Innovative Applications of Fully Automated Electron-Beam-Welding for the Transportation Industry

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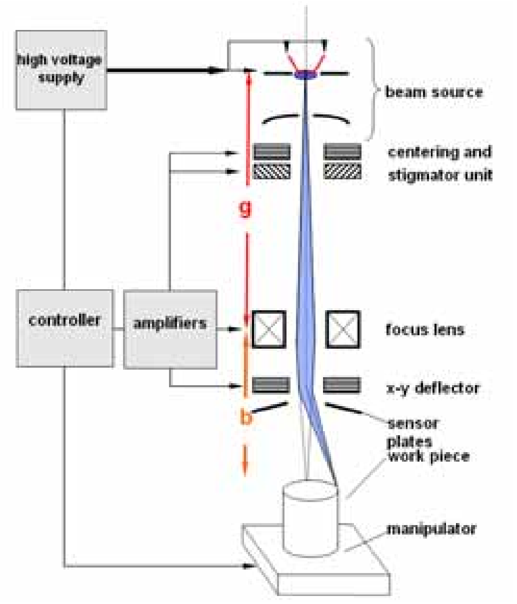
Summary

Electron beam welding is a rather old process compared to the laser process. Already in 1949 there were first successful applications using the energy of the electron beam. These were EB-welding and EB-drilling. With the discovery of the "deep welding effect" the EB welding process is the preferred process for thicker material. Ever since, continuous development showed the potential of the EB-process which has been utilized due to the economical and technological advantages for more and more applications. The range today covers work pieces that have tons of weight, mid size series for the machine building industry and also mass production for automotive. This paper will show the working principles of the present EB-technology followed by various examples of the aircraft, rail, marine and automotive industry, which benefit from its advantages.

1. Working Principle of an Electron Beam Welding Machine

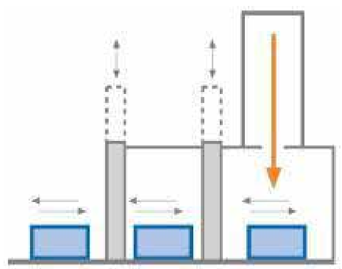
The energy source for electron beam welding is the free electron. These are emitted by means of thermal emission from a tungsten cathode.

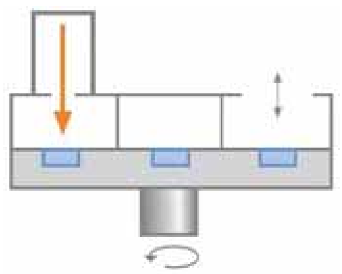


Picture 1:
Setup of an Electron Beam Generator.

The electrons are emitted from the beam source. Followed by a series of magnetic coils of which the focus lens is the most important as it focuses the beam onto the work piece surface. Below the focus lens there are deflector coils that can control the movement of the beam across the surface of the work piece. The electron beam generator is controlled by an up to date CNC, equivalent to modern milling machines.

A strong electrical field between the tungsten cathode and the anode accelerates the electrons. They accumulate high energy usually between 60keV and 150 keV. This kinetic energy of the electrons is converted into heat when the electrons hit the work piece. This process takes place in vacuum as the movement of electrons would be diverted as soon as they collide with any gas molecule. A widened beam of electrons would not have enough energy and energy density to perform welding. The work piece is mounted on a CNC controlled table that takes care of the necessary movements. Today's machines offer lock load systems (Pic. 2) to handle the transport into and out of the vacuum chamber. Thus, the required vacuum does not cause any non productive times.





Pic. 2:
Left: Lock Load Shuttle Machine *Right: Lock Cycle Machine*

1.1. Positioning and Welding with the Same Tool

When electrons hit the surface of the work piece some of them are rejected due to the physical Coulomb effect with almost unchanged energy levels. The so called rejected electrons can be detected by a special sensor. The analysis of the sensor signal reveals information about the surface of the work piece. Similar like electron microscopes do state of the art electron beam welding machines utilize this information for automation purposes.

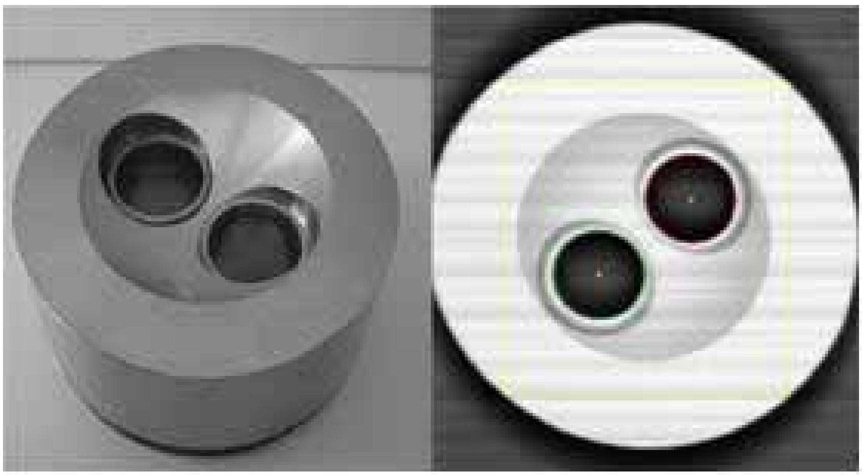
a) b)

