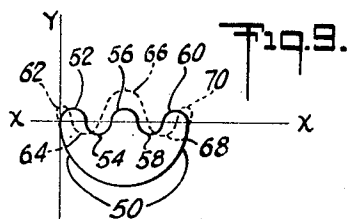
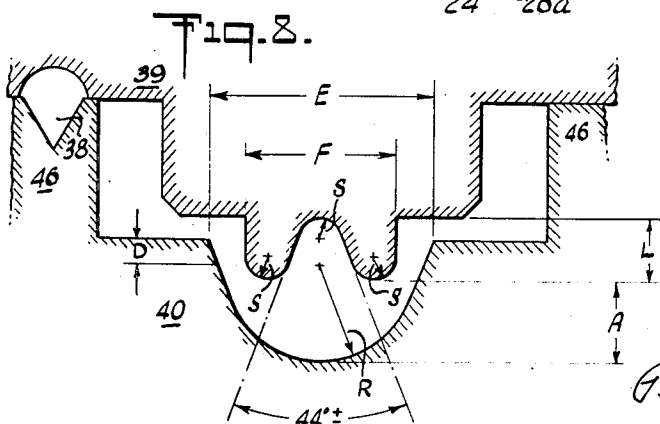
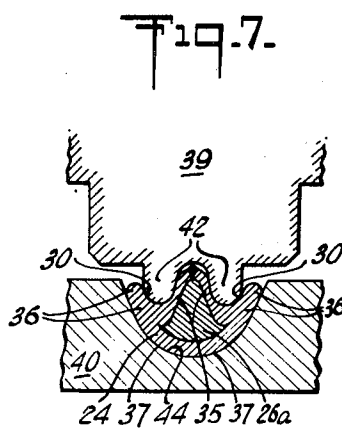
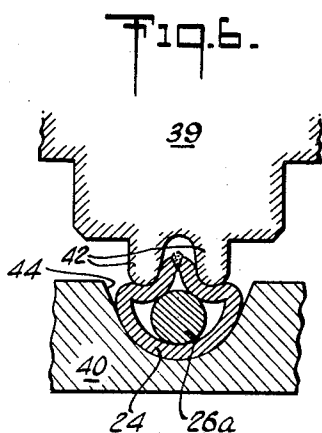
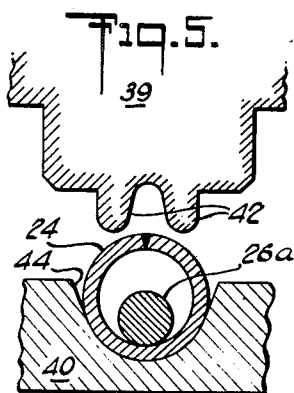
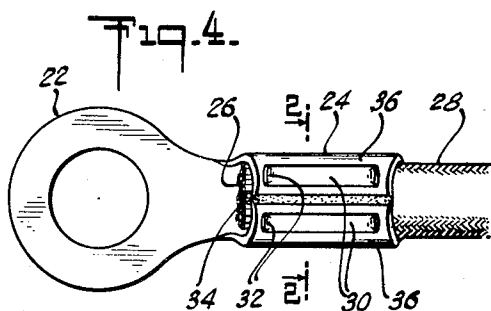
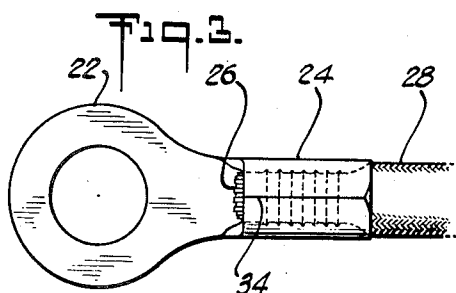
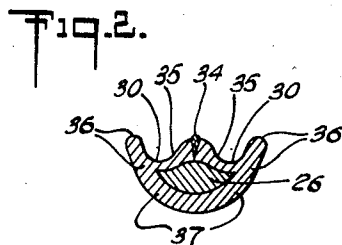
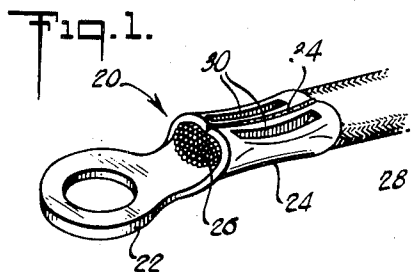


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T. C. FREEDOM
ELECTRICAL CONNECTOR

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UNITED STATES PATENT OFFICE

2,535,013

ELECTRICAL CONNECTOR

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3 Claims. (Cl. 173—269)

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This invention relates to crimped electrical connectors and to crimping dies therefor. More particularly it pertains to a permanently crimped, mechanically strong, corrosion resistant, electrically conductive connection between a terminal connector and an electrical conductor and to the means and method for impressing such a crimp. The connection is of the known general type which is made by telescoping the ferrule of a connector over the bare end of a wire, or wires, either solid or stranded or a combination thereof, and permanently crimping the connector ferrule onto the conductor so as to coin the metals of conductor and connector into a solid work-hardened mass.

