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by

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HUMAN TRANSLATION

FASTC-ID(RS)T-0745-91 13 January 1992

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English pages: 11

Source: Dianzikexue Xuekan, Vol. 12, Nr. 6, November 1990, ppgs. 660-665

Country of origin: China
Translated by: SCITRAN
F33657-84-D-0165
Requester: FASTC/TTTRE/LT Henry
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TITLE: A SEMIEMPHIRICAL FORMULA FOR CALCULATING THE COEFFICIENTS FOR FIELD EMISSION TIP FORMS

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SUMMARY This article presents a formula for calculating the general field emission system tip shape or form coefficient β : $\beta \approx 0.2/[(r_0+h)\ln(2h/r_0)]$. Using this formula and numerical value calculation methods as well as the corresponding formulae put forward by such people as D. Selidovkin, W. Swanson, P. Dyke, and others, we carried out, respectively, calculations and comparisons on values for the four types of field emission systems--those with tips presenting semispherical shapes, ellipsoid shapes, rotating parabolic shapes, and hyperbolic shapes. The results clearly show that calculations using the β values obtained from this article's formula and the results of calculations with the numerical values of electronic computers are basically in line with each other.

BASIC TERMS Field Emission, System Emission Tip, Emission Shape Coefficient

1. INTRODUCTION

At the present time, making use of the principles of field radiation, one creates a field emission electron source (FES). This possesses a small beam spot, high luminosity, low power consumption, long life, and small diffusion of energy, as well as other similar special characteristics. They have already been widely used in SEM[1], STEM[2], electron beam exposure as well as Exie (possibly Gaketsu) electron spectral instruments, and various other types of large model electoptical instruments. However, in FES design, manufacture, and applications, there are still a good number of questions which are urgently awaiting improvements and to be put forward. How to accurately and precisely determine tip shape coefficient β values is precisely one of these. In the area of precisely determining β values, at the present time, besides being able to carry out accurate calculations on several types of simple and regular electrode systems, such as parallel plates, concentric spheres, and so on, for electrode systems with general forms, it is almost difficult to describe them using analytic forms. A good number of scholars have put forward various types of models, obtaining several approximate calculation relationships[3-5]. However, it is still not possible to satisfy the requirements for actual FES development. This article carries out a series of analyses, experiments, and comprehensive attempts, obtaining several significant results.

2. BASIC CONSIDERATIONS AND METHODS OF PROCEEDING

The facts clearly demonstrate that, on the one hand, from our observations of the realization of the creation of practical field emission tips[6], there is no question that, opting for the use of that type of creation method[7], the tip shapes which are obtained, although they approximate rotated parabolic surfaces or hyperbolic surfaces, are very difficult, however, to make completely regular and symmetrical. On the other hand, looking from the standpoint of the general structure of FES source bodies, after all is said and done, it is very simple. It is only composed of a cathode tip and an anode tip. With regard to this type of system, it goes without saying that tip forms are extremely irregular. Not considering the effects of spacial electric charges, the tip surface electric field strengths are, undoubtedly, in direct proportion to the anode potential[8(illegible)], that is ,

$$\varepsilon = \beta_0 U_0 \qquad (1)$$

In this equation, β_0 is the tip shape coefficient. U_0 is the anode potential.

