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(54) **Method of establishing an electrical connection to a conductor on a substrate and an assembly produced by this method.**

(57) A U-shaped metal contact is crimped on to a substrate (2) by means of a pair of parallel-surface dies (10,11) such that plastic deformation of the bight (4) of the contact takes place whereby after removal from between the dies (10,11) the arms (5,6) of the contact remain inherently biased towards each other with the substrate (2) gripped between them.

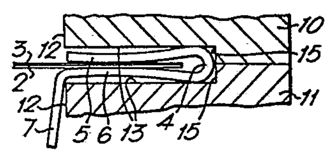

FIG.4.

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Method of establishing an electrical connection to a conductor on a substrate

This invention relates to a method of establishing an electrical connection to a conductor on a substrate, and particularly to a conductor on a surface of a film of insulating material.

Widespread use is made in the electrical and electronics industries of substrates having conductors on one or both of their surfaces. The substrates may comprise relatively thin plastics films, of, for example, polyester or polyimide material. The conductors are provided on the surfaces of the films by several different methods. Silkscreening is widely used as a low cost method of producing extremely thin conductors on the surfaces of the films. Silkscreened conductors are extremely delicate, and are often subject to damage when electrical connections are made to them. Conductors are also provided on surfaces of films by electrodeposition in selected areas and along desired conductive paths, or by depositing conductive metal over the entire surface of a film and then selectively etching the surface to leave the desired conducting paths. These electrodeposited conductors are somewhat more durable than silkscreened conductors but are still relatively fragile. It is also known to laminate thin sheets of conductive metal to a film and etch away the surface of the film to leave the desired conductors. Such laminated metal conductors are relatively durable and relatively thick, but they are also relatively costly to produce.

Electrical connections can be made to conductors on insulating films by soldering methods, but such methods are usually highly labour intensive and therefore costly. Furthermore, care must be taken in making soldered connections to silkscreened and electrodeposited conductors that the conductors on the film are not damaged by the heating of the soldering operation.

Several crimp-type connecting devices are known for use on laminated film/conductor assemblies; see for example U.S. Patent No. 3,395,381. However, while the conductors on such laminated assemblies will withstand the relatively high compressive forces required during the crimping operation, the more delicate electrodeposited and silkscreened conductors are liable to be damaged by these compressive forces during the crimping operation.

According to this invention a method of establishing an electrical connection to a conductor on a substrate, comprising crimping a substantially U-shaped metal contact to embrace the substrate and conductor between the arms thereof, is characterised in that crimping is effected by compressing the contact between a pair of parallel-surface dies through a condition in which the free ends of the arms of the contact engage opposite sides of the substrate, to a condition in which plastic deformation of the bight of the contact has occurred, whereby after removal from between the dies, the arms of the contact remain inherently biased towards each other with the substrate gripped between the arms and one of the arms engaging the conductor on the substrate.

An advantage of the method of this invention is that during the crimping operation the principle crimping forces are applied only to the bight portion of the metal member and not to the arms thereof. The conductors on the substrate are not therefore subjected to these high crimping forces, but are subjected only to much lower forces which are developed in the arms.

This invention will now be described by way of example with reference to the drawings, in which:-

Figure 1 is a perspective view of a portion of a substrate having a conductor on its surface and a substantially U-shaped metal contact for connection to the conductor by the method of this invention;

Figure 2 is a cross-sectional view of a pair of crimping dies for crimping the contact on to the substrate, this view showing the dies in an open position which they occupy at the beginning of the crimping operation;

Figures 3 and 4 are views similar to Figure 2, but showing the positions of the dies at successive stages in the crimping operation;

Figure 5 is a perspective view of the final crimped connection made by the method of this invention;

Figure 6 is a side view of the crimped connection of Figure 5;

Figure 7 is a diagrammatic side view illustrating the manner in which the contact is stressed in the crimped connection of Figures 5 and 6;

Figure 8 is a perspective view of an end portion of a substrate having a plurality of conductors thereon, and a section of a continuous strip of contacts for connection to the conductors by the method of this invention;

Figure 9 is a perspective view of the substrate of Figure 8 with the contacts crimped on to the conductors thereof;

Figure 10 is a fragmentary perspective view of a portion of a strip of double contacts in alignment with two spaced-apart substrates having conductors on their opposed surfaces;

Figure 11 is a sectional side view of a pair of crimping dies for crimping an individual double contact on to the two spaced-apart substrates shown in Figure 10, this view showing the position of the crimping dies at the beginning of the crimping operation;

Figure 12 is a view similar to Figure 11 but showing the positions of the parts at the end of the crimping operation;

Figure 13 is a sectional side view of a crimped connection illustrating the removal of a carrier strip;

Figure 14 is a side view of an idealised contact for use in the method of this invention, which is referred to in a mathematical analysis presented below;

Figure 15 is a view similar to Figure 14, but showing the contact at an intermediate stage in the crimping operation;

Figures 16 and 17 are diagrams referred to in the mathematical analysis;

Figure 18 is a curve referred to in the mathematical analysis;

Figure 19 is a further diagram referred to in the mathematical analysis; and

Figures 20 and 21 are additional curves

referred to in the mathematical analysis.

Figure 1 shows an uncrimped substantially U-shaped metal contact 1 which is adapted to be crimped on to an insulating substrate 2 having a conductor 3 on its upper (as seen in Figure 1) surface, the conductor 3 extending to an edge of the substrate 2. The contact 1 may be of any suitable conductive metal having the required spring properties, such as hardened brass. The contact 1 is substantially U-shaped having an arcuate bight 4 and arms 5 and 6 which are subsequently referred to as cantilever beams, since they function as such in the final crimped connection. An integral post 7 extends from the free end of the arm 6, which post 7 may be connected to a further conductor (not shown), or may be mated with a complementary connecting device (not shown).

Referring now to Figures 2 to 4 also, the contact 1 is crimped on to the substrate 2 by crimping dies 10 and 11 which are mirror images of each other. Accordingly, the structural features of the two dies 10 and 11 are identified by the same reference numerals.

Each die 10 and 11 has a vertically extending front surface 12, a horizontally extending crimping surface 13, and a stop surface 14 which is separated from the crimping surface 13 by a vertically extending shoulder 15. The shoulder 15 is spaced from the surface 12 by a distance such that the shoulder 15 does not engage the bight portion 4 of the contact 1 during crimping.

To crimp the contact 1 on to the substrate 2 by the method of this invention the contact 1 is positioned as shown in Figure 2 with the free ends of the cantilever beams 5 and 6 adjacent to the surfaces 12 and against the surfaces 13. The substrate 2 is positioned between the opposed surfaces of the arms 5 and 6 with the end of the substrate 2 adjacent to the centre of the bight 4.

The dies 10 and 11 are then moved along straight line paths towards each other until the stop surfaces 14 are against each other. The stop surfaces 14 thus determine the final crimp height (the distance between the surfaces 13) in the crimped connection.

During crimping, the free ends of the arms 5 and 6 are moved towards each other until they are against the surfaces of the substrate 2, as shown in Figure 3. During this initial stage of the crimping operation, the position of engagement of the surfaces 13 with the outer surfaces of the arms 5 and 6 moves rightwardly, as seen in Figures 2 and 3 and at the intermediate stage shown in Figure 3 the surfaces 13 will engage the contact 1 at diametrically opposite positions on the bight 4. It will be noted in Figure 3, that the radius of curvature of the bight 4 is substantially unchanged from its original radius.

During the final stage of the crimping operation, and as the dies 10 and 11 move to their fully closed condition shown in Figure 4, the material in the root 8 (Figure 6) of the bight portion 4 is plastically deformed, and the radius of curvature at the root 8 is substantially reduced although the radius of curvature at positions immediately adjacent to the root 8 will be substantially unchanged from the original radius. During this stage, the arms 5 and 6 are resiliently stressed against the surfaces of the substrate 2, and after the dies 10 and 11 are opened and the crimped connection removed from the dies, the arms 5 and 6 will be held in their stressed condition inherently biased towards each other by the plastically deformed root 8 of the bight 4.

