United States Patent [19]

Ota et al.

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[45] **June 3, 1975**

[54] **PULSED FIELD EMISSION TYPE ELECTRON GUN**

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[73] Assignee: **Nihon Denshi Kabushiki Kaisha,** Tokyo, Japan

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[30] **Foreign Application Priority Data**

July 17, 1972 Japan 47-71489

[52] **U.S. Cl.** **315/383;** 315/379

[51] **Int. Cl.** **H01j 29/52**

[58] **Field of Search** 315/14, 30, 31

[56] **References Cited**

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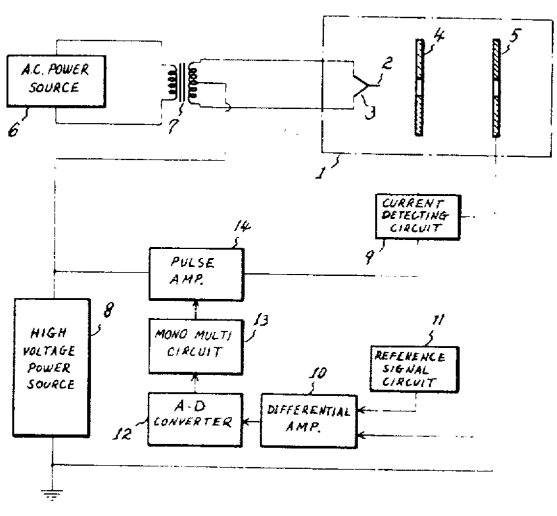
Assistant Examiner—T. M. Blum
Attorney, Agent, or Firm—Webb, Burden, Robinson & Webb

[57] **ABSTRACT**

A pulsed field emission type electron gun in which the pulse voltage peak between the heated emitter and its associated electrode is maintained constant, and the pulse duty factor or emitter heating temperature of bias voltage is controlled to keep the field emitted electron beam constant, during the pulse rest time, thereby prolonging the life of the emitter regardless of any discrepancy between the radius of curvature of one emitter and another.

4 Claims, 18 Drawing Figures



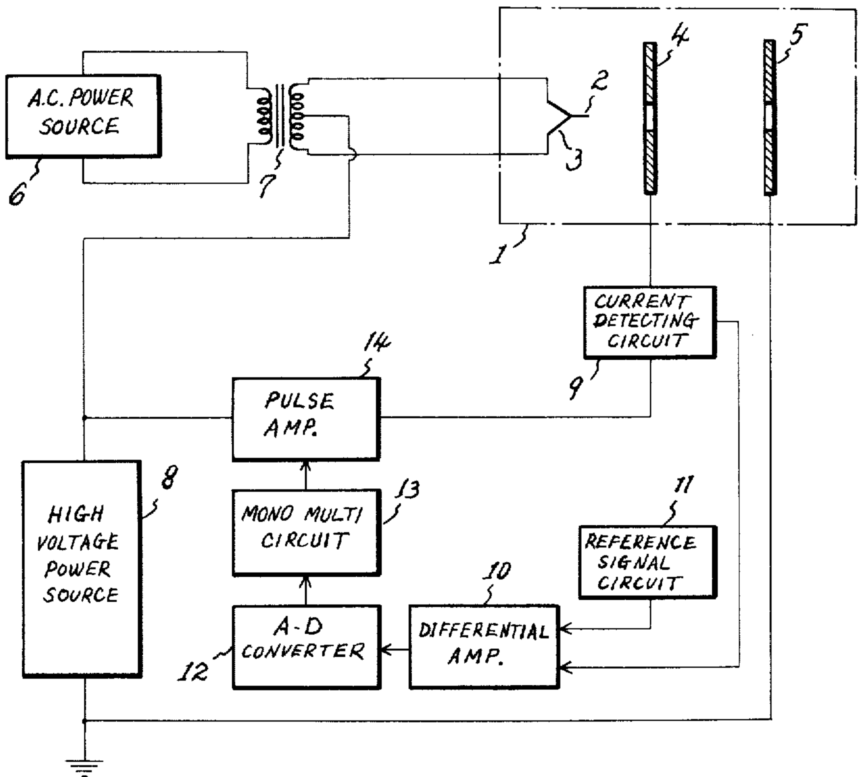

A.C. POWER SOURCE
6
7
2
3
4
5
1
CURRENT DETECTING CIRCUIT
9
14
PULSE AMP.
8
HIGH VOLTAGE POWER SOURCE
13
MONO MULTI CIRCUIT
11
REFERENCE SIGNAL CIRCUIT
10
A-D CONVERTER
12
DIFFERENTIAL AMP.

