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Description

This invention relates to methods of trimming thin metal film resistors.

The invention is particularly, but not exclusively, applicable in manufacturing the graphic tablet disclosed in US 4,087,625, DE 2,753,968, FR 2,376,399 and GB 1,546,317. This tablet is particularly adapted to be mounted on the face of a display (such as a gas panel or a cathode ray tube) because it requires only a single layer of thin transparent metal electrodes in contrast to the construction in which there are two layers of orthoganally extending electrodes (and an intervening layer of insulation) for sensing X and Y co-ordinates of the position of the pen that is held on the surface of the display. The single metal layer is shaped to provide elongated rectangular resistive voltage dividers across the top and bottom edges (or across the side edges) of the active area of the tablet. Complementary shaped triangular electrodes extend along only one dimension from the two voltage dividers. These triangular electrodes are given an alternating voltage that is capacitatively coupled to a pen that is held to a selected point on the display by a user of the display. The pen voltage is proportional to the position of the pen in the X—Y co-ordinate system of the tablet.

It is desirable for the two voltage dividing resistors to be closely linear to establish a linear relationship between the position of the pen along the X dimension and the amplitude of the pen signal. Resistor linearity is less significant for tablet operation in the Y dimension. This linearity can be achieved by forming the resistors and the triangular electrodes on the glass substrate by any technique that is suitable for economical large scale production and by then trimming the resistors individually. A general object of this invention is to provide a new and improved method and apparatus for trimming such a resistor.

US 4,184,062 teaches a resistor made of a strip of film material with a trimming cut made along one edge of the resistor by means of a laser. As the laser trim operation proceeds from one end of the resistor to the other, the resistance to ground of the point of the trimming operation is measured. The slider of a precise master resistor is moved in step with the trimming operation. Where the resistor that is being trimmed is accurate, the voltage at the slider of the master resistor equals the voltage at the point of the trim. Circuits sense any difference between the two voltages and move the cutting operation inward as necessary to raise the resistance of the resistor being trimmed or outward to decrease the resistance of the resistor being trimmed.

This invention seeks to provide a method for trimming a resistor which avoids an ohmic contact probe on the surface of the resistor. It also seeks to trim a resistor to be linear independent of the absolute value of resistance. This invention further seeks to trim a resistor to a linear shape in a way that removes the least amount of the conductive layer and thereby maintains the lowest resistance with linearity. The invention also seeks to provide a new resistor trimming method that is simple to use for making a second trim for increased linearity over a resistor that has had at least an initial trim.

In another prior art technique, small notches are formed along the edge of the resistor to increase the resistance. This technique is accurate only if the measurement and the trim are made together. This invention seeks to provide an improved method for trimming a resistor in which resistance measurements are made independently of the trim operation. This feature is an advantage in a tablet operation because the information about the residual nonlinearity of the tablet is used in aligning the tablet with the display face for a minimum mismatch.

According to the invention, a method of trimming a thin metal film resistor, comprises applying an alternating voltage across the resistor, capacitatively measuring the voltage of the resistor at discrete points along the length of the resistor, storing the measured values, calculating a resistance profile from the measured values, and trimming the resistor along an edge according to the resistance profile.

In a method according to the invention, the resistance of a tablet resistor is first measured at discrete points using a capacitative voltage probe that is similar to the pen used in normal tablet operation. The capacitative probe "sees" an area of the resistor that is large enough to avoid any pin holes in the resistor film affecting the resistance reading. The resistance measurements are stored in a data processing system and are used to calculate a profile for a resistor trim operation. The trim is performed by conventional apparatus such as electro-erosion apparatus. The resistance is measured again and if necessary, a second or subsequent trim is made.

How the invention can be carried into effect is hereinafter particularly described with reference to the accompanying drawings, in which:—

FIGURE 1 shows a tablet in which resistors to be trimmed according to the method of this invention;

FIGURE 2 shows an edge view of the tablet and apparatus for measuring resistance and calculating a resistance profile in one part of the method;

FIGURE 3 is a graph illustrating the resistance measurements;

FIGURES 4 and 5 are graphs illustrating steps in the calculation of the resistor trim profile;

FIGURE 6 is a top view of a resistor of the tablet of Fig. 1 illustrating the trim operation; and

FIGURE 7 is a view similar to Fig. 2 illustrating the resistor trim operation and apparatus.

