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J. B. REDWINE

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METHOD OF MAKING ELECTRICAL CONNECTIONS

Filed March 21, 1961

2 Sheets-Sheet 1

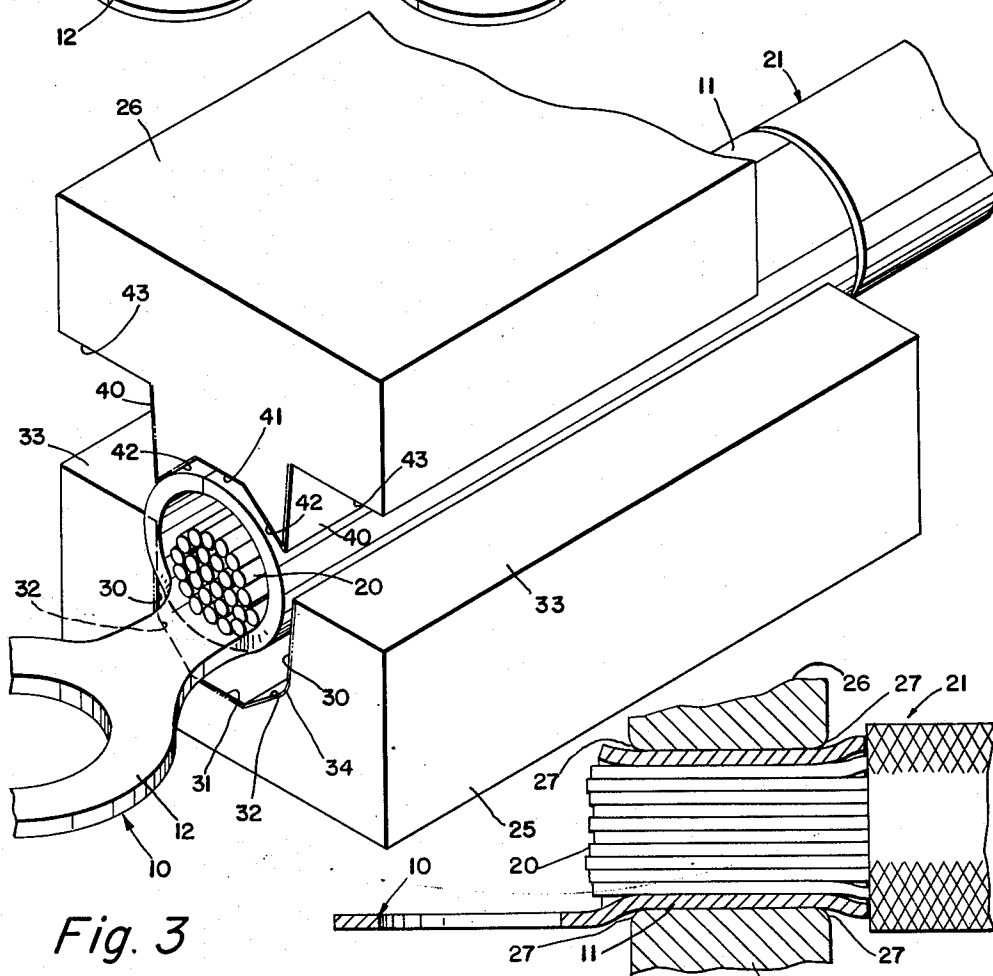
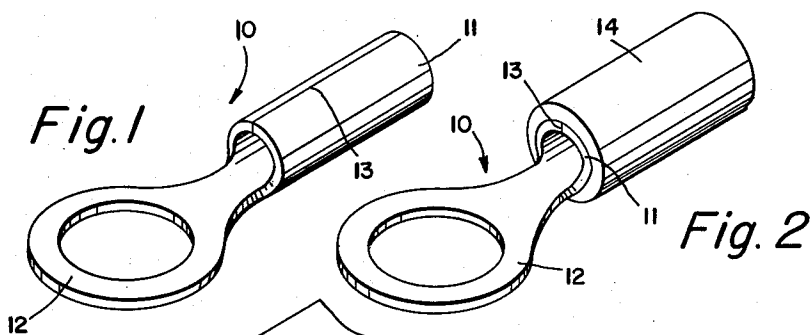