Figure 7 illustrates the manner in which the arms 5 and 6 are stressed in the completed crimped connection. The solid lines show the actual positions of the 5 and 6, and the dotted lines show the positions that the arms 5 and 6 would assume if they were unrestrained by each other. The arms 5 and 6 are thus resiliently urged against the surfaces of the substrate 2 and the arm 5 is maintained in electrical contact with the conductor 3.

The method of this invention can be used with substrates of different thickness, and the contact can be within a wide range of sizes. For example, good results have been obtained with a contact formed of 0.3048mm thick brass having a radius of curvature in the bight of 0.508mm and having arms 2.032mm long. This connecting device was used with a substrate having a thickness of about 0.254mm.

As shown in Figures 8 and 9, contacts 1 can be produced as a continuous strip comprising a carrier strip 20 which is integral with the free ends of the arms 5. A strip of contacts 1, as shown in Figure 8, can be crimped on to respective conductors 3 on a multi-conductor substrate 2 by locating the free end of the substrate between the opposed surface arms 5 and 6 and then simultaneously crimping all of the contacts 1 on to the individual conductors 3, and severing the carrier strip 20 from the ends of the arms 5. This mass crimping operation can be carried out by means of crimping dies of the type shown in Figure 2, and will result in an assembly as shown in Figure 9.

Figures 10 to 13 illustrate the use of the method of the invention to establish connections to conductors 3 on the opposed surfaces of two spaced-apart parallel substrates 2.

Double contacts 1 are produced as a continuous strip on a carrier strip 20 as in Figure 8, and are crimped <u>en masse</u> on to the substrates 2.

Each contact 1 of the strip has a W-shaped double contact at its upper end, the upper contact comprising an arcuate bight 4 having cantilever beam arms 5 and 6 extending therefrom. The free end of the arm 5 is integral with the carrier strip 20 and the end of the arm 6 is connected by a sharp reverse bend to the arm 5 of the lower contact. This lower contact has an arcuate bight 4 and a lower cantilever beam arm 6 from the free end of which a contact pin 7 extends.

The arm 6 of the upper contact and the arm 5 of the lower contact are identified as cantilever beams notwithstanding the fact that their ends are connected by the sharp reverse bend 46. This sharp reverse bend does not appear to affect the functioning of these arms as cantilever beams, as will be described below.

The spacing between adjacent contacts 1 on the carrier strip 20 is the same as the spacing between adjacent conductors 3 on the substrates 2, such that when a section of the strip is positioned between the substrates 2, one of the arms of a contact will be in alignment with a conductor on one of the substrates.

A section of the strip 20 is crimped on to the substrates 2 by crimping dies 10 and 11, as shown in Figure 11. These crimping dies 10 and 11 are mirror images of each other, and the parts thereof have the same reference numerals as used for the corresponding parts in Figures 2 to 4.

To crimp a section of the strip 20 on to the substrates 2, the end portion of the substrates 2 is moved rightwardly from the position of Figure 11 so that the upper substrate is between the arms 5 and 6 of the upper contact and the lower substrate is between the arms 5 and 6 of the lower contact, with the ends of the substrates adjacent the bights 4 of the contacts. Thereafter, the dies 10 and 11 are moved towards each other to their closed position as shown in Figure 12. The upper contact is crimped on to the upper substrate, and the lower contact is crimped on to the lower substrate. After the dies 10 and 11 are opened, the carrier strip 20 is removed, as shown in Figure 13.

As explained above, the arms 5 and 6 of the contacts 1 are resiliently biased against the substrates 2 after the crimping operation has been carried out, and have no tendency to move away from the substrates from their positions shown in Figure 13. Furthermore, the crimping operation does not result in the imposition of extremely high compressive crimping forces on the arms 5 and 6; the maximum crimping forces are rather imposed only on the bight portions 4 so that the possibility of damage to the conductors 3 is minimised.

Under some circumstances it may be desirable to provide projections on the facing surfaces of the arms of a contact for the purpose of penetrating any thin oxide film which may be formed on the conductor on the substrate. Also, the facing surfaces may be provided with barbs for the purpose of penetrating insulation when the method is used for establishing contact with the conductors of a fully insulated flat conductor cable. The use of barbs or other projections is also beneficial in that movement of the substrate and the crimped contact relative to each other will be prevented. If such projections are provided, the contact force would nonetheless be maintained by the stressed condition of the arms of the contact device.

In carrying out the method of the invention the parallel, spaced-apart surfaces 13 of the crimping dies 10 and 11 move towards each other along straight line paths which extend normally of the planes of these surfaces. As the surfaces 13 move in this manner, the positions of engagement of the surfaces 13 with the arms 5 and 6 will be as shown in Figure 3 at an intermediate stage of the crimping operation and further movement of the surfaces 13 toward each other will bring about the desired reduction of the root 8 of the bight 4 and the development of the contact force in the arms 5 and 6.

For a contact having a given geometry, a given initial bight radius R, and on arm length L, a material thickness <u>t</u>, and having given physical properties in the material, such as strength and elastic modulus, there is a crimp height which is reached in an intermediate stage of the crimping operation at which the free ends of the arms 5 and 6 will touch each other. This crimp height is shown in Figure 3, and at this crimp height, there is no significant stress in the arms 5 and 6. It is apparent that it must be possible to crimp the contact further to the crimp height shown in Figure 4 so that the arms will be stressed and loaded against the substrate 2. This means that the material of the contact must be capable of undergoing a substantial amount of plastic deformation at the bight 4 while it is crimped from the position of Figure 3 to the position of Figure 4. If the material is incapable of undergoing this required amount of plastic deformation, it will fail in the bight 4 and the loading force in the arms 5 and 6 will be relieved so that no contact pressure will be developed. Also, the initial radius of the bight enters into these matters, in that if this initial radius is too small, it may be impossible to reduce the crimp height by an amount which will result in the development of the desired stresses in the arms 5 and 6.

It is entirely practical to design specific contacts by using empirical methods in accordance with the considerations discussed above. For example, a connecting device having the desired arm length L and a bight radius R, and of a given material and material thickness, can be designed and crimped as shown in Figures 2 to 4. If it is found that the material fractures at the bight 4 when the final crimp height is reached, the contact can then be duplicated with a different material which will withstand greater strain after yielding, than the original material. In other words, using a material having a lesser strength level than the original material, such as a material which was less violently cold worked during rolling than the original material. Specifically, if it is found that a relatively hard brass terminal fails in the bight 4 upon crimping, a less hardened brass material can be substituted for the original material.

The substitution of material discussed above would result in a loss in the stress levels in the arms 5 and 6 and the reduction in the stressing of the arms would result in a lower contact pressure on the substrate 2. If this reduction in the contact force is not acceptable, the arm length L, or other variables, can be changed when the material is changed. Alternatively, a superior material can be used instead of the original material, which would be capable of withstanding the required amount of radius reduction in the bight without fracture. For example, a phosphor bronze material might be substituted for a brass material.

While empirical methods based on the foregoing discussion can be used to design a contact for use in the method of this invention, it is also possible to design a specific contact in accordance with the mathematical analysis of the method presented below. If this mathematical method is followed, the performance of the contact during crimping, and the contact force which will be developed in the arms can be predicted.

In the following, it is assumed that a connecting device, in accordance with the invention, has a semi-circular bight 4 of radius R and a length g from the centre of the bight 4 to the end of each arm 5 or 6 as shown in Figure 15.