Due to the fact that β_0 is only related to the geometrical shape of electrodes and their sizes, and that the anode potential U_0 is also capable of precise measurements, the result of this is that, if it is possible, for a number of tip electrode systems which possess representative natures, to go through precise measurements or calculations of tip surface electric field strengths and one finds the special characteristics and rules or patterns for their changes, then, there is the possibility, from equation (1), of finding certain types of relationships to precisely calculate β_0. We selected four types of field emission systems the shapes of which were, respectively, semispherical, ellipsoid, rotated parabolic, and hyperbolic in form. Their tip radii of curvature r_0 (r_0 is 1.05×10^{-5}(illegible)) were equal to each other. The distance from the tips to the anode d (d is 0.7 cm) were the same. The anodes were all flat plates. Going through electrolytic tank or cell simulation methods[9] and electronic computers, with regard to the four types of field emission systems described above, in terms of potential distributions between electrodes and tip surface electric field strengths, use was made of step by step amplification, approximation and simulation methods[10] to carry out precision measurements and numerical value calculations. The method was to first make use of simulation methods, taking the various electrodes of the systems which were awaiting measurement (for example, systems in which the tips present a semispherical shape). Then, on the basis of an amplification ratio of 100 fold, we positioned the sliced shapes into the electrolytic tank or cell. With the introduction of tap water, and, in conjunction with a potential of U_0 being added between the electrodes, use was made of D-2 Model automatic electron track or orbit instruments to work out the nine equipotential curves $0.1U_0$, $0.2U_0 \ldots 0.9U_0$. Following this, one takes the equipotential curve $U_1 = 0.5U_0$ to be the new anode. One takes the zone between the tip and the $0.5U_0$ equipotential curve and reamplifies it 50 fold. In the same way, one works out the nine equipotential curves $0.1U_1$, $0.2U_1 \ldots 0.9U_1$. In their proper order, working by analogy, one, step by step, approximates the four types of cathode tip. All together, the amplification multiplier was 9×10^5. One takes the system boundary potential values obtained in the final iteration of simulation and inputs them into an electronic computer. Through iterative substitution, the accuracy is better than 10^{-4}. As far as the carrying out of calculations on the potential distribution within a range approximately 0.75 μm in front of the tip and on tip surface electric field strengths are concerned, the results are as shown in Fig.1. The other three types also had similar simulations and calculations done on them. The results are as shown in Fig.'s 2, 3, and 4.

Here, it is also necessary to explain. In carrying out the simulation measurements associated with the first iteration electrode amplification of 100 fold, we used an ordinary steel needle with a radius smaller than 0.01mm and a radius of curvature that was 1mm to act as the emission tip. At this time, the $0.5U_0$ equipotential curve was located at a place 1.6cm in front of the tip. Due to the fact that this segment of distance was vastly farther and greater than the steel needle's radius of curvature, the tip's radius of curvature and shape were even smaller as a result. As far as the influences from the location and shape of the $0.5U_0$ equipotential curve is concerned, in actuality, they are negligible. In the other three iterations of simulation and amplification, the tip shape and dimensions, by contrast, are manufactured strictly in conformance with requirements.

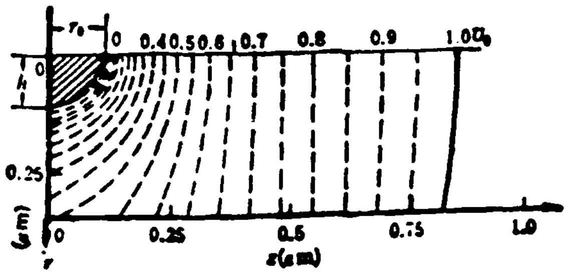

Fig.1 Electric Field Distribution for Tips That Are Hemispherical

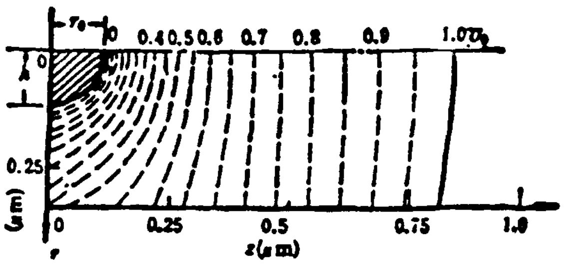

Fig.2 Electric Field Distribution for Tips That Are Ellipsoid

3. ANALYSIS AND COMPARISIONS

From the analyses for the above described four types of tip field emission system electrical potential distributions as well as the calculations for tip surface electric field strengths, it is possible to see that: (1) Within the same type of tip system, the distribution of equipotential lines is not uniform. The closer one approaches the tip, the denser the distribution becomes, and the greater the changes become. By contrast, when they are few and far between, they tend to be uniform. It is clearly shown that surface field strengths are principally determined by tip radii of curvature. Moreover, the tip

