1974

Crimp Type Winding Connections in Hermetic Motors

G. W. Klein
General Electric Company

CRIMP TYPE WINDING CONNECTIONS IN HERMETIC MOTORS

G. W. Klein, Product Design Engineer
General Electric Company, Hermetic Motor Products Department
Holland, Michigan

ABSTRACT

Hermetic motors with all copper conductors have, for many years, been reliably connected by means of a fusion-braze method. The introduction of aluminum magnet wires and the development of machine operations to replace operator controlled hand operations have demanded a new, reliable method for making the connections.

Early evaluations of the several possible methods of connecting led us to study the crimp type mechanical connector in depth. Individual designs of connectors were tested, evaluated, and improved to provide the best possible connection consistent with cost, ease of application, and reliability.

This paper describes the development of tests used to evaluate connections, results of reliability testing, design developments of connectors, and design developments of the crimp designs.

INTRODUCTION

Reliability is the name-of-the-game for hermetic motors. In addition to providing the necessary mechanical power for the compressor, trouble free, long life operation is required. Many years of production of hermetic motors wound with copper wire provided the standard of quality and reliability that would be demanded of the change to motors with aluminum windings.

SELECTION OF METHOD

In addition to the quality and reliability of connections there are the requirements of competitive cost, adaptability to the variations in the many connections, and adaptability to production methods. In hermetic motor applications the galvanic corrosion effects can be neglected because of the dry atmosphere in which the motor operates. Of the several basic methods available for connecting wires of aluminum to aluminum and aluminum to copper, the machine applied crimp type connector was selected.

ELECTRICAL CONNECTION

A connection intended to be a part of the conducting path of electric current must have sufficient area of contact and low enough contact resistance to avoid unacceptable temperature rise. Some metals have low surface to surface resistance whether they are pure metal or oxidized metal. Some metals have low surface to surface resistance as a pure metal but have high resistance when oxidized. Of the common materials used as electrical conductors, copper represents the first condition and aluminum the second one.

Good crimp type connections can be made to bare copper conductors using any of several designs of connectors. Little, if any, effect will be found on contact resistance due to expansion and contraction with temperature changes or due to creep. The connectors must be made of materials having a coefficient of expansion similar to that of the copper conductors.

Good crimp type connections can be made to bare aluminum conductors providing a fresh clean contact surface is obtained and contact pressure is maintained. Loss of contact pressure increases the contact resistance due to less contact area and the immediate build-up of high resistance oxide surfaces.

Insulated magnet wire can be connected without prior stripping off of the enamel if a means is provided to obtain clean, bare conductors in pressure contact with the connector. A means is also necessary to prevent loss of contact due to differential expansion rates and creep.

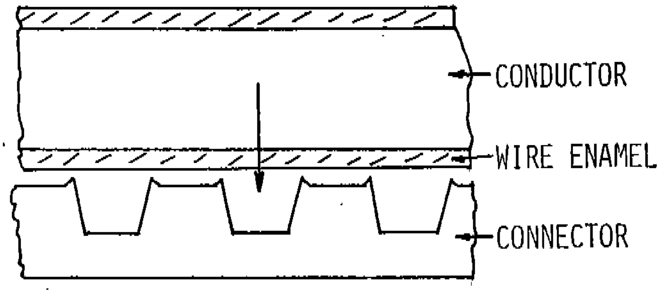
A common method used to obtain a fresh, clean contact surface on the bare or insulated magnet wire conductor is by forcing the conductor to extrude into slots formed in the connector.

Sharp edges at the top of the slots pierce the enamel insulation and oxide as the conductor begins to extrude into the slots. As the conductor continues to be extruded fully into the slot, fresh, clean metal is exposed and placed in pressure contact with the sides of the slots. Figures 1 and 2 illustrate this.

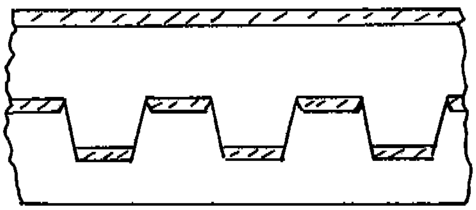
To overcome the adverse effects of differential expansion and creep, multiple slots are provided and the connector is crimped tight enough to maintain adequate contact pressure.

EVALUATION TESTING

The evaluation of new or modified connectors or new or modified crimp tools involves any or all of four tests:



MAGNET WIRE & CONNECTOR
BEFORE CRIMP
FIG. 1



AFTER CRIMP
FIG. 2

1. Visual examination of the connection both externally and by sections through the connection
2. Tensile test of individual wires from the connector
3. Millivolt drop test
4. Life test

As nearly as possible, all tests are designed to be functional to the end use of the motor. One or more of the tests covers each of several critical environmental and operating conditions to which the connection is subjected. These include: time; temperature; electric power; physical strength; and kind of atmosphere. Each of the listed tests are described in the following discussion.