When the dies 10 and 11 move towards each other, they flex the arms 5 and 6 towards each other until the outer ends of the beams touch, as shown in Figure 16. The condition which is shown in Figure 16 may be described as the touch point for the arms 5 and 6 and the surfaces 13 of the dies 10 and 11 will be separated by the touch crimp height H_O. The dies 10 and 11 are moved to a final crimp height H to establish the contact pressure at the ends of the arms 5 and 6. The following mathematical analysis is based on the conditions which exist in Figure 17, that is, the point at which the dies 10 and 11 have caused the free ends of the arms 5 and 6 to load each other.

For purposes of the following analysis, it is assumed that the connecting device comprises two cantilever beam arms, one of which is shown in Figure 17 as a solid line and the other one of which is shown as a dotted line and is symmetrical to the solid line. The arm shown as a solid line is assumed to be fixed at X, and the point of contact with the die 10 is indicated at Y, while the free end of the arm is indicated at Z. The arm 5 would be deflected under the combined loads of F_1 and F_2, F_1 being the load imposed by the crimping die 10, and F_2 being the reactive load imposed on the free end of the arm by the other arm 6.

The following bending moments are present in the cantilever beam shown in Figure 17.

$$\text{I} \quad M_{12} = -F_1(y-L) + F_2 y$$

$$\text{II} \quad M_{23} = F_2 y$$

M_{12} is the bending moment at any point along the section 1-2 of the beam, as a function of y, (the horizontal distance from point 3) and M_{23} is the bending moment at any point along the section 2-3 of the beam. These bending moments can be applied using Castigliano's theorem in the following integral form to calculate the effective elastic deflection δ which exists at the end of the beam (at 3 in Figure 17).

$$\text{III} \quad \delta \doteq \int_1^2 \frac{M_{12}\frac{\partial M_{12}}{\partial F_2}\,ds_{12}}{EI} + \int_2^3 \frac{M_{23}\frac{\partial M_{23}}{\partial F_2}\,ds_{23}}{EI}$$

In this equation E, I and ds denote the elastic modulus, the moment of inertia, and element of path length.

In order to simplify the calculations, it is assumed that the cantilever beam of Figure 17 comprises two straight sections as an approximation as shown in Figure 18. This approximation can be justified because of the fact that the arc along the length of the section 1-2 is relatively short and the section 2-3 is substantially straight to begin with; in other words, both sections (1-2 and 2-3) have a large radius of curvature relative to their lengths.

The integration of equation III produces the following equation:

$$\text{IV} \quad \delta = \frac{F_2 L^3}{3EI}\left\{\sqrt{1+\left(\frac{H}{2L}\right)^2} + \sqrt{1+\left(\frac{H}{2\ell}\right)^2}\left[\left(1+\frac{\ell}{L}\right)^3 - 1\right]\right\} - \frac{F_1 L^3}{3EI}\sqrt{1+\left(\frac{H}{2\ell}\right)^2}\left\{\frac{1}{2}+\left(1+\frac{\ell}{L}\right)^2\left[\frac{\ell}{L}-\frac{1}{2}\right]\right\}$$

The factors under the square root signs appear because of the approximations made in Figure 18 and reflect the fact that the beams are not perpendicular to the assumed applied loads F_1 and F_2.

If it is assumed that the cantilever beam 5 is fully yielded at 1 (a necessary condition), then F_1 can be expressed as follows:

$$\text{V} \quad F_1 = \frac{\sigma_t \, ht^2}{4\ell} + F_2 \left(\frac{L+\ell}{\ell}\right)$$

where ℓ and L are shown in Figures 17 and 18, and σt, t, and h are the tensile strength, material thickness of the beam 5, and the width of the beam, respectively.

In practical cases and for purposes of this discussion, the radius of curvature of section 1-2 of the beam 5 is only slightly changed from initial radius R when the connecting device is crimped to the extent shown in Figure 17. If it is assumed that the radius of curvature of the section 1-2 is the same in Figure 17, as it is in Figure 14, then ℓ can be eliminated as a variable by using the following equation which has been shown to be a good approximation. experimentally.

$$\text{VI} \quad \frac{H}{\ell} = \frac{\frac{H}{R}}{\sqrt{1-\left(1-\frac{H}{2R}\right)^2}}$$

Equation VI was derived by assuming that section 1-2 represents an arm having radius R which has been rotated about 1 in Figure 17 due to the plastic hinge effect at 1. It should

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be noted that ℓ defines the position where the crimping dies load the bight section. Thus, using equation VI enables us to account for the change in the loading position of the dies as a function of the final crimp height H. The loading position in Figures 16 and 17 is the point of contact of the die surface with the beam. This point moves leftwardly as the connecting device is crimped to the position of Figure 17 and, during the final stages of the crimping process when the die is moved downwardly a short distance from the position of Figure 17, the point of contact moves a further distance leftwardly. The verification of equation VI is shown in Figure 19, in which the theoretical curve has been plotted over the observed data points shown as circles.

In addition to expressing $\frac{H}{2\ell}$ as a function of $\frac{H}{2R}$, the relationship of equation VI can be used to express $\frac{H}{2L}$ and $\frac{\ell}{L}$ as functions of $\frac{H}{2R}$ and $\frac{g}{R}$ where g is defined in Figure 18. The distance g was approximated by the following equation.

$$\text{VII} \quad g \cong \sqrt{\ell^2 + \left(\frac{H}{2}\right)^2} + \sqrt{L^2 + \left(\frac{H}{2}\right)^2}$$

Also, the expression for the elastic deflection of the single cantilever beam 2-3, which appears as the first term in equation IV, can be related to the radius R, and the crimp heights H_O (the touch crimp height) and H (final crimp height). To do this we assume that the change in slope at the end of beam 2-3 can be calculated from the change in angle defined by the arc length from the touch point position of the dies to the position that the dies effectively move to in the final state (θ in Figure 18).

Thus we can derive the following relationship which is used to eliminate F_2 in the final equation.

$$\text{VIII} \quad F_2 \frac{L^2}{2EI} \sqrt{1 + \left(\frac{H}{2L}\right)^2} = \frac{\left\{ \frac{(1-X)}{\sqrt{2X - X^2}} - \frac{(1-X_0)}{\sqrt{2X_0 - X_0{}^2}} \right\}}{\left\{ 1 + \frac{(1-X)\,(1-X_0)}{\sqrt{2X - X^2}\;\sqrt{2X_0 - X_0{}^2}} \right\}} = \text{TAN } \theta$$

In this equation, the expression $\sqrt{1 + \left(\frac{H}{2L}\right)^2}$ accounts for the fact that the beam 2-3 is not horizontal and X_0 equals $\frac{H_0}{2R}$ and X equals $\frac{H}{2R}$ are expressions containing the touch crimp height and final crimp heights H_0 and H, respectively.

These substitutions eliminate all variables except the given variable which is $\frac{H}{2R}$, and touch crimp height $\frac{H_0}{2R}$, the parameter P, which equals $\frac{E\dagger}{\sigma_\dagger R}$ and $\frac{g}{R}$ where g is given in Figure 14, $\sigma_\dagger$ being the tensile strength, as noted above. At this stage, all variables have been defined except X_0, which is equal to $\frac{H_0}{2R}$ and the final form of equation IV becomes: -

$$\frac{\delta}{R} = \left(\frac{2}{3}\,\frac{x}{x_2}\right) \frac{\left\{\frac{(1-x)}{\sqrt{2x-x^2}} - \frac{(1-x_0)}{\sqrt{2x_0-x_0^2}}\right\}}{\left\{1 + \frac{(1-x)(1-x_0)}{\sqrt{2x-x^2}\,\sqrt{2x_0-x_0^2}}\right\}} \left\{1 + \frac{\sqrt{1+x_1^2}}{\sqrt{1+x_2^2}}\left[(1+x_3)^3 - 1\right]\right\}$$