662

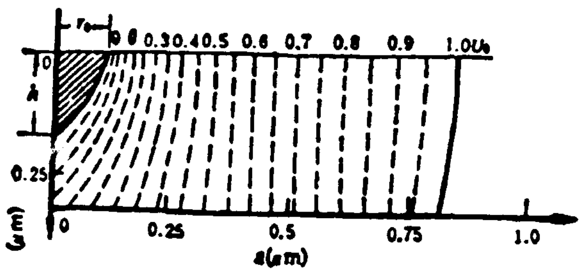

Fig.4 Electric Field Distributions for Tips That Are Hyperbolic in Form

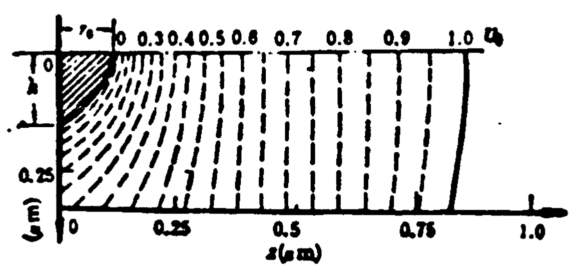

Fig.3 Electric Field Distributions for Tips That Are Parabolic in Form

to anode distance and the anode shape have, relatively speaking, small influences. Surface field strengths are also related to the size of electrode polar angles. As far as polar angles which are between 0° and 30° are concerned, changes in the strength of surface electrical fields are relatively small. It is possible to see them as constant. After polar angles become greater than 30°, surface electric field strengths, then, follow increases in polar angles and rapidly diminish. The results are as shown in Fig.5. (2) In systems with different tips, despite the fact that the radii of curvature are equal to each other and the distances from tips to anode as well as anode shapes are the same, the state of the distribution of equipotential curves among them and their degree of concentration are, by contrast, not the same. Tips which present hemispherical or half spheroid shapes are the most concentrated. Those that present hyperbolic shapes are the most spread out. If one uses $\mathscr{E}_1$ to represent surface field strengths for systems with half spheroid tips and uses

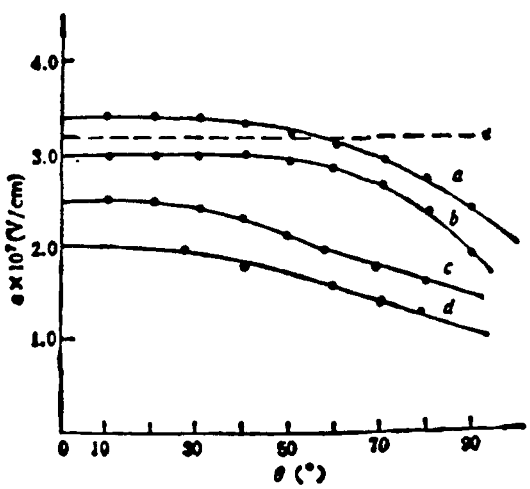

Fig.5 Relationships Between Electric Surface Fields With Different Tips and Polar Angles: a is a half spheroid form, b is an ellipsoid form, c is a parabolic form, d is a hyperbolic form, e is a spheroid form (the anode is infinitely distant)

ε to represent the surface electric fields associated with other tip form systems' surface field strengths, then, $\varepsilon/\varepsilon_0$ follows r_0/h (h is the width of the tip neck section) displaying changes as shown in Fig.6. From the Fig., it is possible to see that tip surface field strengths not only depend in an extreme way on the magnitude of radii of curvature. At the same time, they are also strongly dependent on the thinness and symmetrical nature of tip neck sections.

In relationships to calculate β, in order to be capable of reflecting the reality of the experimental facts described above, on the basis of the foundation in Reference [3] and going through multiple iterations of experimentation, calculation, analysis, and synthesis, one obtains the semiempirical formula below for calculating in a generalized FES tip shape system:

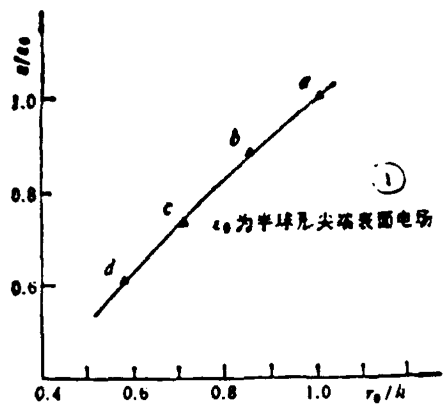

Fig.6 The Relationship of Changes in $\varepsilon/\varepsilon_0$ As It Follows r_0/h. Key: ε_0 is the surface electric field for semispheroid tips.