By way of illustration the present invention will be described in its application to a crimp of an electrical connector first with respect to a stranded electrical conductor and then with respect to a single solid wire electrical conductor.

There are available at the present time several types of crimped connections, one of which is disclosed in the application of Stephen N. Buchanan, Serial No. 559,604, filed October 20, 1944. It is an aim of such connections to be easily made by unskilled labor, not require complicated tools, to be strong in tension, to be resistant for a long period of time to the corrosive action of moisture, sea water and /or other detrimental influences which occur in use and, in the case of a connection to a solid wire, to be resistant to torsional forces between the wire and connector which heretofore have had an insuperable tendency to wedge open the crimped ferrule of the connector.

I have now discovered a crimped connection and dies for making the connection which can readily be produced and used for a wide variety of electrical connections and which for certain applications give better results than any crimped connections or dies of which I have knowledge.

It is an object of my invention to provide a crimp and crimping means of the character described having to a notable extent the characteristics and capabilities set forth. Another object is to provide a crimped connection which can be easily and economically made under mass production conditions and which is highly conductive to electricity, highly resistant to atmospheric corrosion, is strong mechanically, and has a long life. Another object is to provide a crimped connection for solid wire, rod, etc., which retains its excellence under torsional and tensile stress. Yet another object is the provision of a crimp which is uniformly excellent not only with electrical copper components but also with softer metals, such as aluminum, and harder metals, such as Phosphor bronze, beryllium copper, nichrome, or piano wire, and on combinations of hard and soft materials. A further objective resides in the provision of crimping die means, either hand

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operated or power operated, which have novel crimp impressing configurations the correct use of which results in a superior permanent connection such as described between an electrical connector and an electrical conductor. Other objects will be in part pointed out as the description proceeds and will in part become apparent therefrom.

The invention accordingly consists in the features of construction, combinations of elements, arrangements of parts and methods of operations as will be exemplified in the structures and sequences and series of steps to be hereinafter indicated and the scope of the application of which will be set forth in the claims.

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 drawings:

Figure 1 is a perspective view of an electrical connector crimped onto the stripped end of a stranded electrical conductor;

Figure 2 is a sectional view taken transversely through the crimped connector ferrule of Figures 1 and 4 on line 2—2 of Figure 4;

Figure 3 is a plan view showing the connector and conductor of Figure 1 before crimping;

Figure 4 is a view similar to that of Figure 3 showing the parts after crimping;

Figure 5 is a sectional elevation taken through a pair of crimping dies with an electrical connector and a solid wire conductor positioned therebetween, the dies being in open position;

Figure 6 is a view similar to that of Figure 5 showing the dies partially closed;

Figure 7 is a view similar to that of Figure 5 showing the dies almost wholly closed;

Figure 8 is an enlarged view showing in profile the outlines of the dies used in Figures 5—7; and,

Figure 9 shows the outline of a crimped section of a connector superimposed for purposes of comparison upon a graph, to be described.

In Figure 1 an electrical connector is generally indicated at 20 combining a contact portion 22 and a ferrule portion 24. The ferrule portion (see Figure 3) is telescoped over the bare wire end 26 of an insulated conductor 28. Figures 1 and 4 show the connector crimped by indentations 30 onto the conductor. Crimp indentations 30 are in the form of two elongated longitudinally extending depressions having rounded

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ends 32 which terminate a short distance, e. g. one to several times the thickness of the metal, from the inner and outer transverse edges of ferrule portion 24. In the embodiment shown the indentations are located one on each side of a brazed seam 34 running longitudinally along the ferrule portion.

Figure 2 shows the crimp in cross-section and illustrates the manner in which the two parallel indentations form thinned side wall portions 35 extending downwardly from a central hump which includes seam 34, with the folded and coined beads 36 running along the outer edges of the indentations. The portions 35 are work-hardened by the deformation and cold flow of the metal and are under tensile stress because of the stretching they have undergone during crimping. The coined beads 36 form reinforcements extending along the outside edges of the crimp.

