Aug. 14, 1956 S. N. BUCHANAN 2,758,491

CRIMPING DIES FOR ELECTRICAL CONNECTORS

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Fig. 1.

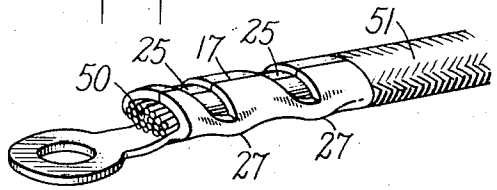


Fig. 2.

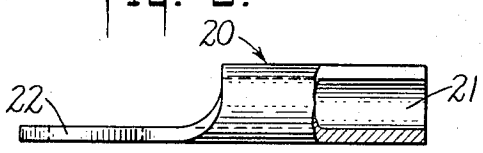


Fig. 3.

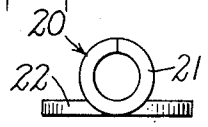


Fig. 4.

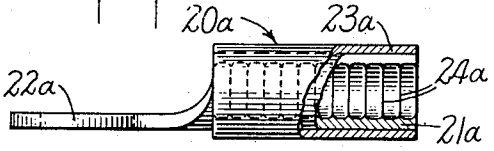


Fig. 5.

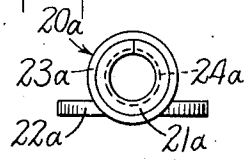


Fig. 10.

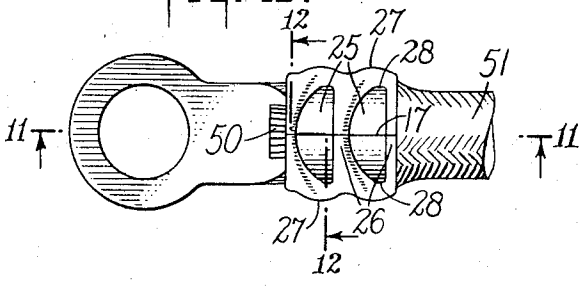


Fig. 12.

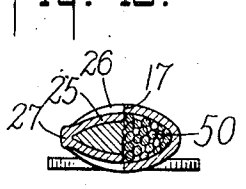
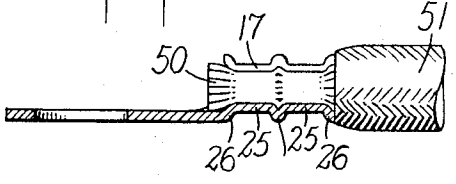


Fig. 11.



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Fig. 6.

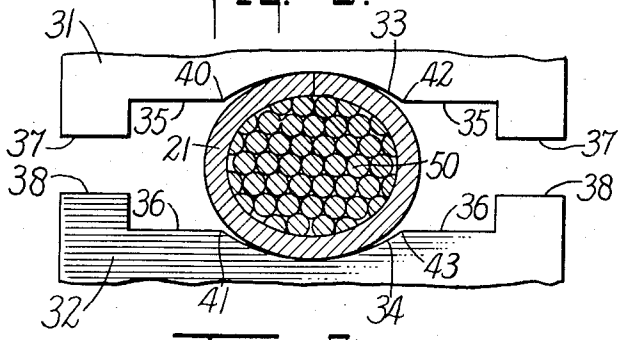


Fig. 7.

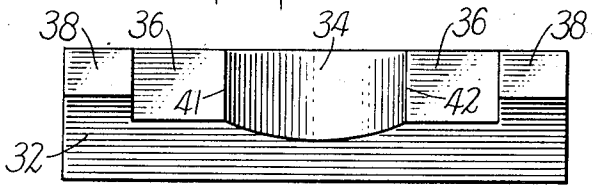


Fig. 8.

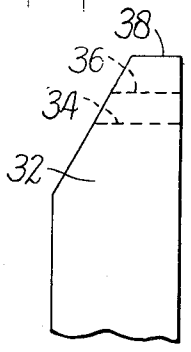


Fig. 9.

