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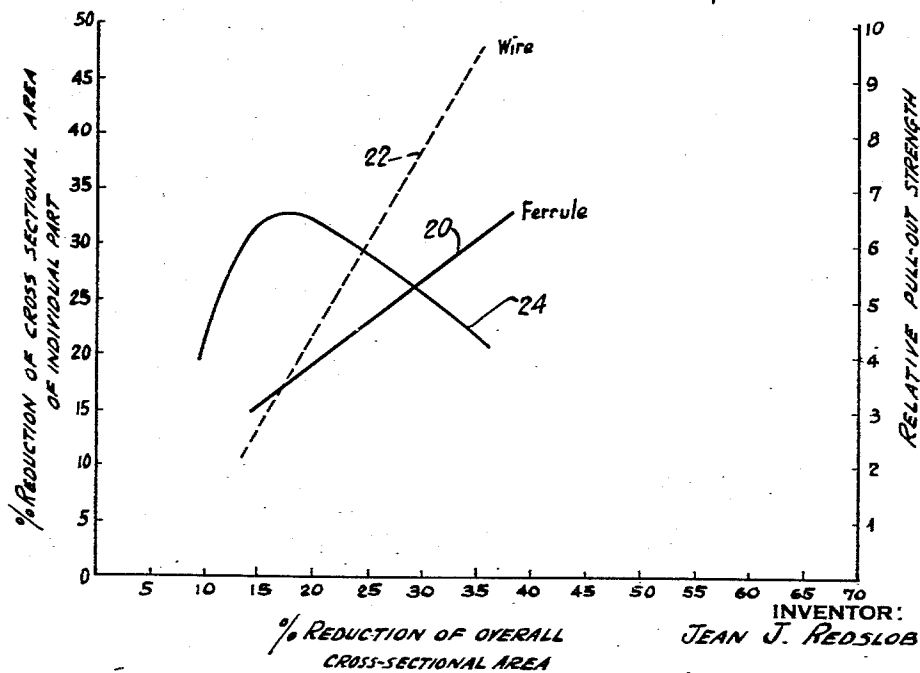
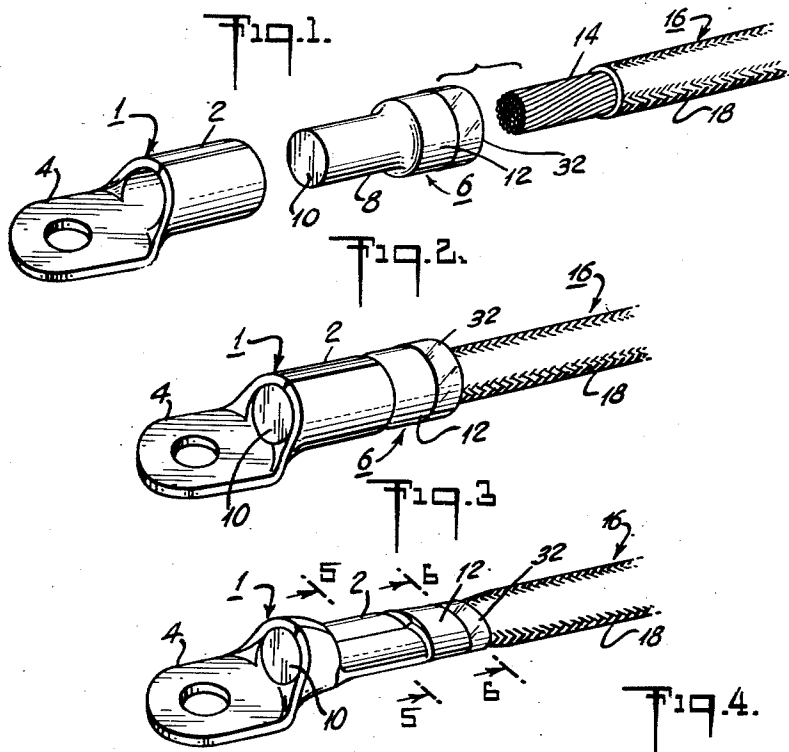
J. J. REDSLOB