Fig. 3

Fig. 5A

INVENTOR.  
JOHN B. REDWINE  
BY *Ely, Peaner & Gordon*  
ATTORNEYS

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2 Sheets-Sheet 2

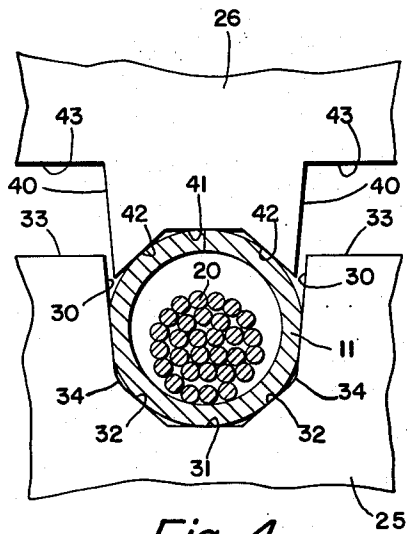


Fig. 4

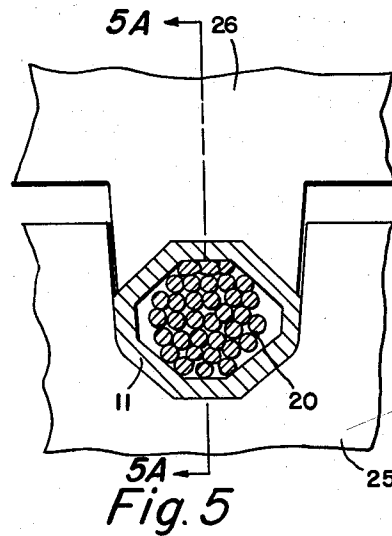


Fig. 5

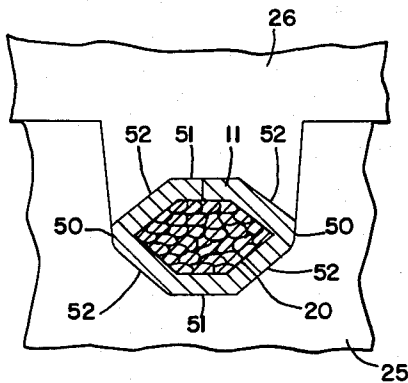


Fig. 6

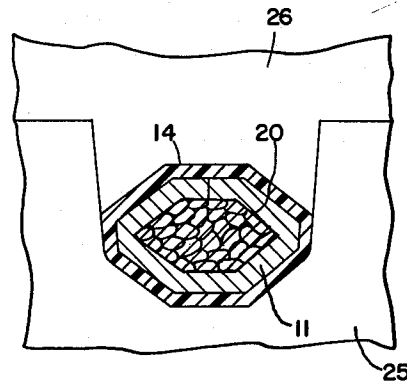


Fig. 7

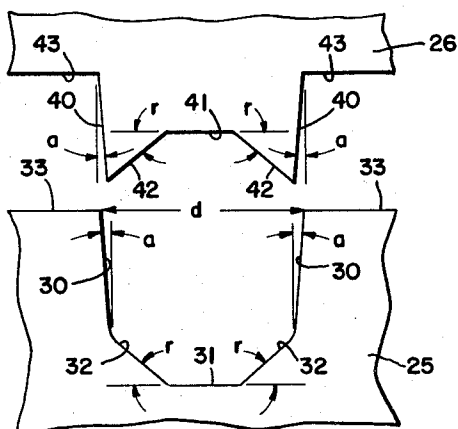


Fig. 8

INVENTOR.