The invention will be described as applied to the trimming of a thin film resistor in a graphic tablet disclosed in US-4,087,625, DE-2,753,968, FR-2,376,399 and GB-1,546,317. The tablet shown in Fig. 1, could be in a substantially vertical plane for use with a display device or in a substantially horizontal plane for use in an application such as providing handwritten input to a computer system. The terms "Top", "Bottom", "Sides" and "Up", "Down", "Right", "Left" will be used to designate positions and directions in the plane of the drawing. Motions in a direction orthogonal to the plane of the drawing will be called "Raising" and "Lowering" as is conventional for describing positions of a hand-held pen.

The tablet has a substrate 12 of glass. A film of a transparent conductor such as indium-tin oxide is vacuum deposited on the surface of the glass and is then etched to form a patten of electrodes identified as 14, 15, 16, 17, 18, 19, 20, 21, 22 and 23. Elongated rectangular electrodes 14 and 15, which act as resistors, extend along opposite edges of the tablet. Small connector electrodes 16 and 17 extend at fixed intervals from the electrodes 14 and 15, respectively. Elongated triangular electrodes 18 and 19 extend in interdigitated formation from the electrodes 16 and 17, respectively, and form the active area of the tablet. These electrodes are energized to establish a voltage that can be sensed capacitatively by a conventional capacitative pen (not shown). The pen voltage is proportional to the position of the pen in either the X or Y dimension, depending on the way in which the electrodes are energized. Screened wide metal tabs 26 and 27 connect to the left ends of the electrodes 14 and 15, respectively. Similar tabs 28 and 29 connect to the right ends of the electrodes. The tabs connect the electrodes to circuits (not shown) for normal operations that establish an alternating voltage gradient across one dimension of the tablet. These tabs are also used to apply test voltages to the electrodes for the manufacturing steps of this invention.

In the preferred orientation, the electrodes extend horizontally and the resistors are located along the sides because the active area is ordinarily made wider than it is high and this orientation of the electrodes permits a smaller area to be used for the resistors.

In subsequent stages of the manufacturing process, additional transparent layers are formed over the layer of metal electrodes. These layers space the pen slightly from the triangular metal electrodes to produce an averaging effect on the voltage of the discrete nearby electrodes that is sensed by the pen. Consequently, the pen does not sense the discrete voltage steps that are established by connector electrodes 16 and 17 when a voltage is applied across the electrodes 14 and 15.

The normal operation of the tablet will be described as an introduction to the related resistance measuring operations.

For sensing the pen position in the Y dimension, the upper resistor electrode 14 (or the lower resistor electrode 15) is held at ground potential all along its length by grounding its two tabs 26 and 28 (or 27 and 29) so that each of the associated triangular electrodes 18 (or 19) is also at ground potential. The lower resistor electrode 15 (or the upper resistor electrode 14) is given an alternating voltage uniformly across its length by connecting both tabs 27 and 29 (or 26 and 28) to an alternating voltage point so that each of the associated triangular electrodes 19 (or 18) also receives this alternating voltage. When a pen is positioned on the tablet, it receives an alternating voltage by capacitative coupling to the nearby triangular electrodes 18 and 19. This capacitative coupling is proportional to the area of the electrodes in the field of view of the pen. When a pen is positioned towards the bottom (or top) of the tablet, is receives nearly the full alternating voltage of the resistor electrode 15 (or 14). As the pen is moved towards the top (or bottom) of the tablet, the capacitative coupling to electrodes 18 (or 19), which are at ground potential, becomes greater and the pen voltage falls in proportion to its Y dimension position.

