Measuring the diameter of electron beam by rotating slit disc

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Abstract. A device for analysing the shape of the electron beam in electron beam welding apparatus has been developed. Experiments has been done with the device. The beam size at different focusing currents and constant beam current has been measured. The performance of the device is shown.

1. Introduction

Electron beam welding is widely used in industries that require high quality manufacturing. This asks for very a precise and stable parameter set. The process is often carried out in vacuum to avoid deflection of the beam and further oxidation of the treated materials.

There is a need for detailed information of the influence of parameters like cathode heating and wear, electron optical alignment, etc [1, 2]. These all influence the beam shape and dimensions and thus the focus conditions. This is especially sensitive when the equipment parameters are fixed within tight tolerances [3, 4].

One of the first techniques for characterization the electron beam consists of a single slit disc and Faraday cup below it. The slit is scanned by the beam and the resulting signal is gathered by the cup. The authors of [5] modified this method by adding a second slit to the disc, perpendicular to the first. The idea behind the two-slit disc is to being able to measure the electron beam in two dimensions simultaneously.

The method proposed by authors of [6] consists of a rotating disc with little pinhole in it. This way the electron beam is measured in “free fall” position and is not deflected. The pinholes are distributed angularly and situated around a mean radius. The signal gathered from the pinholes is relatively low due to their minute radius.

We propose equipment that is combination of the two methods. The idea is to avoid the scanning and deflection of the beam because this could yield additional aberrations which can’t be eliminated after that [3]. That’s why the beam is measured in “free fall” position while the disc is rotating.

The aim of the present study is to develop new equipment for measuring the diameter of the electron beam.

2. Materials and methods

Those kinds of measurements should be performed by either rotating disc or deflecting beam because of the high current density. The rotating disc scanner analyzes the beam in free fall position.
This equipment is based on a rotating disc with multiple slits in it (figure 1). The disc is turning at high speed (up to 3500 rpm). The heat load is relatively low due to the high volume of the disc which assures the evacuation of the incoming energy.

There are 12 equally distant from one another radial slits with width 1mm. Below the beam is situated a small tungsten target in order to gather the signal. The signal after that is taken through a resistance and monitored at oscilloscope. A sample signal is shown in figure 2. The peaks are negative because the electron beam has negative potential when conducting current.

Figure 1. Electron beam chopper device.

Figure 2. Sample signal from an oscilloscope. $I_{\text{beam}} = 5$[mA]; $I_f = 523$[mA].
The electron beam diameter can be calculated using the law of uniform motion

\[ d = t_p v - \delta \]  

(1)

where \( d \) is the electron beam diameter, \( v \) is the velocity of the disc at the point where the beam is falling, \( t_p \) is the duration of a single impulse and \( \delta \) is the width of a slit (figure 6). The velocity is calculated from the time needed for the disc to turn from one slit to the next via the equation

\[ v = \pi r/(6 T) \]  

(2)

where \( r \) is the measured distance between the center of the disc and the falling of the beam \((r=37\text{[mm]})\), \( T \) is the time between the start of two consecutive peaks, and \( \pi/6 \) is the angle between two consecutive slits in radians.

3. Results and discussion

The experiments are carried out with the same velocity with beam current \( I=5 \text{ mA} \) and different focusing current shown in table 1. Images of the gathered signals are shown in figures 2 to 8.

| No | 1     | 2     | 3     | 4     | 5     | 6     | 7     |
|----|-------|-------|-------|-------|-------|-------|-------|
| \( I_f \) [mA] | 523   | 530   | 536   | 542   | 550   | 555   | 560   |

First, we have to calculate the time need for the disc to rotate between two consecutive slits. The period is \( T=1.35\text{[ms]} \) shown in figure 3. The turning velocity of the disc with respect to the electron beam is calculated to be \( v=14.35\text{[m/s]} \) by substituting in equation (2). The method for analyzing the experiment data is shown in figure 10. A typical peak, picked from the gathered signals, is graphed. This graph corresponds to the electron beam that has passed through a single slit. The starting point is chosen near the potential and is this potential difference is plotted against time (the absolute value of the voltage is used because it corresponds to the measured current). Then the duration of this impulse is measured \( t=0.13\text{[ms]} \) in the case if figure 5. The diameter of the electron beam in direction of the turning disc is calculated from equation (3).

Figure 3. Calculating the time for the beam to pass two consecutive slits in the disc.
Figure 4. Different steps in processing the gathered signals.

Figure 5. Duration of a single impulse.

Figure 6. Image of the electron beam passing through a slit.

The calculated electron beam diameters with respect to the focusing current are shown in table 2 and are plotted in figure 7.
Table 2. Diameter of the electron beam with respect to the focusing current.

| № | I_f [mA] | d [mm] |
|---|---------|--------|
| 1 | 523     | 0.865  |
| 2 | 530     | 1.296  |
| 3 | 536     | 2.157  |
| 4 | 542     | 3.018  |
| 5 | 550     | 3.592  |
| 6 | 555     | 3.664  |
| 7 | 560     | 4.74   |

**Figure 7.** Graph of the electron beam current with respect to the focusing current.

4. Conclusion
A device (electron beam analyser) is developed to measure the diameter of the electron beam. The experiments that were carried out show that it is working as intended. The diameter of the electron beam with beam current of 5 [mA] in the plane of the detector is calculated with respect to the focusing current.

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