JOHN B. REDWINE

BY *Ely, Paine & Gordon*

ATTORNEYS

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3,146,519

## METHOD OF MAKING ELECTRICAL CONNECTIONS

John B. Redwine, North Olmsted, Ohio, assignor to ETC Incorporated, Cleveland, Ohio, a corporation of Ohio  
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1 Claim. (Cl. 29—155.55)

The present invention relates generally to the art of crimped electrical connections, and more specifically to crimping dies and methods for cold forging electrical connectors to conductors and to the improved, mechanically strong, electrically conductive connections which are formed thereby.

The invention is particularly concerned with applications involving the joining of either insulated or non-insulated, solderless electrical connectors to stranded and solid wire conductors for the purpose of either terminating the conductors or connecting them to other conductors, such joining being carried out by the known general procedure of telescoping a tubular ferrule portion of the connector over the bared conductor and then cold forging the elements into electrical and mechanical union. As will be made more apparent, the same novel crimping dies and methods to be hereinafter described may be used to advantage with both insulated and non-insulated connectors. Other applications with which the present invention is concerned include the crimping of pressure cable connectors and the clenching of various types of rings and sleeves to ropes, rods and wires.

Many different crimping dies and procedures for joining tubular, ferrule-type connectors to conductors have been evolved in the past in an effort to achieve a crimped electrical connection possessing high mechanical strength and exhibiting good electrical characteristics. Many of these prior developments have found practical application in crimping a particular ferrule construction to a conductor of a limited range of sizes; however, none may be universally employed with the success obtainable with the present invention to crimp the many different types of commercially available connectors to the widely varying conductor sizes commonly encountered. Another general limitation of the prior art is that most of the methods and apparatus for crimping uninsulated connectors cannot be used successfully to crimp insulated connectors, and vice versa.

A typical die apparatus which has been used in the past to crimp uninsulated connectors is characterized by either a single or double indenter which cooperates with a ferrule-receiving nest or matrix to produce what is known as a V and a W crimp, respectively. In use the full crimping pressures are applied through the very small indenter faces to produce high, localized, crimping forces which frequently result in the conductor strand or strands being cut to the extent they break under relatively small tension or when the conductor is flexed or twisted. When the ferrule being crimped is formed with a butt seam, the crimping action of the indentors also has the tendency to break the seam open to allow the escape of conductor strands. As is known to those familiar with this general type of die apparatus, it has the further disadvantage of being impractical to use when crimping insulated connectors since the indentors usually tear or puncture and penetrate through the insulation.

It has been proposed to avoid the above-discussed disadvantages of the "over-crimp" commonly incurred with single and double indenter die apparatus by limiting the penetration of the indenter into the matrix. However, this usually results in an under-crimp and a poor electrical connection. The pull-out strength of the formed connection also is relatively low.

Another typical development over which the present

invention presents definite advantages includes the use of a pair of relatively movable, concave dies, the cavity of one of which is provided with either a single or double indenter configuration. One die is moved into the cavity of the other die to confine the connector ferrule and conductor when performing the crimping operation. While the confined crimping feature of such an apparatus has certain advantages over the single and double indenter die apparatus discussed above, the indentors which are provided prevent the application of a uniform crimping pressure around the periphery of the ferrule. As a result, this type of die apparatus also tends to over-crimp and produce a connection of poor mechanical strength. This latter apparatus also is not suitable for crimping insulated ferrules since it thins and tears the insulation.

More recently, special die apparatus and crimping methods have been evolved to crimp insulated connectors of the type in which the connector ferrule is encased within a sleeve of plastic insulating material. In general die apparatus for this purpose has been characterized by a confined die cavity having opposed, smoothly curved crimping surfaces for producing a so-called "confined crimp." A known die construction of this type included a die matrix and an indenter movable into the matrix with the curved pressure-applying surfaces of the indenter and die matrix being concave and preferably cylindrical, and cooperating to produce a crimp of substantially elliptical cross-section. In theory the smoothly curved crimping surfaces were supposed to prevent excessive reduction in thickness of the insulation; however, in actual practice it has been found that this conventional construction developed unequal crimping pressures around the insulating sleeve and ferrule. As a result, the insulation material was thickened at the sides of the sleeve and unduly stretched and thinned at the top and bottom, thereby decreasing its insulating properties.

