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DEVELOPMENT OF A CRIMP CONNECTOR FOR TRAILING CABLE SPLICES

Prepared for
UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF MINES

by BURNDY CORPORATION
Norwalk, Connecticut 06856

FINAL REPORT

on DEVELOPMENT OF A CRIMP CONNECTOR FOR
TRAILING CABLE SPLICES

Contract No. H0357100

December 1976

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A brief discussion on splice problems is presented as an introductory means and substantiates the need for the development and test programs outlined in this report.

Because of the empirical nature of this effort, time has been devoted to explaining the derivations of the test procedures used. Special attention is given to the splice flexing machine which served as the backbone of the test program.

In order to familiarize persons with connector terminology, a section is devoted to a glossary of pertinent terms. Various types of cable joints are also defined.

The major effort is a connector design parameter study. Utilizing the optimum parameters developed along with the suggested design procedure outlined in Appendix I should result in significantly improved splice performance and thus meet the objectives of this contract.

A field test program was instituted for the purpose of insuring adaptability of connector design and associated installation tooling along with a field performance study.

During the course of work, other significant factors affecting splice performance were uncovered. Although not covered by the scope of this contract, a brief discussion is presented for the purpose of stimulating interest in what is considered other fruitful areas for improved splice performance.

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This report is a summary of the work recently completed as part of this contract during the period June 1975 to December 1976. This report was submitted by the author on December 1976.

Written By Walter J. Frank, Jr.
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Approved By Edward S. Raila
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ABSTRACT

The purpose of the work covered by this contract is to develop a means of designing splice connectors which will significantly improve mine trailing cable splice performance.

A brief discussion on splice problems is presented as an introductory means and substantiates the need for the development and test programs outlined in this report.

Because of the empirical nature of this effort, time has been devoted to explaining the derivations of the test procedures used. Special attention is given to the splice flexing machine which served as the backbone of the test program.

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SECTION I

INTRODUCTION

Present underground coal mining machines receive their power via portable cables known as "trailing cables". These cables connect vehicles such as shuttle cars, to the electrical load centers. Use of this equipment results in a constant paying out and rewinding of the cable via spooling and sheave devices. This results in a continuous flexing, pulling and abrasion action on the cable. In addition, poor lighting, restricted space and other mobile equipment constantly running over the cables, results in an aggregate of operational and environmental conditions, causing frequent cable damage.

Repairing is accomplished by either splicing the damaged cable or replacing the entire trailing cable. Splicing is done most of the time since the resulting down time is usually less than when replacing the entire cable. However, this economic advantage may be significantly reduced because subsequent failures usually occur more frequently at the previously spliced joints.

Improvement in the splice connecting means would obviously increase splice longevity, lessen down time and enhance mine safety.

This report is the result of such an effort which was authorized by Bureau of Mines Contract H0357100 for the development of optimum crimp connector parameters for trailing cable splices.

The scope of this project was limited to only the power connector portion of the splice assembly. The ground connector is not included. Also, it is recognized and should be noted that insulation components, as well as installation procedures, also affect splice longevity and may prove to be fruitful areas for future studies.

SECTION II

DEVELOPMENT OF A TEST PROCEDURE

As a first step, a test means to evaluate existing splice methods, as well as new splice methods, had to be selected.

Since we were directing our attention to the mechanical performance of the splice connector, testing incorporating flexing of conductor and splice, as well as conductor pull out, was felt to fairly represent "in mine" trailing cable conditions. Test procedures outlined in USBM Grant No. GO-133077 entitled "Mine Electrical Systems Evaluation - Cable Splicing" formed the basis of our flex and pullout procedures.

"FLEX TEST"

In order to test splice flexibility, a machine was constructed to simulate shuttle car sheave wheel bending effects, as well as cable reel tension. This machine is shown in Figure 1. For a detailed discussion on the flex machine development and operation, refer to Grant GO-133077. The basic difference between the flex machine built for this contract and the design discussed in GO-133077 is as follows:

1. Sheave wheels are mounted vertically instead of horizontally.
2. A total of 8 test stations are available instead of one.

Other features of the test machine (Figure 1) are:

1. Pneumatic operation
2. Adjustable cycle time
3. Electronic cycle counting
4. Sustained cable tension via a weight and pully system.

The sheaves are 10" in diameter and simulate those used on shuttle cars. The heart of the machine is a double acting air cable cylinder. Pneumatic pressure applied to one side of a piston moves it within the cylinder, pulling a cable around a pulley which imparts the desired for and aft motion to the driven mechanism. Use of this device eliminates the need for the usual long projecting rod of a pneumatic cylinder, thus making a more compact system.

Figure 2 shows the significant components and overall dimension of the flex machine shown in Figure 1.

A cycle time of 10 seconds was selected and adhered to on all testing; that is, the time for the sheaves to complete one trip for and aft. #4 and #2 size cables were tensioned to 175 pounds as listed in Table 63 USBM Grant No. GO-133077. Most of the splice development work was done on single core conductors with a test weight of 100 pounds. This figure was derived by dividing the 175 pound figure (for 2 core conductor) by two and adding a small safety factor by rounding up to 100 pounds.