IX

$$- \left[\frac{\frac{2}{3}\,\frac{x}{x_2} \left\{ \frac{\frac{(1-x)}{\sqrt{2x-x^2}} - \frac{(1-x_0)}{\sqrt{2x_0-x_0^2}}}{1 + \frac{(1-x)(1-x_0)}{\sqrt{2x-x^2}\,\sqrt{2x_0-x_0^2}}} \right\} (1+x_3)}{x_3 \sqrt{1+x_2^2}} + \frac{1}{P x_3 x_4^2} \right] \sqrt{1+x_1^2} \left\{ \frac{1}{2} + (1+x_3)^2 \left(x_3 - \frac{1}{2}\right) \right\}$$

where $X = \frac{H}{2R}$

X_0 = TOUCH VALUE OF X (FIGURE 15)

$$X_1 = \frac{X}{\sqrt{1-(1-X)^2}}$$

$$X_2 = \frac{X}{\sqrt{\left(\frac{g}{R} - \sqrt{2X}\right)^2 - X^2}}$$

$$X_3 = \frac{X_2}{X_1}$$

$$X_4 = \frac{1}{\sqrt{\left(\frac{g}{R} - \sqrt{2X}\right)^2 - X^2}}$$

$$P = \left(\frac{Et}{\sigma_1 R}\right)$$

Equation IX enables us to calculate the effective elastic deflection at 3 in Figure 16. Since in these calculations the direction of F_2 has been chosen as positive with regard to deflection, a positive value for $\frac{\delta}{R}$ indicates a pre-loaded condition exists. On the other hand, a negative value for $\frac{\delta}{R}$ indicates no pre-load will remain after the device is removed from the crimping dies; in other words, the opposing beams 5 and 6 will spring away from each other.

Figure 20 is a geometrical relationship and shows $\frac{g}{R}$ as a function of X_0. This relationship is obtained using the same assumptions that led to the derivation of equation VI.

If a given geometry for the connecting device is chosen, $\frac{g}{R}$ would be known from its

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dimension and X_0 can be obtained from Figure 20. For a given material, stock thickness t and radius R, the parameter P can be calculated and the ratio of deflection to radius, as a function of X, could then be calculated from equation IX. The deflection as determined from equation IX can then be used as a basis for calculating the contact force at the end of the beam after removal of the crimped device from between the dies. The contact force can then be plotted if desired, as a function of X, and as shown in Figure 21. Figure 21 compares the calculated pre-load (solid line) to the values measured for the example given in Figures 20 and 21.

To carry out the calculations for the example given in Figure 21, equation VIII is used to provide data on the elastic deflection of the beam section 2-3. This beam section is elastically deflected during the initial stages of crimping but it becomes partially plastically deformed when it is crimped past the 0.3 value for X, as seen in Figure 21. Although the beam 2-3 is plastically deformed during the final stages of the crimping, the force F_2 can be related to the elastic springback in the plastically deformed beam and thus can be associated with the elastic deflection that remains in beam section 2-3.

An estimate can be made of the value of X at which beam 2-3 begins to plastically deform by replacing F_2 in equation VIII, with the value that defines the beginning of yield at the point of loading, 2, as follows:

$$F_2 = \frac{\sigma_y h t^2}{6L} \qquad \text{X}$$

where σ_Y is the yield strength and h and t are defined above. This equation defines the yield condition for a beam of rectangular cross section having a thickness t and a width h and subjected to a bending moment F_2L.

An upper limit can be placed on F_2 using the fully yielded condition for the section at 2 with the following equation:

$$\text{XI} \quad F_2 = \frac{\sigma_t h t^2}{4L}$$

where σ_t is the tensile strength. Equations X and XI define the range over which F_2 changes as we further crimp the device past the X = .3 value. Thus, by modelling elastic/plastic behaviour of the beam over this range of forces, we can estimate the change in elastic deflection of beam 2-3 as a result of a change in F_2 as crimping continues to final crimp height. This was done for the present example by using equations X and XI as constraints on F_2. The following approximate equation was obtained to estimate the elastic deflection in beam 2-3 during plastic deformation.

$$\text{XII} \quad \frac{F_2 L^3 \sqrt{1+\left(\frac{H}{2L}\right)^2}}{3EI\ R}$$

$$= \frac{2}{3}\left(\frac{1}{P}\right)\left(\frac{X}{X_2}\right)^2 \left\{\frac{\sigma_y}{\sigma_t} + \left(\frac{\sigma_t - \sigma_y}{\sigma_t}\right)\frac{(X_y - X)}{X_y}\right\}\left\{1 + \frac{0.5(X_y - X)}{X_y}\right\}$$

In this equation, the first quantity in curly brackets represents a linear increase in work hardening as crimping proceeds and the second quantity in curly brackets represents a linear increase towards the fully yielded condition. Here $X\gamma$ is the value of X when beam section 2-3 begins yielding at 2.

To summarise, a model has been provided which permits calculation of the effective elastic deflection at 3 in Figure 16 by using either equation VIII for elastic conditions in beam section 2-3 or equation XII for elastic/plastic conditions in the same beam section. From the knowledge of the effective elastic deflection at 3 in Figure 16, the final contact force which subsists after removal of the crimped connecting device from between the dies can be calculated with equation XIII. As mentioned above, the effective deflection at 3 could be positive or negative. When the calculations show that the elastic deflection is positive at 3, then the condition for an effective crimped connection is met and the amount of deflection at 3 is unchanged when the connecting device is removed from between the dies. It is this deflection at 3 which is used to calculate the contact force in the crimped connection, as mentioned above.

$$\text{XIII} \quad F = \left\{ \frac{\frac{Eht}{4}\left(\frac{t}{R}\right)^2\left(\frac{X_2}{X}\right)^3}{\sqrt{1+X_2^2}+\sqrt{1+X_1^2}\left[\left(\frac{X_2}{X_1}+1\right)^3-1\right]} \right\}\left(\frac{\delta}{R}\right)$$

All of the terms in equation XIII have been defined previously. Equation XIII relates the force to the deflection of a cantilever beam as shown in Figure 17 but with the force F_1 of Figure 17 removed.

The solid line curve of Figure 17 which represents the theoretical model analysed above, is in reasonably good agreement with the observed data points shown on this figure. It can therefore be concluded that the theoretical curve can be used to estimate important characteristics of the crimped connection and the effect of crimp height on these characteristics. For example, the theoretical curve shows that when the crimping dies are moved towards each other and the control is crimped only to the extent that the free ends of the arms touch each other, where X is 0.51, the ends of the arms will spring apart after the contact is removed from between the dies. It is necessary that the contact be crimped to an X value of 0.37 before the condition of pre-loading is achieved, that is, before the arms will remain against each other when the contact is removed from between the dies. As a practical matter, the contact will ordinarily be crimped to an X value which is significantly less than 0.37 and the precise X value of the finished crimped connection will produce predictable force in the beams which can be determined from Figure 21. Thus, if the contact is crimped to an X value of 0.2, the beams will exert a contact force of about 1.7 pounds.

The theoretical curve shown in Figure 21 is valid only for the material constants and dimensions which were assumed in the mathematical model discussed above and if different constants were used in the mathematical analysis, a different curve would be obtained. For any assumed set of constants then, a curve of the type shown in Figure 21 can be plotted and from this curve, the behaviour of the crimped connection can be predicted. Curves of this type are thus capable of serving as a valuable design tool and their use will avoid time-consuming and wasteful experimentation in determining dimensions and material constants for a crimped connection in accordance with the invention.

Crimped connections made by the method of this invention have several advantages over previously available crimped connections and over connections made using soldering techniques. Soldering to conductors on thin film substrates is frequently sensitive to the nature of the conductor, and soldering to some types of electro-deposited conductors can be carried out only with great difficulty and with unsatisfactory reliability. A crimped connection made by the method of this invention does not depend upon, and is not affected by, the nature of the conductor.

As mentioned previously, the principle crimping forces are applied to the bight portion of the contact, rather than to the cantilever beam arms. These forces may be quite high, but no damage will be caused to the conductors on the substrate, since the high crimping forces are transmitted through the bight rather than through the arms and the only forces developed in the arms are the contact forces or forces slightly in excess of the contact forces.