It is to be observed that the crimp indentations are considerably elongated; unexpected benefits ensue from this elongated configuration. Among the principal advantages are the greater holding power and resistance to corrosion which result. An additional important factor in the extraordinary tightness and corrosion resistance of the crimp as compared with all prior crimped connections is the peculiar form left by the dies. The bottom seat portion 37 is of the same, or slightly greater, radius as the original ferrule 24, and therefore any spring-back due to resiliency of the metal in the ferrule is toward a shorter radius, so that it hugs tightly the compressed conductor 26. The side portions 35 and 36 have been stretched by the sliding of the dies thereover and are therefore under tensile stress which offsets any tendency of the folded portions 36 to spring back and loosen the grip on the conductor 26. The sharp fold at 30 makes such spring-back of the folded portions 36 mainly transverse to the sides 35 and thus tends to press them more tightly against the conductor 26 instead of relieving pressure. Furthermore, where the indentations 30 are pressed downwardly substantially below the level of the original center of the uncrimped cylindrical ferrule, the upper portions of the ferrule consisting of the side walls 35 and brazed portion 34 have a toggle-like action which, with the aid of reinforcing beads 36, maintains the indentations 30 in their deepest possible positions.

In the prior art crimps the connector ferrule is deformed by necking, flattening or radial dimpling so that initially it makes a tight frictional engagement with the wire of the conductor but after the crimping dies have released the connector the ferrule portions have a tendency to return elastically toward their original shapes. With my present crimp, however, with the indentations 30 depressed along two or more chords respectively, spaced, e. g., as shown, and each relatively deep with respect to the diameter perpendicular to its chord in the original uncrimped ferrule (see Figure 2), there is, as stated above, no unbalanced residual stress left in the crimped ferrule which can open the crimp when it is released from the crimping jaws. The crimped connector is left with the semi-cylindrical seat portion 37 which has, as will be pointed out hereinafter, almost exactly the same radius of curvature as did the uncrimped ferrule so that this seat portion has no tendency to assume any shape other than that shown in Figure 2. The side walls 35 are held under pressure

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by the beads 36, and actually grip the wire between them somewhat after the fashion of a pair of loaded springs. Thus the upper side of the crimp inherently tries to assume a greater concavity rather than to return to its original cylindrical shape.

In addition, because of the wide area and extended length over which pressure is applied to the wire there is little, if any, weakening of the wire and practically no likelihood that the wire will be sheared by the crimping die. The wire is deformed from circular to angular cross-section, but its cross-sectional area remains substantially the same. Thus the relative dimensional ratios of die to wire and ferrule are no longer so critical as was the case with prior crimped connections. For the same reason the crimp holds well on stranded conductors even in those instances where some of the strands have been removed when stripping off insulation; this inadvertent or careless loss of strands has presented more of a commercial problem than might be supposed unless one is aware of the fine accuracy and exact design with which dies, wires and ferrules have been combined in order to achieve the optimum crimping; the presence or absence of two or three strands, when added to ordinary commercial variations in dimensions, may defeat the designer's intent and give an inferior connection with the known crimps under ordinary high speed commercial operation. Tests have shown that with my present invention there is a ferrule elongation of sometimes as much as 20 per cent during the crimping process but because of the shapes of my crimping dies there is no serious mechanical weakening of either the wire or the connection.

The cross-sectional form assumed by the wire is particularly important where the connector is crimped onto solid wire, as shown in Figures 5-7, where the solid wire is designated by reference character 26a, because this cross-sectional shape makes it impossible for a torsional stress or twist upon the wire with respect to the connector to wedge or cam open the crimps in the ferrule. If a solid wire is twisted within the crimped ferrule shown in Figure 7, it tends to be guided by the arcuate portion 37 with relative sliding movement between the two facing arcuate surfaces formed by the interior of the seat portion 37 of the connector and the lower face of the solid wire. Such rotary slippage cannot occur, however, because it is positively prevented on each side of the arc by the more or less tangentially extending portions of the folded side wall in the reinforcing bead 36. Thus there is no mere camming or wedging action, as with prior crimps, but a solid edgewise abutment.