Pic. 3:
Application of rejected electrons for visualization

a) shows pictures of the identical work piece, on the left taken by a regular light optical camera with usual light reflections, whereas the right is the much clearer electron-optical picture.

b) shows the contrast given by the two different materials used to make an EURO coin. The contrast between the different materials is easy to distinguish. The different metal atoms of the two alloys result in different power of the coulomb effect. This makes it possible to use the electron optical visualization for automation purposes

The mentioned possibilities to create a clear picture offer a wide potential for automated welding processes. Modern electron beam welding machines use the visualization to measure and position the joint of the work piece. Automated joint detection makes the process fully automated without any manual interaction necessary.



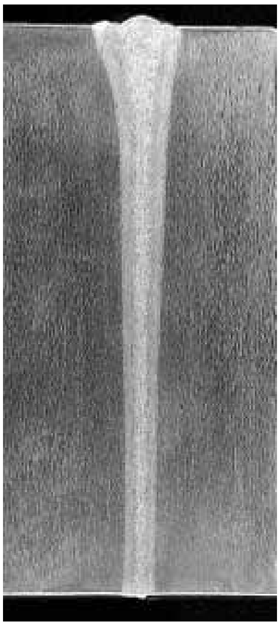
Pic 4:
Application of visualization and image processing in modern EB-Welding machine.

For this work piece two tubes have to be welded into the body. With the image processing of the electron optical image the center of the two tube is automatically identified. This has been of mayor interest for the manufacturer as the cost for a defined positioning of the work piece could be avoided.

Utilizing an identical tool, the electron beam, for measurement and position as well as for the core process of welding offers a big economic potential. For welding only a higher beam power is applied. The possibilities for the image generation and processing are "built in" anyway and do not require any extra components for the machine (except intelligent programming).

2. Applications

The electron beam can weld a variety of different or even dissimilar materials. Also reactive materials are welded with the EB. A little overview is shown in Pic. 5.



steel, 150 mm

Bronze/Steel, 30 mm

Aluminium, 40 mm

Copper, 35 mm

Stainless, 2 mm

Pic 5:
Examples of different welds made by EB-process

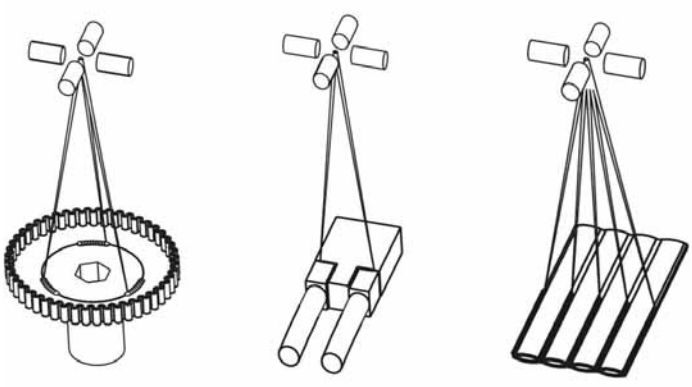
The electron beam offers the so called deep welding effect. Due to the high energy density onto a local spot there are advantages in quality and process sequencing. Single pass welding depth for steel of 100 mm and more are possible, for Aluminium even 200 mm are achieved. The welding depth limit is mainly given by the power rating of the machine. Welding speed vary according to the depth and the process requirement between a few mm per second to several 100 mm per second.

3. Fast Beam Deflection and Multi Pool Welding

The electron beam can be deflected by magnetic fields, similar like shown for the scanning of a work piece shown in picture 2. Due to the limited mass of the electrons the beam can be deflected with almost no inertia. The possibilities for deflection processes are not limited to image generation.

The electron beam can be deflected very fast using appropriate magnetic coils. Thus welding can be done at more than one spot. The deflection system must guarantee to be so fast that the beam returns to each spot after only a few milliseconds to feed more energy into the weld pool. Metallurgical this does not affect the quality of the weld. Distortion can be positively influenced by introducing the welding energy symmetrically over 3 spots, each 120° apart on an axial weld as shown in picture 6 below.

Rapidly changing magnetic fields controlled fast deflection or focusing coils offer further applications like online joint detection or per and post heating. By modifying the focus current the beam can follow changing working distances like in contour changing work pieces of turbines or rotors.