The final crimped connection has relatively limited thickness as is apparent from Figure 6, and it is not therefore very much larger than the substrate on which it is made. Additionally, the width of the contact can be restricted, as compared with previously available crimped connections, and under many circumstances the contact need be no wider than the conductor on the substrate.

Claims:-

1. A method of establishing an electrical connection to a conductor on a substrate, comprising crimping a substantially U-shaped metal contact to embrace the substrate and conductor between the arms thereof, characterised in that crimping is effected by compressing the contact (1) between a pair of parallel-surface dies (10, 11) through a condition (Figure 3) in which the free ends of the arms (5, 6) of the contact (1) engage opposite sides of the substrate (2), to a condition (Figure 4) in which plastic deformation of the bight (4) of the contact (1) has occurred, whereby after removal from between the dies (10, 11), the arms (5, 6) of the contact (1) remain inherently biased towards each other with the substrate (2) gripped between the arms (5, 6) and one of the arms (5) engaging the conductor (3) on the substrate (2).

2. A method as claimed in Claim 1, characterised in that the dies (10, 11) each have a crimping surface (13), and a parallel stop surface (14) which is separated from the crimping surface (13) by a shoulder (15), the crimping surface (13) having a length such that the shoulder (15) does not engage the bight (4) of the contact (1) during crimping.

3. A method as claimed in Claim 1 or Claim 2, characterised in that a plurality of contacts (1) integrally formed with a carrier strip (20) connected to the free end of one arm (5) of each contact (1), are simultaneously crimped on to a common substrate (2) to provide connections to respective conductors (3) on the substrate (2), the carrier strip (20) being removed after the

crimping operation has been effected.

4. A method as claimed in Claim 1 or Claim 2, for use in establishing connections to conductors on the opposed surfaces of two spaced-apart parallel substrates, characterised in that each contact (1) is substantially W-shaped comprising two integrally formed substantially U-shaped contacts each having the free end of one arm (6 or 5) connected by a sharp reverse bend to the free end of one arm (5 or 6) of the other contact.

5. A method as claimed in Claim 4, characterised in that a plurality of the substantially W-shaped contacts (1) integrally formed with a carrier strip (20) connected to the free end of the other arm (5) of one of the substantially U-shaped contacts, are simultaneously crimped on to two spaced-apart parallel substrates (2) with each substantially W-shaped contact (1) providing a connection to a respective conductor (3) on one of the substrates (3), the carrier strip (20) being removed after the crimping operation has been effected.

6. An assembly comprising a substrate having a conductor thereon and a substantially U-shaped metal contact providing a connection to the conductor, characterised in that the assembly has been produced by a method as claimed in any preceding claim.

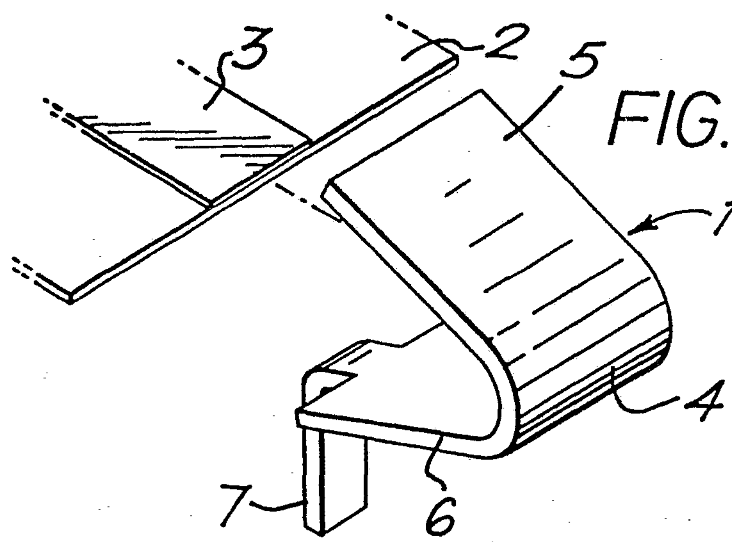


FIG.1.

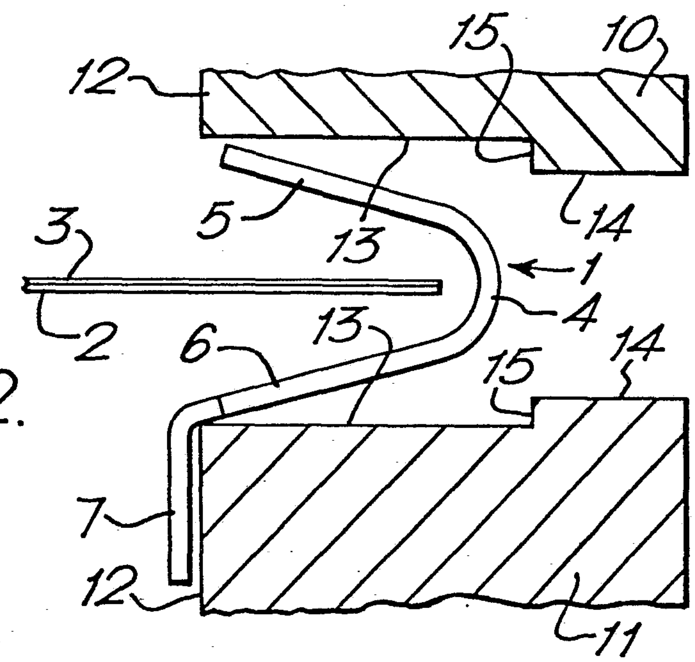


FIG.2.

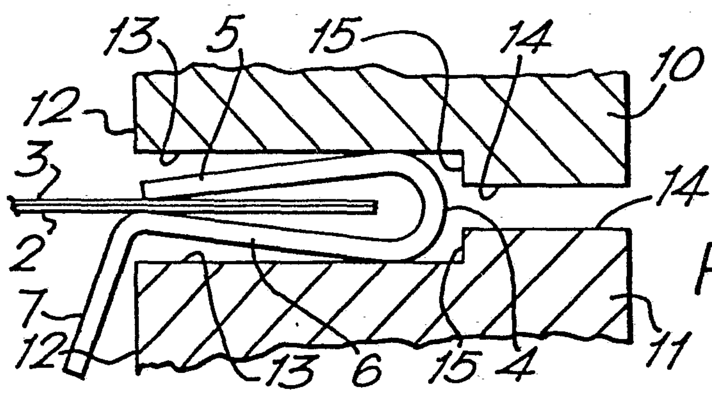


FIG.3.

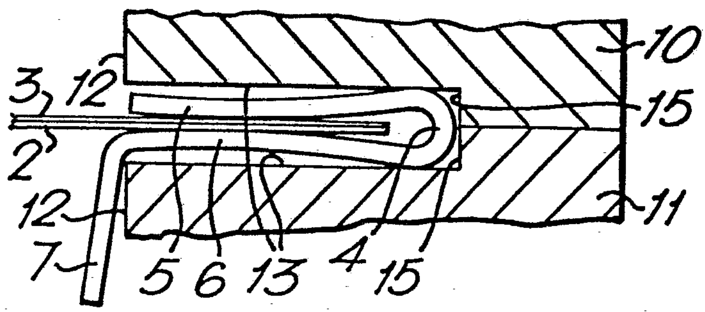


FIG.4.

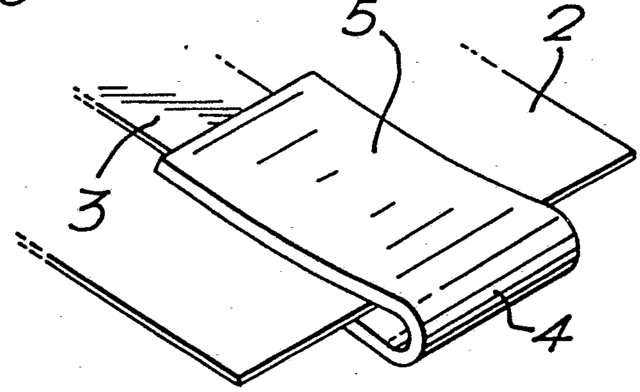


FIG.5.

