Calculation of the Parameters of Perforated Shields For Applications in Electroforming

By Uwe Pilz

In the electroforming process, problems often arise if workpieces with large depth range need to be formed. The application of perforated shields can help manage this situation, but it is not easy to obtain the parameters of those shields. The procedure described in this paper calculates these parameters, using numerical simulation or measurement of the current distribution of the unshielded electrode. The parameters, cavity distance, cavity diameter and maximal shield distance, can be obtained from the current distribution without direct simulation of the perforated shield.

To optimize current distribution in electroforming, nonconductive shields can be used. If large areas with a large depth range are to be used, nonconductive shields are not suitable because of the lack of scattering behind the shield. The solution to this problem is the use of perforated shields. When using circular perforation in hexagonal arrangement, the parameters of such shields are (Fig. 1):

- distance from cathode to shield, d_s
- distance from cathode to anode, d_A
- distance between cavities, d_C
- diameter of the cavities, $2r$
- shield thickness t

The cavity diameter and the cavity distance give the so-called cavity proportion C, which influences the current reduction r_C. C is zero for unperforated shields and 1 for the absence of a shield. It can be easily shown that for circular perforation in hexagonal distribution, C can be calculated using:

$$C = \frac{\pi r^2}{\sqrt{3} d_C^2} \tag{1}$$

Calculation of Current Density Reduction

The shield's influence on the current density depends on the cavity proportion C, the distance from anode to cathode, d_A, and the shield thickness t. To determine this influence, we calculate first the resistance of an arbitrary homogeneous area A between parallel cathode and anode planes without a shield:

$$R_1 = \kappa \frac{d_A}{A} \tag{2}$$

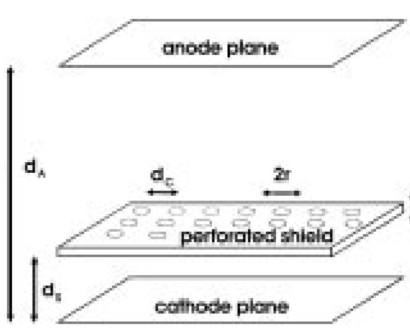

Fig. 1—Parameters of perforated shields.

where κ is the electrical conductivity of the electrolyte. The resistance of the electrolyte in the cavities of a shield in the same area A can be calculated with

$$R_2 = \kappa \frac{t}{CA} \tag{3}$$

The reduction of the current density r_C can be approximated if it is assumed that the electrical field in the volume outside the shield and in the cavities is homogeneous. In this case, the total resistance with shield can be calculated by adding the partial resistances R_1 and R_2. The current reduction is the inverse of the ratio of the corresponding resistances:

$$r_C = \frac{R_1 + R_2}{R_1} = 1 + \frac{t}{d_A C} \tag{4}$$

This simple formula ignores the non-homogeneity of the field around the top and bottom of the shield. Numerical simulation with the help of the boundary element method[1] showed that, for current reductions above 1.3, the error of Eq. (4) is less than five percent.

Determination of Appropriate Shield-Cathode Distance

An electrolyte has the ability to scatter behind a shield. The area partially influenced by a shield is the transitional phase. It depends on the shield distance and the throwing power of the electrolyte, which can be described by Wagner's polarization parameter[2]

$$p = \kappa \frac{\delta\varepsilon}{\delta j} \tag{5}$$

which is measured in cm. Consequently, the size of the transitional phase must be known to select a suitable shield distance for a given problem.

As a measure for the size of the transitional phase, the so-called scattering expanse S was used. This expanse is determined with nonconductive shields and can be used for perforated shields as well. It is defined as the distance on the cathode between the projected edge of the shield and the point under the shield where the current density reaches the half-value of the non-shielded current density.

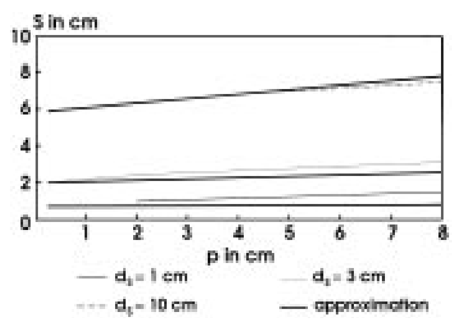

Fig. 2—Scattering expanse behind a nonconductive shield; simulation and approximation function.