FLEX MACHINE

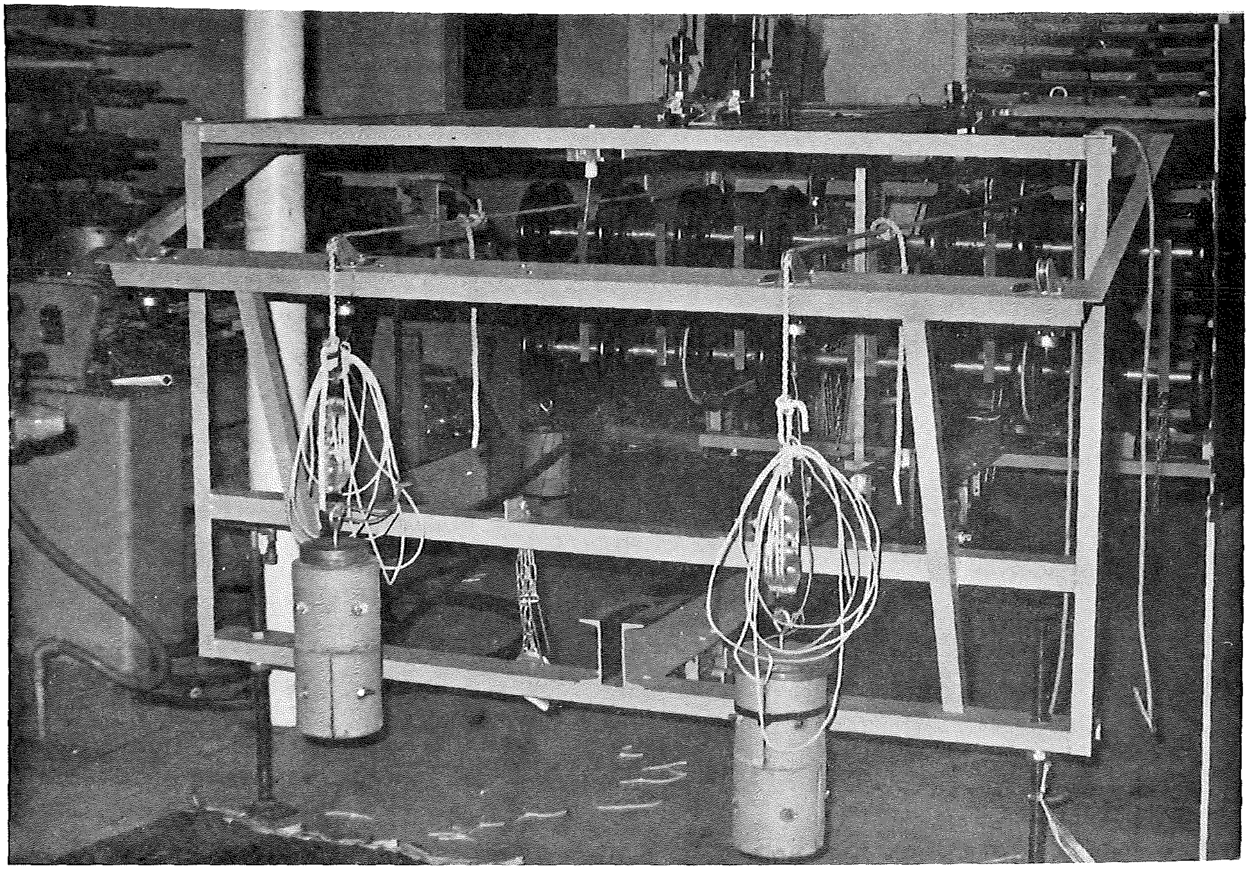


FIGURE 1

FLEX MACHINE

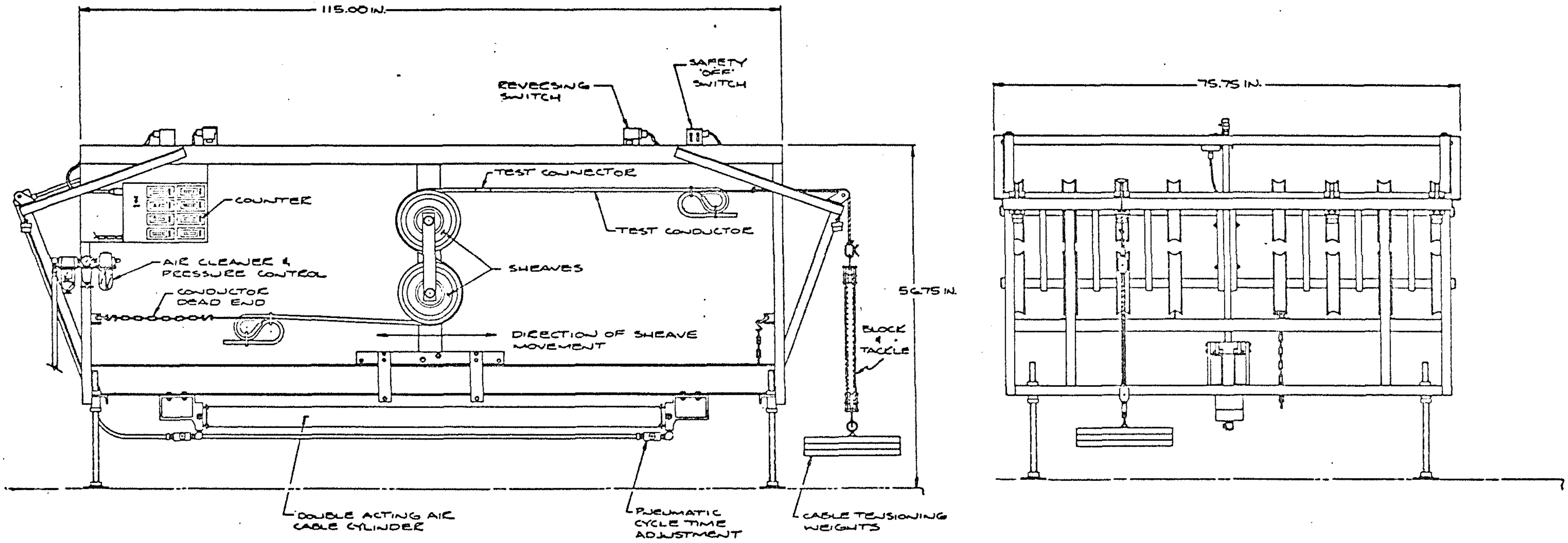


FIGURE 2

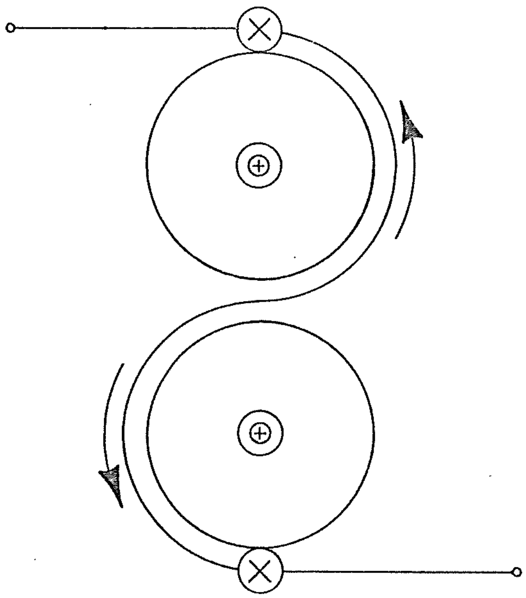
A connector flex life target of 1500 cycles was adopted. This figure was also extracted from Table 63 (GO-133077). Although the 1500 requirement is intended for a completely insulated splice, it was felt it could be conservatively adopted for single core conductor and connector testing. It should be noted that one cycle represents two complete passes through the sheaves which includes two 180° bends one way and two 180° bends the other way for a total of four 180° bends (see Figure 3).

The majority of tests were run with the test connector passing completely through both sheaves. However, it should be noted that at the time of this writing there is a proposed MESA spec. on flex life cycles which tests the splice so that two 180° bends occur per cycle (see Figure 4). This represents one-half the number of bends when compared to passing the test specimen completely through the sheaves. As a result of this the flex cycle test results listed in this report have been converted so they represent the proposed MESA method. Actual tests have verified the 2:1 ratio of flex life between the two test methods.

PULLOUT

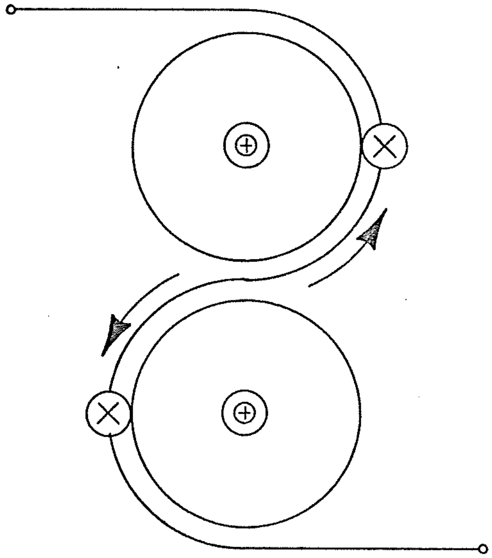
All pullout testing was done on a Baldwin 120,000 pound Universal Test Machine shown in Figure 5. A typical test specimen is shown in Figure 6. A pull rate of 1/2" per min. was used throughout. Test jumpers were 30" min. overall length in order to insure

FLEX BENDING SEQUENCE



X = Connector Stop Location

FIGURE 3



X = Connector Stop Location

FIGURE 4

conductor interstrand load equalization. Both jumper ends were terminated in a method to provide positive gripping and equal conductor strand loading.

Tensile strength requirements were extracted from Page 4 of this contract and Table #62 USBM Grant No. GO-133077 (650 pounds min. for #4 size and 950 pounds min. for #2 size).

RELATIVE RESISTANCE AND HEAT RUN

Although the main consideration for splice connector improvement was based on mechanical performance, the electrical characteristics were also determined. These tests included relative resistance and a heat run and were conducted on connector designs representing the optimum design parameters.

Relative resistance is computed by taking a resistance measurement of a test jumper incorporating the connector. This value becomes relative resistance when the test jumper resistance is compared with that resistance from an equal length of conductor without the connector. Relative resistance readings of 100% or less are considered acceptable and mean that a length of conductor incorporating the connector has an equal or lower resistance than an equivalent length of conductor without the connector.

TENSILE TEST MACHINE

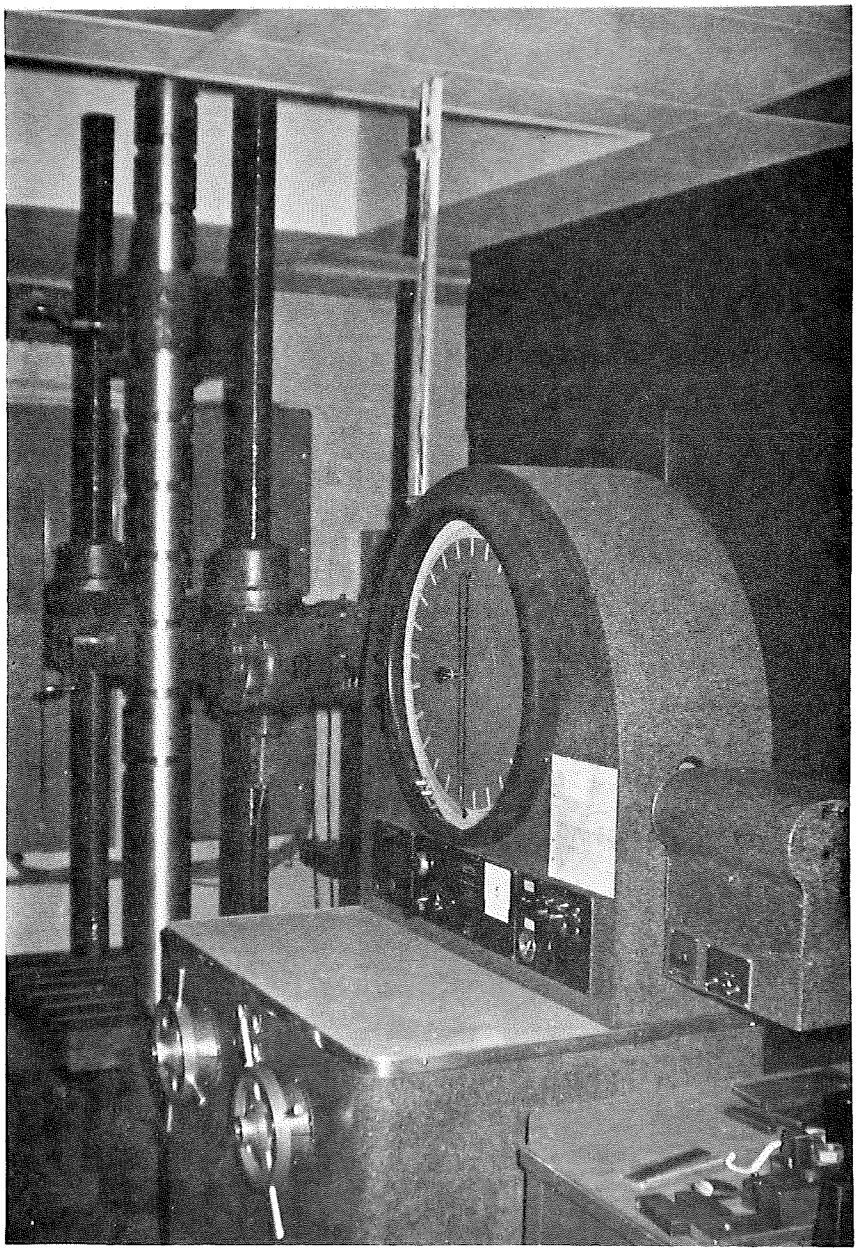


FIGURE 5

TENSILE TEST SPECIMEN

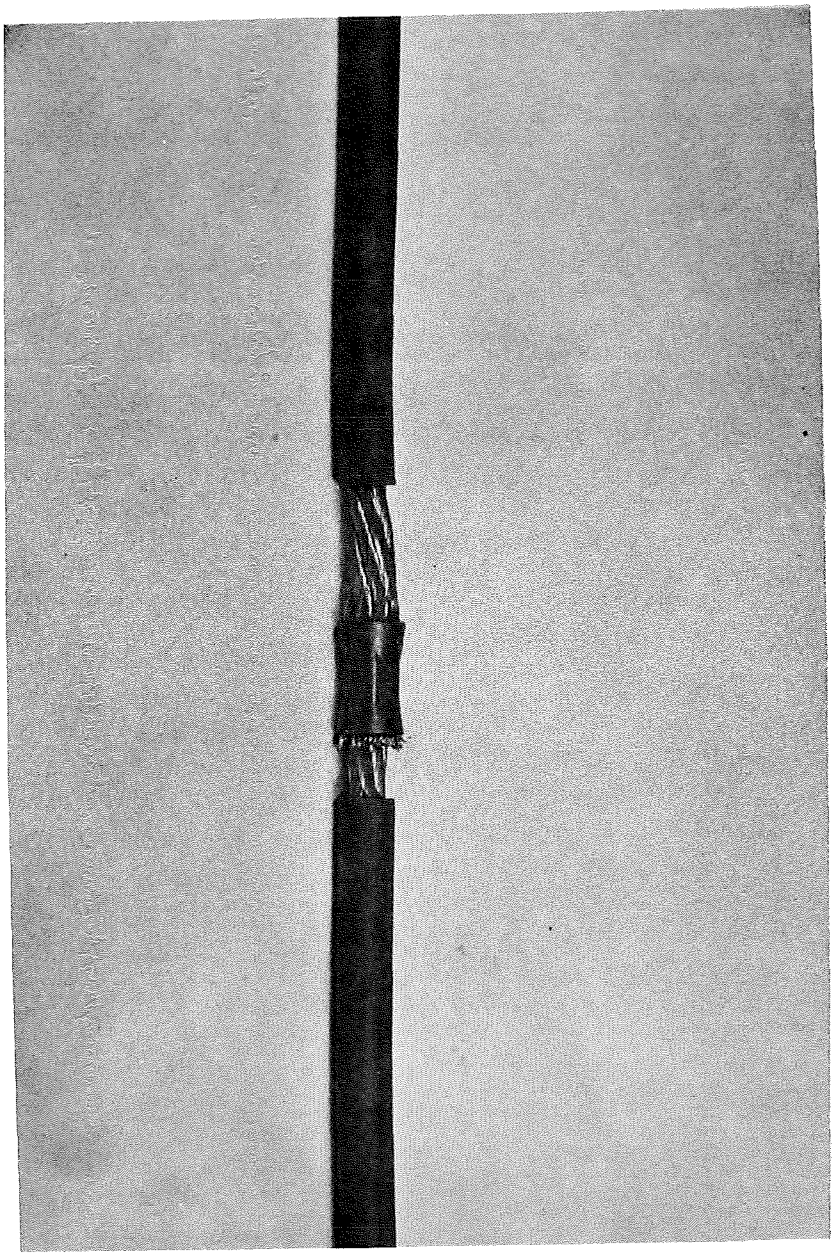


FIGURE 6

The heat run test compares the temperature created by a test current and connector resistance (I^2R) with that of a control conductor without a connector. The connector and control conductor are tested in a series loop for a period of time necessary to obtain temperature stabilization. The test currents selected for this test were those necessary to create total temperatures of 60°C, 75°C and 90°C on the control conductor. These temperatures are measured on the cable strands (not on insulation) and test connector by use of thermocouples. The test temperature levels mentioned represent various conductor ratings based on conductor insulation types.