It also has been found that, upon completion of the final crimping action with the conventional "confined crimping" apparatus, the wall thickness of the crimped metal ferrule was of unequal cross-section because of the non-uniform crimping forces applied thereto. Consequently, the ferrule and contained conductor strands were not usually forged into a solid mass, there being evidence of voids within the crimped ferrule which adversely affected the tensile and pull-out strengths of the connection.

An object of the present invention is to provide a crimped electrical connection which is characterized by improved electrical and physical properties.

A more specific object of the invention is to provide a crimped electrical connection in which a metal ferrule portion of a connector and a bared portion of an electrical conductor are forged into a substantially uniform mass, the crimped connection being characterized by a uniformly equal cross-sectional wall thickness of the ferrule, an absence of voids within the ferrule, and improved tensile and pull-out strengths.

A further object of the invention is the provision of a crimped electrical connection of high mechanical strength and secureness wherein the crimped conductor is not damaged so that connection retains its improved characteristics when subjected to tension and torsional and flexural stresses.

Another object of the invention is to provide crimping dies and methods suitable for forming insulated and non-insulated crimped electrical connections characterized by the features described in preceding objects.

Still another object of the invention is to provide a crimped, insulated electrical connection, and methods and apparatus for forming the same, wherein the insulating

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material of the crimped connector is of substantially uniform cross-section.

In accordance with the present invention, the foregoing objects are attained and the disadvantages of the prior art are overcome by subjecting the connector ferrule to substantially equal and opposite crimping forces around the circumference of the ferrule which are distributed over a large pressure-applying surface area. Since the crimping forces are essentially equal and opposite about the circumference of the ferrule, the metal ferrule can be compressed to the desired limit in order to obtain a connection of excellent mechanical and electrical properties without danger of over-crimping and damaging the conductor.

Another advantage of crimping with essentially equal and opposite crimping forces applied over a large area about the circumference of the metal ferrule is that the metal is caused to flow more uniformly, thereby resulting in a crimped connection in which the deformed ferrule has a wall thickness of substantially equal cross-section. It has been found that, when a ferrule is thus deformed, there is no evidence of voids among the strands of a stranded conductor or between the conductor and the ferrule, and the resulting tensile and pull-strengths of the connection are superior to those of prior art connections.

When the ferrule portion of a connector is covered by an insulating sleeve, the non-metallic insulating material will likewise be uniformly deformed beyond its elastic limit, thereby avoiding variations in the wall thickness of the insulating sleeve and consequent variations in its dielectric and insulating properties.

Other objects and advantages of the invention will become apparent from the following detailed description and the accompanying drawings.

In the drawings:

FIGURE 1 is a perspective view of an exemplary solderless terminal connector adapted to be crimped on a conductor in accordance with the present invention.

FIGURE 2 is a view similar to FIG. 1 but showing the connector insulated in a conventional manner.

FIGURE 3 is a fragmentary perspective view of die apparatus made according to the invention and showing an uninsulated terminal connector and conductor positioned preparatory to a crimping operation.

FIGURE 4 is a fragmentary, vertical cross-sectional view showing the initial stage of the crimping operation.

FIGURE 5 is a view similar to FIG. 4 except that it shows an idealized progressive stage of the crimping operation which is closely approached in practice.

FIGURE 5A is a vertical cross-sectional view taken along the line 5A—5A of FIG. 5.

FIGURE 6 is a view similar to FIGS. 4 and 5 except that it shows still a further progressive stage of the crimping operation.

FIGURE 7 is a view similar to FIG. 6 but showing a fully crimped insulated terminal connector.

FIGURE 8 is a fragmentary end view of the die apparatus.

Referring now to the drawings, the conventional terminal connector shown in FIG. 1 is intended to be merely illustrative of the general ferrule-type, solderless connector construction to which the present invention is applicable, and has been selected only for the purposes of describing the principles of the invention and explaining how these principles may be followed when forming an electrical connection. It is to be understood, therefore, that the illustrated terminal connector is not limiting of the invention and is merely representative of the many practical applications for which the invention is particularly suited.