Pic 6:
Applications for fast beam deflection
Shown are different possibilities for "splitting" the beam to be utilized at multiple pools.
Left: minimizing distortion and increasing productivity
Center and right: productivity increase

4. Applications of EB Welding in Transportation Industry

Demanding tasks for aircraft industry, automotive volume production or safety related components for the rail industry arise for EB-welding anytime. Besides the small seam, the low energy input and thus the resulting minimized distortion are the technical key advantages of the electron beam process. The high welding speeds or even productivity increase by multi pool welding and the possibility for automated and unmanned joint detection economically convince manufacturers to apply electron beam welding.

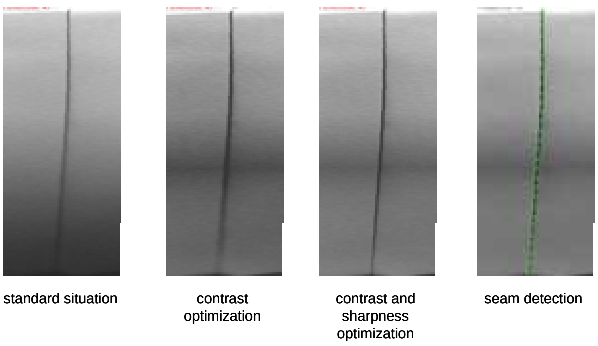
5. Unmanned Welding of Ring of Vanes for Aircrafts

Safety requirements for aviation components call for high standards for the welding process. One of the most advanced electron beam welding machines is currently used by Rolls-Royce for welding titanium components of Trent jet engines.

The ring of vanes (ROV) for a front bearing housing is a structural component of a Trent jet engine. It is assembled from individual vanes and panels which are joined using electron beam welding. Due to the size and complexity of the part and due to thermal expansion during the welding process manual positioning of the joints was required in the past.
Key to the automation is a sophisticated scanning process where the joint in between two vanes is scanned. Because of poor light conditions at the joint the scanning parameter have to be adjusted during the scan. Result is a sharp and clear image of the joint which is the basis for an automatic positioning routine.
Using the advanced pro-beam seam tracking system the positioning process was automated resulting in a significant reduction of processing time. At the same time the quality of the welds could be improved since it no longer depends on the skills of the operator.

The machine is operated with a HV electron beam generator. A CNC controlled 5 axis mechanical manipulator positions the part relative to the electron beam. Powerful vacuum equipment evacuates the process chamber to the process vacuum of 7 x 10^{-4} within less then 15 minutes.

***Pic 7**:*
EB welded front bearing housing for Trent 700



Pic. 8
Sequence of images of joint scanning process

Pic 9:
Universal EB welding chamber type K640 with Trent 700 ring of vanes

6. <u>Optimizing the distortion of work pieces in automotive applications</u>

In automotive industry welding of gear wheels is the largest volume application. This is due to the fact that finished machined parts can be welded to form ratchet wheels,, input shafts, flange-shafts, etc.

Concerning shrinkage the radial weld shall be prioritized in design as there is no blockage for the shrinkage. On the other hand axial welding seams have to be applied for design or economic reasons.

Usually distortion that comes during cooling is so limited that the final product is within normal tolerance range. However, harshness is increased due to minimal run out offsets. Therefore even tighter tolerances for run out are considered by symmetric heat input through multi pool welding. Besides harshness minimizing also cost are reduced by increased productivity.

Pic 10:
Ratchet wheel, Optimized run out tolerance range by multi pool welding
Left: ratchet wheel Center: Detail of grooved synchronizing ring Right: Simultaneous multi pool welding

7. EB-welding of piston rods for shock absorbers

Welding of piston rods is a demanding task concerning distortion and the safety inspection requirements.

Pic. 11
Piston rods for shock absorbers
Left: multiple fixture Right: Individual marking by EB-engraving

At the first glance this looks easy. However, the sequence of the individual process steps is quite critical. High tech cleaning to avoid any porosity in the seam. Proper demagnetizing to prevent beam deflecting and thus joining imperfections. Precise assembly which is checked by EB-scanning for tumble. EB-scanning for exact beam positioning, tack welding. Followed by work piece preheating just locally at the joint to prevent an increase in hardness above tolerance range. Welding and finally engraving an individual number onto the work piece surface. All process steps are logically controlled by the CNC and engraving only takes place if all previous process steps have been completely fulfilled without deviation. Finally a 100% run out check and ultra sonic testing for welding imperfections is made All data are documented in an integrated data protocol which guarantees absolute traceability for any individual work piece.

8. Engine block Cooling Channel

To upgrade the power output of a gasoline engine the diameter of the cylinders has been increased. Thus the wall between the cylinders of the cast engine block was to thin as to allow for casting of a cooling channel. Therefore a groove of 0.8 mm width has been milled in the wall between the cylinders forming the cooling channel. To close the top after machining an Al-sheet was inserted and EB-welded on both sides with a seam of 8mm depth. The quality of the seams had to assure the water tightness. The volume production at the OEM was realized by lock-load transfer EB-machine.