Fig. 1

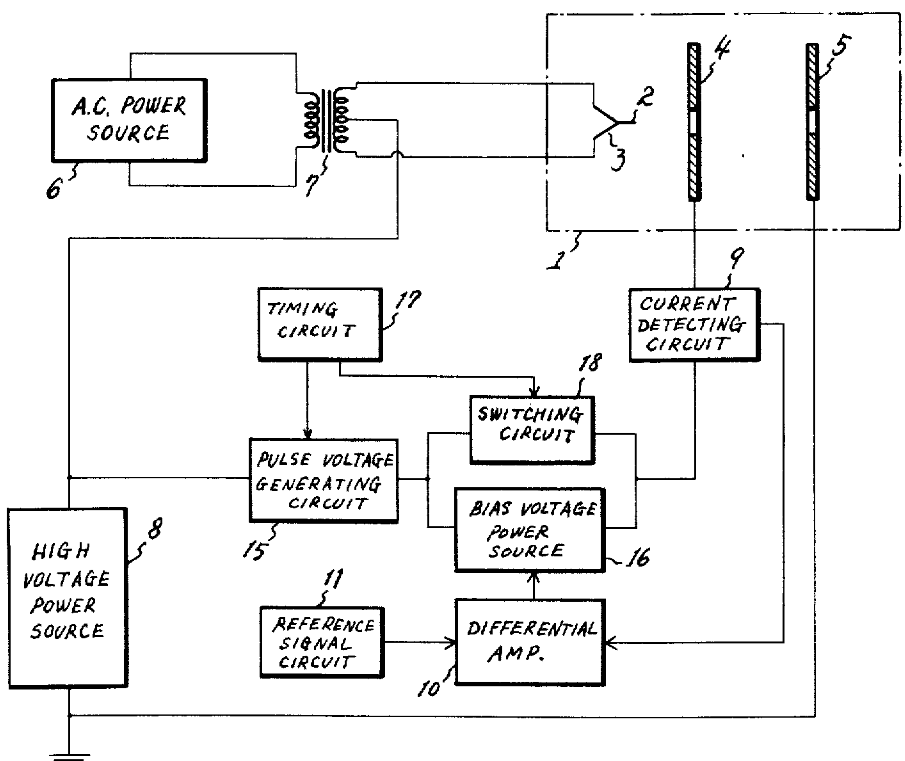

A.C. POWER SOURCE
6
7
2
3
4
5
1
9
TIMING CIRCUIT
17
CURRENT DETECTING CIRCUIT
18
SWITCHING CIRCUIT
PULSE VOLTAGE GENERATING CIRCUIT
BIAS VOLTAGE POWER SOURCE
16
15
8
HIGH VOLTAGE POWER SOURCE
11
REFERENCE SIGNAL CIRCUIT
DIFFERENTIAL AMP.
10

Fig. 4

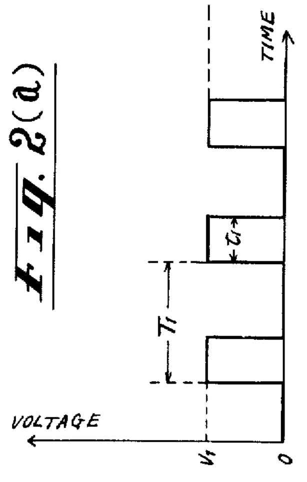


Fig. 2(a)

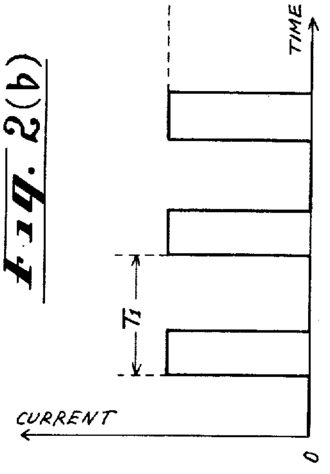


Fig. 2(b)