The illustrated terminal connector 10 is of the usual construction and comprises a cylindrical ferrule portion 11 and an attached tongue 12 adapted to cooperate with a binding post or the like. As is known to those skilled

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in the art, the connector 10 may be stamped from a flat sheet of a malleable, electrically conductive material, such as, for example, copper or a copper alloy, steel, aluminum and the like, into a shape having oppositely extending ear portions which are thereafter rolled or bent into edge abutment to form the ferrule seam 13.

In FIG. 2, the terminal 10 is shown insulated in a known manner by a sleeve 14 of electrical insulating material which is telescopically mounted around the ferrule 11. The sleeve 14 may suitably be formed from any of a number of different plastic materials possessing the desired insulating qualities and which resist fracture during cold deformation. Typical plastic materials useful for this purpose are nylon, various vinyl chlorides, vinyl chloride-vinyl acetate copolymers, vinylidene chloride-vinyl chloride copolymers, and the like. If desired, an intermediate tube (not shown) of a soft brass or other deformable material may be interposed between the ferrule 11 and the outer insulating sleeve 14, as is well known in the art.

In the formation of crimped electrical connections, the bared end 20 of a conductor 21 is positioned within the connector ferrule 11 which is then crimped to the conductor end to form a uniform, solid mass. In FIGS. 3 and 5A, the conductor insulation is shown as abutting the rear end of the ferrule; however, the rear end of the ferrule may be made with an enlarged diameter and extended in telescoped relationship over a portion of the conductor insulation, as is common practice in many connector constructions. The conductor 21 may be stranded as shown, or a solid conductor, or both, i.e., a heavy solid conductor surrounded by a number of smaller strands.

The forging or crimping of the ferrule 11 to the bared conductor end 20 is accomplished with the crimping dies 25 and 26 which comprise one aspect of the present invention. These dies may be mounted in suitable, commercially available, hand or power-actuated crimping tools or apparatus. Preferably, the cooperating dies 25 and 26 terminate short of the ferrule ends to avoid the danger of causing the inner end edges of the ferrule to bite into and damage the conductor during the crimping operation. Alternatively, the rear end edge of the ferrule may be internally flared or chamfered and the crimping dies constructed to extend beyond the rear ferrule end. When the ferrule 11 is constructed to enclose a portion of the conductor insulation as suggested above, the dies 25 and 26 may be mounted adjacent another set of dies for crimping the enlarged diameter portion (not shown) of the ferrule 11 to the enclosed conductor insulation in firm supporting relationship therewith.

As shown most clearly in FIG. 5A, it is also desirable to construct the dies 25 and 26 with slightly radiused end edges 27 in order to eliminate any sharp edges on the dies which would otherwise weaken the connector ferrule when it is compressed and crimped onto the conductor. This latter construction is particularly advantageous when using the dies to crimp connectors provided with insulation sleeves 14, since the presence of sharp end edges on the dies tend to thin and puncture the insulation sleeves to thereby permanently decrease or destroy their insulating value.

The die 25 constitutes a female die nest or matrix of the crimping unit and the die 26 constitutes a male die member which is movable into cooperation with the nest to peripherally confine the ferrule 11 during the crimping operation. In accordance with the broad principles of the present invention, the male die 26 has a concave ferrule-contacting end which includes at least two flat, angularly related surfaces, while the cavity of the female die 25 is defined by at least three flat, angularly related surfaces, including two upwardly and outwardly sloping side surfaces. Thus constructed, it will be seen that the male and female dies cooperate to form an enclosed crimping chamber which is generally polygonal and which includes at least five crimping surfaces.

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According to its preferred and more specific form of construction illustrated in the drawings, the die nest or matrix 25 comprises a symmetrical five-sided ferrule-receiving cavity which is defined by two opposed side surfaces 30, a lower horizontal surface 31 and two, equal length, angularly disposed, corner surfaces 32 between the die surfaces 30 and 31. In order that a crimped connector can be readily removed from the die nest cavity without sticking therein, the cavity is formed to have fillets 34 between the side surfaces 30 and the corner surfaces 32 (FIGS. 3 and 4).