Visual Examination

A number of decisions can be made based on visual examinations. New crimping tools may be found to be poorly designed if excessive deformation of the wires is found at the exit from the connection. Minimum damage to the wires would warrant further testing of that design.

Sections taken through different locations and directions in the connector will reveal to what extent the wire is extruded into the slots and whether or not good electrical contact is obtained. The shape of the crimp can be evaluated in relation to the condition of the wires. Figure 3 shows an idealized connection.

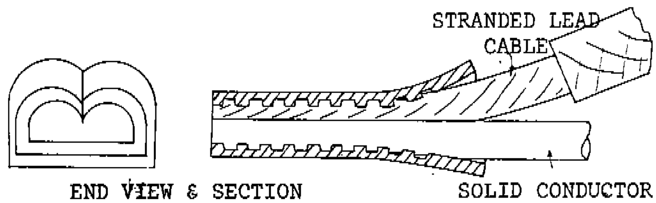


FIG. 3

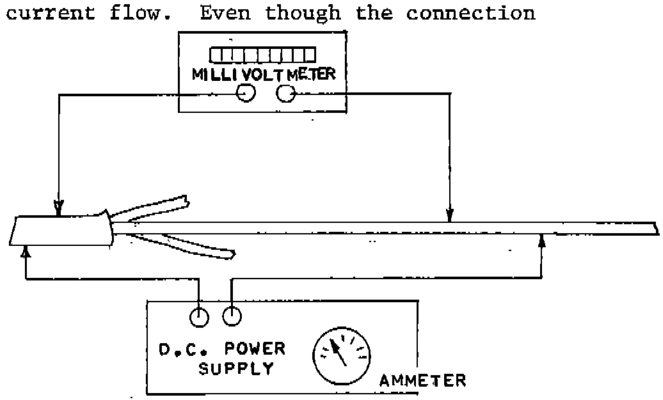
Tensile Test

Each wire is pulled in an axial direction from the connector. This, in addition to the visual test, helps to determine the effect of crimp height, shape of crimping tools, and position of connector relative to the crimping tools. With proper crimp design, the strength of the connected wire at the connection will be very nearly as high as the wire away from the connection. The Figure 3 illustrates the use of the last two slots as strain relief each having reduced penetration of the conductor into the connector slots.

The strength of the wire is reduced in proportion to the reduction in cross section area unless it is mechanically held at the flared end of the connector. Operations required in the finishing of stators produce bending and tensile stresses in the wires. These stresses may be resisted successfully with a good design, properly manufactured.

Millivolt Drop Test

A common method of measuring the electrical quality of a connection is by means of a millivolt drop test. As shown in Figure 4, in addition to the actual connection resistance, the resistance in the connector and in the wire are added together to give a total resistance to the current flow. Even though the connection



MILLIVOLT DROP TEST

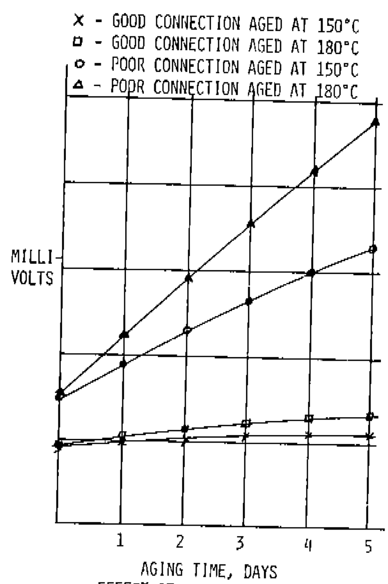
FIG. 4

resistance is a relatively small part of the total, it is the most variable and variations in connection quality can be detected.

It is important to specify a number of details in this test in order to minimize test error. For a given type or size of connector the location of the pick-up points for the MV meter should be closely controlled. A small shift in position will significantly change the value measured. The distance between the pick-up points must be held to a close tolerance for the same reason. The current value from the D.C. supply must be held to a close tolerance also. The MV value will vary in proportion to the current value.

One of the problems in making connections is to avoid uncontrolled variations which result in poor connections. A poor connection is one whose millivolt drop measurement is greater than normal and/or whose millivolt drop will increase significantly due to aging. A good design with controlled set-up and correct positioning of the wires will give millivolt drop test data, for a given wire size, conforming to a normal distribution with a standard deviation of about 2%.