For a connector to pass the heat run test, it must run at least equal to or cooler than the control conductor. Figure 7 shows a typical heat run set up.

HEAT RUN TEST

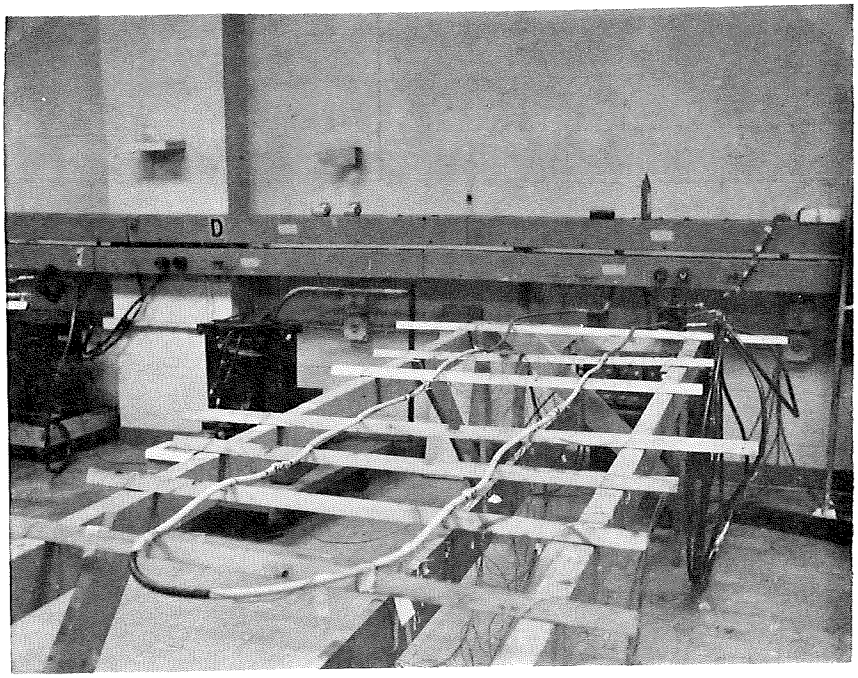


FIGURE 7

SECTION III

PERTINENT CONNECTOR DESIGN TERMINOLOGY

In order to eliminate the need for terminology explanations in the Connector Parameter Development section of this report, a glossary of frequently used terms is presented.

1) 'T' dimension: This is a measurement across the crimping die parting line on the connector after crimping. (see Figure 8) It is a measure of compression for a given crimp profile. It is also a useful inspection tool in the field to insure proper compression.

2) Contact length: A longitudinal portion of the conductor and connector which is compressed to a constant cross section and predetermined amount of compression.

3) Crimping tool: A tool providing the necessary mechanical advantage to apply the necessary forces to crimp the connector and conductor. Tools are usually hand or hydraulically actuated.

'T' DIMENSION

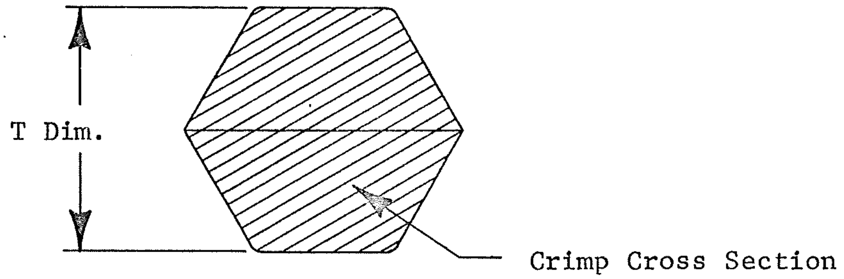


FIGURE 8

FLARE ANGLE

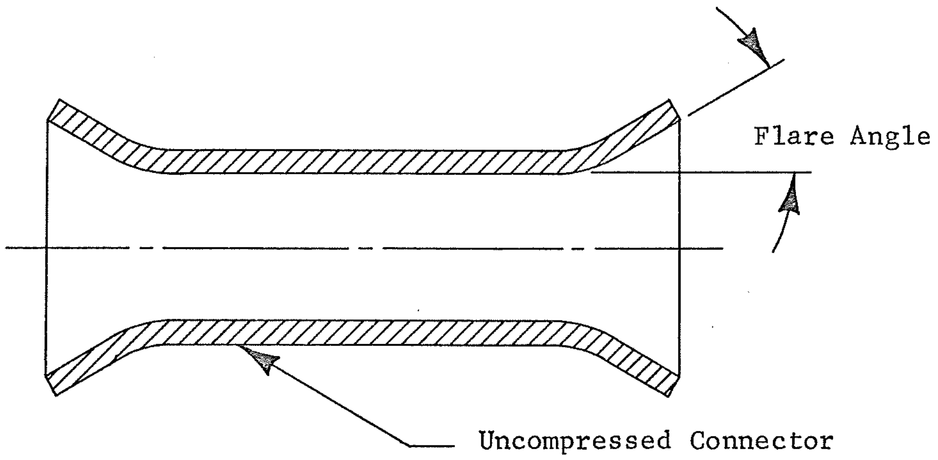


FIGURE 9

4) Crimping Die: A profile of the desired crimped cross section which is part of the crimping tool or is supplied as an individual part for assembly to the tool.

5) Crimping force: That amount of force required to deform the connector and conductor to the required crimped cross section.

6) Crimped profile: A cross section showing the geometric shape of the crimped connector and conductor.

7) Crimped cross section: See crimped profile.

8) Die Profile: Similar to crimped profile except a shape which is incorporated in the die and is imparted to the connector and conductor during crimping.

9) Flare angle: An angle designed into the connector to facilitate easy entrance of stranded conductors. (see Figure 9)

10) Percent Compression: This is a measure of compression and includes both connector and conductor. It results in becoming the crimped section. Percent compression

is calculated by comparing the connector and conductor material cross section (without air spaces) to that after crimping. In this report a figure of 100% compression means that the connector and conductor were compressed to a cross section equivalent to the amount of material in both conductor and connector or to a "solid condition". Percent compressions less than 100% are referred to as (-) __% below solid. Conditions greater than 100% are referred to as (+) __% above solid.

11) Residual stress: That amount of stress left in the crimped area after removal of crimping tool.

12) Stress relief angle: A transition from the crimped cross section to a non stressed or lesser stressed cross section. This angle graduates the stress on the individual conductor strands and thus reduces the effects of stress concentration resulting from crimping action.

13) Tool handle force: The force required to close the handles of a crimping tool to produce the required crimp on connector and conductor.

14) Cable: Two or more conductors assembled within a common jacket. (i.e. Flat-Twin Portable power cable)

15) Conductor: A single element consisting of an assembly of ropes and stranded wires. (i.e. two conductors make up a twin portable cable)

16) Core Conductor: The individual insulated conductors in a cable.

17) Ropes: A single part of the conductor consisting of an assembly of stranded wires (the conductor used in testing consisted of 7 ropes per conductor).

18) Strands: The individual wires making up a rope.

19) Strand fretting: The interaction of one strand against another causing wear and eventual strand rupture.

20) Shroud: A portion of the connector which circumferentially covers the conductor insulation. Used primarily to seal the contact area from moisture by either taping from shroud to insulation or crimping shroud over insulation.

21) Flash: Excess connector material which forms outside the crimp profile at the crimping die parting line; usually the result of over crimping (too much compression) or improper die design.

SECTION IV

DEFINITION OF CONDUCTOR JOINTS

The four conductor joint types investigated are as follows:

Lap
Butt
Crowsfoot
Modified Crowsfoot

A lap joint is made by overlaping the conductors in the appropriate connector and then crimping both conductors at the same time. Figure 10 shows a lap joint configuration.

A butt joint is made by inserting each conductor into the ends of an appropriate connector and crimping each conductor. Joined conductors remain on the same centerline. Figure 11 shows a butt joint configuration.

A crowsfoot joint is made by fanning out the ropes of each conductor, assembling the two conductors so that every rope of one conductor fits between every two ropes of the other conductor, sliding connector over both conductors and crimping. Figure 12 shows a crowsfoot joint configuration.

A modified crowsfoot joint is made by fanning out the ropes of one conductor, inserting the other (unfanned) conductor into the