The cooperating male die 26 presents two side surfaces 40 movable into contiguity with the confining surfaces 30 of the nest 25 when the die is moved into the die nest cavity to perform the crimping operation. The lower, pressure applying end of the male die 26 is in the form of a symmetrical three-sided cavity defined by an upper, horizontal surface 41 corresponding to the opposed surface 31 and two opposite, downwardly and outwardly sloping surfaces 42 of equal length which correspond to the surfaces 32. Preferably the die 26 is provided with horizontal shoulders 43 which cooperate with a top surface 33 of the die 25 to limit movement into the die nest cavity.

When the die 26 is moved into the die nest cavity, the two die elements cooperate to form an eight-sided confined crimping chamber defined by the pressure-applying surfaces 30, 32, 31, 32, 30, 42, 41 and 42 (FIG. 4). In accordance with the principles of the present invention, this eight-sided crimping chamber is constructed so that the diametrically opposed surfaces 31 and 41 and 32 and 42 of the nest 25 and the male die 26, respectively, are parallel and of substantially equal length. The distance between the side surfaces 30 of the nest 25 is approximately equal to or slightly less than the outer diameter of the uncrimped ferrule 11, while the length of the surfaces 31, 32, 41 and 42 and the angle which the sloping surfaces 32 and 42 make with the horizontal are selected so that substantially equal and opposite crimping pressures are applied to the ferrule as the male die is moved into the nest. As will hereinafter be discussed in more detail, the dimensions of the crimping chamber, that is, the length of the pressure-applying surfaces, the horizontal angle of the surfaces 32 and 42 and the vertical angle of the surfaces 30, depend upon the size of the ferrule to be crimped and may be varied to achieve the optimum crimping action for ferrules of different sizes.

Because of the advantageous die construction discussed above which transmits substantially equal and opposite crimping forces, the metal of the ferrule will be caused to flow uniformly as it is cold forged by the dies. Thus, in the progressive crimping operation illustrated in FIGS. 3, 4, 5 and 6, the initial contact of the ferrule 11 by the die 26 (FIG. 3) serves to center the ferrule at the mouth of the die nest cavity. In this position, the male die surface 41 is slightly spaced from the top of the ferrule 11 while the surfaces 42 are in tangential contact therewith. The lower half of the ferrule extends within the die nest cavity with the top surface 33 of the die nest 25 being very nearly coincident with the cross-sectional horizontal center line of the ferrule.

As the dies 25 and 26 are further brought together, the sides of the ferrule 11 are slightly flattened against the surfaces 30 and the ferrule is forced to the bottom of the die nest cavity (FIG. 4). At this point all eight pressure-applying surfaces of the cooperating dies are in contact with the ferrule so that a progressive increase in the crimping force causes the ferrule to assume substantially the octagonal configuration illustrated in FIG. 5, wherein the top and bottom portions of the conductor end 20 are slightly flattened against the corresponding inner surfaces of the ferrule, and the inner sides of the ferrule are spaced from the conductor end.

The female die 25 serves to constrain the ferrule 11

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against lateral expansion beyond its original diameter so that continued movement of the male die 26 into the die nest cavity will gradually decrease the vertical height of the ferrule and simultaneously affect a uniform increase in its wall thickness until, in the final stage of crimping illustrated in FIG. 6, the conductor fills and conforms to the inside of the ferrule. This final crimping stage is reached when the die surfaces 33 and 43 are in abutment, thereby assuring that the conductor has been compacted to the desired extent and the ferrule and conductor have been forged into a substantially solid mass without damage to the conductor.