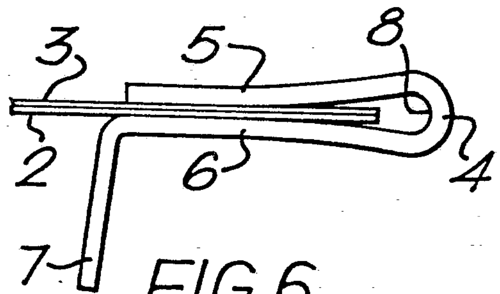
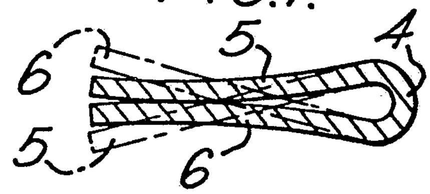


FIG.6.

FIG.7.



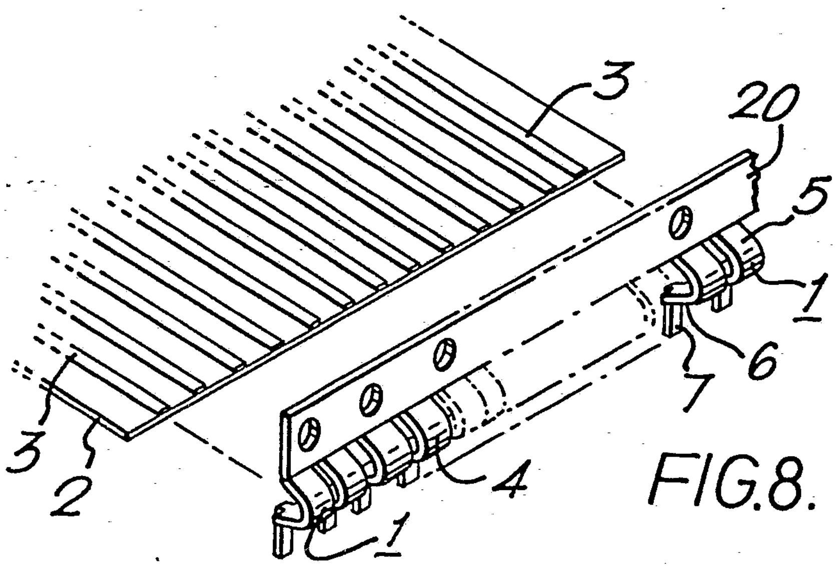


FIG.8.

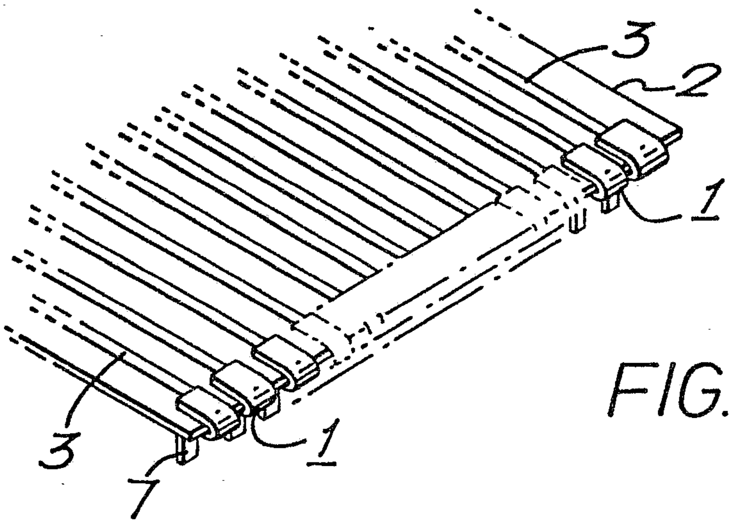


FIG.9.

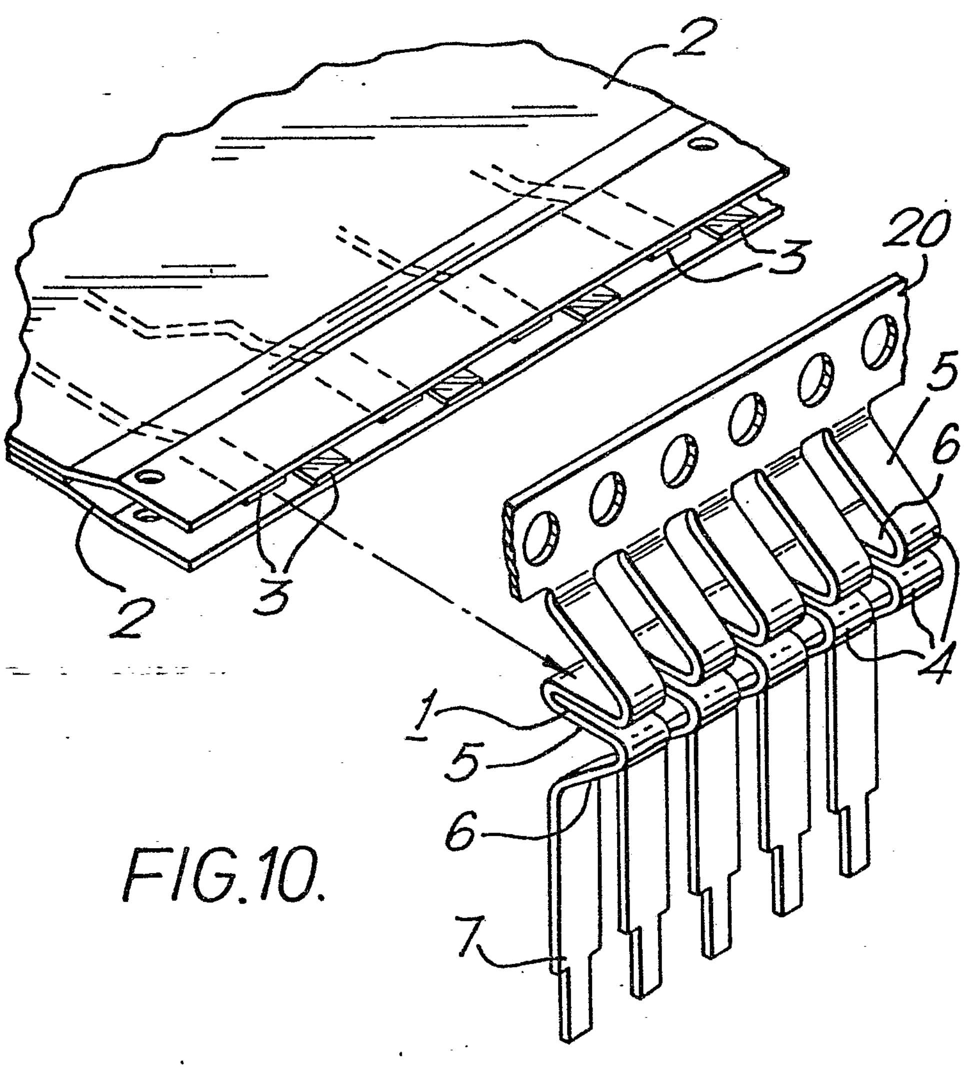


FIG.10.

FIG.11.

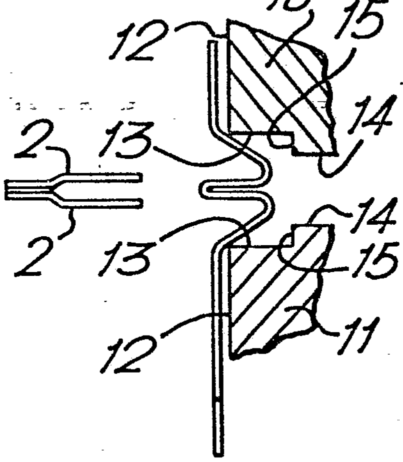


FIG.12.