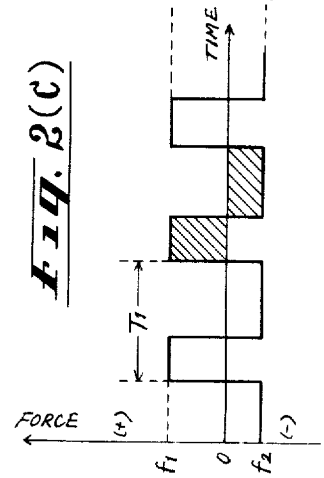


Fig. 2(c)

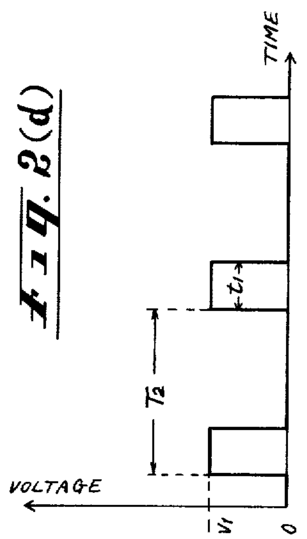


Fig. 2(d)

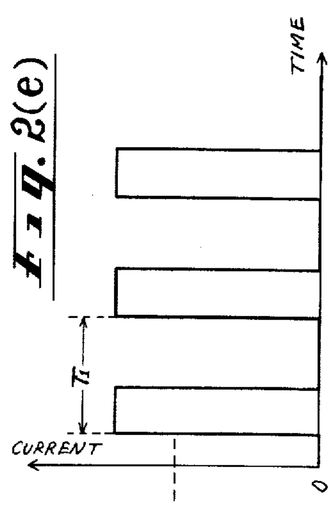


Fig. 2(e)

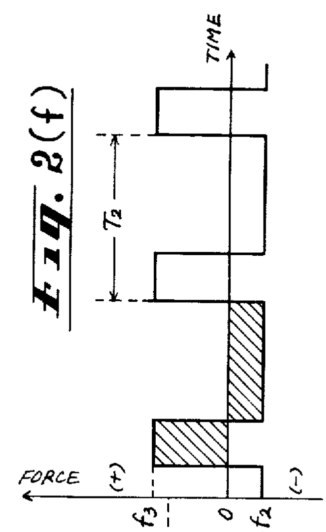


Fig. 2(f)

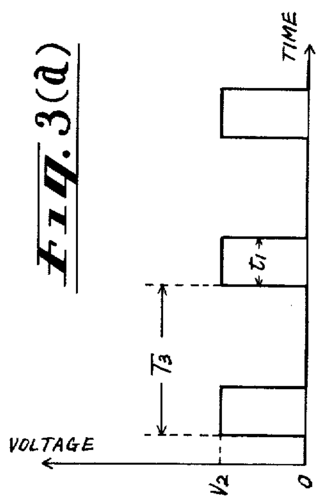


Fig. 3(a)

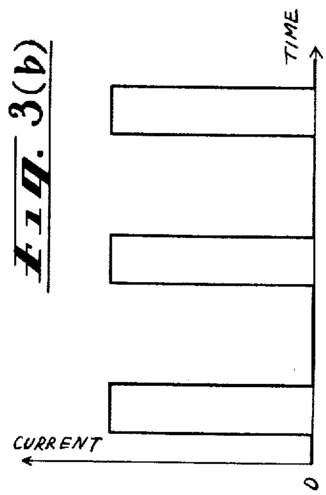


Fig. 3(b)

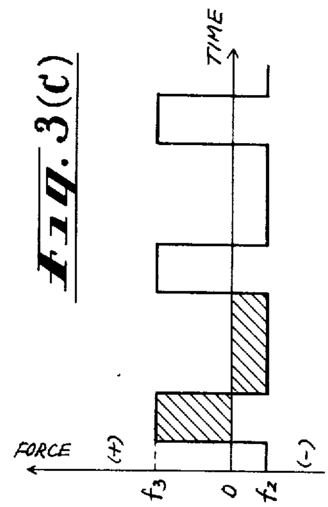


Fig. 3(c)