When the tablet is operated in the mode just described, the movement of the pen horizontally across the tablet without a change in position of the Y dimension should produce no change in the pen voltage. To achieve this tablet linearity, the voltage at each connector electrode 17 (or 16) must be kept essentially identical in spite of the fact that the capacitative charging current for triangular electrodes 18 and 19 flow in resistor electrodes 14 and 15 and are greater toward the outside ends of the resistor electrodes than toward the middle. Accordingly, for accuracy in the Y dimension operation, the resistor electrodes 14 and 15 should have a lower resistance value. The thickness of resistor electrodes 14 and 15 is limited by the requirement that the associated triangular electrodes 18 and 19 must be thin in order to be transparent. The thickness of the electrodes is of the order of 130 nm. The width of the resistor electrodes 14 and 15 is limited by the requirement to make the active area of the tablet as large as possible within the limited overall dimensions of the glass substrate 12.

For sensing the position of the pen in the X dimension, the left (or right) ends of both resistor electrodes 14 and 15 are held at ground potential and the right (or left) ends are given the same alternating voltage. The two resistor electrodes 14 and 15 are made linear so that the potential at a connector electrode 16 of a triangular electrode 18 is identical to the potential at the connector electrode 17 of the corresponding triangular electrode 19. A pair of triangular electrodes 18 and 19 then has the effect of a single rectangular electrode at the potential of the associated connector electrodes 16, 17. When a linear tablet is operated for sensing the position of the pen in the X dimension, the pen can be moved up and down the tablet at a constant X dimension position without changing the voltage that is sensed by the pen. When the pen is moved from left to right across the tablet, the pen voltage increases uniformly (or decreases, if the connections are reversed). For this operation both resistor electrodes 14 and 15 must be linear so that the alternating voltage will be identical at corresponding points on the two resistor electrodes. However, it is not necessary for the total resistances of the two resistor electrodes to be identical. Thus, an object of this invention is to provide a resistor trim operation that maintains the lowest resistance possible for each individual tablet (in contrast to trimming the resistors of each tablet to a specified resistance value).

Measuring Resistor Linearity

A resistance measuring probe 34 (Fig. 2) has a metal electrode 35 and a dielectric body 36 preferably of a plastics material having a high dielectric constant to enhance the capacitative coupling. The electrode 35 is spaced by dielectric from a tablet electrode to establish a capacitative circuit so that the probe voltage is related to the voltage of the tablet electrode as in normal tablet operation using a pen.

The tablet comprising the substrate 12 and the electrodes is positioned in a vacuum check or other suitable fixture (not shown) and the probe 34 is connected by conventional means, represented by line 38, to an X—Y stepper positioning mechanism 39. The probe is first positioned at one end of resistor electrode 15 approximately on the centre line (to avoid edge effects) and then stepped along the resistor electrode in increments of about 12.7 mm (.50 inch). During this resistance test, an oscillator 40 supplies an alternating voltage to the tab 29 located at the right end of resistor 15 and the tab 27 at the left end of the resistor is connected to ground. Thus, the voltage of oscillator 40 appears between tabs 29 and 27 and resistor electrode 15 resistively divides this voltage so that an alternating voltage gradient appears along the length of the resistor. This alternating voltage is linear with respect to the length of the resistor according to the uniformity of the resistance. The voltage of the area of resistor electrode 15 under probe 34 is capacitatively coupled to the electrode 35 and this voltage is transmitted to a conventional analog-to-digital converter 44. Digital values of the voltage are supplied to a conventional data processor 45 which processes and stores the incremental values. The processor 45 is also connected to control the operation of the stepper mechanism 39.

It will be understood that the alternating voltage may be applied to opposite ends of the electrode 15, and that the operation is repeated for the electrode 14.

This capacitative measurement technique avoids several problems that can be encountered with ohmic contact probes. For example, the spacing between electrodes 15 and 35 produces an averaging effect as has been explained for the operation of the tablet. The spacing is made great enough to average out the effect of pin holes that may occur in resistor electrodes 14 and 15, because the probe electrode "sees" an area of the electrode that is suitable in size. Otherwise, the spacing between electrode 35 and electrode 14 or 15 is made small to produce good capacitative coupling for a strong signal and to avoid effects from any nearby edge of the resistor electrode so that the resistor electrode appears as an essentially infinite plane.