As shown, the finally crimped connection formed by the ferrule 11, and the conductor end 20, has a symmetrical cross-sectional shape of octagonal configuration defined by relatively short side surfaces 50, top and bottom surfaces 51, and sloping corner surfaces 52. This symmetrical cross-sectional shape is characterized by approximately equiangular disposition of the corner surfaces 52 with respect to the parallel top and bottom surfaces 51 and by a substantially equal length of each pair of diametrically opposed surfaces. The cross-sectional width of the crimped connection, that is, the distance between the side surfaces 50, is slightly less than the outer diameter of the uncrimped ferrule, while the cross-sectional height or distance between the surfaces 51 is preferably  $\frac{1}{3}$  to  $\frac{1}{2}$  of the original outer diameter of the ferrule.

Another significantly novel feature of the above-described crimped connection is that the cross-sectional wall thickness of the ferrule is substantially equal at all points. This is a result of the equal and opposite crimping forces which are uniformly applied around the periphery of the ferrule while decreasing its diameter in one plane and simultaneously constraining it against radial expansion to thereby cause the metal of the ferrule to flow and thicken uniformly as the ferrule is compressed. Tests conducted on the crimped connections comprising the present invention have shown the ferrule and conductor to be forged into a solid mass with no evidence of voids within the ferrule, thus assuring stronger and more secure connections than those of the prior art. For example, typical results of tensile tests indicate at least 20% better pull-out strength than single indent, double indent, and conventional confined crimped connections. It also has been shown that the tensile strengths of the crimped conductor portions are increased to 80 to 100% of the tensile strength of the uncrimped conductor wire.

Another important advantage of uniformly applying substantially equal and opposite crimping forces to the connector is that the dies may be used interchangeably to crimp both uninsulated and insulated connectors, such as shown in FIG. 2. When crimping such connectors, the male die 26 is moved into the nest 25 to affect the essentially same progressive crimping stages discussed in connection with FIGS. 3, 4, 5 and 6. In essentially the same manner the sleeve 14 is progressively caused to assume the symmetrical, octagonal shape of the confined crimping chamber and to transmit the crimping forces to the ferrule, thereby affecting the desired crimped connection shown in FIG. 7. Although an intermediate insulation supporting tube has not been shown between the ferrule 11 and the sleeve 14, the presence of such a tube does not alter the crimping action, and it will also be deformed into the characteristic octagonal shape. The dies for accomplishing the foregoing operation on insulated connectors will usually have slightly larger dimensions than dies for crimping uninsulated connectors to a conductor of comparable size because of the presence of the insulation sleeve which increases the effective size of the connector ferrule portion.

The substantially equal and opposite crimping forces which are exerted by the dies 25 and 26 as the insulation sleeve is compressed and simultaneously constrained against radial expansion produce a novel insulated connection which is characterized in part, by a uniform thick-

ness of insulating material around the ferrule or optional intermediate supporting tube. Because of its final uniform thickness, the compressed insulation sleeve 14 advantageously exhibits optimum dielectric strength. This improved insulated connection of the invention can be readily distinguished from prior insulated connections formed with conventional confined crimping apparatus, which permit the insulation sleeves to radially expand at the same time they are compressed, in that the sleeves are materially thickened in the areas of radial expansion and are unduly thinned and stretched in the zones where the compressive forces are applied. In addition to the foregoing advantages, the application of uniform, equal and opposite crimping forces around the insulation sleeve 14 in accordance with the practice of the invention appears to avoid any undesirable concentration of pressure which would tend to damage the insulation sleeve 14.

Referring again to the construction of the dies 25 and 26, reference is made to FIG. 8 which illustrates how surface dimensions and angular relationships may be varied to accommodate ferrules of different diameters. The side surfaces 30 of the die nest 25 are shown as extending downwardly from the upper die surface 33 and slightly inwardly toward each other to form angles "a" with the vertical. The side surfaces 40 of the male die 26 are disposed at similar angles "a" from the vertical so that the surfaces 30 and 40 will mate when the male die is moved into the die nest cavity. When applying connectors to conductors of small and moderate wire sizes, e.g. No. 22 AWG and moderately larger wires, excellent results have been attained with the angles "a" being very nearly 0°. However, as the wire size becomes relatively larger, as for example No. 4/0 AWG wire, it has been found desirable to increase the angles "a" up to as much as approximately 10°. Taking FIGS. 6 and 8 in conjunction, it will thus be seen that a horizontal median plane bisecting either the side surfaces 30 of the die nest cavity or the side surfaces 50 of the crimped ferrule will form angles therewith of from very nearly 90° to as much as 100°, depending on the wire sizes.