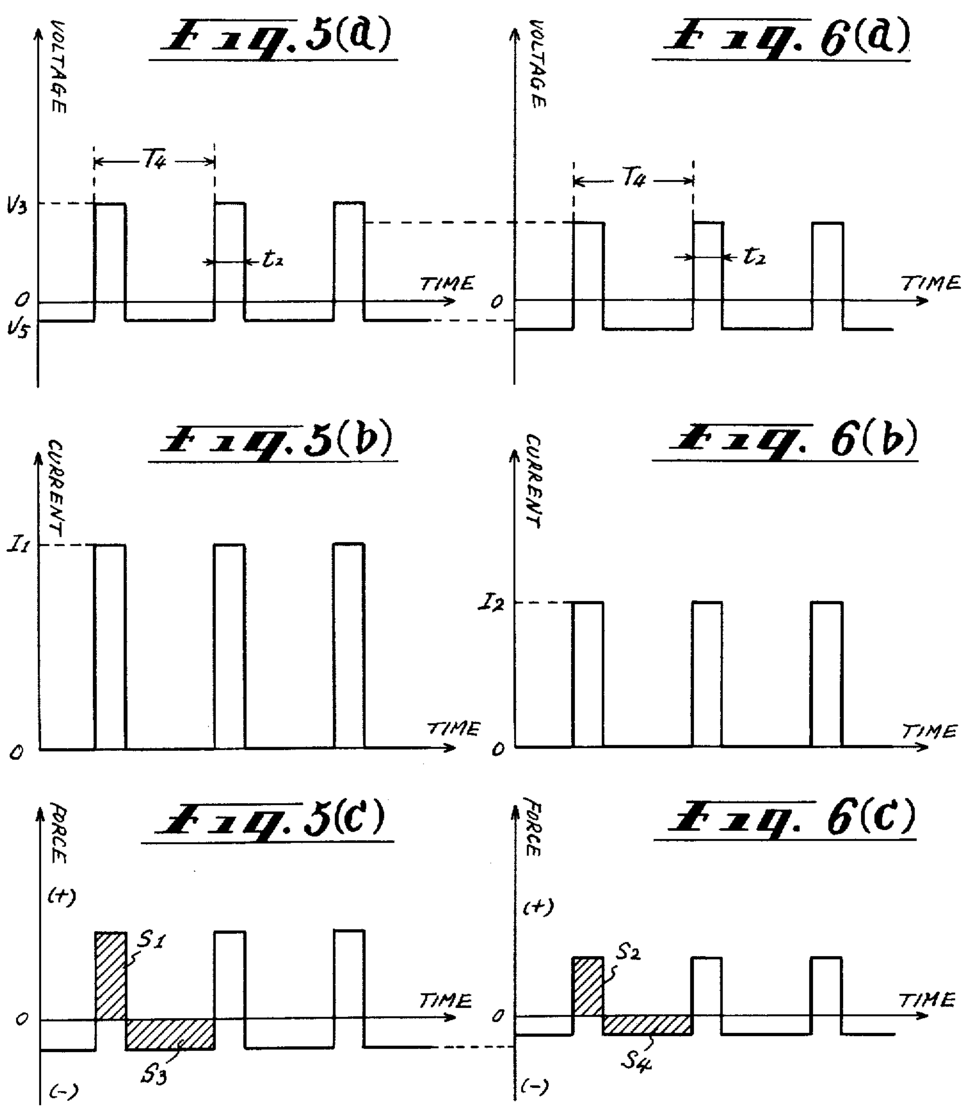


Fig. 5(a)
VOLTAGE
T4
V3
t2
TIME
0
V5
Fig. 6(a)
VOLTAGE
T4
t2
TIME
0
Fig. 5(b)
CURRENT
I1
TIME
0
Fig. 6(b)
CURRENT
I2
TIME
0
Fig. 5(c)
FORCE
(+)
S1
TIME
0
S3
(-)
Fig. 6(c)
FORCE
(+)
S2
TIME
0
S4
(-)