The Resistance Data

Figure 3 is a graph which illustrates the data obtained from the resistance measuring apparatus just described. The numbers 0 to 10 along the horizontal axis represent discrete sample points. The vertical axis represents the voltage measurement, equivalent to the resistance to the grounded tab 27. A line connecting points on the graph illustrates that the resistor is slightly nonlinear. The non-linearity is measured by calculating a least mean squared error linear function by linear regression analysis (a conventional statistical function) and by comparing the actual voltage or resistance values with this linear function. If the points are within a suitable percentage (preferably 0.25%), the resistor is accepted for product use without the trim operation.

Figure 4 is a graph which illustrates the next stage in processing the data represented in Fig. 3. In Fig. 4, the left-hand vertical axis represents the incremental resistance or difference between the sample point identified on the horizontal axis and the preceding sample point obtained by subtracting one resistance value from the next. The height of a point in Fig. 4 corresponds to the slope of the line in Fig. 3.

The highest incremental resistance, in this case at points 5 and 6, is obtained by comparison and a normalized resistance for each point obtained by dividing each value by the highest value, which occurs at points 5 and 6. The right-hand vertical axis indicates the normalized resistance values. Thus, points 5 and 6 have normalized values of 1 and the other points have smaller normalized values. The normalized values are used to determine the absolute width of the trim as explained hereinafter. The normalized resistance values are subtracted from 1 to give the graph in Fig. 5, a mirror image of Fig. 4. At points 5 and 6, which have maximum incremental resistance values and normalized resistance value of 1, a zero value occurs.

The graph of Fig. 5 is a suitable profile for the resistor trim operation. No trim should be required at points 5 and 6 of highest incremental resistance. Similarly, the greatest trim should be made at point 2, where the lowest incremental resistance is measured.

The Trim Operation

The trimming cut is preferably made by a spark erosion apparatus as shown in Fig. 7, but similar metal cutting operations can be made by a laser, and the invention is applicable to various metal cutting techniques. The data processor 45 supplies the appropriate commands to the X—Y stepper positioning mechanism 39 to position an electrode 50 of a conventional spark erosion device along the required path. The electrode 50 is connected in circuit with a current source 51 for the spark erosion apparatus and is in contact with the resistor electrode 15.

The mechanism 39 moves the electrode 50 along the length the X dimension of the resistor electrode in steps of a fixed distance preferably 2.54 mm (0.1 inch) or one fifth of the distance between sample points. At the end of a step, the mechanism 39 under the control of the processor 45 moves the electrode sideways (up or down in the Y dimension) by an amount equal to one fifth of the difference between the normalized resistances at adjacent sample points. Thus, the trim profile of Fig. 5 is followed in a step fashion by the electrode 50 and the actual trim approximates a continuous function of resistance with respect to position on the resistor electrode.

This has been exaggerated for illustration in Fig. 6, where the incremental resistance at points 7 and 8 is only two thirds of the maximum value which occurs at points 5, 6 and 10. Because the incremental resistance is approximately proportional to the width of the resistor, reducing the width between points 7 and 8 to two thirds the total width raises the incremental resistance to the value at the maximum points.

The electrode 50 makes a cut 53 that produces a selvedge 15' which is not electrically connected to the main body of the electrode 15.

After the resistors have been trimmed, the resistance measurement and data processing is repeated. In many cases, a single trim brings the resistance with the desired linearity. If not, a second trim is made. This operation is similar to the steps already described except that the width of the second trim is calculated from the line 53 of the first trim.

The invention is useful in other applications where a metal film resistor is to be trimmed to be linear but the actual resistor value can be within a specified range. Although the capacitative probe and the associated alternating voltage circuits have been found particularly useful with metal film resistors because the probe avoids the problems that are caused by pin-holes when only contact probes are used, the invention may also be useful in applications in which the film is electrically insulated or otherwise cannot be suitably contacted by an Ohmic probe. The invention can be implemented with various kinds of mechanical stepping apparatus and with a variety of metal cutting techniques. The statistical and mathematical techniques for calculating the trim profile from the resistance samples are well known and can be implemented readily in many programming languages. The analysis of the resistance measuring technique has been presented in terms of resistance measurements, but it can be presented equivalently in terms of conductance (the reciprocal of resistance) or from other viewpoints.