To the best of my knowledge the cross-section which I have shown in Figure 7 is the first one in any crimp which positively resists torsional stress and prevents rotation of a solid wire within the connector ferrule. In all of the prior art solid wire crimps which have come to my attention, the solid wire, after it is deformed by the crimp, has a combination camming and wedging action when rotated which inevitably opens the ferrule and releases the pressure grip of the crimp. In actual tests of my invention, however, I have found wherever a connector is twisted with respect to a piece of solid wire that ultimately the wire itself will twist apart at some point beyond the connector but that the grip of the connector on the solid wire is never cammed open and re-

laxed. In this respect my crimp quite excels the various crimps already known.

In the case of some kinds of wires, the hardness of the conductor is such that the wire, or strands, cannot be readily deformed. A solid Phosphor bronze wire or a steel piano wire are examples of such conductors. Also the physical characteristics of the connector have some bearing upon the extent to which the conductor can effectively be deformed. Where a relatively hard conductor, compared to the connector ferrule, is used, there is advantage in preliminarily deforming the conductor portion which is to be inserted in the connector ferrule. Thus the crimping tool may include (see Figure 8) a V notch 38 across one jaw face and an opposing flat or arcuate surface on the opposing jaw face so that the hard wire may be deformed before crimping to a triangular, or nearly triangular, cross-section approaching that of the crimped conductor 26a shown in Figure 7.

I have also found that the crimp (see Figure 4) is more satisfactory where the rounded ends 32 are provided and where the indentations are not permitted to overlap either end of the connector ferrule. In order to resist surface corrosion it is advantageous to use smoothly rounded and polished dies so that the tinned surface of the connector is not broken. The surface remains more resistant to corrosion if no sharp impressions which might puncture the tin coating are permitted to occur. Indenting die portions which are smoothly curved, as viewed in cross-section, and are rounded at their ends to form the portions 32, and which are highly polished seem to be most satisfactory.

In Figures 5-7 the upper and lower dies 39 and 40 for making the crimp are shown. A connector 24 and a solid wire conductor 26a also are illustrated. Die 39 is provided with a pair of indenting ribs or indentors 42 and lower die 40 is provided with an arcuate cavity 44 which serves as a nest or matrix for the ferrule. A pair of stops 46 (see Figure 8) limit the extent to which die 39 may be made to approach die 40. In the present embodiment the V-shaped notch 38 for preforming a conductor wire is located in a stop portion 46. The inside diameter of ferrule 24 is substantially greater than the external diameter of wire 26a, as will be brought out in greater detail hereinafter. The fact that there is a substantial difference between the over-all diameter of the wire and the inside diameter of the ferrule makes for ease and speed during assembly of the wire and ferrule—especially where stranded wire is being used.

Figure 6 shows ferrule portion 24 partially collapsed with its portions which will become side walls 35 just coming into contact with the exterior of wire 26a. Further closing of dies 39 and 40 effects a tangential wiping action of walls 35 upon the wire until the configuration illustrated in Figure 7 is reached wherein these side walls have been thinned and work-hardened and the reinforcing bead 36 has been extruded. This tangential wiping assures a bright metal-to-metal contact over a wide area within the crimps irrespective of oxide or other coatings which may have been present. Preferably during the entire procedure the radius of curvature of cavity 44 substantially coincides with the radius of curvature of the original exterior of ferrule portion 24. In practice there is advantage in making the cavity radius at least one thousandth of an inch greater than the ferrule exterior radius.

A comparison of the crimped ferrule of Figure 2 with that of Figure 7 shows that the central hump which includes seam 34 is lower in the former, where the crimp is on a stranded conductor, than in the latter, where it is upon a solid wire conductor. This results from the fact that the "wiping" action already described tends to slide the strands over one another to give a flattened over-all form. The hump of Figure 2 is lower than the topmost portions of beads 36; the hump of Figure 7 is substantially higher than the topmost portions of beads 36. The more finely stranded the conductor, the more even the distribution of internal crimping pressures and the lower the hump, due regard being had to the properties of the metals present.