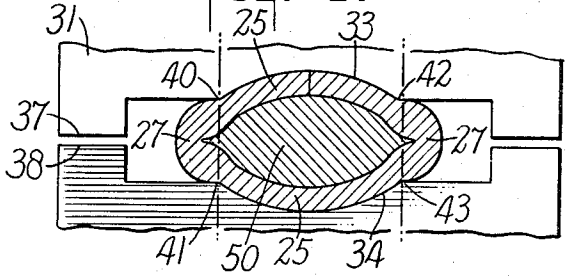


Fig. 13.

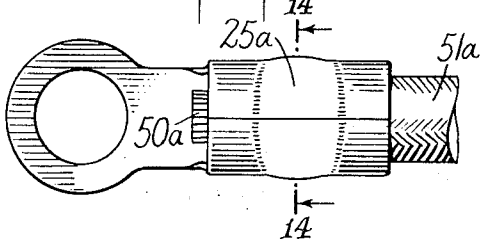


Fig. 14.

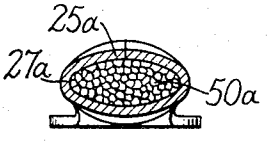
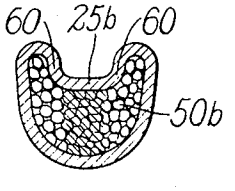


Fig. 15.



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CRIMPING DIES FOR ELECTRICAL CONNECTORS

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Continuation of application Serial No. 720,296, January 4, 1947, which is a division of application Serial No. 559,604, October 20, 1944. This application December 6, 1951, Serial No. 260,125

3 Claims. (Cl. 81—15)

This invention relates to electrical connections and, more specifically, to electrical connections of the type adapted to be permanently impressed onto an electrical connector and conductor by a crimping operation. This application is a continuation of my application, Serial No. 720,296, filed January 4, 1947, now abandoned, which application was a division of my prior application Serial No. 559,604, filed October 20, 1944, now Patent No. 2,554,813; which earlier application is a continuation-in-part of my application Serial No. 421,408, filed December 3, 1941, now Patent No. 2,379,567, and application Serial No. 474,935, filed February 6, 1943, and later abandoned.

Connectors of the type which make mechanical and electrical connection by crimping onto a conductor had been known before these inventions, but such earlier connectors were not without inherent defects or disadvantages. In many of them the bond between the connector and the electrical conductor had not been sufficiently tight nor permanent to provide for all of the stresses which are imposed subsequently in use, with the result that the end of the electrical conductor sometimes pulled loose from the electrical connector. In other terminals the crimped portion which forms the bond between the connector and the conductor has been so deep that the ferrule of the connector and some of the wires of the conductor were seriously weakened, with the result that the tensile strength of the connection was unsatisfactory. Another defect found in many connections of this type lay in the fact that moisture or other foreign matter could creep into the compressed portion of the connector to promote corrosion of the contact surfaces and thus to lower the electrical conductivity through the connection.

It is an object of the present invention to provide an improved connection wherein the connector is premanently attached to a wire or like member by a crimping operation. Another object is the provision of a crimped connection in which neither the ferrule nor the wire is damaged by the crimping. A further object is to provide a permanent electrical connection of high conductivity. Yet a further object is the provision of an improved method of connecting a ferrule to a wire. Still another object is the provision of crimped connectors having shapes and dimensions adapted to concentrate expansive forces in the strongest portions thereof. A further object of the invention is to provide a new and improved solderless connector in which a crimped ferrule is effectively held against bending and in firm gripping contact with the wires. Other objects will be in part pointed out as the description proceeds and will in part become apparent therefrom.

I have by my present invention demonstarted that an electrical connector of the type provided with a ferrule for connection to a wire, etc., can be permanently attached to an electrical conductor by compression dies with a permanent low-resistance connection of highest quality, if the die surfaces which do the compressing are of size and form such that their dimensions bear a certain relationship to the ferrule to be crimped and so that they first flatten and compress the ferrule in a predetermined manner and then coin the metal of the ferrule as hereinafter described. A crimped portion of a ferrule made in accordance with the invention actually is of reduced interior perimeter and not merely flattened or folded. By correctly shaping the coining areas of the dies and by using a crimping concavity of the optimum radius of curvature, the available force of compression may be utilized efficiently to compress the ferrule and the conductor therewithin into a substantially solid and integral mass, and the residual stresses are balanced so that the contact surfaces do not spring back when the connection is released from the dies, but actually are held together under pressure such that a truly conductive connection is established.