Claims

1. A method of trimming a thin metal film resistor (15), comprising applying an alternating voltage across the resistor, capacitatively measuring the voltage of the resistor at discrete points along the length of the resistor, storing the measured values, calculating a resistance profile from the measured values, and trimming the resistor along an edge according to the resistance profile.

2. A method according to claim 1, in which the calculation of the resistance profile includes calculating incremental resistance values between discrete points (Fig. 4).

3. A method according to claim 2, in which the calculation of the resistance profile includes normalizing the incremental resistance values to the maximum incremental resistance value (Fig. 4).

4. A method according to claim 3, in which the resistance profile is derived from the normalized incremental resistance values by deducting them from the maximum normalized incremental resistance value (Fig. 5).

5. A method according to any preceding claim, in which additional points on the resistance profile are calculated by interpolation between values at adjacent discrete points (Fig. 6).

6. A method according to any preceding claim, in which the capacitative voltage measurement is effected by positioning a capacitative probe (34) at a sufficient distance above the resistor to avoid the effects of any pinholes in the resistor.

7. A method according to claim 4 or any claim appendant thereto, in which the resistor is not trimmed at the point of maximum normalized incremental resistance value, whereby a minimum increase in total resistance is achieved.

8. A method according to claim 5 or any claim appendant thereto, in which the resistor trimmer is stepped in a plurality of steps between points according to the profile which approximates to a continuous function.

9. A method of trimming the thin metal film resistors of a graphic tablet of the type having two resistors (14, 15) located along opposite edges of the tablet and having interdigitated triangular elements (18, 19) extending from the resistors in the active area of the tablet, comprising the steps of trimming each resistor along an outside edge by a method according to any preceding claim.

Revendications

1. Procédé pour ajuster une résistance à couche métallique mince comprenant les étapes consistant à appliquer une tension alternative (40) aux bornes de la résistance (15), à mesurer de façon capacitive la tension de la résistance en des points discrets sur la longueur de cette résistance, à mémoriser les valueurs mesurées, à calculer un profil de résistance à partir des valeurs mesurées et à ajuster la résistance le long d'un bord conformément à ce profil de résistance.

2. Procédé selon la revendication 1, selon lequel le calcul du profil de résistance inclut le calcul de valeurs incrémentales de la résistance entre des points discrets (figure 4).

3. Procédé selon la revendication 2, selon lequel le calcul du profil de résistance inclut la normalisation des valeurs incrémentales de résistance à la valeur incrémentale maximum de résistance (figure 4).

4. Procéde selon la revendication 3, selon lequel le profil de résistance est obtenu à partir des valeurs incrémentales normalisées de résistance, par soustraction de ces dernières de la valeur incrémentale maximum normalisée de résistance (figure 5).

5. Procédé selon l'une quelconque des revendications précédentes, selon lequel des points supplémentaires sur le profil de résistance sont calculés par interpolation entre des valeurs en des points discrets voisins (figure 6).

6. Procédé selon l'une quelconque des revendications précédentes, selon lequel la mesure de tension capacitive est effectuée en disposant une sonde capacitive (34) à une distance suffisante audessus de la résistance afin d'éviter les effets de trous d'épingle dans la résistance.

7. Procédé selon la revendication 4 ou n'importe quelle revendication dépendante de cette revendication, selon lequel la résistance n'est pas ajustée au point de la valeur incrémentale maximum normalisée de résistance, ce qui permet d'obtenir un accroîssement minimum de la résistance totale.

8. Procédé selon la revendication 5 ou n'importe quelle revendication dépendante de cette revendication, selon lequel l'ajustement de la résistance est échelonné suivant une pluralité de pas entre des points conformément au profil qui se rapproche d'une fonction continue.