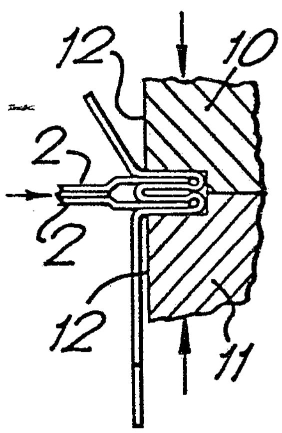


FIG.13.

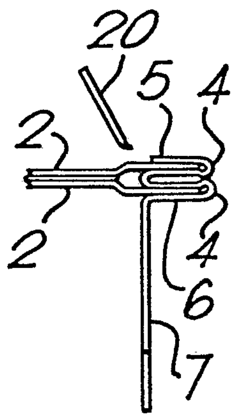


FIG.14.

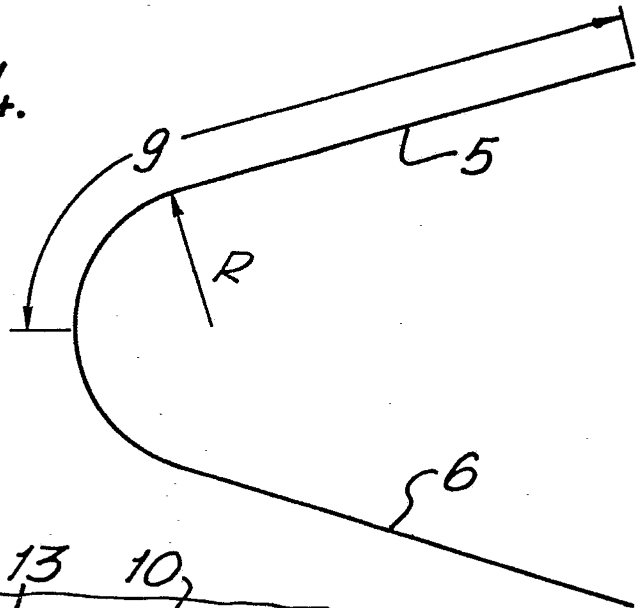


FIG.15.

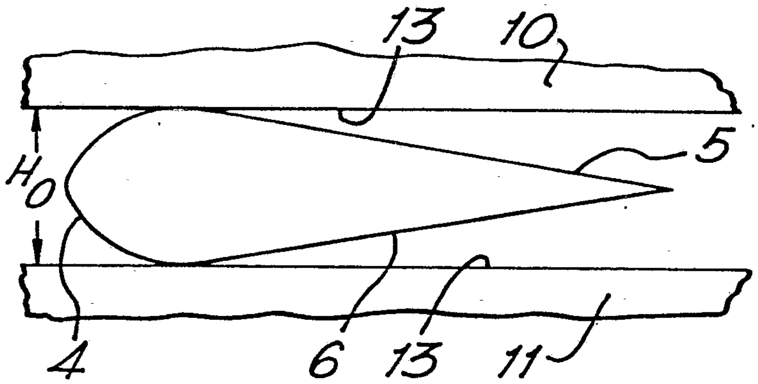


FIG.16.

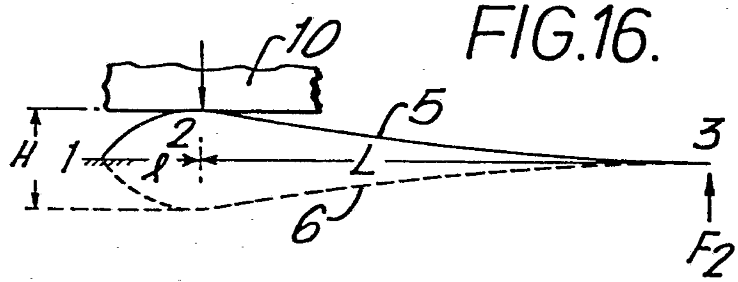


FIG.17.

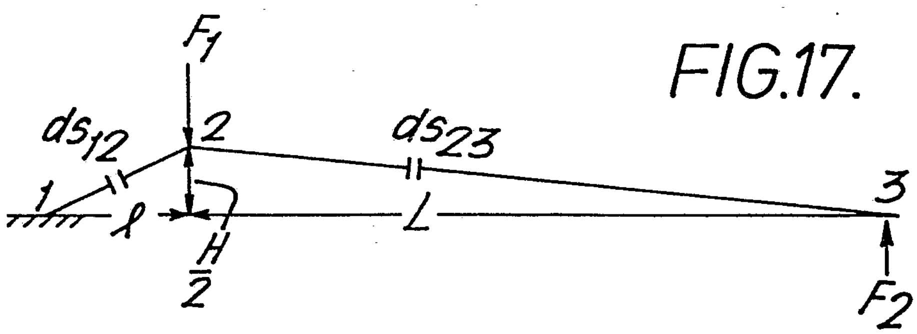


FIG.18.

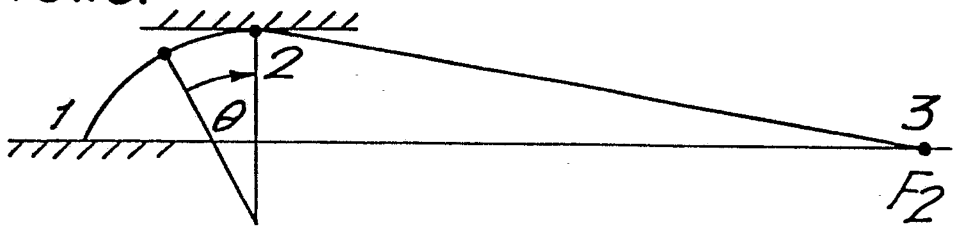
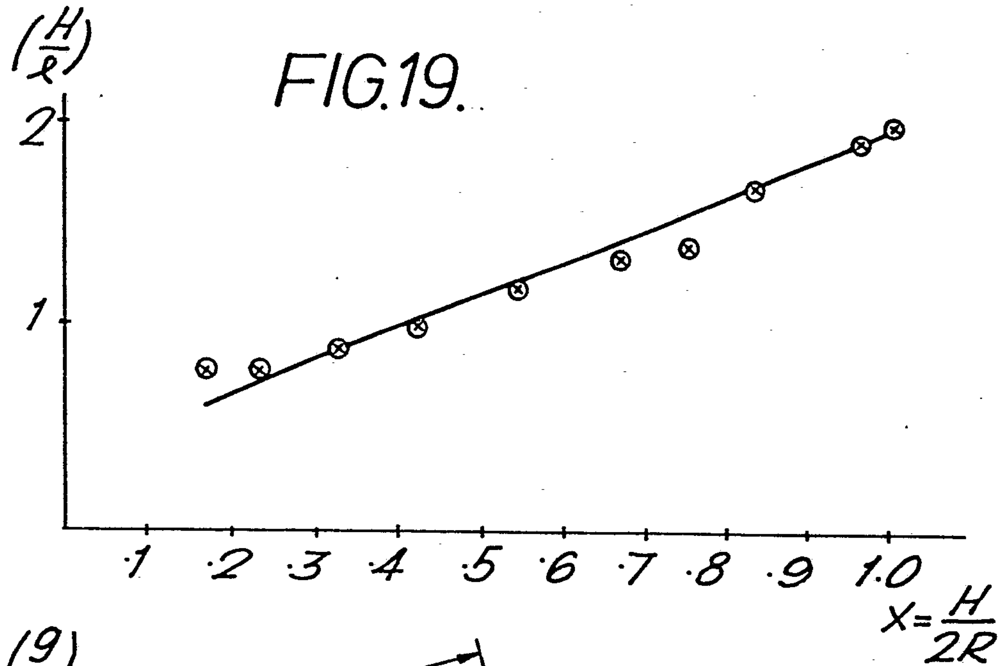


FIG.19.