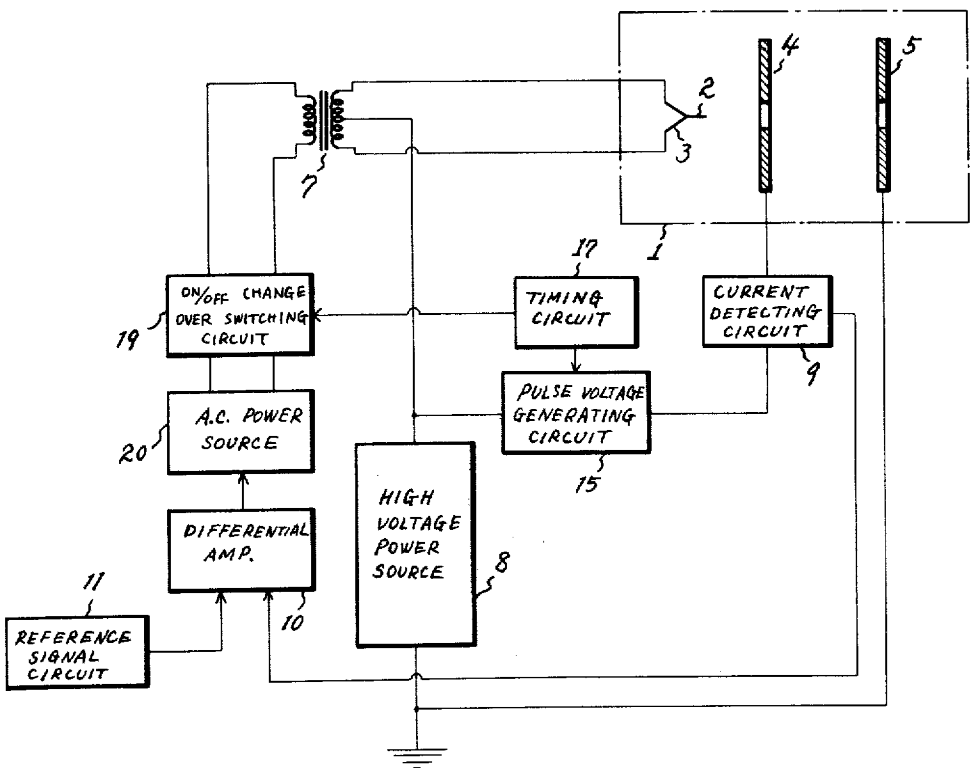

ON/OFF CHANGE OVER SWITCHING CIRCUIT
A.C. POWER SOURCE
DIFFERENTIAL AMP.
REFERENCE SIGNAL CIRCUIT
HIGH VOLTAGE POWER SOURCE
TIMING CIRCUIT
PULSE VOLTAGE GENERATING CIRCUIT
CURRENT DETECTING CIRCUIT
1
2
3
4
5
7
8
9
10
11
15
17
19
20

Fig. 7

PULSED FIELD EMISSION TYPE ELECTRON GUN

This invention relates to devices for prolonging the working life of the emitter in a pulsed field emission type electron gun.

Most field emission type guns in current use are of the so-called "cold emission" type, whereby the gun chamber is maintained at a superhigh vacuum, in the order of 10^{-9} to 10^{-10} Torr, and field emission takes place without heating the emitter. The superhigh vacuum is required to prevent residual gas ions from bombarding the emitter or residual gases from forming on the emitter either of which are a potential cause of emitter damage. Maintaining the gun chamber at such a high vacuum, however, requires a large capacity pump, intricate mechanical structures, such as a vacuum seal, etc., substantial financial outlay in addition to which, the operating procedures are complicated.

An alternative to cold emission type field emission is to heat the emitter, thereby making it unnecessary to maintain the gun chamber at a superhigh vacuum in order to protect the emitter against damage due to gas ion bombardment, etc. However, heating the emitter causes an abnormal growth known as crystal buildup to form on a specific crystal plane at the emitter tip. The crystal buildup is due to the intensity of the electric field and the high temperature generated during field emission. To counteract this crystal buildup phenomenon, pulsed field emission is usually practiced. In other words, by using pulsed field emission, dulling occurs at the emitter tip during the pulse rest time; that is, the time when the field is weak and the emitter is maintained at high temperature. As a result, the crystal buildup which takes place when a pulsed field is generated and the dulling which takes place during the pulse rest time act to cancel each other out, thereby bringing about a state of equilibrium.