9. Procédé d'ajustement des résistances à couche métallique mince d'une tablette graphique du type comportant deux résistances (14, 15) situées le long de bords opposés de la tablette et comportant des éléments triangulaires interdigités (18; 19) s'étendant à partir des résistances dans la surface active de la tablette, incluant les phases opératoires d'ajustement de chaque résistance le long d'un bord extérieur selon un procédé conforme à l'une quelconque des revendications précédentes.

Patentansprüche

1. Verfahren zur Trimmung eines Metalldünnschichtwiderstandes, nach welchem eine Wechselspannung (40) am Widerstand (15) angeleft wird, die Spannung des Widerstands an diskreten Punkten entlang der Länge des Widerstandes kapazitiv gemessen wird, die Meßwerte gespeichert werden, eine Widerstandsprofil aus den Meßwerten berechnet wird und der Widerstand längs einer Kante gemäß dem Widerstandsprofil getrimmt wird.

2. Verfahren nach Anspruch 1, bei welchem die Berechnung des Widerstandsprofils das Berechnen von inkrementellen Widerstandswerten zwischen diskreten Punkten beinhaltet (Fig. 4).

3. Verfahren nach Anspruch 2, bei welchem die Berechnung des Widerstandsprofils das Normieren der inkrementellen Widerstandswerte auf den maximalen inkrementellen Widerstandswert beinhaltet (Fig. 4).

4. Verfahren nach Anspruch 3, bei welchem das Widerstandsprofil von den normierten inkrementellen Widerstandswerten durch Abziehen derselben vom maximalen normierten inkrementellen Widerstandswert hergeleitet wird (Fig. 5).

5. Verfahren nach irgendeinem vorstehenden Anspruch, bei welchem zusätzliche Punkte auf dem Widerstandsprofil durch Interpolation zwischen Werten benachbarter diskreter Punkte berechnet werden (Fig. 6).

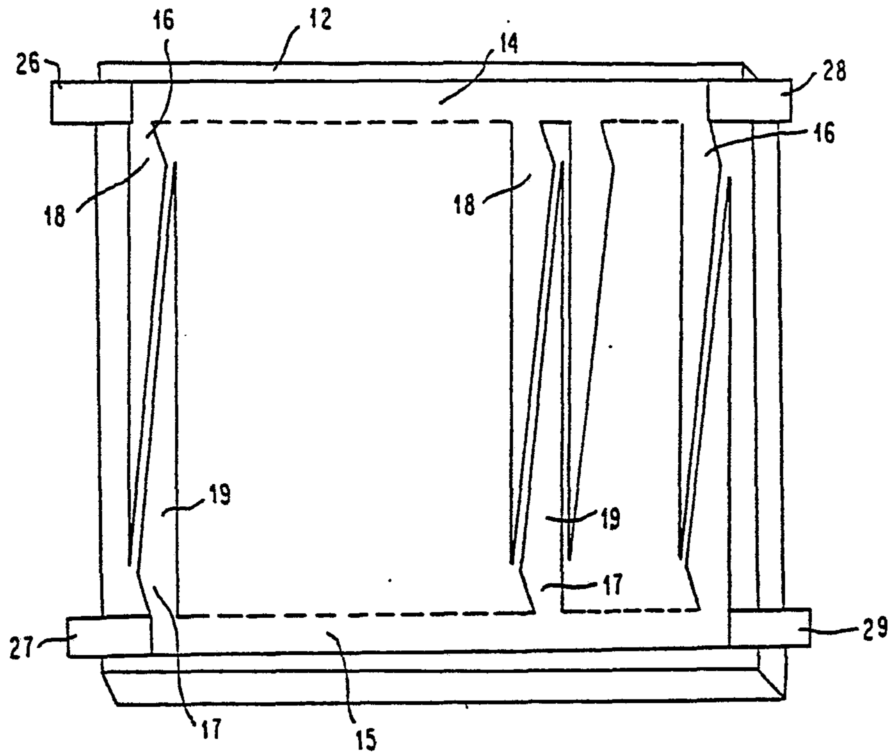
6. Verfahren nach irgendeinem vorstehenden Anspruch, bei welchem die kapazitive Spannungsmessung durch Positionieren einer kapazitiven Sonde (34) in ausreichendem Abstand über dem Widerstand zur Vermeidung der Wirkungen von Nadellöchern im Widerstand ausgeführt wird.