The edge portions of the ferrule fold and undulate during the closing of the dies, and coining surfaces are pressed into the folds so re-distributing and work-hardening the metal as to destroy any tendency toward re-opening.

In this specification and the accompanying drawings I have shown and described a preferred embodiment of my invention and various modifications thereof; but it is to be understood that these are not intended to be exhaustive nor limiting of the invention but, on the contrary, are given for purposes of illustration in order that others skilled in the art may fully understand the invention and the principles thereof and the manner of applying it in practical use so that they may modify and adapt it in various forms, each as may be best suited to the conditions of a particular use.

In the accompanying drawings, in which the invention is specifically illustrated:

Figure 1 is a perspective view of an electrical connector attached to an elecrical conductor in a manner embodying the invention;

Figure 2 is an elevational view, partly in section, of a rolled ferrule type electrical connector;

Figure 3 is an end view of the electrical connector illustrated in Figure 2;

Figure 4 is an elevational view, partly in section, of a modified form of rolled ferrule type electrical connector;

Figure 5 is an end view of the electrical connector illustrated in Figure 4;

Figure 6 is an elevational view, partly in section, of the electrical connector illustrated in Figures 2 and 3 positioned over the end of an electrical conductor and between the jaws formed by a pair of crimpng dies;

Figure 7 is a plan view of the die surfaces of the lower die of Figure 6;

Figure 8 is a side elevation of the die of Figure 7;

Figure 9 is an elevational view similar to that of Figure 6 but showing the dies closed upon the electrical connector and crimping it onto the electrical conductor;

Figure 10 is a plan view of a crimped connector embodying the invention;

Figure 11 is a sectional view taken along the line **11—11** of Figure 10;

Figure 12 is a sectional view taken along the irregular line **12—12** of Figure 10;

Figure 13 is a plan view of a connector bearing, for purposes of illustration, a crimp not embodying the present invention;

Figure 14 is a sectional view taken along the line **14—14** of Figure 13; and

Figure 15 is a view similar to that of Figure 14 but showing, by way of further example, another crimp not embodying the present invention.

Figures 2 and 3 illustrate an electrical connector, generally indicated by **20**, having a ferrule portion **21** and

a terminal contact portion **22**. Preferably the electrical connector is made of relatively soft, tinned copper, that is, of copper sufficiently soft to be readily coined between crimping dies but at the same time such that it will retain a permanent set impressed by the dies to maintain the high quality of the electrical connection. Fully annealed, pure, high-conductivity copper is advantageous in that it is readily formed as described and is work-hardened by the bending and coining so that it cannot be as readily deformed from its crimped condition.

Figures 4 and 5 illustrate a modified type of electrical connector which may be used in practicing the invention. In this instance the electrical connector, generally indicated by **20***a*, includes a ferrule portion **21***a*, a terminal contact portion **22***a*, and a seamless sleeve **23***a* positioned around the ferrule portion. Annular serrations or ridges **24***a* are provided, in some instances, on the interior of ferrule portion **21***a* to afford an anchor between the electrical connector and an electrical conductor.

It has been found advantageous in an electrical connector of this type to form the ferrule portion **21***a* of dead soft, pure, ductile copper and to form the sleeve **23***a* of a relatively harder copper, so that the soft copper on the interior of the ferrule may be compressed with plastic flow into the fullest contact with every strand of the electrical connector and so that the metal will take a permanent set without spring back from the crimped condition, while the harder integumentary member will tend to restrain the deformation and thus hold the seam of the inner ferrule tightly closed and to some extent also may direct inwardly extrusion of metal from between the coining dies, whereby metal which otherwise might merely escape outwardly is accumulated in thickened borders around the coined areas such that the trapped stresses tend to maintain high pressure of the coined areas against the wire.