In Figure 8 I have shown profiles of the dies in their closed positions and have indicated thereupon various dimensions. Thus, the dimension F is the over-all distance across the indentors. Dimension S is the radius of curvature on the end of each indenter and of the fillet between the indentors. Dimension L is the over-all height of each indenter. Dimension E is the over-all distance across the cavity. Dimension R is the radius of curvature of the cavity. Dimension D is the depth below the upper surface of the lower die of the center of the radius of curvature of the cavity. And dimension A is the clearance distance, when the dies are closed, between the lowest points on the indentors and the deepest point in the cavity. Using these dimensions, and with a balancing of what is theoretically desirable on the one hand with commercial economy and practicability on the other, I have arrived at the following equations for reference purposes in designing dies for different ferrule sizes:

$F = \text{ferrule outside diameter} \times .746$

$S = \text{ferrule outside diameter} \times .102$

$L = \text{ferrule outside diameter} \times .312$

$E = \text{ferrule outside diameter} + \text{approximately } .015''$

$R = \frac{1}{2} \text{ ferrule outside diameter} + .001''$

$D = .020''$

$A = \text{ferrule outside diameter} \times .37$

Of these various dimensions some are more important than others. Thus, it is not essential that each indenter have a true radius S on its bottom nor that this radius be present in the fillet between the indentors. The indenter bottoms may follow a curve similar to a section of an ellipse, hyperbola, parabola, etc., or some combination of curves so long as the shape is one which will not shear through the tinned ferrule surface during the crimping operation and will permit the metal to flow ahead of and under the die, as in metal drawing or spinning operations, and outwardly between the upper and lower dies to form the folded beads 36. I have found it beneficial in resisting subsequent surface corrosion to put a high polish, even an optical finish, on the surfaces of the indentors. Usually there is no contact made during crimping between the brazed seam portion 34 of the ferrule and the fillet between the two indentors. The shape of this fillet accordingly is usually immaterial, except insofar as the strength of the dies themselves is concerned and so long as adequate space is afforded into which the hump portion of the ferrule can flow to relieve the pressure.

The dimension R is ordinarily important. For general purposes satisfaction is obtained where R is maintained equal to the outside radius of curvature of the ferrule, plus a slight amount to allow for easy insertion and clearing of the tool.

In some cases a smaller ferrule than a die nominally calls for can advantageously be used, for example, where the conductor is resistant to cold flow under crimping pressures as compared to the resistance of the ferrule. The length of the indentors, characterized as dimension L, is important to the extent that this dimension has a bearing upon the value of dimension A; also where a hard conductor wire is present, unless dimension L is about as great as the approximation suggests the hard wire may be pushed into or through the bottom wall 37 of the ferrule. Dimension A is important in that it determines the cross-sectional area of the finished crimp. Dimensions D and E are relatively unimportant so long as they are so selected that there is no unreasonable lateral flashing of ferrule metal across and between the flat die surfaces during the final closing stages of the dies. Where insulated tubing is subsequently to be telescoped back over the crimp it is advantageous that the over-all width of the crimped ferrule, between beads 36, be kept at a minimum; the approximations given above for values D and E give about the minimum over-all width of crimped ferrule which is feasible from a commercial standpoint.

The dimension F seems to be more important; for if sufficient clearance for ferrule beads 36 is not provided, the internal pressures go too high. Thus the ferrule metal might be caused to fill completely the space between the indentors, making the ferrule stick in the upper die. The included angle between the tangents to the interior side walls of the indenting ribs at their midpoints (i. e. where they cross the x axis, see Figure 9) varies between thirty-five degrees and sixty degrees with an average value of about forty-four degrees, depending upon the size of the ferrule, and of the wire, and whether stranded or solid wire is used. Where this included angle is small, the friction and resistance to metal flow are small and the central hump of the crimp will be high; where this included angle is greater the hump will be lower. Care must be taken not to make the angle too large or else pressures will be too high and too much ferrule metal will be caused to seek relief and flow in other directions such as laterally out of the dies.

It seems to be advantageous to observe certain relationships between wire cross-sectional area and interior diameter of uncrimped ferrule, although these vary somewhat where very hard conductors are present and under other special circumstances. I have found that certain sizes of terminals or electrical connectors can advantageously be used over a range of wire diameters substantially in accordance with the following table:

American Wire Gauge	Ferrule O. D.	Ferrule I. D.	Wire Diameter	Ratio of Wire Diameter to Ferrule O. D.	Ratio of Wire Diameter to Ferrule I. D.
22-16	.136	.066	.025 Min.	1:5.45	1:2.64
			.051 Max.	1:2.67	1:1.28
16-14	.160	.090	.051 Min.	1:3.15	1:1.76
			.064 Max.	1:2.5	1:1.41
12-10	.221	.134	.080 Min.	1:2.76	1:1.67
			.102 Max.	1:2.17	1:1.31
8	.286	.177	.129	1:2.21	1:1.37
6	.359	.237	.162	1:2.21	1:1.46
4	.453	.301	.205	1:2.21	1:1.46
			Mean Ratio.	1:2.51	1:1.60