2,815,497

CONNECTOR FOR ALUMINUM WIRE

Filed April 23, 1953

2 Sheets-Sheet 1



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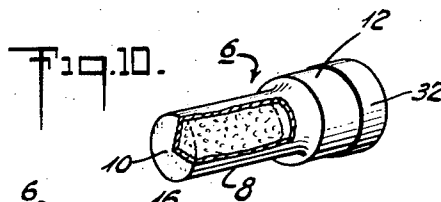
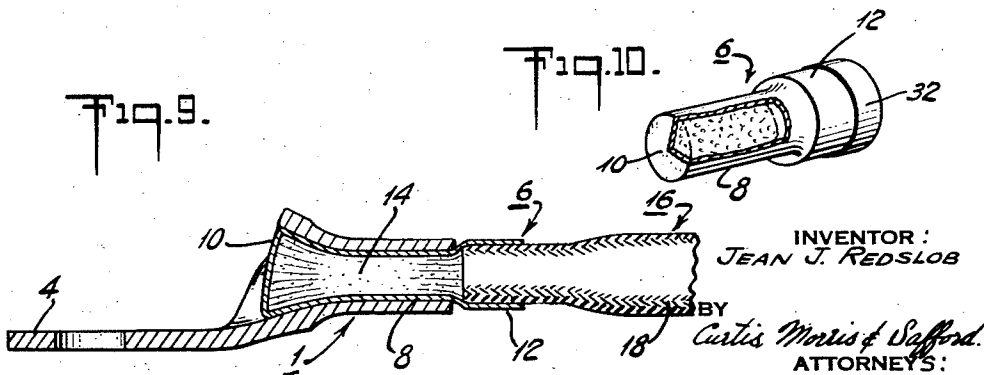
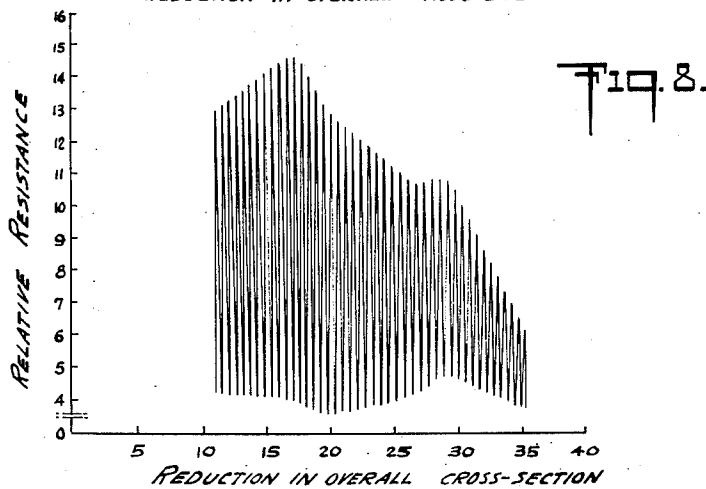
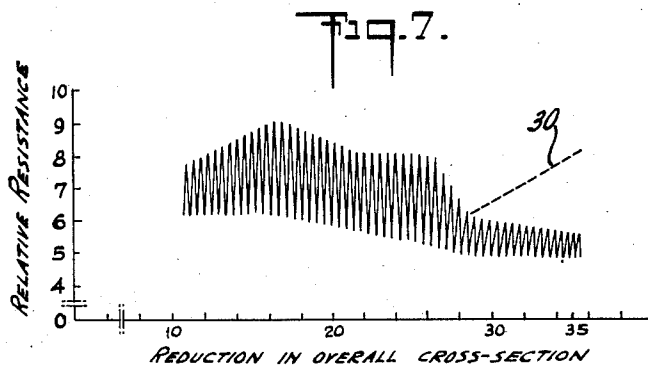
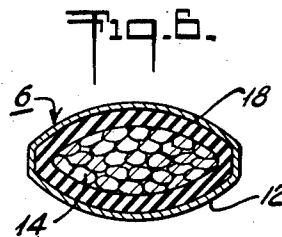
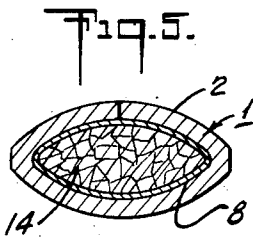
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CONNECTOR FOR ALUMINUM WIRE

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2 Sheets-Sheet 2



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1

2,815,497

CONNECTOR FOR ALUMINUM WIRE

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Application April 23, 1953, Serial No. 350,653

10 Claims. (Cl. 339—276)

This invention relates to connectors for use with aluminum wire. More particularly, it relates to terminals and connectors which are attached to aluminum wire by crimping. Such connectors may be used for example to provide a corrosion-resistant highly-conductive junction between aluminum and copper conductors or between two aluminum conductors. These connectors may be in the form of terminals of the type which connect the end of a wire to a stud or other fastening means or they may be constructed to connect together two or more wires of the same or dissimilar metals.

In order to provide a satisfactory connector for aluminum wire, a number of requirements must be met. The connector must provide adequate current-carrying capacity and good electrical conductivity between the aluminum wire and the other conductor. This conductivity must be maintained over a long period of time and under adverse conditions as when the connection is exposed to moisture, corrosive atmosphere, repeated changes in temperature, etc. The connector must be such that it can be applied easily and rapidly to the aluminum wire, preferably by a simple crimping operation eliminating the need for soldering, welding or brazing. The connector must not be excessively large and the cost of fabricating the connector and securing it to the conductor must be low to provide maximum commercial utility.

Many attempts have been made to solve the problems that arise in devising a connector having the above characteristics, but for the reasons pointed out below, no fully successful commercial connector has been made heretofore. This is true even though several of the individual problems involved in making a good connection have been solved or partially solved by earlier workers, for no solution was found or incorporated in these connections for other problems, so that no one fully satisfactory connector resulted. Because no fully successful connector has been devised heretofore, there has been no guide to which of the so-called solutions could be used in the construction of a satisfactory connector. It will become apparent from the later consideration of the specific problems that the solution of one of the problems in the construction of the connection depends upon the solution for other of the problems, so that a satisfactory connection cannot be made merely by assembling individual known features without respect to their inter-relationship as applied in the particular connection.