LAP JOINT

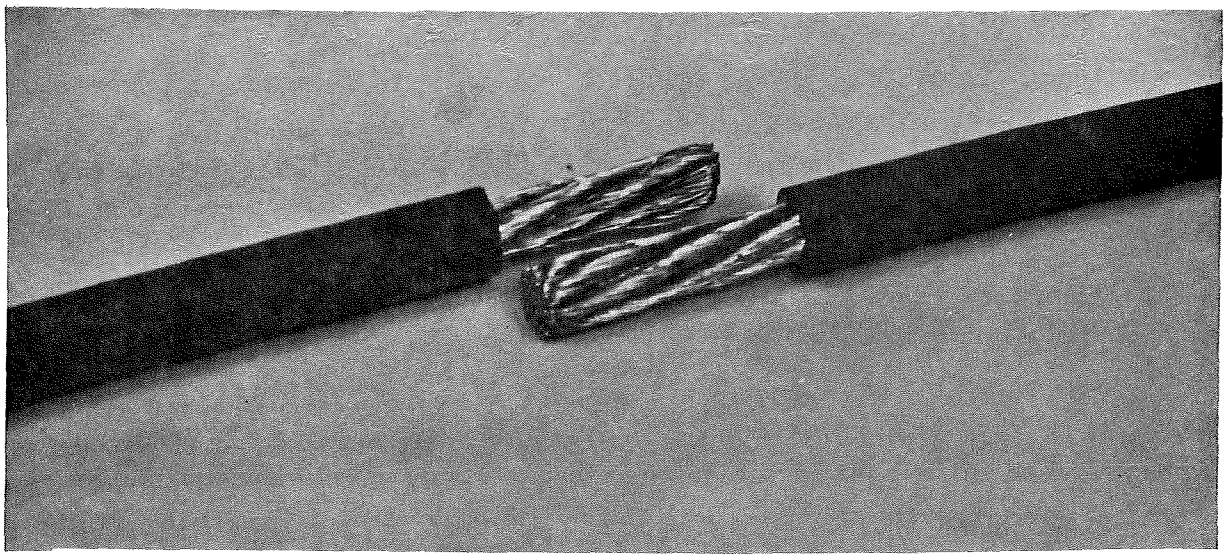


FIGURE 10

BUTT JOINT

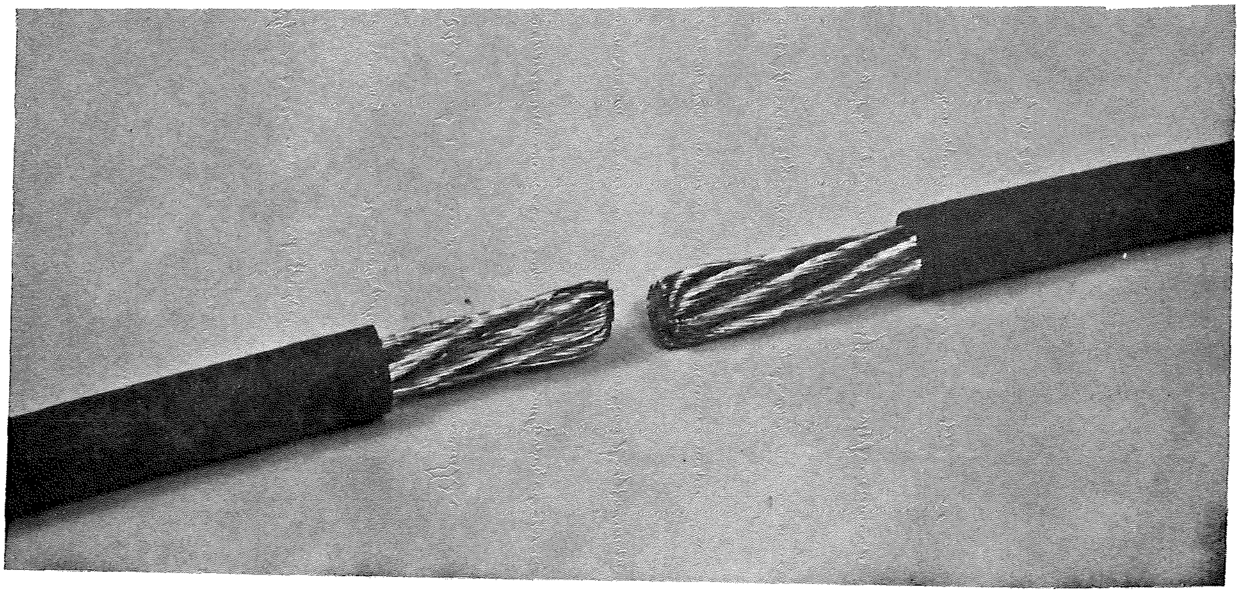


FIGURE 11

CROWSFOOT JOINT

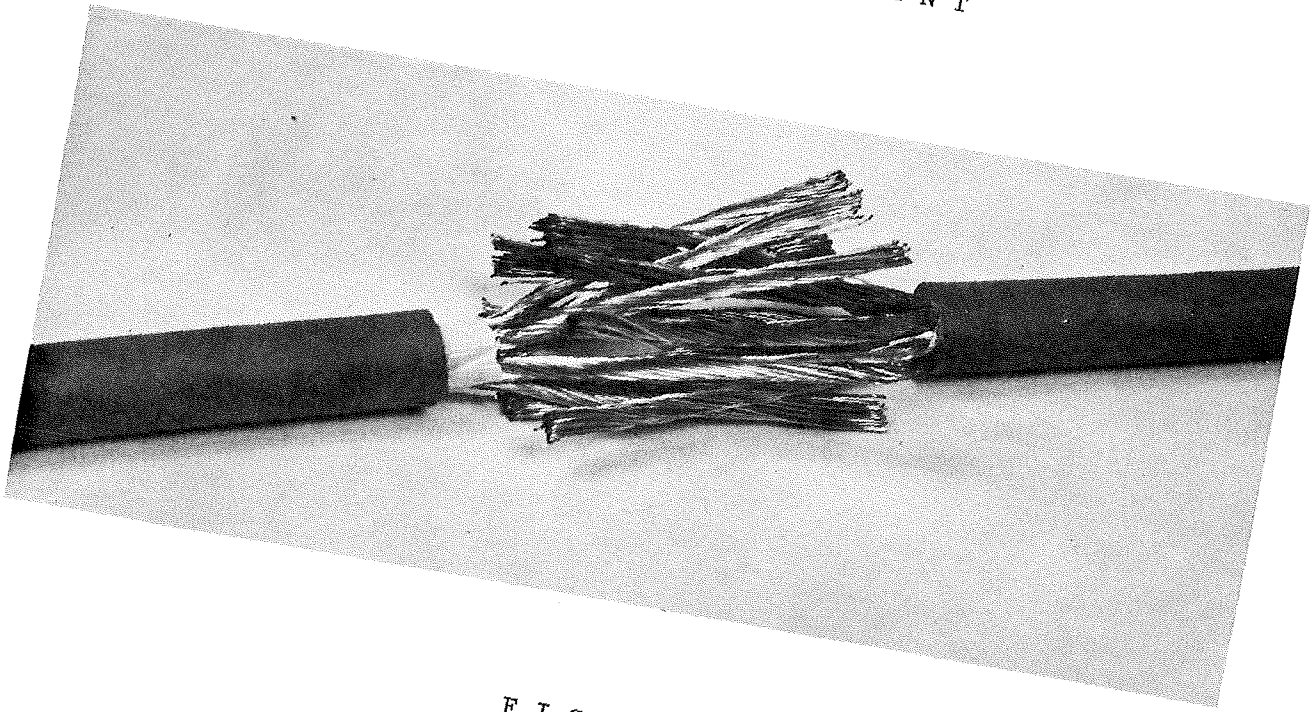


FIGURE 12

MODIFIED CROWSFOOT JOINT

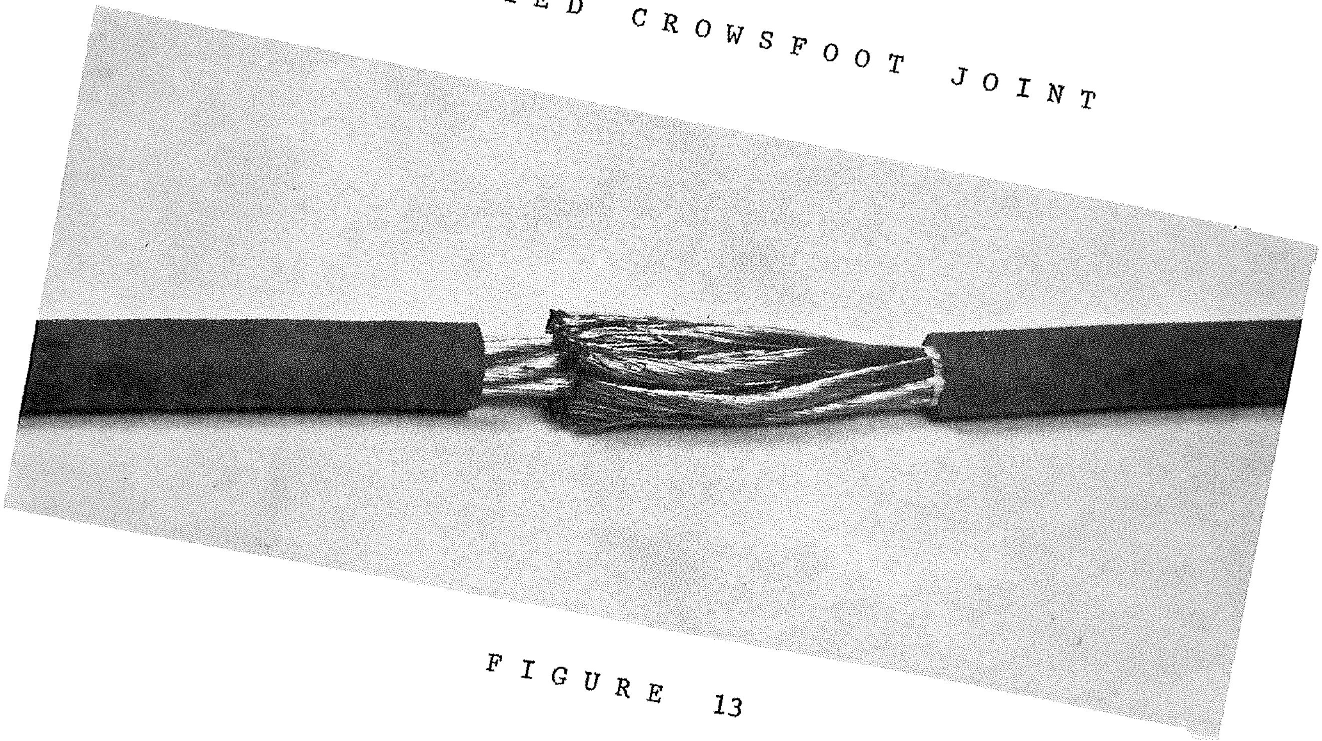


FIGURE 13

center of the fanned conductor, sliding the connector over both conductors, and crimping. Figure 13 shows a modified crowsfoot joint configuration.

Advantages and disadvantages of these joints as related to trailing cables are as follows:

Lap Joint

Advantages:

1) One crimp completes joint.
2) Easier longitudinal alignment of cable conductors resulting in conductor tensile load equalization.
3) Relative freedom in conductor longitudinal movement, prior to crimping, without jeopardizing effective contact length.
4) Short overall length.

Disadvantages:

1) Not suitable for incorporation of full circumferential stress relief which relates directly to flex life.
2) A couple action occurs, which causes connector to twist when tension is applied to conductors. This may result in lowering pullout strength and undesirable movement in an insulated splice.
3) Only a partial flare angle is possible to assist in insertion of second conductor.
4) Wide variations in interconductor strand fretting.

Butt Joint

Advantages:

1) Each conductor has its own individual contact pocket. This eliminates interconductor strand fretting.
2) Relatively simple conductor preparation and installation.
3) Minimum circumferential dimensions.
4) "In line" (no couple) loading of conductors.

Disadvantages:

1) Difficult to obtain longitudinal alignment of conductors without altering contact length.
2) Overall length longer than other joint types.
3) Two crimps required when not feasible to incorporate double crimps in one die.

Crowsfoot

Advantages:

1) One crimp completes joint.
2) Easy longitudinal alignment of conductors for tensile load equalization.
3) Relatively high pull outs for equivalent contact lengths and compression.
4) "In line" (no couple) loading of conductors.

Disadvantages:

1) Most difficult cable preparation and installation.
2) Wide variation in interconductor strand fretting.

Modified Crowsfoot

Advantages:

1) Same as crowsfoot. In addition, the cable preparation is simpler since only one conductor is fanned out. Also, the connector is very easy to install (flare angle not required). Prior installation on conductor before fanning ropes allows connector to slip easily over both conductors.