The factors governing the maintenance of this state of equilibrium, namely, crystal buildup versus dulling may be listed as follows:

A. Emitter tip radius of curvature.
B. Pulse voltage peak value.
C. Bias voltage during the pulse rest time.
D. Pulse duty factor.
E. Emitter heating temperature.

The pulse voltage is the voltage applied between the emitter and the electrodes for generating an intense electric field at the emitter tip so as to obtain field-emitted electrons from the emitter. Accordingly, the electric field intensity at the emitter tip is determined by the peak value (B) of the pulse voltage and the radius of curvature (A) of the emitter tip. The field emission electron current varies exponentially with the field intensity. Even if all of the factors listed above are set at their optimum values and the requirements for equilibrium are met, the equilibrium cannot be restored once it is upset.

Furthermore, it is difficult to precisely machine the curvature of the emitter tip. Assuming, for example, that the average working life of an emitter with a radius of curvature deviation of 1 per cent is 500 hours, the average working life of an emitter with a radius of curvature deviation of 10 per cent is about 1 hour. Such being the case, in order to ensure equilibrium it is necessary to reset **B**, **C**, **D**, and **E** each time the emitter is replaced.

It is, therefore, an advantage of this invention to prolong the working life of the emitter. Another advantage of this invention is to keep the field emission current stable.

Towards this end, the embodiments according to this invention incorporate means for controlling pulse duty factor, emitter heating temperature, or bias voltage under the condition that the peak value of the pulse voltage is maintained constant.

Keeping the peak value of the pulse voltage constant is advantageous in that information on the radius of curvature of the emitter tip, namely, on crystal buildup and dulling can be obtained by detecting the field emission electron current. For example, as crystal buildup develops, the field emission current increases and, as crystal dulling develops, the field emission current decreases. As a result, by controlling these factors to keep the field emission current constant, the original shape or radius of curvature of the emitter tip can be maintained and the working life of the emitter prolonged.

Other objects and advantages of this invention will become apparent from the following detailed description read in conjunction with the appended drawings of which:

FIG. **1** is a schematic diagram showing an embodiment according to the invention;

FIGS. **2**(*a*)–**2**(*f*) and **3**(*a*)–**3**(*c*) are schematic drawings for explaining the function of the embodiment shown in FIG. **1**;

FIG. **4** is a schematic diagram showing another embodiment according to the invention;

FIGS. **5**(*a*)–**5**(*c*) and **6**(*a*)–**6**(*c*) are schematic drawings for explaining the function of the embodiment shown in FIG. **4**; and,

FIG. **7** is a schematic drawing showing yet another embodiment according to the invention.

FIG. **1** shows an embodiment of this invention in which the field emission current is kept constant by controlling the duty factor of the pulse voltage. An electron gun chamber **1** is maintained under vacuum. An emitter **2** has a filament **3** for supporting and heating the emitter. An electrode **4** generates an intense electric field at the emitter tip, and an anode **5** is maintained at ground potential for accelerating the field emission electrons.

A heating A.C. power source **6** includes an insulating transformer **7**. The potential at the midpoint of the secondary winding of the transformer **7** is equal to emitter potential and a D.C. high voltage source **8** is provided between the said midpoint and the anode **5** maintained at ground potential.

Since most of the current emitted from the emitter is absorbed by the electrode **4** due to the large emission dispersion angle, the output of the current detecting circuit **9** connected between the electrode **4** and said emitter can be considered as approximating the current emitted from the emitter. This output can be detected by measuring either the average value, the peak value or the effective value of the pulse current. The current detecting circuit may be connected between the emitter **2** and the high voltage source **8**. Further, the current detecting circuit can be replaced by a device which directly or indirectly detects current from the electron beam path.

The output of the current detecting circuit **9** is fed into a differential amplifier **10** together with the output of a reference signal circuit **11** and compared. The D.C. output signal of the differential amplifier **10** is then converted by an analog digital converter **12** into a train of pulses which are time-modulated. The output of the converter **12** in turn is converted by a monostable multivibrator (mono-multi) circuit **13** into pulse signals having constant time of pulse duration. Further, the output of the multivibrator circuit **13** is applied to a pulse amplifier **14** which controls the duty factor of the pulse voltage applied between the emitter **2** and the electrode **4.** The duty factor is the ratio of the length of pulse t_1 to the time between the start of each succeeding pulse T_1.