The parameters of the angle "a" are the distance "d" across the mouth of the die nest cavity, the length of the pressure applying surfaces 31, 32 and 41 and 42 and the angular disposition of surfaces 32 and 42. As will be readily apparent from the above discussion, the dimension "d" is particularly critical since, in order to assure that the crimped connection will be formed with an absence of voids and that the ferrule 11 (as well as the insulation sleeve 14) will have a uniform thickness, the ferrule 11 should be restrained against radial expansion as it is compressed. Consequently, the dimension "d" is usually made very nearly equal to or slightly less than the outside diameter of the uncrimped ferrule.

The lengths of surface 31, 32 41 and 42 and the angles "r" which the surfaces 32 and 42 make with the horizontal are selected to assure that the desirable, substantially equal and opposite crimping forces will be transmitted to the confined ferrule. Within a range of wire sizes from No. 22 AWG to No. 4/0 AWG, the angles "r" may be varied between approximately 30° and 45° in order that all the pressure-applying surfaces will peripherally confine and be substantially tangent to the ferrule at the start of the crimping action (FIG. 4). The lengths of the pressure-applying surfaces will, of course, be varied as the angle "r" is changed. Stated in terms of the crimped connection shown in FIG. 6, this die construction results in the equiangularly disposed corner surfaces 52 of the ferrule forming an included angle with the top and bottom surfaces 51 of approximately 135° to 150°.

It will thus be apparent from the foregoing description that the invention provides for an improved crimped elec-

trical connection characterized by a symmetrical octagonally deformed, connector ferrule having a substantially uniform cross-sectional wall thickness and an absence of voids within the ferrule. Not only does the crimped connection of the invention exhibit superior mechanical properties over connections of the prior art but the manner in which the connector ferrule and conductor are forged together into a uniform solid mass results in a connection possessing excellent electrical properties in which the conductor is neither damaged by over-crimping nor too loosely confined within the ferrule.

It will also be apparent that the invention provides apparatus and methods which are particularly well suited to the formation of electrical connections having the above-described beneficial characteristics. Advantageously, these methods and apparatus may be used to crimp insulated and uninsulated connectors of various other types than the illustrated terminal connectors.

Another particular advantage afforded by the crimping die construction of the invention is the provision of the octagonal confined crimping chamber which presents a large surface area over which the substantially equal and opposite crimping forces are applied to the connector ferrule around its periphery.

The terms "vertical," "horizontal," "top," "bottom," "side," and so forth are used in the foregoing description and in the following claim only in a relatively sense in describing the invention as shown in the drawings and thus are not intended to exclude connection configurations and methods and apparatus which are not orientated as illustrated, but which could be so orientated so as to respond to relative terminology used herein.

Many modifications and variations of the invention will be apparent to those skilled in the art in light of the above teachings. It is to be understood, therefore, that the invention may be practiced within the scope of the appended claim otherwise than has been specifically disclosed.

What is claimed is:

In the method of clenching a malleable ferrule onto an electrical conductor extending axially within the ferrule by subjecting the ferrule to radially directed compressing forces for forging the ferrule and conductor into a substantially solid mass, the improvement comprising supporting said ferrule between a pair of opposed, slightly converging side surfaces, said side surfaces contacting said ferrule at points spaced below a horizontal plane passing through the axis of said ferrule and converging inwardly toward a vertical plane passing through the axis of said ferrule, forcing the ferrule downwardly along said side surfaces to apply equal compressive forces to said ferrule, increasing said equal compressive forces while applying six additional equal and opposite compressive forces by contacting the periphery of the ferrule with three pairs of opposed, flat surfaces and continuing the application of said six additional forces until said ferrule has an octagonal cross section which is symmetrical with respect to said vertical plane.

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