Probably the most serious difficulty with connectors heretofore constructed has been the lack of reproducibility and reliability. Based on past technology, it is not a particularly difficult task to construct a connector for aluminum wire that apparently meets all of the requirements set forth above. But if a large number of connectors are fabricated as nearly like the sample as possible, wide variation is found in the characteristics of the connections made when the connectors are secured to aluminum wire. A certain number of the connectors may appear to make acceptable connections, others make less satisfactory connections, and still others result in connections that are

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wholly unsatisfactory. Thus, the reproducibility of the connector is poor and it is unsatisfactory for extended commercial production.

Moreover, if the particular connectors which appeared to make satisfactory initial connections, are subjected to life tests, it is found that certain of the connections fail prematurely, thus indicating a lack of reliability.

To be commercially acceptable, a connector must be reproducible in large quantities and each resulting connection must be free from any possibility of premature failure. Even one electrical failure among many hundreds of connections, would render that type of connector unsatisfactory for commercial use, particularly in aircraft, even though all of the other connections performed satisfactorily.

The present invention is directed to the achievement of a wholly satisfactory and commercially acceptable connector for aluminum wire and is embodied in a connection formed by the combination of certain original features with certain features heretofore known but which had never been used in such combination as to produce a completely satisfactory connector. The particular combination of elements and steps embodied in the aluminum connection system to be described below results in a connector that meets all of the requirements set forth above as to conductivity, mechanical strength, corrosion resistance, size, etc. and which can be reproduced in large quantities without the inclusion of numbers of defective connectors, thus eliminating all initially faulty connections and premature electrical or mechanical failures.

These and other aspects, advantages, and objects will be in part apparent from and in part pointed out in the following description considered in connection with the accompanying drawings, in which:

Figure 1 is an expanded perspective view of the parts of a connector and shows the aluminum wire to which they are to be secured;

Figure 2 is a perspective view of the connector of Figure 1 after being assembled and positioned on the wire but before it has been crimped;

Figure 3 is a perspective view of the connection resulting from crimping the assembly shown in Figure 2;

Figure 4 is a graph for assistance in explaining the principles of the invention;

Figure 5 is an enlarged cross-sectional view taken along line 5—5 of Figure 3 showing the shape of the ferrule and wire after crimping;

Figure 6 is a graph showing the relationship between extent of crimping and the resistance of the connection;

Figure 7 is an enlarged cross-sectional view taken along line 7—7 of Figure 3 showing the shape of the insulation support after crimping;

Figure 8 is a graph showing the relationship between extent of crimping and resistance of the connection after a life test;

Figure 9 is an enlarged longitudinal sectional view of a connection in accordance with the invention; and

Figure 10 is a perspective view of the thimble of Figure 1 showing the plastic cap for retaining the corrosion-inhibiting jelly within the thimble.

One important problem in making connection to aluminum conductors arises because of the thin coating of oxide which covers the exposed surfaces of aluminum. This oxide coating is very thin and hard and clings tenaciously to the surface of the aluminum. If the coating is removed by abrasion or other means, a new oxide coating forms immediately, if the aluminum is exposed to the atmosphere, and continues to build up in thickness for a short time after which the film thickness does not increase further under usual conditions. An increase in temperature however will cause a further build-up in film thickness.

In order to make a satisfactory electrical connection to the aluminum, it is necessary to remove this oxide coating so that contact can be made with the exposed virgin metal and, in order to maintain good electrical conductivity, it is necessary to prevent the oxide coating from reforming and increasing the resistance of the connection. Even a slight oxide coating is objectionable because the increase in resistance which it produces causes a greater amount of heat to be generated in the connection; the resulting increase in temperature causes an even more rapid build-up of the oxide coating.

This oxide coating may be removed chemically, as by the action of hydrofluoric acid, or mechanically, as by abrasion. This coating appears also to be relatively inelastic so that if the surface of the aluminum is stretched the oxide layer will break apart, forming new areas of exposed metal.

Once the oxide has been removed, the aluminum can be plated with an oxide-resistant metal, or one whose oxide is electrically conductive, thus effectively reducing or preventing the formation of aluminum oxide. Such a procedure may be used to alleviate the oxide problem on the connector itself, but no such plating is present on the aluminum wires to which the connector is to be secured.

Accordingly, the oxide must be removed from the wire by mechanical means, such as by abrasion, scouring, or stretching, at the time the connector is secured to the wire. Moreover, this removal of oxide must be so complete in every connection that no "hot-spots" will develop to accelerate the reformation of the oxide and cause premature failure of the connection.

One step in accomplishing this oxide removal is to crimp the bare aluminum wire in the ferrule portion of the connector to such an extent as to cause substantial stretching or extrusion of the wire accompanied by a scouring action produced by differential longitudinal extrusion between the ferrule and the wire. Such crimping and extrusion must be accomplished in such manner as to maintain satisfactory mechanical strength and at the same time allow for the necessary variations which occur in field use without causing any electrical or mechanical failures.

Figure 1 shows a terminal 1 comprising a tubular ferrule 2 and an integral-connected tongue portion 4. The ferrule and tongue are formed, in this example, of aluminum with all of the exposed surfaces, including the inside of the tubular ferrule 2, plated with an adherent layer of tin, as will be described later.

