# ELECTRON BEAM WELDING FOR HIGH GRADIENT SUPERCONDUCTING CAVITY

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*Abstract*

Relations between electron beam welding parameters and geometries of weld beads are studied. It was found that a beam generator position and a welding direction affect a geometry of weld bead dramatically. Carbon including contaminants found after the chemistry are also commented.

## INTRODUCTION

Accelerating gradients of superconducting RF (SRF) cavities have been improved over the last decades. Many of them, however, have been limited by electron field emissions and thermal magnetic breakdowns triggered by locally enhanced electric and magnetic fields. Since these phenomenon are often observed on electron beam welding (EBW) seams [1, 2], the optimization of the EBW seam is thought to be effective for an improvement of the accelerating gradient, where the optimized EBW seam is assumed to have

1. a geometry of weld bead to suppress the electric and magnetic field enhancement, and
2. a minimized number of defects.

The item 1 is thought to be a problem of optimizing EBW parameters. On the other hand the item 2 is thought to be a problem of optimizing both EBW parameters and processes of surface treatments.

In this paper, as a first step of an approach to the item 1, relations between EBW parameters and geometries of weld beads on Nb test-pieces are described. An approach to the item 2 is also commented.

## EXPERIMENT

Nb test-pieces with weld beads were prepared in KEK cavity fabrication facility (CFF), where all equipments needed to make cavities are in one clean environment.

First a number of Nb test-pieces with sizes of $150\,\mathrm{mm} \times 150\,\mathrm{mm} \times 2\,\mathrm{mm}$ were prepared, which were cut from cavity-grade Nb sheets supplied from Tokyo Denkai. Then pre-weld etchings were apllied to these coupons at the CFF, where $10 - 30\,\mu\mathrm{m}$ of materials were removed by using the 1:1:1 BCP solution. Following ultrapure water rinsing, etched test-pieces were carried to the next room where the EBW machine (Steigerwald Strahltechnik EBOCAM KS110-G150 KM-CNC) were installed. Then weld beads were formed on test-pieces by varying parameters as shown in Table 1, where a product $V_a I_b$ is a input beam power, $v$ detrmines a input power per unit legth through $V_a I_b / v$, and $I_f$ is a current on the focus coil to adjust focal length, which determines a power density on the surface of test-pieces. A combination of a generator position and a welding direction determines a relative direction of gravity acting on molten Nb. Table 2 is a summary of possible combinations of a generator position and a welding direction. Schematic layouts corresponding to the combinations are shown in Fig. 1.

Table 1: EBW parameters used in this study. The welding direction is defined by a direction that a beam sweeps on the coordinate system fixed on the Nb test-piece. It should be noted that in an acutual EBW processes the beam generator is fixed and a position of a Nb test-piece is changed.

| **Generator position** | **Vertical** |
|---|---|
| **Welding direction** | Horizontal |
| **Accelerating voltage** $V_a$ (kV) | 60, 90, 120 or 150 |
| **Beam current** $I_b$ (mA) | 10 - 40 |
| **Focus current** $I_f$ (mA) | 1000 - 3000 |
| **Welding speed** $v$ (mm/s) | 3 or 5 |

| **Generator position** | **Horizontal** |
|---|---|
| **Welding direction** | Downward, Upward or Horizontal |
| **Accelerating voltage** $V_a$ (kV) | 60, 90, 120 or 150 |
| **Beam current** $I_b$ (mA) | 10 - 40 |
| **Focus current** $I_f$ (mA) | 1000 - 3000 |
| **Welding speed** $v$ (mm/s) | 5 |

Geometries of underbeads were then examined. A width, height and depth of an underbead, which is the melted zone on the side of the Nb coupon opposite the side the electron beam is incident, was measured by using a surface profiler (Veeco Dektak 150).

## GEOMETRIES OF UNDERBEADS

Figure 2 shows typical profiles of underbeads for various combinations of the generator position and the welding direction. Figure 2(a) has its peak at the center, Fig. 2(b) has its peak at the left-hand side of the figure and has a valley at the right-hand side of the figure, Fig. 2(c) has a trapezoidal

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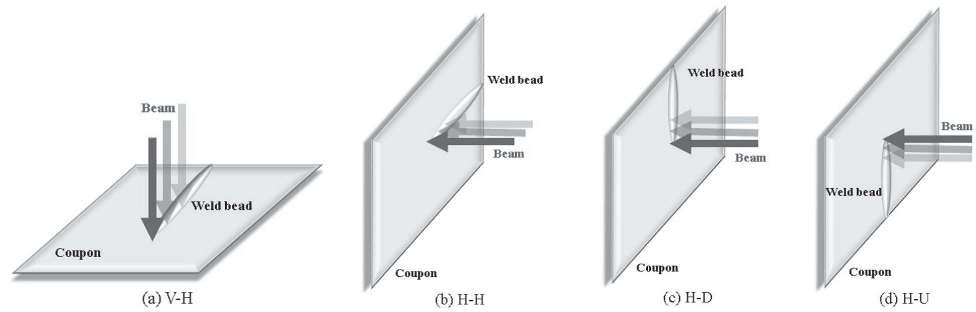