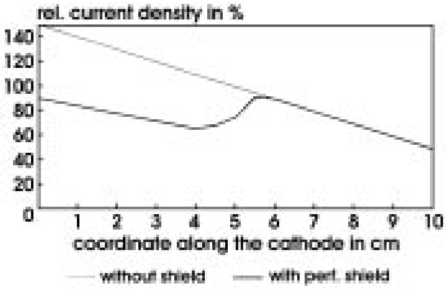

Fig. 3—Current density with and without a perforated shield.

For calculation of the scattering expanse, simulation of an edge of a shield was made with help of the boundary element method. Figure 2 shows the scattering distance depending on Wagner's polarization parameter p for various distances d_s. For choice of an appropriate shield distance, at least an idea of the scattering distance is needed. Therefore, the calculated values were approximated for values of p between 0.25 cm and 10 cm, and values for d_s between 1 and 10 cm by a bilinear function:

$$S = d_s(0.028cm^{-1}p + 0.65) \tag{6}$$

This formula yields S with sufficient accuracy; the mean-squared-error is 0.3 cm in the given parameter range.

The current density behind the shield is not exactly uniform because of effects of the cavities. It was found by numerical simulations that, without polarization, the current density variation is below 10 percent if the shielded distance is equal to the cavity distance. Under the influence of polarization, the variation will be more even. The shield distance should be 2-3 times larger than the cavity distance. The same value may be acceptable in problematical cases, however.

Determining Perforated Shield Parameters

Calculation or Measurement Of Current Distribution without Shield

Using the current distribution without shields, areas on the cathode must be defined that should be influenced by separate shields. In most cases, 2-4 different shields are sufficient. The area with the least current density remains without a shield.

Calculation of Average Current Densities

Average current densities can easily be determined graphically from the current density plot. Its proportion to the lowest current density yields the current density reduction for each area.

Calculation of Required Cavity Proportions

For each area, the cavity proportion necessary can be derived using Eq. (4).

Selecting Usable Shield Distance

The larger the shield distance, the more easily constructible the shield. Shields away from the cathode can have larger cavities and need not follow exactly the cathode shape. Using Eq. (6), it can be decided whether the selected distance causes too large a transitional phase.

Calculation of Cavity Distance and Diameter

The shield distance should be 2 times larger than the cavity distance. If a cavity distance has been selected, the cavity diameter can be calculated with Eq. (1).

A Simple Example

Calculation of Shield Parameters

Assume a current density, changing linearly between 150 and 50 percent, as shown in Fig. 3. Moreover, the cathode-to-anode distance d_A is assumed to be 10 cm and the polarization parameter p to be 1 cm. An area of 0 to 5 cm on the cathode is to be influenced with one single perforated shield with a thickness t of 1 mm.

The average current density j_1 in the area to be influenced is 125 percent; the average density j_2 of the remaining area is 75 percent. The current density reduction is calculated to be 1.67:

$$r_C = \frac{j_1}{j_2} \tag{7}$$

Using Eq. (4) we can now calculate the necessary cavity proportion:

$$C = \frac{t}{d_A\,(r_C - 1)} \tag{8}$$

C is calculated to be 0.015. If a shield distance d_s of 0.5 cm is selected, a cavity distance d_C of at least 1 cm is required. With this value, the cavity diameter can be derived with help of Eq. (1)

$$2r = d_C\sqrt{\frac{2\sqrt{3}C}{\pi}} \tag{9}$$

and is found to be 1.3 mm.

Prediction of Current Density Distribution with Shield

The current density found contains three different regions: Below the shield, but far away from the shield's edge: In this area, the resulting current density can be derived from the original current density divided by the current reduction. The area near the edge: In this area, the current density cannot be calculated without the help of computer programs. The unshielded area far away from the edge of the shield: In this area, the current density remains uninfluenced. Figure 3 shows the resulting current density. It can be seen that the highest current density would be reduced from 150 to 91 percent with a single perforated shield.

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References

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