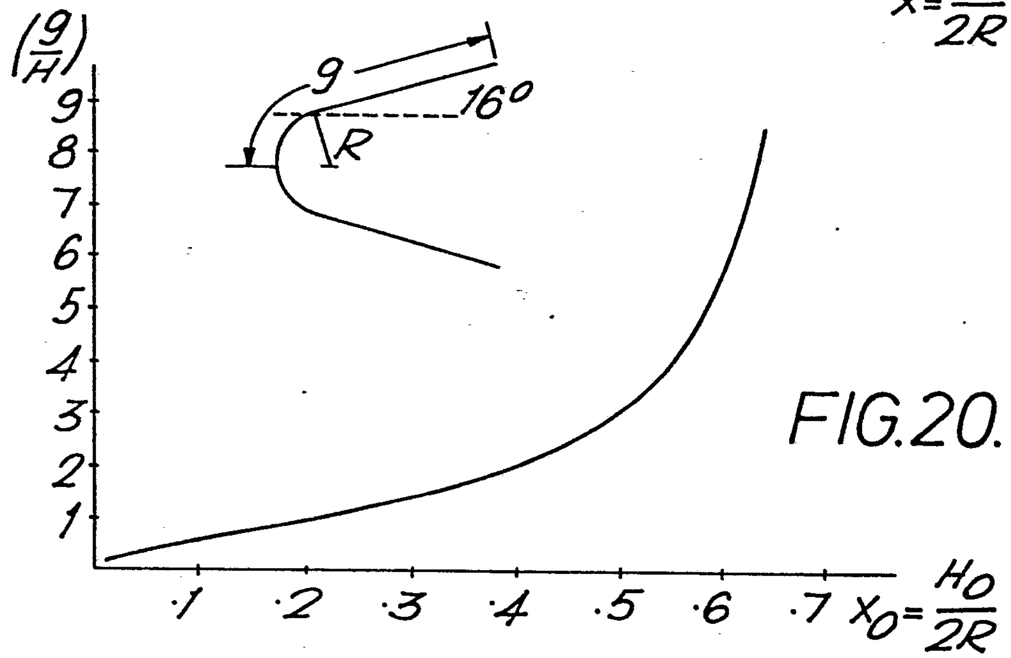
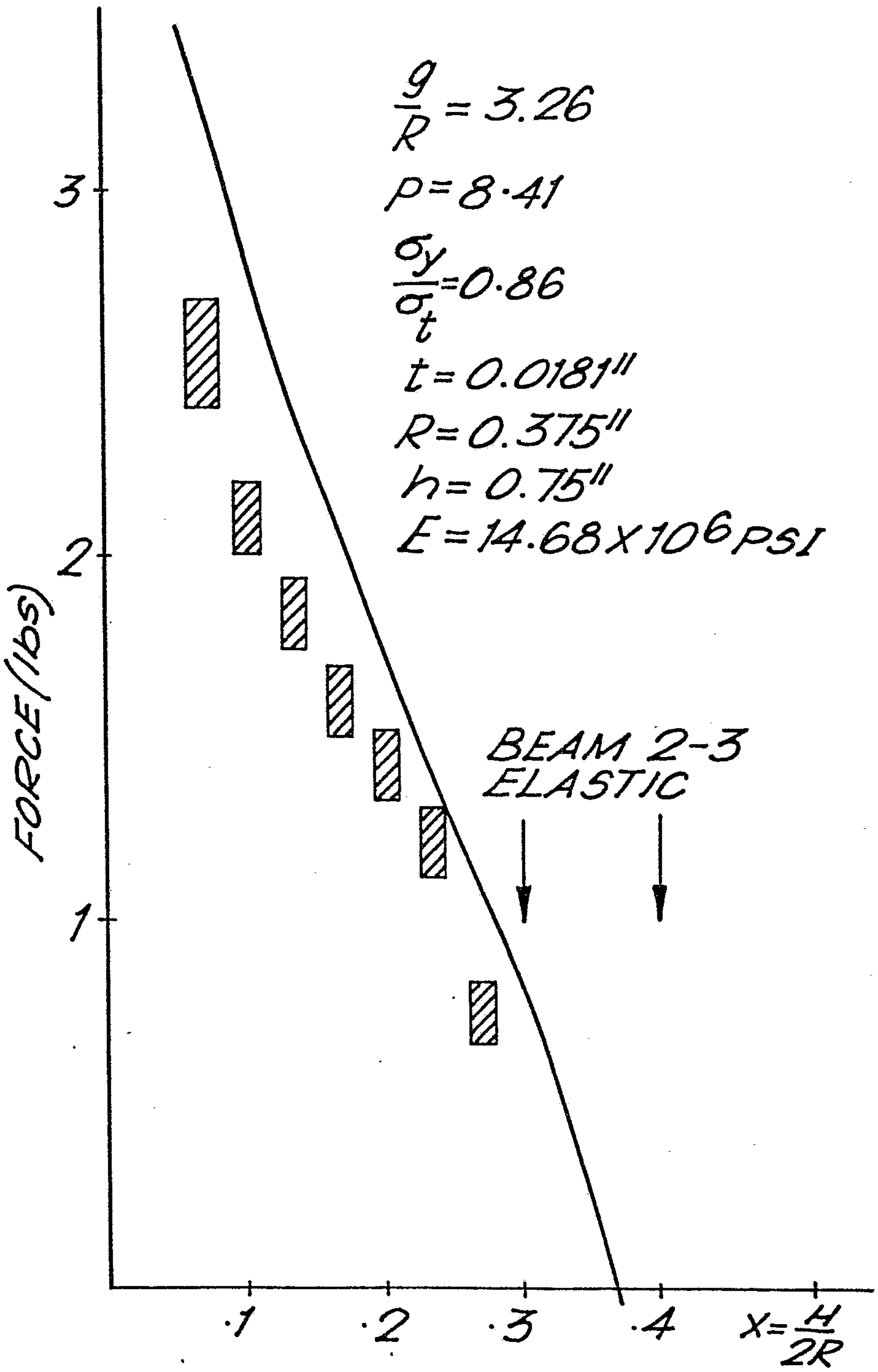


FIG.20.

FIG.21.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p = 8·41
σy/σt = 0·86
t = 0.0181"
R = 0.375"
h = 0.75"
E = 14·68 X 10^6 PSI
BEAM 2-3
ELASTIC
FORCE/(lbs)
3
2
1
·1
·2
·3
·4
X = H/2R

0038882

Application number

European Patent Office

EUROPEAN SEARCH REPORT

EP 80 30 1330.9

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim
	US - A - 4 085 998 (OWENS) * column 3, lines 31 to 49; column 3, lines 56 to 64; fig. 3 and 4 * --	1,3,6
E	DE - A1 - 2 847 163 (SIEMENS) * page 5, lines 10 to 30; fig. 1 to 3 * --	1,3,6
A	US - A - 4 129 351 (SUGIMOTO et al.) * column 11, line 53 to column 14, line 42; fig. 13 to 15 * ----	

CLASSIFICATION OF THE APPLICATION (Int. Cl.3)

H 01 R 23/70

TECHNICAL FIELDS SEARCHED (Int.Cl.3)

H 01 R 23/68
H 01 R 23/70
H 01 R 23/72

CATEGORY OF CITED DOCUMENTS

X: particularly relevant
A: technological background
O: non-written disclosure
P: intermediate document
T: theory or principle underlying the invention
E: conflicting application
D: document cited in the application
L: citation for other reasons

&: member of the same patent family, corresponding document

X The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
Berlin	07-01-1981	HAHN

EPO Form 1503.1 06.78