the flexibility for partial hardening of functional surfaces. As a consequence, it is possible to keep the inner ductility of a part for higher dynamic strength and process only the areas where friction occurs or forces are induced in the work-piece. In addition it is possible to process several areas with different power densities simultaneously.

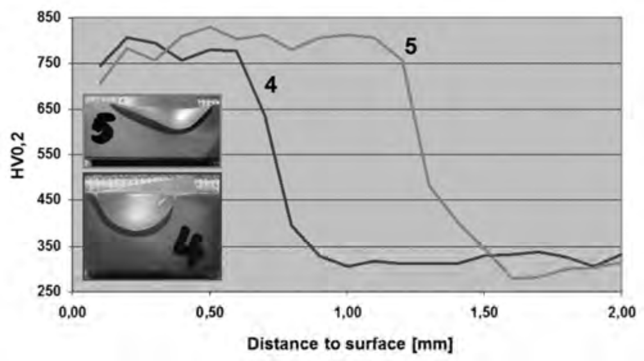

Fig. 2 Typical hardening depth on EB processed workpieces

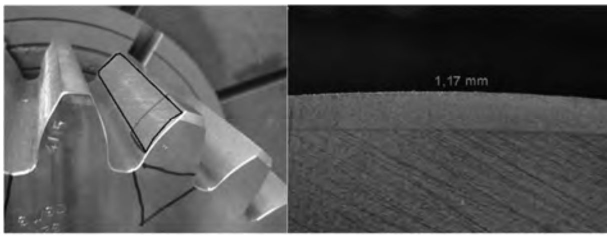

Fig. 3 left: Gear-wheel prototype EB hardened tooth flanks, right: Hardness increase zone (tooth cross section)

EB drilling and cutting of sheet metal processes are mostly present in the food, paper and insulating industries. A highly focused beam drives the process by melting the material in µ-s pulses, which causes a melt pool evolving in the material due to thermal conduction. The molten material is casted out the keyhole by the expansion of an underneath backer which evaporates abruptly when the beam irradiates on it (silicone compounding). Holes from 60 µm in diameter can be achieved effectively depending on the sheet thickness matching aspect ratios up to 1/20. Concerning the process stability, 4 to 6% of the holes are potentially out of tolerance. Beside holes, also narrow slots can be cut out (fig. 3).

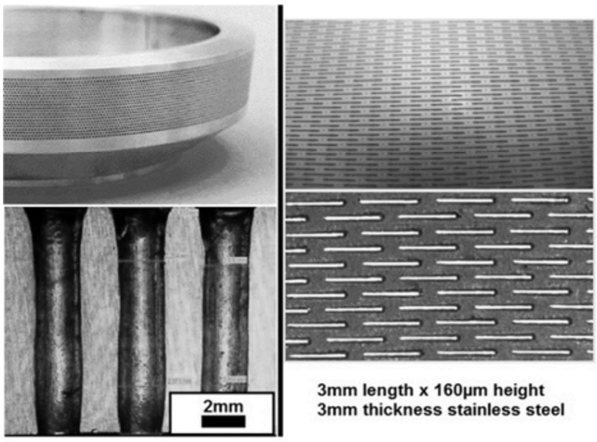

Fig. 3 top-left: Sieve food industry, bottom-left: drillings in 10mm material thickness, right: slot drilling in stainless steel

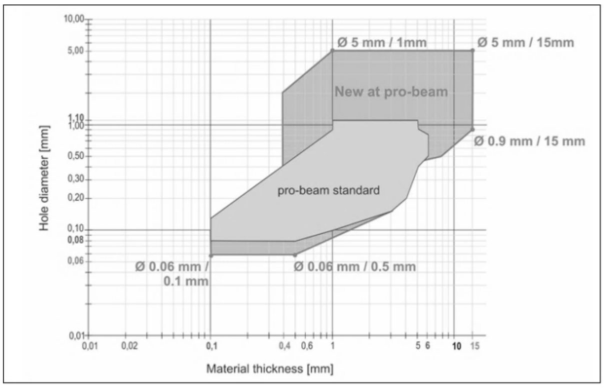

Fig.4. EB drilling spectrum (hole diameter vs material thickness) at pro-beam

At present, there can be provided a range of hole-geometries like in fig. 4. When taking laser drilling as a comparison (where typically holes within a range of 10 µm to 250 µm are drilled), the EB drilling process is usually more cost-efficient at higher output rates and bigger hole diameters.