Figure 6 illustrates the electrical connector of Figures 2 and 3 positioned over the end **50** of an electrical conductor and caught between an upper die member **31** and a lower die member **32**. Member **31** is provided with a concave die surface **33** while member **32** is provided with a concave die surface **34**. These concave die surfaces lie, respectively, between upper flat die surfaces **35** and lower flat die surfaces **36** and each of said surfaces **33** and **34** has a chord or width approximately equal to the diameter of the electrical connector ferrule. As shown for example in the drawing, the chordal dimension may be equal to the inside diameter of the ferrule; and it may vary from the over-all diameter of the ferrule portion of the connector to about three fourths of that diameter. (Note.—In speaking of "width" of the crimp or die, reference is being made to the horizontal dimension as shown in Figures 6 and 7, that is, the dimension crosswise of the ferrule; in speaking of "length" of the crimp or die, reference is being made to the vertical dimension in Figure 7 and horizontal dimension in Figure 8, that is, longitudinally of the ferrule.) Beyond the flat die surfaces there is provided on the upper die a pair of die stop portions **37** and on the lower die a pair of die stop portions **38**, to be described in greater detail hereinafter.

Figure 9 illustrates the manner in which the concave die surfaces compress the electrical connector and conductor as die members **31** and **32** are brought toward one another during a crimping operation. The cross section and perimeter at the portion receiving the crimp are actually reduced and compressed; but the side portions of the ferrule, which lie between flat die surfaces **35** and **36**, do not actually receive very much direct compression from the flat die surfaces until the final movement of the die. That part of the force of compression which is concentrated at the portions of the ferrule which overlie and underlie the electrical conductor is directly utilized in compacting the strands of the conductor **50** and flowing the overlying and underlying portions of the ferrule into substantially perfect conformity with the contacted surfaces of the electrical conductor and to some extent in extruding metal of the ferrule from under the dies to the borders of the crimps.

With older types of crimping by "dimple" indentations (see Figure 15) or "necking" of the ferrule to smaller circumference, the closely packed wires around the exterior of the stranded conductor tend to form an arch or tube in which each wire is supported on the next, with the result that the strands of wire within such arch or tube are not satisfactorily compacted and corrosion easily enters the crimped area along the interstices between these wires. This tendency is minimized by the application of the crimping forces according to the present invention, as will be described, so as to displace some of the outer wires and cause collapse of the arch. At the same time, the concave surfaces tend to limit the extent of collapse and confine the strands of the electrical conductor so that the wire is not merely flattened, as would be the case if it were hit with a hammer or clamped in a vise (see Figures 13 and 14).

Although the shape of the crimp as shown in Figure 1 may appear difficult to form in a die, I have found that it can be simply achieved as described and claimed in my application, Serial No. 474,935, filed February 6, 1943. Briefly, the die is made by forming a cylindrically-shaped transverse groove, that is, a groove conforming to a portion of a cylindrical surface, in a simple dihedral angular die.

As best shown in Figures 7 and 8, each die member **31**, **32** tapers toward the die surfaces; hence, the concave die surfaces **33**, **34** become longer as they become deeper due merely to the taper of the die stock. The radius of curvature of the concave surfaces **33**, **34** is somewhat greater than the outside radius of the ferrules upon which the dies are to operate so that, as the dies close upon a ferrule, the longer portions first come into contact with the surface of the ferrule. Figures 6 and 9 show how these longer portions of the die surfaces may be made to engage the ferrule along the seam where the butt edges of the ears of the rolled-up ferrule are brought together, so as to support these edges and to aid in keeping them from separating. Due to this greater area, the initial pressure exerted for collapsing the "arching" of the stranded wire produces first a flattening of the ferrule to elliptical form and a collapse of any tube or arch of wire strand, and then coining of the die into the top and bottom portions of the ferrule, as seen in Figure 6, with consequent flow of metal to the borders of the crimp area without excessive reduction in thickness at the center of the crimp area. In the final stage of the crimping (see Figure 9), the compression of the sides of the ferrule results in extrusion of metal from between the die surfaces at and beyond shoulders **40**, **41**, **42**, **43** and back into the ellipitical space between the die surfaces **33** and **34**, and at the same time in a readjustment of the metal in these side portions, which destroys any tendency to spring back from the flattened form.