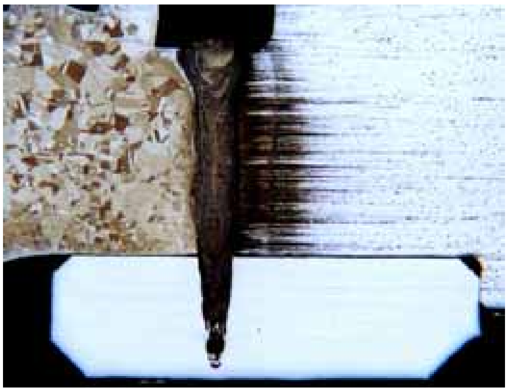
Pic. 12
Engine block with welded cooling channel
Left: Top view of the engine block *Right: Macro cross section of cooling*

Pic. 13
Lock-Load-Transfer EB Machine for 4 Cylinder Engine Blocks

9. EB- Welding of Pressure Sensors

Pressure sensors for common rail injection systems require almost contradicting conditions. On the one hand the welding seam has to be very deep to stand the pressure of about 2.000 bar and on the other hand the heat input has to be limited not to damage the nearby electronics. The electron beam could offer the solution by welding a extremely narrow seam with a ratio of depth to width of 12 : 1.

To avoid any out of specification welding the assembled sensors are measured by EB-scanning just before welding. As these tiny work pieces have a higher risk of tumbling this criterion is scanned. Only when it is within the allowable range the welding process starts. Otherwise the work piece will be rechecked for reassembly. Volume production of these sensors is realized on 2 lock-load-shuttle machines each with 20 spindle fixtures. The cycle time for 20 work pieces is about 90 seconds.



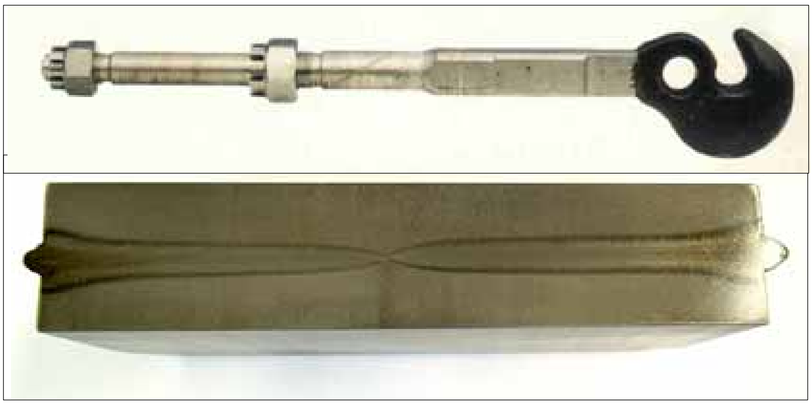
Pic. 14
Pressure Sensor with macro cross section showing the seam connecting 3 dissimilar steel grades

10. Safety Parts for Rail Industry

Rail industry is well known for their high levels of requests in regard to reliability and safety. Such components are the railcar couplings. For cost reduction purposes the couplings were redesigned and split into the coupling ring and the housing. This should alow to manufacture all different varieties from standardized rings and housings. The EB-process has been choosen for the radial welding connection.

Pic. 15
Two different Railcar coulings

For regular locomotive hooks the design has been changed in the same manner. The hook itself is forged and the long shaft is made from rolled or longitudinal forged bars. The rectangular cross section is welded by two EB seams, one from each side.



Pic. 16
Locomotive Hook
Top: Completed Hook Bottom: Macro Cross Section

11. <u>EB-Welding of Hightech-Propulsion Systems for Marine Industry</u>

Large towing boats in a harbor are required to rotate on the spot. A core element of this special drive, the rockers arms are welded by two radial welds each with 30 mm welding depth. To guarantee a smooth rotation on the fixture counterweights have to be applied. After welding the seams are 100% ultra sonic tested.

Pic. 17
Rocker Arm for Propulsion System
Left: Rocker Arm on Fixture with Counter Weights Right: Towing Boat rotating on the spot

12. Conclusion and Outlook

After more than 50 years the Electron Beam welding process today is a wide range player in the industry. For any kind of application there are EB-welding machines available. The reproducible quality and the excellent economics are main reasons for this process in the transportation industry. Besides quality the technical advantages of minimal heat input and thus lowest distortion are often the criteria for electron beam welding. The EB-machines today do cover the full range of side processes from tack welding over preheating to joint detection and individual part marking, which is an additional advantage compared to individually sequenced processes. The newer features like multi pool welding and online quality supervision will further enlarge the range of applications for the electron beam process.