A thin-walled thimble 6 formed of tin-plated aluminum includes a cylindrical insert portion 8 having a closed end 10 and a larger open-end cylindrical insulation-supporting portion 12. The insert portion 8 of the thimble 6 is filled with a moisture resistant grease in which are dispersed abrasive particles, as will be described later, and is adapted to receive the bared end portion 14 of an insulated aluminum cable 16. The surface of the thimble 6 is plated with tin. It is not always essential that the inner surface be fully plated, particularly over the areas where it is not necessary to make electrical connection. The enlarged insulation supporting portion 12 of the thimble extends over the insulation covering 18 of the cable. The insert portion 8 of the thimble is then placed inside the ferrule 2 so that the assembly appears as shown in Figure 2. The ferrule portion 2 and the insulation support 12 of the thimble are then crimped in a confining die to form the connector in the manner indicated in Figure 3.

During this crimping operation, the ferrule 2 and the wire 14 are both extruded so that by the stretching action new surfaces, free of oxide, are exposed on the aluminum wire 14, and on the inner surface of the thimble 8 if it is unplated or only partially plated. This new surface appears not only on the outside surface of the wire

adjacent the inner surface of the thimble, but also along each of the strands of the wire 14 which will form a compact bundle where the strands are in intimate electrical contact.

In addition there is a differential lengthening between the wire 14 and the thimble 6, which is extruded along with the ferrule 2. For the purposes of this discussion, it can be assumed that the insert portion 8 of the thimble and the ferrule 2 act as a unit during extrusion and that the metal of the thimble and the ferrule move in unison at their interface.

At the start of the crimping action, the ferrule extrudes at a faster rate than the wire; subsequently as the crimping action continues the wire extrudes at a faster rate than the ferrule. The relative rates of extrusion are indicated in Figure 4 for one particular connector and wire combination. The solid line 20 shows the reduction in cross-sectional area of the ferrule, in the area where the crimping force is applied, as a function of the reduction in the overall cross-sectional area of the ferrule and wire. The broken line 22 shows the reduction in cross-sectional area of the wire as a function of the reduction in the overall cross-sectional area of the ferrule and wire. It will be noted that with an overall reduction in cross-sectional area of less than about seventeen percent, a greater reduction occurs in the cross section of the ferrule than in the wire; at seventeen percent overall reduction, the wire and ferrule have been reduced equally, and beyond seventeen percent a greater reduction occurs in the cross section of the wire than in the ferrule.

The differential longitudinal movement of the wire and the surrounding surface caused by these different rates of extrusion produces a scouring action that assists in removing and breaking up the oxide coating of the aluminum wire 14.

It appears to be advantageous in making a good initial contact and in maintaining the high conductivity, for the oxide surface to be broken or separated, in the areas where it is not entirely removed, into a mosaic-like pattern with individual oxide particles of small area dispersed over the area of exposed virgin metal. This action is aided by the presence of abrasive granules within the ferrule around the wire when the crimping operation takes place. These granules, which are hard and advantageously have sharp points, corners, or edges, apparently are forced into and penetrate the oxide film or at least cause a weakened place producing a focusing of the stresses and providing a place where a tear or break in the oxide film can occur readily. The presence of a large number of such particles insures that the oxide will be broken into a large number of separate areas to provide the most desirable contact surface.

These granules may be electrically conductive, as when formed of particles of nickel or other metal, or they may be non-conductive, as when aluminum particles are used. In order to provide a carrier for these particles and for other purposes to be discussed later, the particles are dispersed in a water-resistant grease such as petrolatum.

A particular compound which has been found to be satisfactory is a mixture of equal parts by weight of petrolatum jelly and nickel powder having an average particle size of about that which will pass through a 300 mesh screen. These particles advantageously are pointed or sharp edged so as to achieve the desired cutting action. As noted above, particles of materials such as corundum, which is electrically non-conductive, can be used, thus indicating that the primary function of these particles is not in making linking or bridging contacts between the wire 14 and the thimble 6.

The crimping action by which the wire and ferrule are secured together must be such as to produce sufficient extrusion to obtain, by the actions described above, intimate electrical contact between the aluminum wire and the thimble and between the strands themselves, and at the same time it must not be so severe as to break or excessively

weaken the aluminum wires and produce a poor mechanical connection. It has been found that with indentation type crimps sufficient extruding action cannot be procured while maintaining adequate mechanical strength. This does not mean that individual connectors which appear to be entirely satisfactory cannot be made with indentation type crimps but that such connectors when made in large quantities result in a certain number of defective or short-lived contacts, thus rendering the connectors undesirable for commercial use. However, by using a confined crimp, a number of advantages are achieved, particularly if the crimp is such as to increase by deformation the area of contact between the wire 14 and the thimble 6. Such a crimp is shown in the perspective view of Figure 3 and the cross-sectional shape is shown in Figure 5. It will be noted that the flattening of the ferrule and wire during the crimping operation materially increases the area of contact between the thimble 6 and the wire 14.

Using a crimp of this type, it has been found possible to carry the extrusion to a point that insures that every connection will perform satisfactorily. To accomplish this, the extrusion is greater than that which gives maximum tensile ("pull-out") strength. With most connector designs, it has been considered dangerous to crimp the connection beyond the point of maximum tensile strength but a number of advantages will be shown to follow from this unusually large compression.