The relationships between the radius of curvature of the concave die surfaces **33** and **34** and the outside radius of the ferrule, as well as the angle subtended by the concave dies, are important; and a change in such relationships may result in one crimp which differs from another in no apparently material regard but having actually double the pull-out strength of the other crimp.

For maximum strength in the resulting crimp, the ratio of the radius of curvature of the concave die surface to the outside radius of the ferrule should be greater than 1, but small enough so that, when the distance between the flat die surfaces **35—36** is equal to the doubled thickness of the ferrule wall, there is still sufficient space within the collapsed ferrule to contain the solid cross-sectional area of wire **50**. Obviously this limit depends upon the relation of the total solid cross section of the wire and the radius of the ferrule chosen

to be crimped onto it. This choice, however, is not unlimited. If the ratio of radii becomes too great, that is, if the curvature of the die surfaces **33** and **34** becomes too flat, the holding power of the crimp will suffer. For best results I have used ratios on the range 1⅛ to 1⅔ with best results at a ratio of 1.4 to 1.5. Good results are obtained when the subtended arc of each concave die surface **33** and **34** is in the range from about 60° to about 90°. The best results have been obtained with an arc of about 85°–90°. Correspondingly, the chordal distance across the concave die surface (that is, the chord of its arc) should be about 1⅛ to 2 times the length of the outside radius of a ferrule to be crimped.

These relationships mean that the chordal distance will be on the order of four-fifths to one and one-half times the radius of curvature of the concave die surface for any given die.

Finally, the best results have been attained when the cross-sectional area of the crimped section (shown in Figure 9 between the dot and dash construction lines), neglecting the area of the copper extruded beyond the sides of the concave die segments **33** and **34**, is, when the final coining step is completed and stops **37—38** are brought together, about six tenths of the initial area included within the outer periphery of the ferrule before it was crimped. This relation is predetermined in the tool shown by the dimensions of the stop portions **37, 38**, but it may obviously be determined in other ways.

It is to be noted that the invention permits some latitude of sizes and shapes; that is, absolutely precise configurations are not essential. It seems to suffice if the dimensions are kept within the general ranges specified. And correspondingly, the crimp surface need not follow a literally perfect arc. The arcuate shape appears to be best, but deviations therefrom are permissible.

In the ordinary construction prior to my present invention, if a ferrule were collapsed or bent onto a wire, after the bending or collapsing pressure had been released the two ferrule ears would have a tendency to spring back or reopen outwardly along their fold lines, so that the gripping action on the wires would be somewhat relaxed. Also, if the two ferrule ears were not connected together along their line of juncture, they would tend to open farther, by bending outwardly along their fold lines under stresses encountered during use.

As a feature of the present invention, the ferrule is crimped in such a way as to give a secure grip and maintain a pressure contact. For that purpose it is important that, except for the folded edges, the ferrule walls are spread to a larger radius of curvature so that the tendency to spring back imposes pressure on the engaged wires. The special treatment according to this invention obliterates the tendency to spring back at the folded edges.

The ferrule is, in effect, corrugated on each face by a series of narrow flattened areas formed at spaced positions to give alternate fold sections **25** and **26** (see Figures 10–12) of different fold angles and thicknesses, as shown. This corrugation in itself gives rigidity; and beyond that it is my belief that the more acutely folded edges **27** have their tendency to spring back substantially obliterated by the coining, which causes plastic flow of the metal in the fold and thereby largely wipes out stress conditions in the metal which may have been left from the bending of the wall. The same pressure which coins the exterior of the ferrule under the die also produces coining on the interior so that the interior surface of the ferrule conforms more accurately to the surfaces of the wires. The coining at the exterior, moreover, by extruding metal from under the die, causes a thickening of the borders around the crimp, so that these areas as well as the metal on the interior of the ferrule and in the wires, are stressed in compression; thus any tendency to recovery results in increase instead of diminution of the contact pressure. The strength of the crimp may also result, at least in part, from the fact that both the bending and the plastic flow effect a work-hardening in these zones.