7. Verfahren nach Anspruch 4 oder irgendeinem darauf rückbezogenen Anspruch, bei welchem der Widerstand am punkt des maximalen normierten inkrementellen Widerstandswerts nicht getrimmt wird, wodurch eine minimale Zunahme des Gesamtwiderstandes erzielt wird.

8. Verfahren nach Anspruch 5 oder irgendeinem darauf rückbezogenen Anspruch, bei welchem der Widerstandstrimmer in einer Anzahl von Schritten zwischen Punkten gemäß einem Profil, das eine kontinuierliche Funktion annähert, in Stufen fortbewegt wird.

9. Verfahren zur Trimmung eines Metalldünnschichtwiderstands einer graphischen Tafel mit zwei Widerständen (14, 15), die längs gegenüberliegender Kanten der Tafel angeordnet sind und interdigital angeordnete dreieckige Elemente (18, 19) aufweisen, welche sich von den Widerständen in den aktiven Bereich der Tafel erstrecken, mit den Verfahrensschritten des Trimmens eines jeden Widerstands längs einer äußeren Kante nach einem Verfahren gemäß irgendeinem vorstehenden Anspruch.

FIG. 1



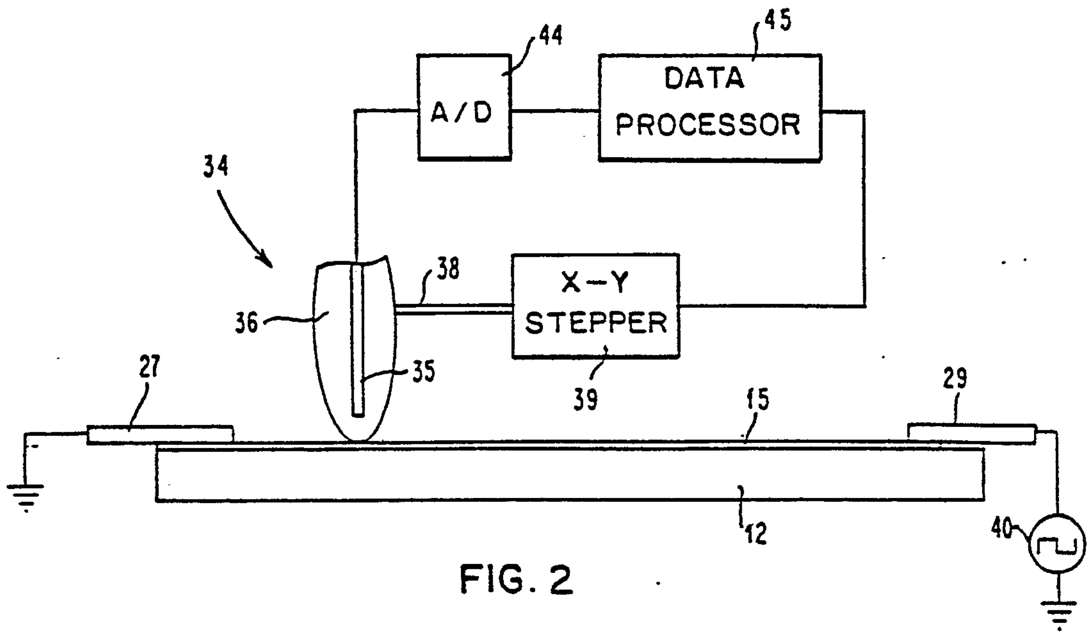

44
45
A/D
DATA
PROCESSOR
34
38
X-Y
STEPPER
36
35
39
27
29
15
12
40

FIG. 2

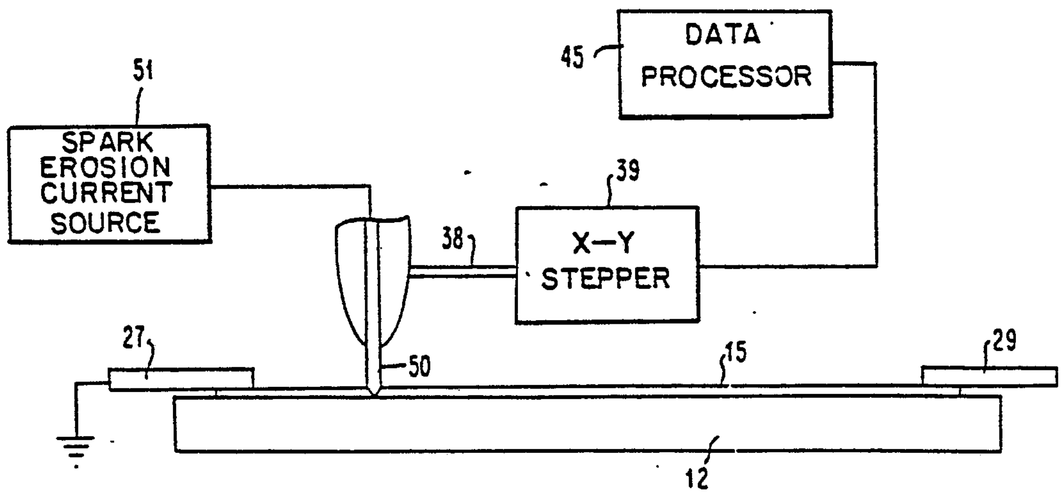

DATA
PROCESSOR
45
51
SPARK
EROSION
CURRENT
SOURCE
39
38
X-Y
STEPPER
27
50
15
29
12

FIG. 7

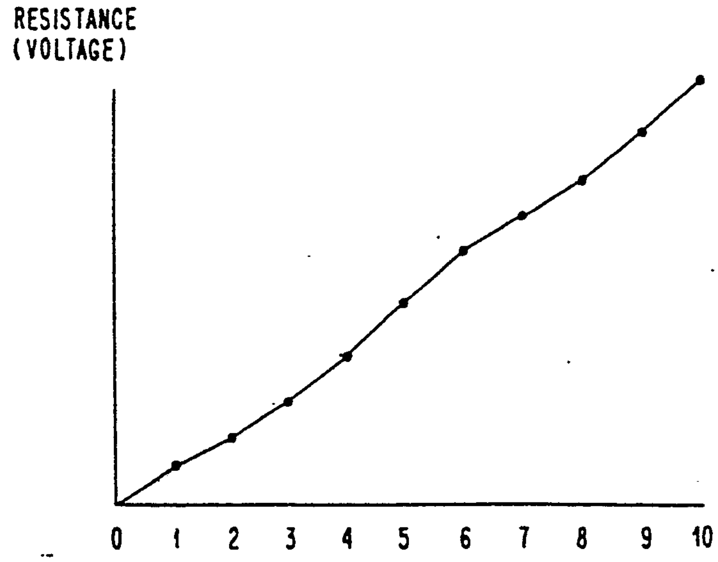


FIG. 3

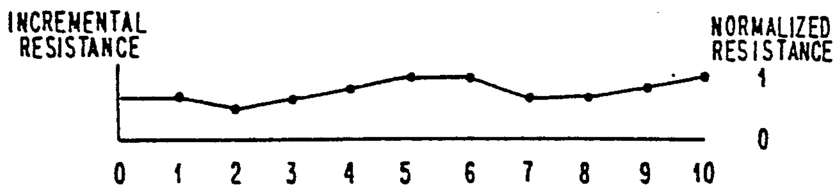


FIG. 4

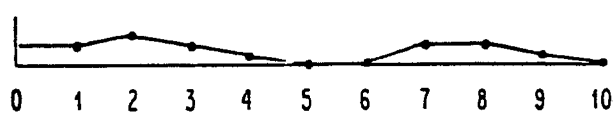


FIG. 5

FIG. 6