Disadvantages:

1) Wide variations in interconductor strand fretting, however, to a lesser degree than crowsfoot.

SECTION V

CONNECTOR PARAMETER DEVELOPMENT

The connector development program is basically empirical in nature. Definition of design parameters and isolation of variables formed the basis of a methodical test program. Utilization of sound engineering judgment and analysis to arrive at the required interrelated optimum parameters has resulted in design methods which should result in splice connectors meeting the "proposed" mechanical MESA requirements. (For example: 1500 minimum flex cycles on #4 and # 2 conductor and 650 pounds and 950 pounds pullout on #4 and #2 conductor respectively.)

It should be noted that design methods discussed in Appendix 1 were arrived at by the testing discussed in this section. Extrapolation of criteria or the development of mathematical relationships for other conductor sizes is not possible because of the wide and unexpected variations in performance resulting from combinations of parameter changes. However, prudent use of the general design procedures recommended should result in optimum connector performance with minimum effort and consumed time.

During the connector parameter development program, every effort was made to eliminate variables so that the true effects of the design parameter being studied could be evaluated. In keeping with this thinking, it should be noted that the type (manufacturer) cable used throughout testing was kept constant. (Note section devoted to performance differences resulting from different cable manufacturers.)

The first step toward development of an optimum connector design was the establishment of a base line by testing presently available connectors. Flex and pullout results were run on #4 259 strand insulated core conductor with results shown in Table 'A'. It should be noted that the appropriate installation tool was used where required. Table 'A' also shows flex life of a complete conductor (no connector) and the effects of removing a 1" length of insulation from a complete conductor (no connector).

The following list indicates the significant design parameters investigated:

1. Connector cross section
2. Crimping force
3. Connector metallurgy
4. Joint type
5. Conductor overlap
6. Insulation stripped distance from connector
7. Crimp contact length
8. Percent compression
9. Crimp profile
10. Crimp stress relief
11. Flare angle
12. Shroud

TABLE 'A'

FLEX & PULLOUT RESULTS ON PRESENTLY AVAILABLE CONNECTORS COMPARED TO CONDUCTOR WITHOUT CONNECTOR

TESTING DONE ON #4 259 STR INSULATED CORE CONDUCTOR

SAMPLE	JOINT TYPE	FLEX CYCLES		PULLOUT	
		NO OF CYCLES AVERAGE	FAILURE MODE	POUNDS AVERAGE	FAILURE MODE
Type 'A' (Indent)	Lap	738	Strand Rupture At Connector Mouth	562	Conductor Slip
Type 'B' (Hose Clamp)	Lap	758	"	——	"
Type 'C' (open ring, hammer installed)	Lap	534	"	322	"
Type 'D' (Indent)	Lap	620	"	547	"
Square Knot	——	690	Strand Rupture At Edge Of Knot	719	Strand Rupture
Core Conductor (No Connector)		359,028	Strand Rupture	——	——
Core Conductor (1" length of insulation removed no connector)		70,334	Strand Rupture	——	——

See section "Development Conclusions" for matrix summation of parameter effects.

The following is a detailed discussion of the design parameters investigated and serves as the basis for the design methods presented in Appendix I.

CONNECTOR CROSS SECTION (WALL THICKNESS)

This parameter includes the I.D. and O.D. of the connector which results in the connector wall thickness. In crimp type connectors, the connector cross section area is responsible for providing adequate area for the conductance of electrical energy as well as the maintenance of sufficient residual stress after crimping to insure cool efficient transmission of electrical energy and also meet mechanical requirements.

The first step is to develop the connector I.D. This should be arrived at by selecting an I.D. that will insure easy assembly of the uncompressed conductor. Excessive clearance should be avoided, as it results in larger O.D. dimensions, which can result in undesirable metal flash after crimping to the required compressed levels.

The O.D. should be the resultant of that amount of material necessary to retain the required residual stress. One method to determine if there is sufficient wall thickness, is to measure 'T' dimension before and after pullout and flex testing. No change in

'T' dimension will indicate adequate wall thickness for maintaining residual stress. This, along with calculations to insure sufficient connector cross section area when compared to conductor cross section area (making allowance for any differences in connector material conductivity) should result in the proper wall thickness.

Usually between one and two times conductor cross section is a good starting point for connector cross section derivation.

CRIMPING FORCE

Since the scope of this contract did not include connector installation tooling, our work was confined to the utilization of crimping forces available in existing connector tooling. Only simple hand actuated tools considered suitable for use in a mine environment were considered. As a result, the Burndy MD6-6 Tool with a 9000 pound crimping force maximum was adopted (see Figure 27). Connectors designed to compress to the required 'T' dimension within this force limitation would guarantee a constant controlled compression; a feature not obtained with many of the presently used mine connector installation tools.

The compression of a connector is based on the following relationship:

$$P = AS$$

Where:

P = Crimping force

A = Crimping area

S = Compressive strength of connector and conductor material

From this one can vary the crimp area by either increasing or reducing the crimp length and thus usually utilize the crimping force available. In the case of reducing crimp area, additional crimps may be necessary to obtain required contact lengths. The design methods outlined in Appendix I should result in one crimp required up to at least #2 str. size. This is based on the 9000 pound crimping force and metalurgical considerations.

CONNECTOR METALLURGY

Many copper bearing alloys were investigated for use as a connector material. In this selection, careful consideration must be given to the electrical and mechanical performance requirements of the connector. In the case of a crimp type connector the material must accept excessive deformation without the inclusion of incipient cracks. A materials mechanical property must be such as to insure sufficient residual stress after crimping in order to meet the necessary performance requirements. Electrical conductivity is also another important material characteristic.

After reviewing all material requirements, only a high conductivity annealed copper appeared best suited for a crimped mine splice application.

Supporting this selection is the desirability to select a connector material that is similar to the conductor material. This will maintain equivalent material coefficients of expansion so that under conditions of electrical heating and cooling, the elements of the joint can expand and contract together and thus maintain the required contact force for stable resistance.

After connector fabrication, no surface finish other than an acid etch, to remove oxides from the annealing operation, is recommended.

Although the conductor is tin plated, the connector contact surface does not need oxide inhibiting, (unless subjected to unusual conditions) since the crimping force is sufficient to break up and disperse any soft copper oxide. Plating of the connectors exterior surface is not required since presently used splice insulation systems seal out moisture. Also, most of the insulating materials are of a synthetic nature and thus eliminate the need for plating of copper components as was the case with sulfur cured natural rubbers.

In order to facilitate the proper forming of the connector without the susceptibility to creating incipient cracks, a full anneal of the connector after fabrication is recommended. Assuming proper connector cross section area, sufficient work hardening of the material will occur during the crimping process to insure adequate residual contact force.

JOINT TYPE

The first portion of the connector development test program was to determine which type of joint (lap, butt, crowsfoot or modified crowsfoot) is least susceptible to flex failure. Testing was done on #4 259 str. insulated core conductor. In order to minimize variables the following design parameters were held constant.

1) Hex crimp cross section selected because of resulting uniform crimping stress distribution.
2) 5% compression below solid. This figure produced acceptable pullout values.
3) .342 contact length - also result of acceptable pullout values.
4) Straight longitudinal crimp profile.
5) Zero stress relief.
6) Zero flare angle.
7) Zero shroud.
8) Equal crimping force by virtue of crimping dies butting.
9) Connector metallurgy constant by use of ETP Copper fully annealed.

In addition it was found that the distance from the end of the cable insulation to the end of the connector has a significant effect on flex life. This was illustrated on a butt type joint with the following results:

Insulation touching connector: 1344 cycles
Insulation .25 from end of connector: 1210 cycles
Insulation 3.00 from end of connector: 252 cycles

As a result, this parameter was also added to the list of controlled parameters. All insulation strip distances to connector were held at .25" where possible.

An investigation into effect of conductor overlap on a modified crowsfoot joint showed no significant difference in flex life as follows:

Zero overlap - 526 cycles
.50 overlap - 704 cycles
1.00 overlap - 582 cycles

However, for the purpose of good sample control, conductor overlaps were held constant throughout testing.

The following lists flex life cycles on the four joints considered:

Lap Joint: 298
402
456
498
Av. = 414, Median = 398, Spread = 200
Pullout 796 lbs.

Crowsfoot: 940
1254
2124
2310
Av. = 1657, Median = 1625, Spread = 1370
Pullout = 1084 lbs.

Modified Crowsfoot: 888
1356
1420
1830
Av. = 1373, Median = 1359, Spread = 942
Pullout = 1060 lbs.

Butt: 944
994
1210
1344
Av. = 1123, Median = 1144, Spread = 400
Pullout = 833 lbs.

Based on this data the modified crowsfoot and butt joint were selected as the best candidates for the development of an optimum performing splice. The decision was based on the following:

1) Although the lap joint gave the most consistant readings (200 spread) they were the lowest. Effective stress relief angles would be difficult to incorporate on a circumferential basis. Also the lap joint responds to a couple action when under tension, which would create an undesirable disturbance in an insulated joint.

2) Although the crowsfoot gave the highest individual reading it also resulted in the widest spread (1370). It is also felt that the crows foot joint would have an unacceptable degree of difficulty when making the splice in a mine environment.

3) The modified crowsfoot was selected over the crowsfoot because of its relative ease in assembling the joint and its reduced spread (942) while still producing relative high values.

4) The butt joint was selected because of surprisingly high values relative to its length and the low spread (400) of results. Also, the butt joint is relatively simple to make and the more consistent interstrand geometrical relationships should minimize variations due to strand fretting.

CRIMP CONTACT LENGTH & PERCENT COMPRESSION

These two parameters will be discussed together since they both significantly affect one another.

In order to minimize the conductor bending angle (see Figure 14) the connector should be as short as possible to maximize flex life. Also, the amount of compression should be minimum to minimize conductor strand stress concentration and thus obtain maximum flex life. An optimum design is the judicious balance of these parameters to obtain required pullout and maximum flex performance. Testing was done on the two selected joints; modified crowsfoot and butt.

The butt joint will be discussed first. The .342 contact length and 5% compression below solid resulted in an acceptable 833 pound pullout as discussed in the preceding section "Joint Types" and served as the starting point for this investigation. With all other parameters held constant, as previously noted, the contact length was varied and resulted in pullouts shown in Graph #1. A decreasing change in contact length resulted in poorer pullouts; however, resulted in improved flex life, also shown in Graph #1. This substantiated the fact that the shorter the contact length, the less conductor bending angle and thus the greater flex life. It also directed us to look at possible ways of increasing pullout on the short contact length as follows:

1) increase compression
2) add a grit material to the connector contact surface in order to increase the coefficient of friction and also form a mechanical lock between connector and conductor.