The curve 24 of Figure 4 shows the relative pull-out strengths of connectors with different amounts of compression applied to the connector during the crimping operation. It will be noted that with increasing reduction of the cross-sectional area, the tensile strength rises rapidly until it reaches the maximum pull-out strength at a cross-section reduction of about eighteen percent. Beyond this point, the pull-out strength decreases but at a slower rate, that is, the slope of the curve beyond the point of maximum pull-out strength is less than the slope of the curve at reductions of cross-section less than that which produces maximum pull-out strength. Even at forty percent reduction in overall cross-sectional area, adequate pull-out strength is obtained. It will be clear that by crimping the terminal beyond the point of maximum pull-out strength, connections with more uniform mechanical strength characteristics will be obtained. For example, if the connector is crimped to produce a reduction in cross-sectional area of fourteen percent, the curve 24 indicates a relative pull-out strength of six will be attained. This same pull-out strength can be attained with a reduction of about twenty-six percent. However, it will be seen that any variation in the extent of crimping, and there is likely to be considerable variation under the conditions of use in the field, causes a greater variation in pull-out strength when the connector cross-section is reduced only to the fourteen percent range.

The electrical characteristics of the connection are affected also by the extent of crimping. The shaded portion of the graph of Figure 7 indicates the relative initial resistance of the connections as a function of the reduction in overall cross-sectional area. The upper and lower limits of the shaded area represent respectively the maximum and minimum resistance measurements of a relatively large number of connectors like the one shown in Figures 1 to 3. All variations in procedure, such as manufacturing tolerances and the manner of crimping, were controlled within the closest practicable limits.

If a relative resistance of 7 (Figure 7) is taken as an acceptable minimum value of initial conductivity, it will be seen that with a reduction in overall cross-sectional area of only eleven percent, a certain proportion of the connections will be entirely satisfactory from the standpoint of electrical conductivity, but others will have such high resistance as to be completely unsatisfactory.

An increase in the extent of crimping to a reduction in cross-sectional area of about seventeen percent, causes

but little change in the resistance of the best connections, but the spread in resistance between the best and poorest of the group increases rapidly: the poorest of the connectors has higher resistance than other connectors crimped to a lesser extent. From lines 20 and 22 of Figure 4, it will be seen that below this reduction of seventeen percent, the ferrule has been extruded more than the wire, but that at greater extrusions the wire is extruded more than the ferrule.

With reductions in cross-section between about seventeen and twenty-six percent, there is little change in the spread between maximum and minimum resistance readings, but the resistance decreases steadily over this range. However, at a reduction of twenty-six percent, the conductivity of a substantial number of the connectors still is below the acceptable limit.

With greater reduction in cross section, from twenty-six to about twenty-eight percent, there is continued improvement in the resistance of the best connectors; but an even more rapid improvement occurs in the resistance of the poorest connectors so that the spread or range in conductivity between the poorest and best connectors of the group is reduced markedly. At twenty-eight percent reduction, every connector of the group shows an acceptable resistance measurement.

Continued extrusion to a reduction in cross section of thirty-six to thirty-seven percent produces further improvement in conductivity with little change in the spread between the best and the poorest of the connectors. At thirty-six percent reduction, the best connectors have substantially the theoretical conductivity; that is, the same conductivity which the structure would have if the connector and wire were formed integrally of a single piece of metal.

It will be clear that the above results and advantages are attained only if all factors influencing the quality of the connection are carefully controlled with the application of all of the principles and techniques discussed herein.

The improvement in the conductivity of the poorest connections of the group by this large extrusion is likely due at least in part to the scouring action between the wire and the thimble caused by the different rates of longitudinal extrusion. However, the stretching of the metal is also a factor as this breaks the oxide film and exposes the virgin metal. It will be clear that the relationship between the scouring action and stretching of the interfacial surfaces as a function of the cross-sectional area depends to some extent upon the initial relative areas of the ferrule and the wire. Accordingly, a more accurate measure, but one more difficult to employ as a practical matter, is the ratio in reduction in cross-sectional areas of the wire and the ferrule in the crimped portion of the connection. With most connectors using a confined crimp, the crimping operation should be continued until the wire has been reduced in cross-section at least 1.37 times as much as the ferrule; the reduction may be as great as 1.54, and the preferred operating range is 1.48 to 1.54.

In the preferred embodiment of the connector described above, the only surfaces from which the aluminum oxide needs to be removed by the extrusion process is that of the wire; accordingly the reduction in cross-section of the wire is an important consideration. It is found that with the procedures and structures specified herein, that a reduction in the cross-sectional area of the wire of 35 to 50 percent is satisfactory and the preferred operating range is 42 to 50 percent.

It is important that the good electrical contact that has been made be maintained over a long period of time. For example, the contact may be destroyed by loosening of the crimp, by corrosion, or by reformation of the oxide coating on the aluminum. It has been found important to seal the terminal to prevent the entrance of corrosive vapors or liquids and also to prevent the entrance

of air and water vapor which would accelerate corrosive galvanic action and hasten the reformation of the oxide coating.

In addition to this sealing, which will be described more fully later, the virgin metal surfaces must be maintained in pressure engagement with the inner surface of the thimble 6 so as to retain the high electrical conductivity and to impede further the formation of oxide on the aluminum surface.

However, when aluminum is maintained under pressure the aluminum tends to "creep" or cold flow so that the pressure with which the surfaces are held together is decreased.