Two of the depressed areas **25** on each side of the ferrule are shown in the drawings spaced from the sides and ends of said ferrule to leave the raised fold sections **26** at each end of the ferrule as well as between the two depressed areas **25**, and to leave the bulges **27** at the sides of said ferrule. As a result of this construction there is formed along each folded side of the ferrule a continuous and undulated border rib which adds to the rigidity of the ferrule, and which thereby aids in resisting the spreading apart or expanding of the opposed, depressed wire-gripping sections **25**.

By way of comparison contrast the crimp of Figures 10–12 with that of Figures 13 and 14, where the ferrule is simply flattened. The axis of the fold down each side of the ferrule in Figure 13 forms substantially a straight line offering no great resistance to reopening. But the axis of the fold down each side of the ferrule of Figure 10 has a distinct sinuousness which offers inherent resistance to reopening. It cannot be reopened without further flow of metal to allow the fold axis to straighten. Furthermore, the area adjacent crimp **25*a*** is not reinforced toward the sides by longitudinal swaging of metal, as is the case with the crimp of Figure 10. The metal is caused to flow in my crimp into a bead surrounding the crimped surface; and this bead is stronger toward the folded portions of the crimp because of the increased longitudinal swaging of metal by the narrowing side die portions and wedge-like tool surfaces.

Figure 15 shows another type of crimped connection. Here, side walls **60** are drawn around crimp surface **25*b*** by the dimple-type crimp impressed. During the crimping operation tensional stresses of considerable magnitude are set up in side walls **60**. Any elastic return of metal following the drawing operation would loosen the grip of the crimp. My crimp is not dependent upon any such drawn construction. It is secure because of a combined cold flow and work-hardening under compression. The reinforcing portions **26** and the bead around the crimp tend to maintain the compression. And in addition, it is effective through the entire cross section of the crimp so as to compact the whole and thus preclude longitudinal seepage of moisture and corrosion. But a crimp such as shown in Figure 15 leaves a multiplicity of capillary-like interstices inviting deterioration, loss of holding power, and loss of electrical conductivity.

In the crimping operation, it is desirable to form first one pair of opposed depressed areas **25**, and then form the second adjoining pair. In this way the crimped area first formed is subjected to further compressive stress, as the result of the inherent resiliency of the ferrule metal, during the second crimping operation. This second crimping operation, therefore, imparts to said areas a more effective and corrosion resisting contact.

Tests of sample terminals made by sectioning through the crimped area have shown that the metal of the ferrule and the metal of the wires within the ferrule are actually so pressed and fitted together that no substantial voids are left between them; such perfection, however, is not necessary for many uses of the invention, and good electrical connections may be made with a lesser compression of the wires. Such sectioning is illustrated in the left-hand portion of Figure 12. The right-hand half of this figure represents a section taken beyond the crimp.

Accelerated corrosion tests have shown that with terminals made as described above under suitable crimping pressure, salt spray or other corrosive liquid does not penetrate into the crimped areas except as it may eat its way by slow corrosion. Thus, the electrical contact is not only the equal at its outset but is substantially the equal in permanence of a well soldered connection. If a high crimping pressure is used there may be a degree

of cold welding between the wires and ferrule, particularly in the case where tinned wire is used, or whether other coating of metal is present which exhibits a relatively high plastic flow or diffusion under the crimping pressure.

Another surprising advantage of the connection just described is in its extraordinarily high breaking strength. With an ordinary crimped-on terminal, the wire tends to be weakened so that it will break at the edge of the terminal with a pull very much below the normal tensile strength of the wire. With a single crimp, spaced at least one-sixteenth of an inch from the end of the ferrule and the crimp made substantially as shown, a pull test under vibration of approximately 90 per cent or more of the normal tensile strength of the wire is attained, but this falls off rapidly as the edge of the crimp approaches closer than one-sixteenth of an inch to the edge of the ferrule, dropping to 50 per cent or less if the crimp actually overlaps the edge with a sharp-edged ferrule.

As a further protection against the reduction in tensile strength by crimping, the edge of the ferrule toward the wire is rounded or sloped gently in order to protect to a substantial extent against the effect described above; so that even if the crimp is carelessly placed so as to overlap the edge, excessive reduction in the pull test strength would be avoided.