Increasing compression was rejected because of generating a flash condition which would be unacceptable from an insulating point of view. The addition of a grit material was looked into next. The I.D.'s of the sample butt connectors with .171 contact length were coated with various grits. These samples were subjected to pullout tests with the following results:

CONDUCTOR BENDING ANGLE RESULTING FROM FLEX TEST

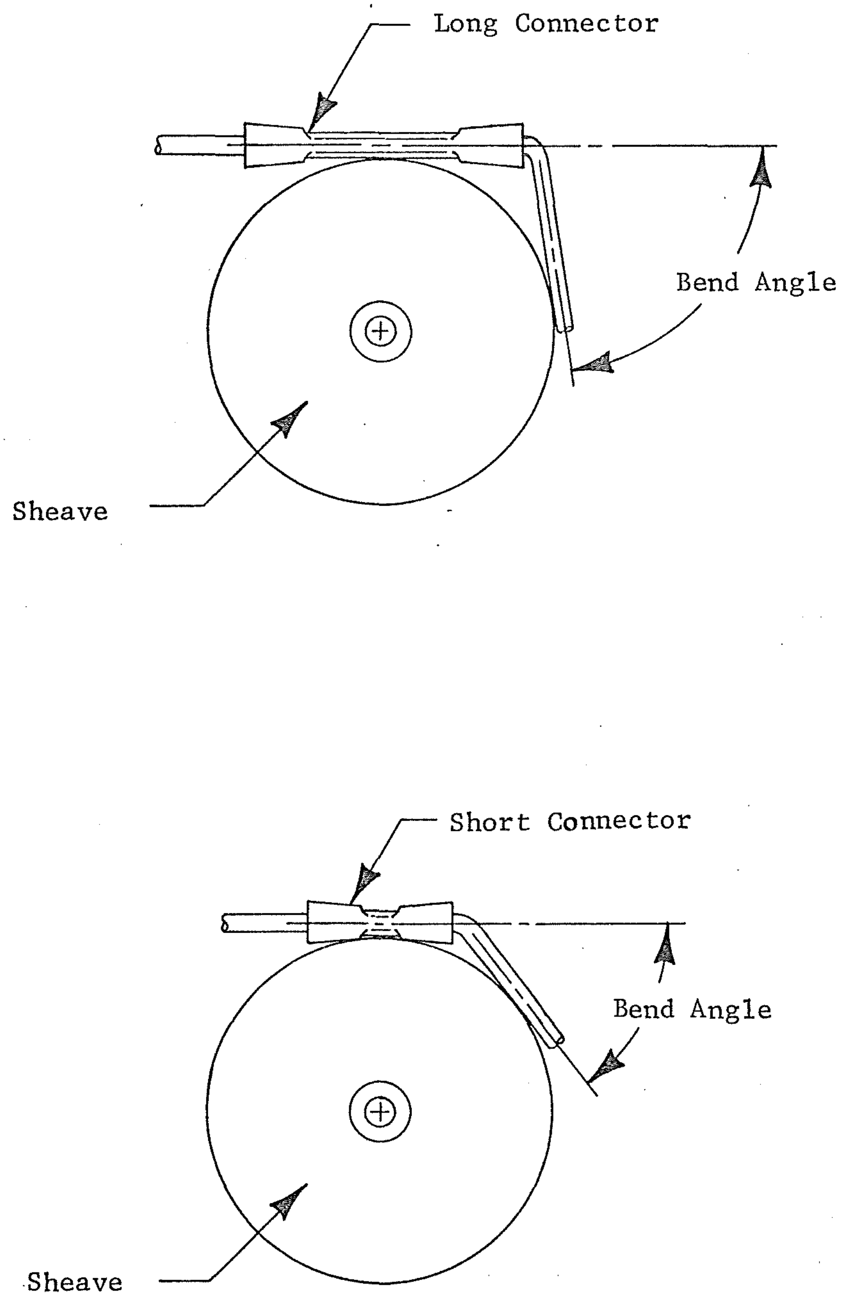
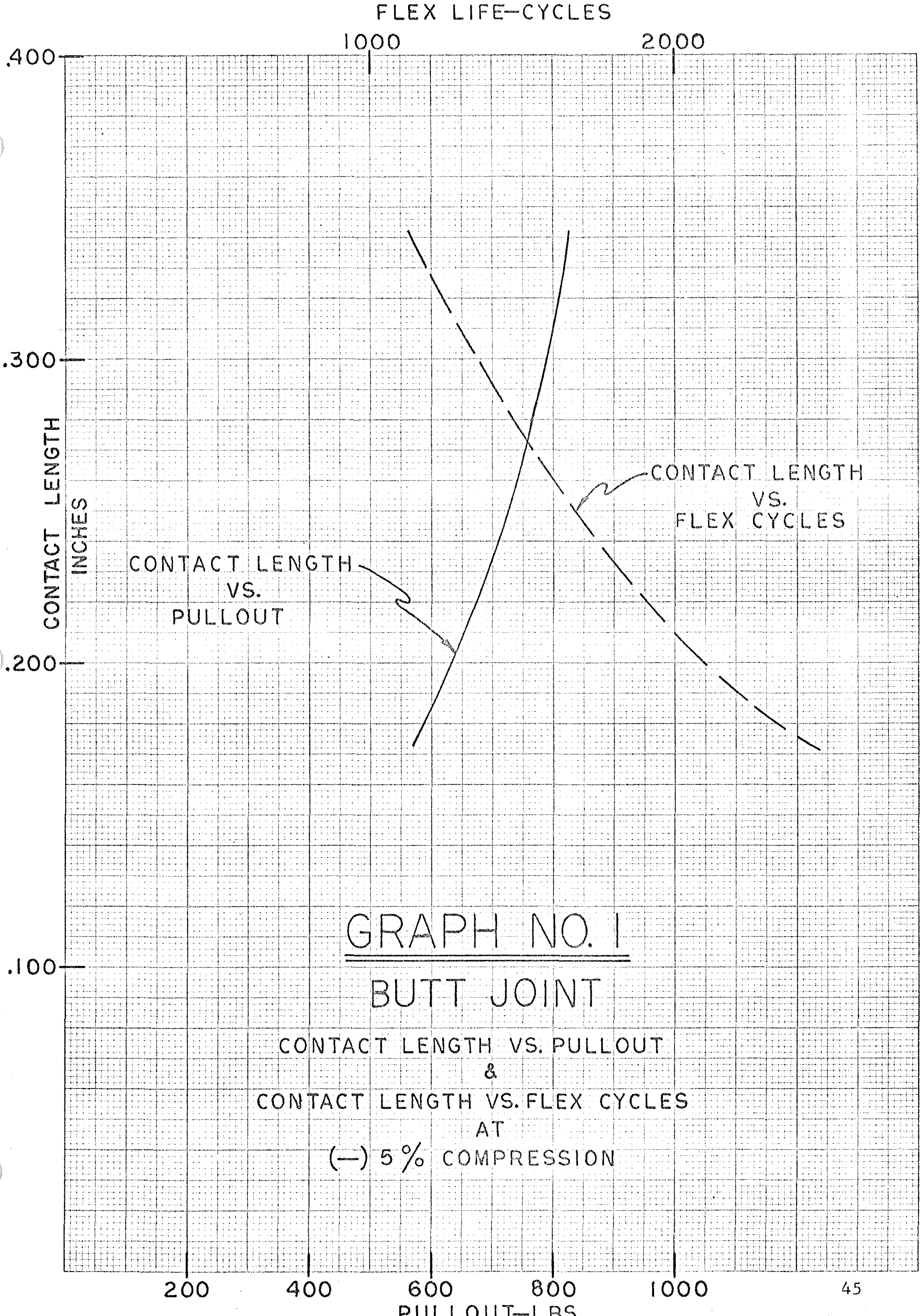


FIGURE 14



GRAPH NO. 1

BUTT JOINT

CONTACT LENGTH VS. PULLOUT
&
CONTACT LENGTH VS. FLEX CYCLES
AT
(—) 5% COMPRESSION

BUTT JOINT

Crimp Contact Length	Grit Type	Pullout-Lbs.	Mode of Failure
.171	Pen A14	397	Slip
.171	Grade 46RA	342	Slip
.171	C8	566	Slip
.171	C8	527	Slip

Pen A14 is a Burndy contact grease incorporating silicon carbide grains. Grade 46RA is silicon carbide grains of significantly larger size than in Pen A14. Grit 'C8' is berryllium copper in grit form. All of the grits tried are used for the specific purpose of increasing pullout strength in compression connectors.

No improvement is noticed when comparing the values listed above with those in Graph #1. It is felt that the grit approach was unsuccessful because of the many small wire strands (259) making up the conductor. These strands do not present a single large enough and strong enough member for the grit to lock into as is the case with common 7 and 19 strand conductor constructions.

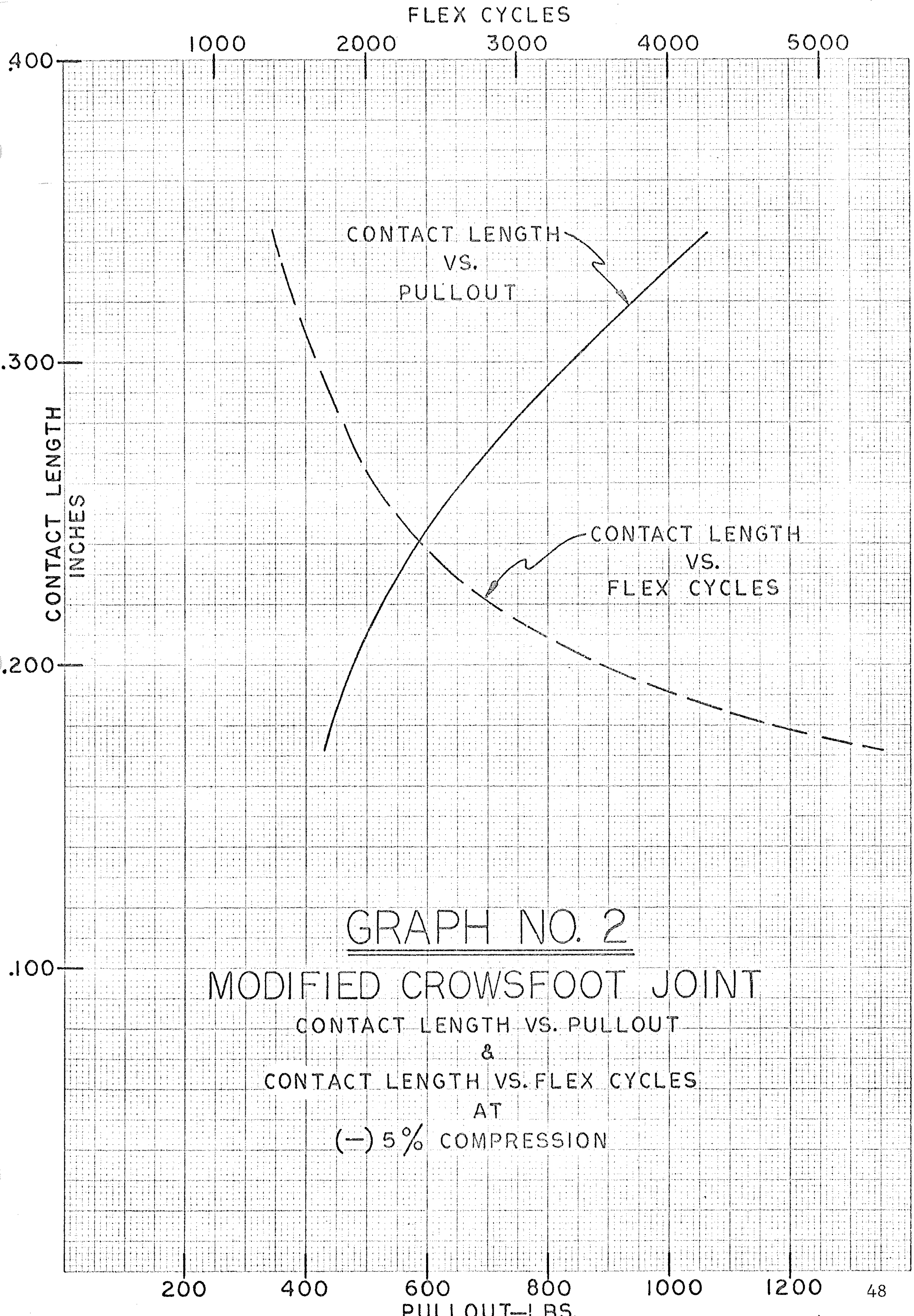
Referring to Graph #1, the .256 contact length represents the shortest length at 5% compression below solid to produce an acceptable pullout. For maximum flex life, crimping must only stress the conductor sufficiently to obtain a pullout value of only that amount required plus a safety factor to guarantee consistence of acceptability.