This creep may be only a cold flow action in which the aluminum changes in shape so as to decrease the concentration of stresses or it may include a "breathing" (or oscillating) action in which the aluminum wire after it is compressed initially continues to move, shrinking away from the adjacent surfaces. This movement sets up reverse stresses which cause the wire subsequently to reverse its movement, the cycle repeating with gradually diminishing amplitudes of movement until a fairly stable equilibrium is established. The interfacial pressure, however, may have been reduced materially increasing the resistance of the connection and promoting faster formation of the oxide layer.

It has been found that the adverse effects of the creeping of the aluminum can be minimized by spreading the crimping action over a relatively large area so that the unit pressure is decreased and the area of contact surface is increased so as to reduce the current density and lessen the possibility of temperature rise as a result of a limited amount of creeping by the aluminum.

The importance of the aluminum thimble 6 may not be apparent readily as it appears to add two additional aluminum surfaces from which the oxide must be removed and to insert into the electrical circuit an additional series interfacial contact surface area. However, the benefits to the connection far outweigh these apparent disadvantages. The oxide film problem is solved in part by removing the oxide and plating the terminal with tin, and the presence of the thin aluminum thimble improves the conductivity of the connection so that the additional series contact area is not in fact a disadvantage.

The advantages of the thimble 6 are fully realized only when the crimping action is carried out to the extent recommended above. This is partly because the thimble with its closed end is used as a cylinder in which the petrolatum jelly and abrasive particles are placed and in which the pressure during the crimping operation is increased to such an extent that the abrasive jelly, which is distributed between the individual strands by the piston action when the wire is inserted in the thimble, produces weakened parting lines in the oxide film. Sufficient pressure to accomplish this is reached only during the last part of the extrusion process and then only if the thimble or ferrule is closed at one end and at the opposite end the insulation-supporting thimble is crimped tightly around the insulation 18 to prevent the jelly from being forced out around the outside of the insulation. The shape of this crimp which advantageously is similar to the crimp on the ferrule is shown in the perspective view of Figure 3 and the cross-sectional view of Figure 5.

The presence of the thimble makes substantially no change in the minimum resistance readings, that is, if the thimble is omitted, a certain number of the connectors of a group will have the low resistance readings indicated by the lower limit of the shaded area of Figure 7.

However, other connectors in the group would exhibit a marked increase in resistance in the region corresponding to an overall reduction in cross-sectional area of twenty-eight to thirty-seven percent; this is indicated by the broken line 30 in Figure 7. Thus, the spread between the best and the poorest of the group of connectors is

markedly increased, with some of the connectors having a resistance higher than the acceptable minimum.

From the foregoing, it will be clear that without the thimble it would be disadvantageous to crimp the connectors so as to reduce the cross-sectional area by more than twenty-eight percent. This was undoubtedly one factor in disguising the need for unusually large amounts of compression and in rendering misleading tests made without the presence of the sealed end thimble.

In addition, the thimble 6 provides for support of the insulation 18 adjacent the end of the ferrule 2 and prevents the concentration of forces at this point. This distribution of the stresses makes the connection more resistant to lateral or bending forces and increases its endurance when subjected to vibration tests.

Moreover, the thimble 6 which is closed at one end and at the other end is tightly compressed around the insulation, seals the region where the pressure contacts are made thereby making the entrance of air, moisture, corrosive fumes or liquids, etc., much more difficult and materially increasing the life of the connection.

This sealing is aided also by the presence of the petrolatum jelly in the connector and by the fact that during the last portion of the crimping operation the jelly is placed under high pressure and forced in each tiny internal crevice and is forced between the strands of wire 14 and back along the wire into the portion covered by the insulation thus retarding the entrance of gases or liquids into the ferrule by traveling along the interstices between the strands.

The importance of extending the crimping action to produce a reduction in cross-sectional area beyond twenty-eight percent when a closed thimble is used is indicated by Figure 8, which shows the resistance measurements made on a group of connectors which were fabricated and crimped as the ones which provided the measurements for the shaded area of the graph of Figure 7, but which were subjected to an accelerated life test in a corrosive environment. The lower limit of the shaded area of Figure 8 indicates the resulting resistance of the best connectors of the group while the upper limit indicates the resistance of the poorest connectors of the group.

It will be seen from the upper limit of the shaded area of Figure 8 that with any reduction in cross-section between eleven and thirty-seven percent, a certain number of the connectors of the group were entirely satisfactory so far as corrosion resistance is concerned. Other connections, however, showed an excessive increase in resistance as indicated by the upper limit of the shaded area.

It will be noted that when the extrusion is carried beyond twenty-eight percent reduction in cross-sectional area, the spread between the best and poorest connections, after the corrosion life test, is reduced markedly, and that the connections continue to improve with further reduction in cross-sectional area, at least to the limit of about thirty-six percent. Accordingly, it is advantageous to extend the crimping action to produce the maximum reduction in cross-sectional area. The preferred range with the confined crimp is between thirty-four and thirty-seven percent reduction in overall cross-sectional area at the center of the crimped portion.