Figure 1: Schematic layouts of combinations of a generator position and a welding direction. (a) V-H: the vertical generator position and the horizontal welding direction, (b) H-H: the horizontal generator position and the horizontal welding direction. (c) H-D: the horizontal generator position and the downward welding direction, and (d) H-U: the horizontal generator position and the upward welding direction.

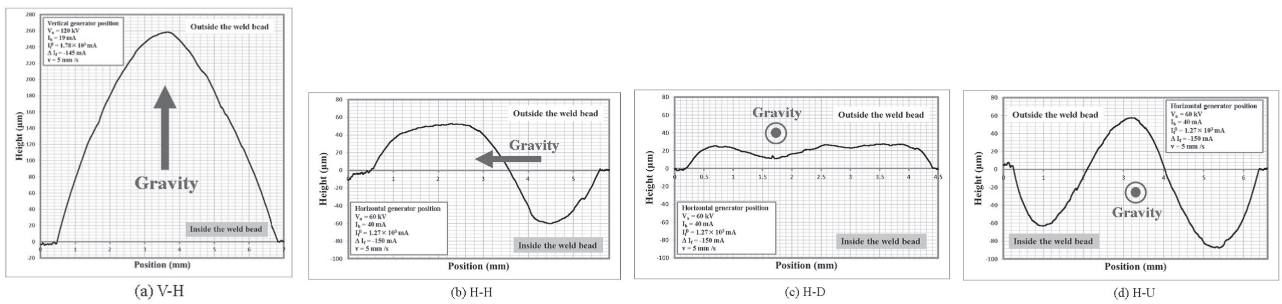


Figure 2: Typical profiles of underbeads for various combinations of a generator position and a welding direction. (a) V-H: the vertical generator position and the horizontal welding direction, (b) H-H: the horizontal generator position and the horizontal welding direction. (c) H-D: the horizontal generator position and the downward welding direction, and (d) H-U: the horizontal generator position and the upward welding direction.

Table 2: Combinations of a Generator Position and a Welding Direction, and their Abbreviations

| Abbreviation | Generator position | Welding direction |
|---|---|---|
| **V-H** | Vertical | Horizontal |
| **H-H** | Horizontal | Horizontal |
| **H-D** | Horizontal | Downward |
| **H-U** | Horizontal | Upward |

profile, and Fig. 2(d) has its peak at the center and valleys on both the sides.

Figure 3(a) shows a relation between a peak height and an underbead width for the combination V-H, where the EBW parameters are varied as shown in Table 1 except for the generator position and the welding direction. As seen in Fig. 3(a), a peak height is proportional to a width. Fig. 3(b) shows a relation among a peak height, a valley depth and an underbead width for the combination H-H, where the EBW parameters are varied as shown in Table 1 except for the generator position and the welding direction. Neither a peak height nor valley depth shows a simple linearity as a function of the underbead width in contrast to the combination V-H. The difference between Fig. 3(a) and Fig. 3(b) reflect differences of geometries between the combination V-H and H-H.

The geometry of the underbead for the combination V-H can be interpreted as follows. Since the Nb test-piece is parallel to the ground, molten Nb gravitate toward vertical to the test-piece, namely the upside of Fig. 2(a). As a result, an under bead with a peak at its center is formed. The geometry of the underbead for the combination H-H can also be interpreted in much the same way. Since the Nb test-piece is vertical to the ground and the weld bead is parallel to the ground, molten Nb gravitate toward parallel to the test-piece and vertical to the weld bead. As a result, the downside of the underbead, namely, the left-hand side of the figure swells. Results from the combination H-D and H-U are difficult to interpret. Their geometries are also thought to be due to the direction of the gravitation, but the detailed explanation remains to be seen.