The following tabulation shows pullout and flex cycles obtained with the .256 contact length and 5% compression below solid parameters.

Pullout Lbs.	Mode of Failure	Flex Cycles	Mode of Failure
729	Slip	1636	Strand Rupture
748		2742	" "
692		1244	" "
693		2124	" "
AV = 700 Median = 720 Spread 56		AV = 1936 Median = 1993 Spread 1498	

Contact length and percent compression parameters for the modified crowsfoot joint were studied in a similar manner. Graph #2 shows pullout and flex cycle versus contact lengths at the 5% below solid compression. All other parameters were held constant as previously noted.

In an effort to utilize the shortest contact length and obtain maximum flex life with acceptable pullouts, grit was again investigated but without success. Although we were able to come close to meeting the 650 pounds pullout on a .256 contact length with grit, flex testing did not show any significant improvement as noted in the following table.



GRAPH NO. 2

MODIFIED CROWSFOOT JOINT

CONTACT LENGTH VS. PULLOUT
&
CONTACT LENGTH VS. FLEX CYCLES
AT
(—) 5% COMPRESSION

Contact Length	Flex Cycles Without Grit	Flex Cycles With Grit	Pullout Without Grit	Pullout With Grit
.342	1374	———	1060	———
.256	2070	729	642	648
.171	5480	———	433	475

In addition to the reasons for grit failure discovered on the butt joint, it is also felt that the above data on flex cycles "with grit" indicates the grit contributes to the cable interstrand fretting and thus does not allow a shorter contact length to be used. The grit used in these tests was a Burndy berryllium copper grade 'C8'.

In still another effort to meet the pullout with minimum contact length, it was found that by shaping the connector as shown in Figure 15, additional compression could be applied without generating flash. Holding all other parameters constant, percent compression on the .252 contact length, was increased to 10 and 15% beyond solid with resulting acceptable increased pullouts of 814 pounds and 963 pounds respectively. However, flex cycle readings of 994 (10%) and 1492 (15%) do not show any significant improvement over the .342 contact length (5%) design, again indicating the need to balance compression and contact length to gain maximum flex life.

MODIFIED CROWSFOOT CONNECTOR

WITH SHAPED PROFILE

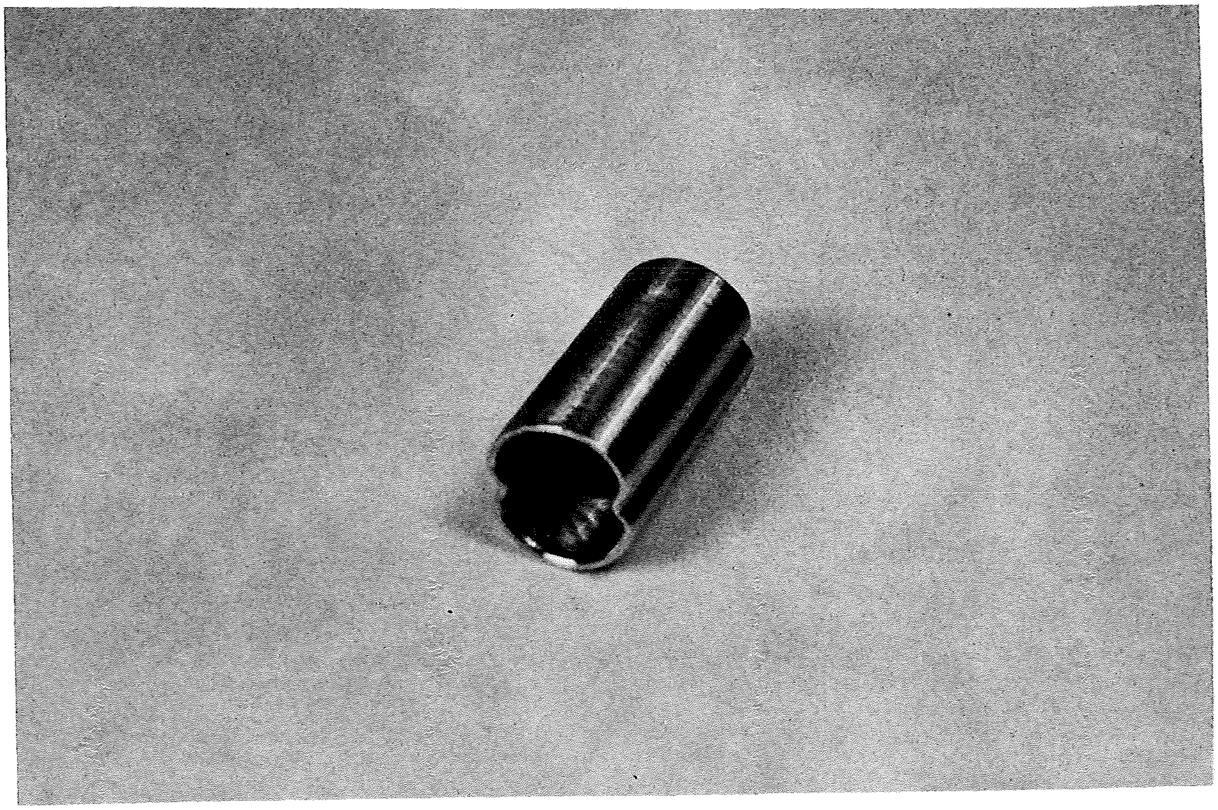


FIGURE 15

At this point the .342 contact length was reinvestigated. Since this length produced pullout values well above the 650 pounds requirement, samples were tested with less compression (+4.5% above solid) for both pullout and flex life with the following acceptable results:

Contact Length	Pullout Lbs.	Mode of Failure	Flex Cycles	Mode of Failure
.342	996	Slip	3000	Strand Rupture
.342	787	Slip	1790	" "
.342	695	Slip	2252	" "
.342	911	Slip	1596	" "
Av. = 847 Median = 846 Spread = 301			Av. = 2160 Median = 2298 Spread = 1404	

The following summarizes the contact length and percent compression parameter study on #4 259 str. conductor.

Joint Type	Contact Length	% Compression
Butt	.256	(-) 5% Below Solid
Modified Crowsfoot	.342	(+) 4.5% Above Solid

CRIMP PROFILES

All work up to this point was conducted using a hex crimp profile for reasons previously mentioned. A study was now made on #4 259 str core conductor to determine the effects of different geometric profiles in relation to pullout and flex cycle performance. The following crimp profiles were studied:

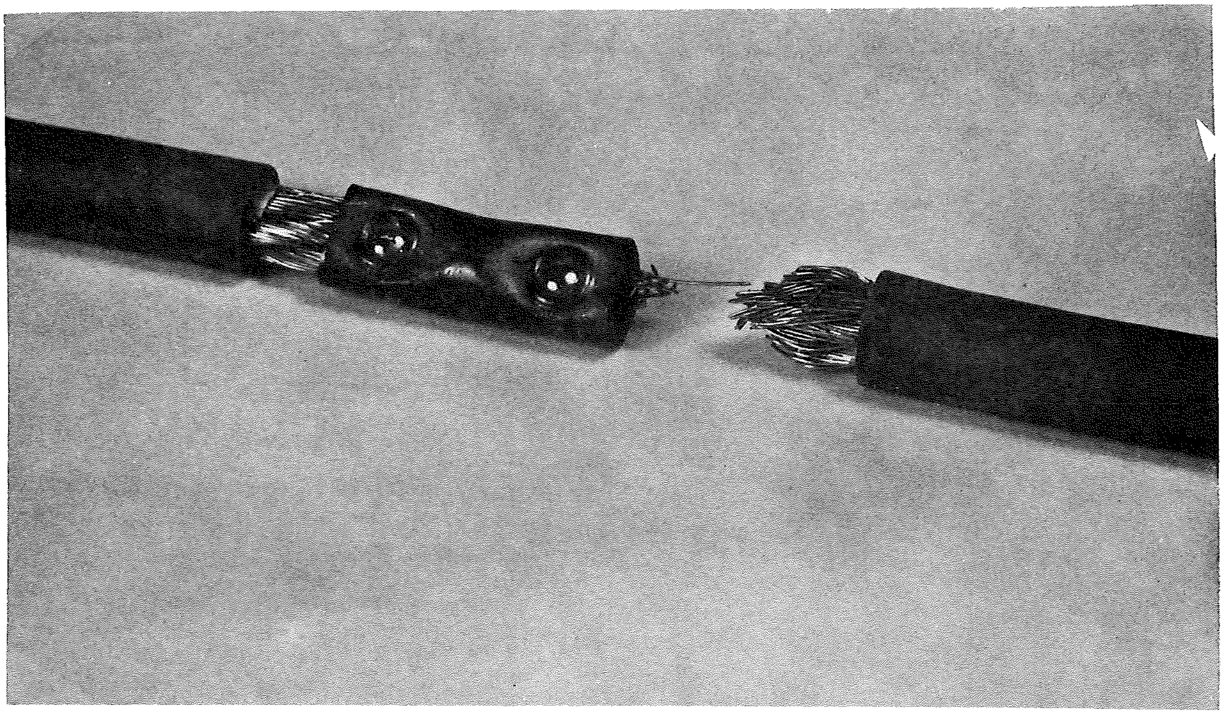
Indent (Figure 16)
Square (Figure 17)
Round (Figure 18)

Prior to flex cycling, each type crimp was designed to meet the 650 pound pullout requirement with one crimp per conductor. The butt type joint was selected for this investigation because of its relatively simple cable interstrand geometric relationship.