FIGS. **2**(*a*), **2**(*b*), **2**(*c*), **2**(*d*), **2**(*e*), and **2**(*f*) show, as an example, that in the embodiment described in FIG. **1**, a pulse duty factor (t_1/T_1) of 0.4 may maintain the equilibrium. FIG. **2**(*a*) indicates this pulse height of the pulse amplifier **14** has a constant value V_1. FIG. **2**(*b*) indicates the output of the current detecting circuit **9.** FIG. **2**(*c*) shows the state of the emitter tip under stress. The negative direction represents surface tension giving rise to crystal dulling and the positive direction represents the force of an electric field resulting in crystal buildup. In a state of equilibrium, the shaded areas in FIG. **2**(*c*) are equal. That is to say, the product of the pulse width t_1 and the electrostatic force f_1 is equal to the product of the rest time ($T_1 - t_1$) and the surface tension f_2 of the tip respectively. Should the equilibrium be upset, a buildup, for example, develops and the detected value of the emission current varies as shown in FIG. **2**(*e*). FIG. **2**(*e*) shows the condition after a change in current but before duty factor correction. Assuming that said current increases, a reference signal and its difference signal are emitted from the differential amplifier **10.** The pulse amplifier is then automatically controlled by the A-D converter and the multivibrator and the pulse duty factor is decreased (for example, (t_2/T_2) = 0.3) as shown in FIG. **2**(*d*). As a result, the period of time during which the emitter tip sustains surface tension increases as shown in FIG. **2**(*f*), and the radius of curvature of the emitter tip increases until it becomes equal to the radius of curvature in equilibrium.

FIGS. **3**(*a*), **3**(*b*), and **3**(*c*) show that at a different output pulse height of the pulse amplifier a different duty factor will provide equilibrium. Hence, an increase of pulse height to V_2 will result in an increase in current. The A-D converter and multivibrator will then adjust the duty factor based on the output of the differential amplifier which is indicative of equilibrium conditions. In this case, equilibrium can be retained by a pulse duty factor (t_1/T_3) of 0.32.

The embodiment described in FIG. **1** controls the duty factor of the pulse voltage by varying the pulse duration time.

However, it is possible to vary the pulse width and keep the pulse period constant with effective results.

FIG. **4** shows a second embodiment of this invention in which a constant field emission current is maintained by controlling the bias voltage during the rest time of the pulse voltage. In this embodiment, the voltage applied to the emitter **2** and the electrode **4** is the output of the pulse voltage generating circuit **15** and the bias voltage source **16.** The period of the pulse voltage generating circuit **15** is synchronized with the input signal from the timing circuit **17.** Further, the output of the timing circuit **17** controls the switching circuit **18,** which is on when the pulse voltage is applied, but is off at other times. Thus, the output of the bias voltage source is applied between the emitter **2** and the electrode **4** only during the pulse rest time.

The output of the pulse voltage generating circuit **15** must be connected so that the potential of the electrode **4** is positive with respect to that of the emitter, but the output of the bias voltage source **16** can be connected regardless of the polarity of the potential of the electrode **4** with respect to that of the emitter. Nevertheless, the negative potential is better since it helps to block thermions from the emitter. Although the effect of the bias voltage on the dulling of the emitter remains unchanged, regardless of the polarity as long as the magnitude is constant, dulling is impeded as the voltage rises and the buildup phenomenon is noted when the voltage exceeds a certain level.

FIGS. **5**(*a*), **5**(*b*), and **5**(*c*) and FIGS. **6**(*a*), **6**(*b*), and **6**(*c*) depict the different states of equilibrium with reference to the embodiment shown in FIG. **4,** in which the duty factor (t_2/T_4) of the pulse voltage is kept constant. But the bias voltage during the rest time of the pulse must be varied as shown in FIG. **5**(*a*) and FIG. **6**(*a*), so as to meet the equilibrium requirements, where field emission currents (I_1 and I_2) of different values are required as shown in FIG. **5**(*b*) and FIG. **6**(*b*). When a greater field emission current ($I_1 > I_2$) is needed, equilibrium is obtained by increasing the preset value of the pulse voltage ($V_3 > V_4$) and decreasing the absolute value of the bias voltage ($|V_5| < |V_6|$) simultaneously. As a result, as shown in FIG. **5**(*c*) and FIG. **6**(*c*), the amount of emitter deformation due to buildup (corresponds to the shaded sections of S_1 and S_2) is equal to the amount of emitter deformation caused by dulling (corresponds to shaded sections of S_3 and S_4).