Advantageously, the line of juncture **17** where the two ears of the ferrule are brought together extends centrally across the crimped areas so that on neither side of this line will the stock of the ferrule have to act with an effective cantilever arm greater than one-half the width of the crimped ferrule.

The depressions **25** are preferably substantially ellipitical or segmental in plan (that is, simulating the area between a chord and its arc) except that the points may be cut off by short parallel sides **28**, and are preferably arranged as shown. This results in an actual coining of the metal with production of lateral bulges **27** in which the side areas of the metal are compressed solidly into said bulges **27**, while the metal at the sections **26** between the two pairs of opposed depressions **25** and toward the ends of the ferrule retains a smooth elliptical cross section which, as described above, is reinforced by longitudinal extrusion of copper from the crimp areas. This construction also serves to afford optimum depressed areas **25** so as to grip effectively the wires **50**, and to give maximum amounts of raised bead-like areas along the folded sides of the ferrule where it is needed most for rigidity.

The corrugations in the opposed facing surfaces of the ferrule formed by the alternate depressed and raised ferrule sections **25** and **26** serve not only to hold the ferrule as described against relaxing outwardly, but also serve to wrinkle the wires in the ferrule. This wrinkling of the wires assists in preventing said wires from being pulled out of the ferrule.

Figure 1 shows generally crimps **25**, such as result from crimping operations as illustrated in Figures 6 and 9. The crimps there shown are only illustrative of my invention, however, and one, two or more crimps may be used, depending upon the purposes for which the ferrule is intended. Likewise, the showing of Figures 6–9 is illustrative. The dies shown in Figures 6–9 may be closed together by any suitable mechanism, power operated, or hand, or pedal operated.

As many modifications of the invention are possible and as many variations in the forms illustrated and described will be necessitated in adapting the invention to the many instances in which it may be used, the accompanying specification and drawings should not be construed in any way to limit the scope of the invention. The scope of the invention, on the contrary, is intended to be limited solely by the boundaries defined by the accompanying claims.

I claim:

1. In apparatus of the class described and adapted to crimp a ferrule onto an electrical conductor, a pair of dies having opposed die surfaces adapted to engage the ferrule between them and to compress it onto, and compact it with, the conductor, the central area of at least one of said dies being recessed to receive the central portion of the ferrule when thus compacted and portions of the die being extended laterally from opposite sides of said recessed area and adapted to compress portions of the sides of the ferrule, each die having two opposite sides which taper dihedrally toward one another in the direction of the working surface, the axes of the concave die surfaces extending substantially perpendicularly with respect to the plane of at least one of said opposite sides, whereby the more recessed portions of the concave die surface are of relatively greater length, and abutment means associated with said dies and operative to prevent further closing thereof after the area between the recessed die surfaces has been reduced to at least two thirds of the area of a circle of diameter equal to the width of said recessed die surfaces.

2. In apparatus of the character described, a pair of opposed jaws provided with crimping dies including: a central cylindrically concave die surface extending arcuately between a pair of flat die surfaces disposed in the same plane, the length of the maximum chord across the arcuately concave central die surface being to the radius of curvature of said central die surface as the range of from one-and-one-third to two is to the range of from one-and-one-third to one-and-two-thirds, and said central die surface being longer at its more deeply recessed portions than where it meets said flat die surfaces; said apparatus including abutment means having portions defining surfaces which come into opposing contact to prevent further approach of said jaws after the distance from the deepest part of one concave die surface to the deepest part of the other concave die surface is less than the length of said chord.

3. In apparatus of the class described and adapted to crimp a ferrule onto an electrical conductor, a pair of dies having opposed die surfaces adapted to engage the ferrule between them and to compress it onto, and compact it with, the conductor, the central area of at least one of said dies being recessed to receive the central portion of the ferrule when thus compacted and portions of the die being extended laterally from opposite sides of said recessed area and adapted to compress portions of the sides of the ferrule, each die having two opposite sides which taper dihedrally toward one another in the direction of the working surface, whereby the more recessed portions of the concave die surface are of relatively greater length, and abutment means associated with said dies and operative to prevent further closing thereof after the area between the recessed die surfaces has been reduced to at least two thirds of the area of a circle of diameter equal to the width of said recessed die surfaces.

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