Mean ratio of total cross-sectional area of electrical conductor to cross-sectional area of ferrule opening is 1:2.56. The principal reasons

for the nonuniformities of ratios lie in the facts that (1) for the smallest ferrules a greater thickness of sheet material is desirable from a production standpoint than is theoretically required and (2) the terminals are made from sheet material which is supplied in set gauges of thickness which do not, in each case, coincide exactly with the theoretical requirements. The ratio of wire diameter to ferrule inside diameter accordingly is more nearly consistent with the theoretical values than is the ratio using ferrule outside diameters. Where larger sizes are involved larger variations may safely be made. In general, ferrule wall thicknesses may satisfactorily be taken as equal to $.184 \times$ ferrule outside diameter.

In figuring wire cross-sectional areas, the area in circular mils for a solid wire is equal to the (diameter in mils)²; for stranded wire the area in circular mils is equal to (diameter in mils of one strand)² times the number of strands. It will be appreciated that insofar as concerns the present invention, when figuring wire cross sections it is immaterial whether the wire metal present in the ferrule comes from one conductor, or from several which have been brought together into the single ferrule. And when I speak of the wire or conductor cross-sectional area within a ferrule, it may refer to the cross-sectional area of a single external conductor, or to the total of the cross-sectional areas of several external conductors which come into the same ferrule.

In Figure 9, I have shown a comparison of the cross-section of a crimped connector on solid wire with a graphed figure plotted on x and y rectangular coordinates. The outline of the crimped cross-section is shown in dotted lines and the outline of the graph is shown in solid lines. Both outlines coincide through a semi-circle indicated by 50 which forms the bottom portion of each figure. The upper portion of the graph is composed of five 180° sine wave loops plotted along the x axis. The loops indicated at 52, 56 and 60 are positive with respect to the y axis; loops 54 and 58 are negative with respect to the y axis. The upper portion of the outline of the crimp is also composed of five loops indicated by numerals 62, 64, 66, 68 and 70 of which 62, 66 and 70 are positive with respect to the y axis and 64 and 68 are negative. It is to be observed that loop 66 (representing the central hump) is substantially larger (both along the y axis and along the x axis) than loop 56 and that the positive dotted loops 62 and 70 on each side of loop 66 are smaller along the x axis than are the corresponding loops of the sine wave. In the case of a crimp onto stranded wire or extremely soft solid wire loop 66 might have a y value less than that of loop 56. Different diameters of wire within a given ferrule also will give different heights to the central hump of the crimped connector.

From the foregoing it will be observed that crimps and crimping dies embodying my invention are well adapted to attain the ends and objects hereinbefore set forth and to be economically manufactured, since the separate features are well suited to common production methods and are subject to a variety of modifications as may be desirable in adapting the invention to different applications. Thus, in some instances, it may be more satisfactory to locate the indentors in the lower die and have the upper die consist of a punch carrying on its lower end a

concavity having a radius of curvature which conforms approximately to the radius of curvature of the ferrule to be crimped, as pointed out above. If the ferrule is not seamless nor secured at the seam, it is desirable to orient it with the abutting edges of the seam in the cavity 44 and advantageously at the bottom of the cavity.

I claim:

1. An electrical connector comprised of a tubular ferrule telescoped over and crimped onto a bare electrical conductor, the resulting body as viewed in section presenting an unbroken periphery including a convex portion extending for about half of the periphery and, for the other half, a portion including a middle projection and two side projections mutually separated by two deep grooves, said projections and grooves extending longitudinally of the ferrule, the projections on either side of said middle projection being comprised by folded-over portions of the ferrule which are in intimate mutual contact.

2. An electrical connector comprised of a tubular ferrule telescoped over and crimped onto a bare electrical conductor, the resulting body as viewed in section presenting an unbroken periphery including a convex portion extending for about half of the periphery and, for the other half, a portion including a middle projection and two side projections mutually separated by two deep grooves, said body being symmetrical on opposite sides of a line bisecting the middle projection and the midpoint of said convex portion, said projections and grooves extending longitudinally of the ferrule, the projections on either side of said middle projection being comprised by folded-over portions of the ferrule which are in intimate mutual contact, said conductor being substan-

tially triangular as viewed in section with its apex aligned under the middle projection whereby the trapped stresses in the connection tend to maintain the depth of the grooves.

3. An electrical connector as claimed in claim 2 in which the conductor is a single strand solid wire.

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