$$\beta = 0.2 \Big/ \left\{ \left[r_0 + \frac{(h_1 + h_2)}{2} \right] \ln \left[\frac{(h_1 + h_2) d}{r_0 (h_1 + h_2 + d)} \right] \right\} \qquad (2)$$

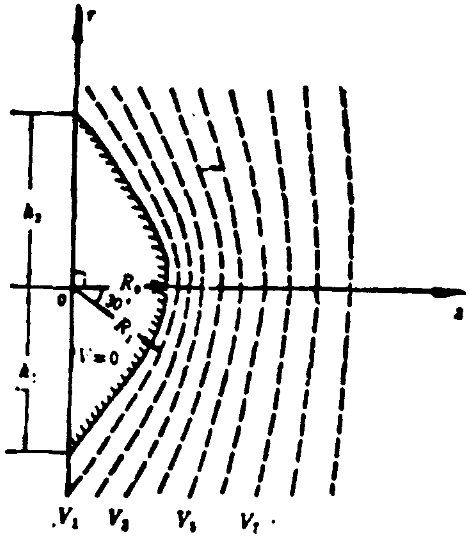

Fig.7 Concentric Sphere Model of Tip Emissions (R_0 is the radius of curvature after amplification. h_1 and h_2 are the upper and lower neck widths after amplification.)

In the equation, r_0 is the tip radius of curvature. h_1 and h_2 are, respectively, the widths of the upper and lower tip neck sections. d is the distance from tip to anode.

Equation (2) clearly shows that (1) the radius of curvature of the tip and the width of neck sections have considerable influence on ; (2) the upper and lower tip neck section widths are not the same. values are also different. It is clearly shown that β values are also related to symmetry characteristics of tips. (3) The distance from tip to anode d, in the expression, is placed in a logrithmic quantity. Speaking in terms relative to r_0 and h, it has relatively small effects on β.

Let $h_1=h_2=h_{0(\text{illegible})}$, and $(h_1+h_2) << d$. Then, equation (2) is capable of being simplified to be

若令 $h_1=h_2=h$，且 $(h_1+h_2)\ll d$，则(2)式可简化为

$$\beta \approx 0.2/[(r_0+h)\ln(2h/r_0)] \tag{3}$$

In order to prove the reliability and accuracy of equation (3), one makes use of the three types of methods below in order to compare and explain.

(1) As far as using electronic computers on various tip systems to carry out numerical value calculations is concerned, one precisely and accurately determines tip surface field strength $\mathscr{E}$ values. One then compares these with anode potentials U_0 (in our experiments, we selected U_0 = 3kv), solving for the corresponding β_c values. One uses the values in question to carry out comparisons with β values calculated with equation (3). The results are as shown in Fig.1.

(2) From an analysis of the special characteristics of the distribution of equipotential curves in Fig.1, 2, 3, and 4, it is possible to see that, despite the fact that various tip shapes differ very greatly, in the cathode section with polar angles smaller than 30° and the adjacent first equipotential surface, however, it is possible, in all cases, to see them as two concentric spherical surfaces as shown in Fig.7. If one makes the cathode potential be zero, the first equipotential surface potential is V_1. Going through a solution of Laplace equations, it is possible to prove that the cathode surface electric field strength is

$$\mathscr{E}_0 = R_1 M V_1/[R_0(R_1 - R_0)] \qquad (4)$$

In this equation, M is the electrode amplification multiplier number. R_0 and R_1 are, respectively, the tip radius of curvature after amplification and the radius of curvature of the first equipotential surface. The reason for this is that

$$V_1 = nU_0 \qquad (5)$$

In this equation, n is the electrical potential ratio coefficient (under the conditions in our experiments, n is 1.2×10^{-1}).