B. Emerging processes

To the thermal induced processes, there are some processes to mention which modify the surface in structural, mechanical or chemical way such as micro structuring, surface sculpting and additive manufacturing, layer removal and cladding / hard surfacing.

Micro structuring (fig. 5) is used for example to precisely put micro cavities with short pulses in a functional surface in order to improve tribological properties. In this case wear can be reduced on sliding surfaces and the micro structure can be helpful as a failsafe running function. Conventional cavity depths lie between 20 and 1000 µm and the surrounding material is optionally hardened in a following step.

Surface sculpting describes the partial melting of a surface in order to move the material to a defined spot or area. Fine fins, honeycombs and high aspect ratio features can be realized on the base surface. Promising application field is the design of heat exchangers in order to enable custom thermal flow optimized structures which would lead to significant raise of efficiency (up to 63% compared to conventional systems) [1]. This method could be stated rival to additive manufacturing but tends to be faster for small structures.

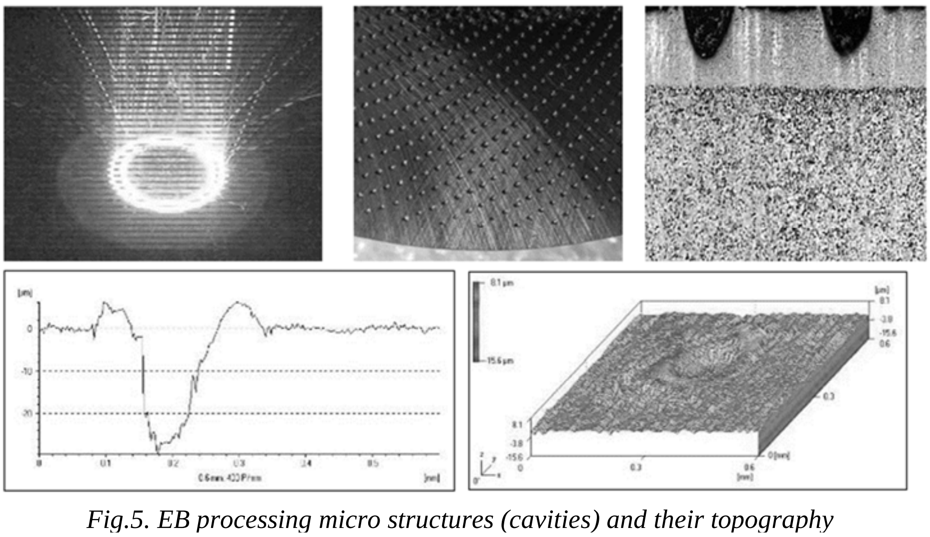

Fig.5. EB processing micro structures (cavities) and their topography

The removal of thin layers in a defined structural design is again a laser dominated field of application, but has also the potential to higher effectiveness because of the limited laser scan speeds. However it is restricted to short pulses, ablation by sublimation (cp. ultrashort laser pulses) due to pulse lengths underneath the picosecond regime is not feasible. Thermal input can be rather reduced by high scan velocities. Application in optics and electronics (e.g. partial removal of anti-reflex coating layers or scribing on semiconductors) could be possible.

When changing materials characteristics with a non-thermal induced mechanism of action, there are processes like EBID (electron beam induced deposition), electron sterilization or plastics modification to mention a few.

EBID works by setting up layers from decomposing molecules with a very fine electron beam. Molecules have to contain atoms which match the target material. Resultant nanostructures may be used for repairing masks used for the chip industry.

An already wide spread application is the electron sterilization meaning the penetration of the target in order to expose the target to the ionized radiation which leads to germ-killing. Free radicals also neutralize DNA and virus fragments which makes the process interesting for food and medicine industry. The radicals are also used for radical polymerization on lacquer coatings containing vinyl and acryl groups which is quite ecologically because no solvent is needed [10].

Material modifications- especially on synthetic or biological polymers can be also done in order to achieve better mechanical properties, smoothen / roughen the surface topography or change the wetting behavior on technical surfaces.

Conclusions

The EB technology offers a wide range of process possibilities due to its power scalability, flexible beam guidance and the physical properties of the beam-material interaction. Besides welding, some industrial processes (hardening, drilling, micro structuring, engraving or electron beam melting) have become accepted which mostly direct compete with laser processes. Though, the full potential of EB processing seems not to be used yet.

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