## DISCUSSION

The combination V-H has larger weld bead than others, but it has no sharp edge. Thus it is thought to be harmless. The combination H-D also has no sharp edge, and is thought to be harmless. On the other hand the combination H-H and H-U has a sharp edge at the right-hand side of Fig. 2(b) and sharp edges at both the sides of Fig. 2(d), respectively, which are in danger of enhancing electric fields and trigering electron field emissions. Thus the combina-




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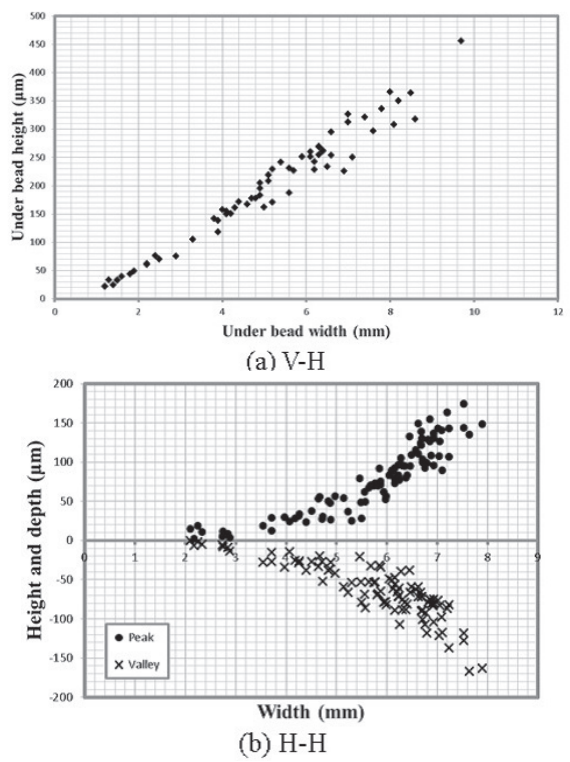


Figure 3: (a) A relation between a peak height and an underbead width for the combination V-H. (b) A relation among a peak height, a valley depth and an underbead width for the combination H-H. The EBW parameters are varied as shown in Table 1 except for the generator position and the welding direction.

tion V-H or H-D is expected to be better in these four combinations. Detailed calculations on field enhancement for each geometry should be performed to compare the combination V-H and H-D. It should be noted that geometries of weld bead of an acutual cavity could differ substantially from those of Nb test-pieces.

## SUMMARY AND OUTLOOK

Relations between electron beam welding parameters and geometries of weld beads were studied. It was found that a combination of a generator position and a welding direction affect a geometry of weld bead dramatically. Some combinations yield geometries that could enhance electric fields, and some are thought to be harmless. An optimum choice of a combination has not been clear. Detailed calculations on field enhancement for each geometry should be performed.

As mentioned above, our goal is to obtain the optimized EBW seam that satisfies two items shown in the introduction. The item 1 was the subject of this paper. The item 2, the investigation of conditions to minimize a number of defects, is a challenging problem, and seems to be more difficult than the item 1. Recently contaminants found after the BCP and the electropolishing are attracting attention as a clue about this challenge [3, 4]. Fig. 4 shows examples of contaminants found after the BCP, which includes carbon and oxygen, or carbon, nitrogen and oxygen. Neither their chemical structures nor the origin of carbons are known. It is speculated that these carbon including contaminants may cause a pit formation at the EBW seam (see Fig. 5). An X-ray imaging of the EBW seams may reveal the pit formation mechanism [6].

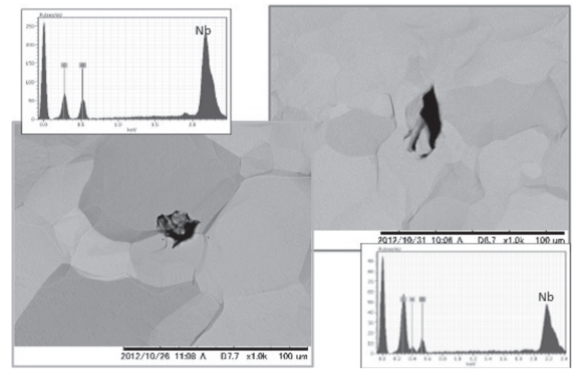


Figure 4: Examples of contaminants found after the BCP [3]. The contaminants include carbon and oxygen, or carbon, nitrogen and oxygen.

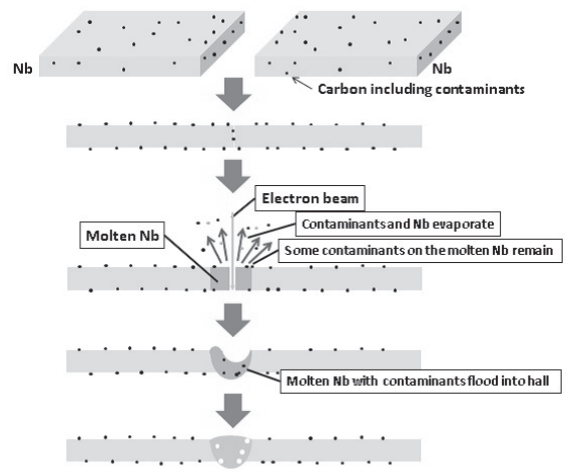


Figure 5: Schematic layouts of the speculated pit formation mechanism [3]. Contaminants involved in molten Nb cause a pit formation.

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