Taking equation (5) and substituting into equation (4), one then obtains the shape coefficient to be

$$\beta_0 = R_1 n M/[R_0(R_1 - R_0)] \qquad (6)$$

Because of the fact that R_0 and R_1 are capable of being directly measured from the graphs of electrical potential distributions, it is possible, as a result of this, to precisely determine β_t. In the same way, one takes β_t and carries out comparisons with β. (See Table 1.)

(3) Taking the values of r_0 and d discussed above as well as the polar angle a to be 10^o, these parameters and others like them are respectively substituted into the formulae put forward by D. Selidovkin[3], W. Swanson[4], and P. Dyke[5], as well as other similar people. In conjunction with that, one solves for the corresponding values of β. (See Table 1).

From Table 1 it is possible to see that, under conditions which are entirely the same, the β values which are obtained by the use of this article's formula and the results obtained from the use of electronic computers and equation (6) are basically in line with each other. This clearly shows that equation (3) is correct and accurate. The reason for this is that it not only considers tip radii of curvature but also considers thickness and symmetry characteristics of the neck portions of tips in terms of their influence on β.

尖端形状 (1) / 比较 (2)	半球形 (3)	椭球形 (4)	抛物形 (5)	双曲形 (6)
(7) 尖端曲率半径 $r_0(10^{-5}cm)$	1.05	1.05	1.05	1.05
(8) 尖端颈的宽度 $h(10^{-5}cm)$	1.05	1.23	1.49	1.81
(9) 尖端表面场强 $\mathscr{E}(10^7V/cm)$	3.4126	2.9459	2.4818	2.0675
$\beta_0(10^4cm^{-1})$	1.1375	0.9819	0.8273	0.6892
$\beta_t(10^4cm^{-1})$	1.1531	0.9221	0.8012	0.6334
$\beta(10^4cm^{-1})$	1.3740	1.0303	0.7708	0.5662
D. Selidovkin $\beta_s(10^4cm^{-1})$		6.3725	1.6141	1.5246
W. Swanson $\beta_w(10^4cm^{-1})$	2.0103	2.0103	2.0103	2.0103
P.Dyke $\beta_d(10^4cm^{-1})$	1.1743	1.1743	1.1743	1.1743

Table 1 A Comparison of Various Types of Calculation Results[1)] (1) Tip Shape (2) Comparison (3) Semispheroid (4) Ellipsoid (5) Paraboloid (6) Hyperboloid (7) Tip Curvature Radius (8) Width of Tip Neck (9) Tip Surface Field Strength 1) In the Table, β_0 is the results from electronic computer calculations. β is the results from calculations using equation (6). β s(illegible) is the results from calcuations using equation (3).

4. SUMMARY

As far as using the formula put forward in this article to do calculations on tip shape systems is concerned, it is not only reliable. It is also simple and convenient. When doing calculations, it is not necessary to give consideration to the actual shape of the tip. It is only necessary, when making the tip, to make precise measurements of the radii of curvature and upper and lower neck widths, and that is all. Today, in this time of wide spread applications of optical microscopes and SEM to this, it is extremely easy to do. After calculating out values for β , it is then possible to precisely determine tip surface field strengths and current densities. This aids in both the improvement and raising of FES design and emission characteristics.

REFERENCES

[1] A.V. Crewe, et al., *J. Mol. Bio.*, 48(1970)3, 375—382.

[2] A.V. Crewe, et al., *J. Appl. Phys.* 39(1968)13, 5861—5868.

[3] A.D. Selidovkin, *Radio Eng. and Electronic Phys.*, 28(1983)7, 105—110.

[4] L.W. Swanson, et al. *J. Appl. Phys.*, 46(1975)5, 2029—2031.

[5] W.P. Dyke, et al., *J. Appl. Phys.*, 24(1953)5, 570—576.

[6] Yang Deqing, et.al.; "Microprocessing Technology", 1988, No.1, pp.30-34

[7] Yang Deqing, et.al.; Yunnan University Journal, 10(1988)2, 167-171

[8] Cheng Huan, et.al.; " Cathode Electronics", Northwest Telecommunications Engineering Institute Press, Xian, 1986, p.102

[9] Ni Xie, Ren Qingke; "Course in Electroptics", Peoples Education Press, Beijing, 1961, p.42

[10] Yang Deqing; Yunnan University Journal, 10(1988)3,217-221

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