As mentioned above, it is desirable for the ferrule 2 and the thimble 6 to be plated with a corrosion-resistant metal. Tin plating has been found to be most advantageous. If the ferrule 2 is formed of copper, it can be tin-plated readily in the usual manner. The aluminum thimble 6 (and the ferrule 2 if it is formed of aluminum) can be plated with any of the known methods so long as an adherent tin coat is obtained. Many different methods of plating aluminum are known, see, for example, U. S. Patent No. 1,147,718 to Hall (1915) or the plating procedures reviewed in the July 1952 issue of *Plating* beginning on page 755.

In a preferred process, the aluminum is etched with a mixture of three parts concentrated nitric acid to one

part concentrated hydrofluoric acid for about one minute to remove the oxide coating. The aluminum is then washed and given a flash coating of zinc by dipping it in a zincate solution comprising one part zinc oxide, six parts sodium hydroxide and twelve parts water by weight, after which it is washed, flash coated with copper in a bath of one part sodium carbonate, one and one-half parts copper and two and one-quarter parts sodium cyanide, rinsed again, and electroplated with tin in the usual manner.

After the tin plating has been applied, it is caused to reflow by heating the plated article to a sufficiently high temperature to melt the tin and, if desired, subjecting it to mechanical agitation or vibration while it is at this temperature. This reflowing of tin is conventional practice and the techniques and apparatus for accomplishing it are well known. However, it has been found advantageous after the tin has been reflowed, to electroplate an additional layer of tin on the surface of the tin that has been reflowed.

Reflowing of the tin tends to seal pin holes and to distribute the tin better over or around minute imperfections. The exact effects of the subsequent tin electroplating are not known but measurements indicate an improvement in the conductivity of connections, that is the upper limit of resistance is decreased thus reducing the spread in quality between the best and poorest connections.

The tin plating can be applied also by rolling process to the flat sheet from which the connector is formed. Thus, by forming the connectors from commercial tin-clad aluminum, the necessity for a separate plating operation may be avoided. This effect is particularly important when the crimping is carried beyond a cross-sectional reduction in area of twenty-eight percent.

In a preferred embodiment of the present invention, the connector shown in Figures 1 to 3 was formed of aluminum. The tongue 4 and ferrule portion 2 were formed of 3S grade aluminum and the thimble was drawn from a thin sheet of 2S grade aluminum.

The ferrule 2 and the thimble 6 were plated with zinc followed by tin which was reflowed and replated, all as described above.

For use with stranded aluminum wire having a cross-sectional area of 0.033 square inches, the ferrule 2 had a cross-sectional area of 0.0844 square inches before crimping.

The thimble 6 was filled about half full of jelly such as a mixture of petrolatum and nickel powder. Other grease or jelly compounds, such as silicone grease, cup grease, waxes, resins, etc., can be used with any desired kind of abrasive particles but the mixture of Vaseline and nickel powder has been found entirely suitable. In practice the jelly is placed in the thimble which is sealed with a cellulose cap 32, as shown in Figure 10, for convenience in shipping and handling.

The cap 32 is removed or punctured by the bared wire 14 of the cable 16 which is inserted into the smaller portion 8 of the thimble 6 and extends substantially to the end 10 thereof. When cap 32 is punctured to permit insertion of the wire end, this cap remains as an element of the finished connection, as shown in Figure 3. If the cap is removed, the finished crimped connection does not include a cap as an element thereof but presents the appearance of Figure 9. The insulation covering 18 extends within and substantially to the end of the enlarged portion 12 of the thimble.

The smaller portion 8 of the thimble is about the same length as the ferrule 2 so that when it is inserted into the ferrule 2 the closed end 10 is at one end of the ferrule and the insulation-supporting sleeve 12 is adjacent the other end.

The wire and connector assembly is then placed in a suitable crimping die, such as that described by Holtzapple in application Serial No. 73,946, filed February 1,

1949. This die should crimp both the ferrule and the insulation supporting sleeve and the crimps should be of the confined type and advantageously have the general shape indicated in Figures 3, 5, 7, and 9.

The ferrule 2 and insulation support 12 can be crimped simultaneously so long as the insulation support 12 is firmly sealed around the insulation before the final crimping movement of the ferrule. If desired the support 12 can be crimped first and the ferrule 2 crimped subsequently.

The crimping is continued until by extrusion the cross-sectional area has been reduced from thirty-four to thirty-seven percent within the area of the crimp, that is, the difference in the total cross-sectional area of the wire and ferrule before and after crimping divided by the total area before crimping and expressed as a percentage. This reduction may be from twenty-eight to thirty-seven percent, but the preferred range, for reasons already pointed out is between thirty-four and thirty-seven percent.

If desired, the ferrule 2 can be formed of copper. The copper should be tin plated in the usual manner and the remaining procedure is the same as with the aluminum ferrule.

From the foregoing, it will be apparent that the connector described herein is well suited for making electrical and mechanical connection to aluminum wire and that it takes full advantage of the inter-relationship between the different parts of the connector and with respect to the series of steps forming the final electrical connection, the principles of the invention being set forth so that the connector can be fabricated and applied readily and so that it can be modified as necessary for adaptation to each particular use.