Sample connections tested after aging will have a slightly higher average millivolt drop value. The severity of the aging will determine the amount of increase. Connections with higher than normal values of millivolt drop will have a much greater increase due to aging. Aging is usually done at an elevated temperature (150°C to 180°C) for 3 to 4 days. Figure 5 illustrates the effect of time and aging temperature on MV drop.



EFFECT OF AGING ON MV DROP
FIG. 5

Life Test

Life tests were designed to verify the results of the previous tests, on a larger scale. Incorporated into these tests are: temperature cycling; peak temperatures above normal or expected excursions in compressor applications; extended periods of time; a large number of connections; monitoring of actual temperatures and resistances; variables of construction (crimp height, connector design, crimp shape, etc.)

A typical life test cycle is shown in Figure 6.

LIFE TEST
TYPICAL TIME VS. TEMP. CYCLE

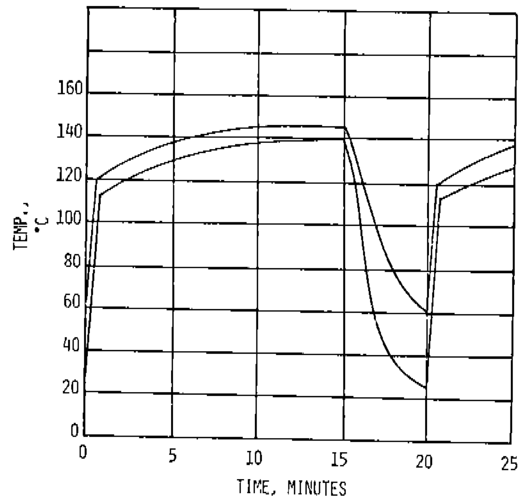


FIG. 6

The time cycle repeats every 20 minutes. The rapid initial temperature rise is accomplished by passing current through the wires at a rate of about 16 000 amperes per square inch for aluminum and 26 000 for copper wires. When the desired temperature is reached, power is switched to a value that, with assistance from heaters in the test chamber, will hold the temperature for fifteen minutes. Then a five minute forced air cooling brings the wires and connections to the starting condition again. The temperatures plotted are connector temperatures as monitored by thermocouples. The wire temperatures are somewhat higher.

In order to run such a life test, a series of connections are made up into "chains." There may be 15 to 24 connections in a chain and as many chains as desired. Where variables are included in the test (such as crimp height), the total number of connections must be sufficient to be able to make a reliable comparison between the differences being tested. Total number of connections used so far, per life test, has run from 800 to 2 000. The number of variables ranged from two to six. The chains are placed in a test chamber where the ambient temperature can be controlled by auxiliary heaters and forced cooling. Some tests have been made in pressure vessels using a refrigerant atmosphere and others in oven-like chambers with air atmosphere. Changes in the connection quality are monitored by visual observation and chain resistance measurements at weekly or other intervals. The total life test may run up to four months or more. In order to determine life capability of a design, the peak temperature at the start of the test may be only 100°C and then increase in increments of 10°C at intervals of about two weeks. The low starting temperature allows one to determine whether or not a gross weakness is present in the parts to be tested. As the temperature is increased, the tendency to failure increases rapidly. This procedure also permits the determination of maximum temperature capability.

PROCESS CONTROL

The manufacturing process is monitored by means of visual, tensile, and millivolt drop tests as outlined above. In addition, crimp height measurements, incoming inspection of connectors, and tool checks on all crimping tools are used to assure high quality connections.

PRODUCT DEVELOPMENT

As indicated earlier in this paper, it is necessary to have not only an initial good connection but the connection must remain good through the expected life of the product. The actions affecting the quality of a connection as it performs its function in a hermetic motor are:

1. Crimping operation
2. Winding forming forces
3. Expansion and contraction due to temperature changes
4. Creep

Crimping Operation

Details of the connector and crimp design are discussed above. The actual crimping operation is very important and several controls are necessary. These include capability of holding the crimp height within the specified tolerance, hold feed position closely, and maintain tools in the proper condition.

Additional controls are necessary to make sure each individual wire is making good electrical contact in the finished connection. The way the wires are positioned just prior to the crimping action and the way the wires react to the motions involved in the crimping operation affect the final product. Fixturing may be used to hold the several wires in a predetermined position and control their movement during the crimping action.

The variety of wire sizes and types of connections must be a strong consideration in developing the connector and the operation of making the connection. All of the motors we make for refrigerator, freezer, window air conditioner, and other applications except some central air conditioner and commercial applications are single phase. The range of wire sizes is quite large: #30 to about #18 AWG for the start winding; #22 to about #15 AWG for the run winding; and #18 to #10 AWG fine stranded lead cable. Combinations of small size start winding wire, large size run winding wire, parallel poles or multi-stranding, and the fine strands of lead cable make it important to assure optimum positioning of each wire. One wire in a parallel circuit making a poor contact in a connection can cause a redistribution of current between the wires, overloading some, or a source of excessive heating at a connection.