FIG. **7** shows a third embodiment of this invention in which a constant field emission current is maintained by means of controlling the thermal temperature of the emitter. In general as the temperature rises, buildup and dulling also advance even in the same field. Consequently, the advance of both buildup and dulling can be made equal by setting the emitter temperature for the pulse duration time and that for the rest time at different values.

In the embodiment shown in FIG. **7,** the emitter **2** is heated only during the rest time of the pulses. For this end, the output of the pulse voltage generating circuit **15** and the on/off change over of the switching circuit **19,** provided at the input side of the insulating transformer **7** which transmits the emitter heating power **20,** are synchronized by means of the timing circuit **17.** When the switching circuit **19** is on, the output from the A.C. power source **20** is supplied through the transformer **7** and into the filament **3.** This output is controlled by the output of the differential amplifier **10.** Consequently, the output of power source **20** is small when the field emission current detected by the detector **9** is below the given value, depending on the output of the reference signal circuit **11,** but large when the given value is exceeded.

This embodiment is the so-called "cold emission type apparatus," in which the emitter is not heated during field emission. The same effect can also be achieved by an emitter heating type apparatus in which the heating temperature is controlled. As described above, the apparatus embodying this invention has such outstanding features as a stable field emission current in the electron gun, which is maintained at a comparatively low vacuum, and an emitter with prolonged working life. This invention includes an apparatus which is capable of a field emission of a large duty factor and period, for example, a pulse duration of one hour and a rest time of one second.

Having thus described the invention with the detail and particularity as required by the Patent Laws, what is desired protected by Letters Patent is set forth in the following claims:

1. A field emission type electron gun comprising:

a. an emitter having a tip,

b. a control electrode,

c. a power supply for supplying a pulse voltage having a constant peak value between said emitter and control electrode such that during the pulse an intense electric field in the vicinity of the emitter tip causes field emission therefrom and for supplying a bias voltage between pulses,

d. means for heating said emitter,

e. means for detecting the emitter current and

f. means responsive to the emitter current for adjusting one of the heating means and/or power supply to maintain the current substantially constant whereby the radius of curvature of the emitter tip remains substantially constant.

2. A field emission type electron gun comprising:

a. an emitter having a tip,

b. a control electrode,

c. a power supply for supplying a pulse voltage having a constant peak value between said emitter and control electrode such that during the pulse an intense electric field in the vicinity of the emitter tip causes field emission therefrom and for supplying a bias voltage between pulses,

d. means for heating said emitter,

e. means for detecting the emitter current and

f. means responsive to the emitter current for adjusting the power supply to vary the duty factor to maintain the current substantially constant whereby the radius of curvature of the emitter tip remains substantially constant.

3. A field emission type electron gun comprising:

a. an emitter having a tip,

b. a control electrode,

c. a power supply for supplying a pulse voltage having a constant peak value between said emitter and control electrode such that during the pulse an intense electric field in the vicinity of the emitter tip causes field emission therefrom and for supplying a bias voltage between pulses,

d. means for heating said emitter,

e. means for detecting the emitter current and

f. means responsive to the emitter current for adjusting the power supply to vary the bias voltage between pulses to maintain the current substantially constant whereby the radius of curvature of the emitter tip remains substantially constant.

4. A field emission type electron gun comprising:

a. an emitter having a tip,

b. a control electrode,

c. a power supply for supplying a pulse voltage having a constant peak value between said emitter and control electrode such that during the pulse an intense electric field in the vicinity of the emitter tip causes field emission therefrom and for supplying a bias voltage between pulses,

d. means for heating said emitter,

e. means for detecting the emitter current and

f. means responsive to the emitter current for adjusting the heating means to maintain the current substantially constant whereby the radius of curvature of the emitter tip remains substantially constant.

* * * * *