What is claimed is:

1. An electrical connection comprising a cable having a multi-strand aluminum wire core and an outer sheath of pliable insulating material, a bared portion of the aluminum core extending beyond the end of the insulation, a connector having a tubular ferrule portion, a thin-walled aluminum cup having an open end and an enlarged portion adjacent thereto, an inhibitor jelly including dispersed abrasive particles therein, said jelly being within said cup, said connection being assembled with the enlarged end of the cup extending over the insulating sheath of the wire and the remainder of the cup around the bared wire with the ends of the wire near the closed end of the cup, the ferrule portion of the connector extending over the smaller portion of the cup and being crimped therearound in a confined crimp, the combined cross-sectional area of the connection including the ferrule and wire, in the crimped region, being between thirty-three and thirty-seven percent less than when in its assembled relation before crimping, the wire having a cross-sectional area in the crimped region at least thirty-five percent less than in adjacent uncrimped portions, and the enlarged portion of the cup being compressed tightly around the insulation sheath and in substantially water-tight engagement therewith, said jelly being distributed throughout the interior of said cup and filling every interstice therein between adjacent strands of the core and between the core and the cup.

2. A connection as claimed in claim 1 wherein said ferrule is formed of aluminum and both said ferrule and at least the outer surface of said cup are plated with tin.

3. A connection as claimed in claim 1 wherein said ferrule is formed of aluminum and both said ferrule and at least the outer surface of said cup have an outer coating of tin and a coating of zinc intermediate the aluminum and the tin.

4. An electrical connection comprising a cable having an outer sheath of pliable insulating material and an inner core of aluminum wire which extends beyond the end of the insulation, a connector having a tubular ferrule portion, an aluminum thimble having an open-ended tubular insulation-supporting portion and a tubular body

portion of smaller diameter formed integrally therewith, the body portion having a closed end opposite the insulation-supporting portion, said connection being assembled with the insulation-supporting portion of the thimble extending over and being compressed tightly around the sheath of said cable and the body portion of the thimble covering the bared portion of the core, the ferrule portion of the connector extending over the body portion of the thimble with one portion thereof compressed substantially completely around the periphery thereof, the cross-sectional area of the connection, including the ferrule and cable core, in the said crimped portion being between twenty-eight and thirty-seven percent less than when in its assembled relation before crimping, the reduction in cross section being greater than that reduction in cross-section which would provide the maximum pull-out strength, and inhibitor jelly having abrasive particles dispersed therein filling every interstice within said crimped portion of the connector.

5. An electrical connection as claimed in claim 4 wherein said ferrule is aluminum having an outer coating of tin thereon.

6. An electrical connection as claimed in claim 5 wherein said ferrule is formed of copper and both said thimble and said ferrule have an outer coating of tin.

7. An electrical connection comprising a cable having an outer sheath of pliable insulation and an inner core of aluminum wire extending beyond the end of the insulation, a connector having a tubular ferrule portion, an aluminum thimble having an open-ended tubular insulation-supporting portion and a tubular body portion of smaller diameter formed integrally therewith, the body portion having a closed end opposite the insulation-supporting portion, said connection being assembled with the insulation-supporting portion of the thimble extending over and being compressed tightly around the sheath of said cable and the body portion of the thimble covering the bared portion of the core, the ferrule portion of the connector extending over the body portion of the thimble with one portion thereof compressed uniformly around the periphery, the ratio in the percentage reduction of the cross-sectional area of said wire in said crimped portion to the percentage reduction of the cross-sectional area of said ferrule at the same point being between 1.37 and 1.54, and a viscous water-resistant material filling every interstice within said thimble.

8. An electrical connection comprising an aluminum wire, and a connector having a tubular ferrule, said connection being assembled with the ferrule of the connector extending over the aluminum wire and being compressed therearound, the compression extending substantially completely around the periphery of the ferrule, the cross-sectional area of the connection, including the ferrule and wire, in the crimped region being between

thirty-three and thirty-seven percent less than when in its assembled relation before crimping, the wire having a cross-sectional area in the crimped region at least thirty-five percent less than in adjacent uncrimped portions.

9. An electrical connection comprising an aluminum wire and a connector having a tubular ferrule, said connection being assembled with the ferrule of the connector extending over the aluminum wire and being compressed therearound, the compression extending substantially completely around the periphery of the ferrule, the cross-sectional area of the connection, including the ferrule and wire, in said crimped portion being between twenty-eight and thirty-seven percent less than when in its assembled position before crimping.

10. The method of making a connection to an aluminum wire cable having an outer sheath of insulating material and a central core of aluminum wire extending beyond the end of the insulation comprising the steps of forming a tubular metal ferrule, forming an aluminum thimble having a body portion and an insulation-supporting portion, placing an inhibitor with abrasive particles therein inside said thimble, placing the body portion of said thimble over the bared portion of said wire with the insulation-supporting portion extending around the end portion of the insulation, placing said ferrule around said body portion, compressing said insulation-supporting portion of said thimble around said insulation sheath by the application of compressive force substantially around the periphery of said insulation-supporting portion, and compressing said ferrule and said thimble onto said wire by the application of uniform pressure substantially around the periphery of said ferrule, said compression of the ferrule being continued until within the crimped region the cross-sectional area of the connection, including the wire and the ferrule, has been reduced by at least twenty-eight percent, the insulation-supporting portion of the thimble being compressed into substantially water-tight engagement with said sheath before completion of the compression of said ferrule.

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