Strength Of The Connector

The type of material, thickness of material, and shape of the crimped connection all affect the strength of the connection. If a good connection is made initially and then the connector relaxes deterioration of the connection takes place. Contact pressure must be maintained in order to preserve the low contact resistance desired. Crimp shapes have been developed which, with the other connector properties have been used successfully for many years.

Expansion And Contractions Due To Temperature Changes

Closely related to strength is the effect of temperature variations on the maintenance of good contact between the wires and the connector. The initial crimping operation stresses both the wires and the connectors. If additional stresses due to expansion and contraction with temperature changes cause relaxing or separation of the parts, deterioration takes place. The strength of the connector, crimp shape and crimp height values have been determined which minimize the effects to a negligible degree.

Creep

Creep is defined as "time-dependent strain occurring under stress." The strain produced by the stress imposed on aluminum wire can be restrained by the design of the connector. Multiple serrations or perforations plus sufficient strength of the connector accomplish this.

RELIABILITY

The cost of in-warranty failures and the customer inconvenience due to any failure make it imperative to produce a reliable product. Cost of manufacture is, of course, a major consideration for the producer of the motor. The hermetic compressor application is quite different from most any other. The sealed system containing many components with the flow of refrigerant and oil through the system, the many hours of operation per year, and the tendency toward higher operating temperatures have been considerations in our development program and the manufacturing processes.

DEVELOPMENT OF THE CONNECTOR

A number of variations of connectors have been listed in catalogs. Several were selected for test and production evaluation. Initial trials showed the need for improvements in machine capability to hold crimp heights and feed positions accurately. This has been accomplished by minor modifications of equipment and the development of new crimping machines by the several suppliers.

The "insulation piercing" connectors are capable of making electrical contact from the connector to the enamel insulated magnet wire. Figures 1 and 2 illustrated this. As accelerated life test results were obtained it became evident that very close control was required to be sure the crimp heights and shapes and position of the wires in the connections were all held to close tolerances. It also became evident that the connections would pass all of the tests with wider tolerances if the wires were all stripped prior to connecting. The extra cost of wire stripping was acceptable as an interim requirement while further development studies were conducted.

Insulation piercing connectors used in most of our tests had transverse serrations machined into the connector stock before forming into a "U" shape. Connectors of this type were available with five or seven serrations. The seven serration connector was selected and intensively tested under many conditions of crimp height, crimp shape, size and number of wires, wire conductor hardness, and types of enamel. Tolerances were established for the several variables and life tests were conducted. The design proved to be satisfactory when all wires were stripped. No failures were ever found when the wires were stripped prior to connecting. Life test cycles of Figure 6 were used with connections to unstripped aluminum wires. The peak temperature values, after starting at 100°C peak, reached between 130°C and 140°C when failures began to occur. When the peak temperatures were reduced by about 10°C the continuing life test produced no more failures.

The demonstrated capability of this design was not considered satisfactory for use with unstripped aluminum wires. Normal operating temperatures are considerably below the temperature causing failure in this experiment. However, some temperature excursions do occur and a greater capability was desired in order to anticipate higher operating temperatures which might become common in the future.

Analysis of sample connections as well as a study of the mechanics of these connections led us to believe that an increase in the number of serrations would be beneficial. At the same time some minor modifications of shape were studied to improve several manufacturing problems. An increase was made in the number of serrations from seven to nine. The several tests outlined under Evaluation Testing above were used to evaluate the revision. All tests showed an improvement over the seven serration connector. With unstripped aluminum wires no life test failures were found at extended periods of time with peak temperatures of 175°C to 180°C, which was the highest obtainable in existing test equipment.

This new higher temperature capability is very significant to improved reliability. It should be noted that the previous discussion on Process Control is important to the product so that there is not only the capability of making a reliable product but that the day-in and day-out production is maintained at a high quality level.

It is significant that the Hermetic Motor Products Department of the General Electric Company began to use mechanical connecting of magnet wires over ten years ago. At first, and for some time, the production rate was very low. As the development program progressed and production experience was gained the production rates were increased. There are now several million stators in use having mechanical connections. At first these were made with the seven serration design and all wires were pre-stripped. Later the nine serration design was placed in production use with most of the connections made without prior stripping of the aluminum wires. There is no evidence that these are not of the same high reliability as the many millions of copper wound motors produced over many years.

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