The following summarizes the results of this effort.

			Pullout			Flex			
Type Crimp	Crimp Contact Length	% Comp	Av	Median	Spread	Av	Median	Spread	High/Low
Hex	.256	-5.0	700	720	56	1936	1993	1498	2742/1244
Indent	MR4-10M #6 Groove		760	760	80	1229	1046	1148	1620/472
Square	.342	-11	849	856	48	626	618	68	652/584
Round	.342	-18	392			See Comment #4			

INDENT CRIMP



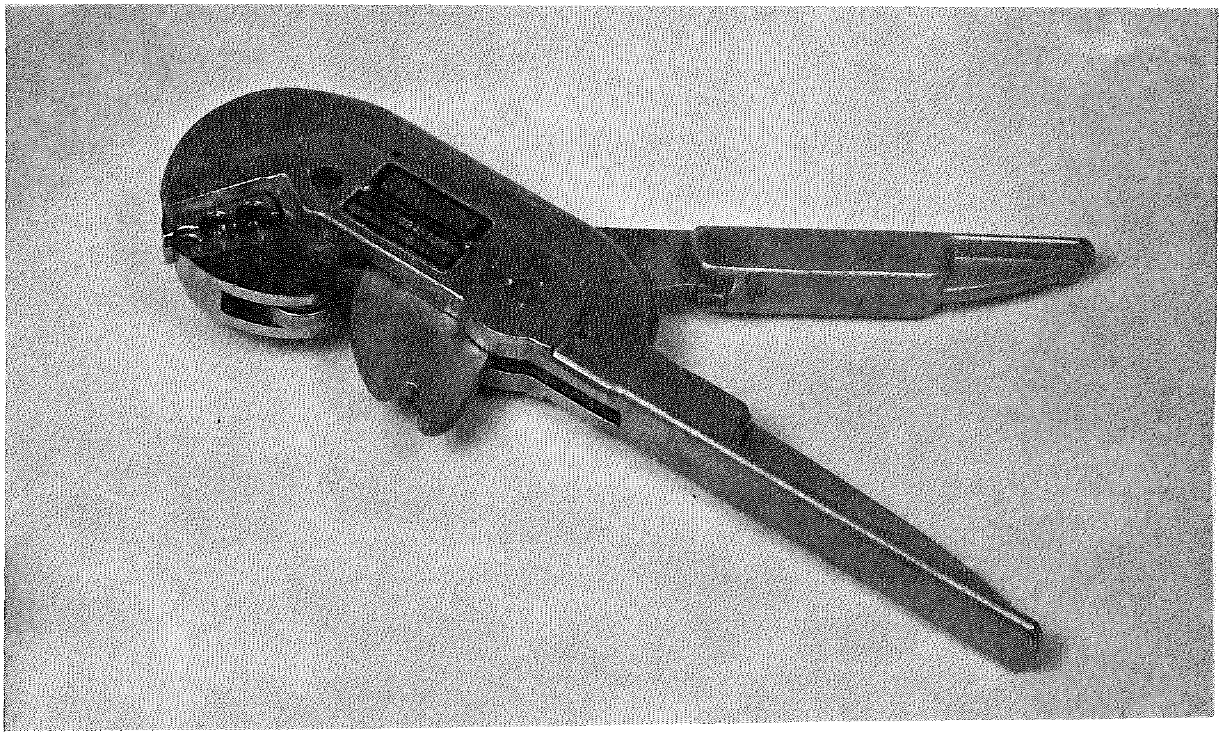


FIGURE 16

SQUARE CRIMP

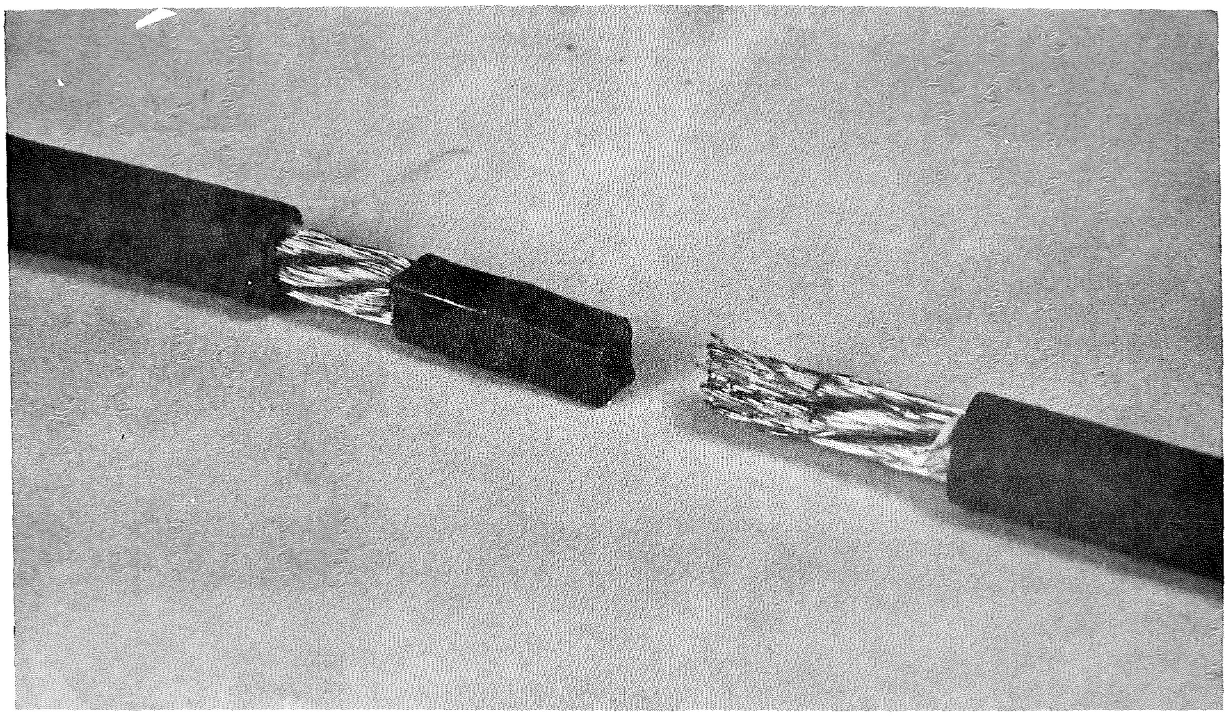


FIGURE 17

ROUND CRIMP

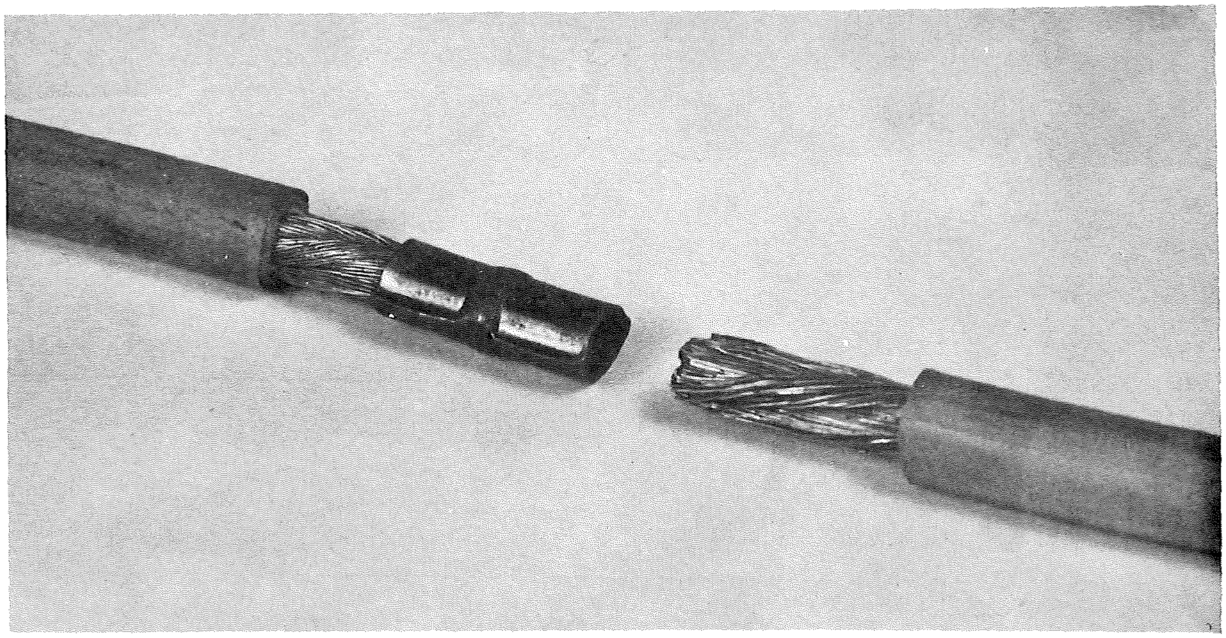


FIGURE 18

CRIMP PROFILE COMMENTS

1) The MR4-10M and #6 Groove is a Burndy installation tool incorporating an indentor and nesting groove suitable for the #4 259 str. conductor (see Figure 16).

2) It should be noted that the indent type of joint requires sufficient material on each side of the indent to allow for connector material deformation. Also, the connector to conductor contact length must be long enough so that the conductor does not have a tendency to slip out from under the indent. The 1.06 connector length tested was a minimum length allowing for these considerations. The high compression and added contact length required by the indent correlates with the poorer flex life.

3) The square crimp when tested with 5% compression below solid yielded an average pullout of 658 pounds. This was considered too close to the 650 pound minimum. Compression was increased up to 11% below solid which resulted in the acceptable pullout values noted. However, the added compression again resulted in poorer flex life.

4) The round crimp profile study was abandoned after unsuccessful attempts to meet the 650 pound pullout requirement. With a .342 crimp contact length and 5% compression below solid copper condition, 172 pound pullout was obtained. Increasing compression to 18% below

solid resulted in an increase to 392 pounds. Based on the necessity of significantly increasing the .342 contact length to achieve acceptable pullout, and the knowledge that longer crimp lengths result in poorer flex life, the round profile study was dropped.

As a result of the crimp profile parameter study, the hex profile (see Figure 19) was selected based on its known uniform stress distribution and its ability to meet the required minimum pullout with maximum flex life.

CRIMP STRESS RELIEF

The crimp stress relief study was conducted on both butt and modified crowsfoot type joints, using #4 259 str. conductor.

The basis for designing the stress relief is shown in Figure 20. This results in a transition angle (stress relief angle) between the fully compressed section and the uncompressed connector I.D. This angle graduates the stress to zero at the connector entrance.

Because the stress graduation contributes to conductor compression, it is possible to reduce the full compressed crimp contact length, and still meet pullout requirements. In addition, shorter contact lengths were made possible by slightly increasing the percent compression from (-)5% to (-)7% below solid. The previously discussed

HEXAGON CRIMP PROFILE

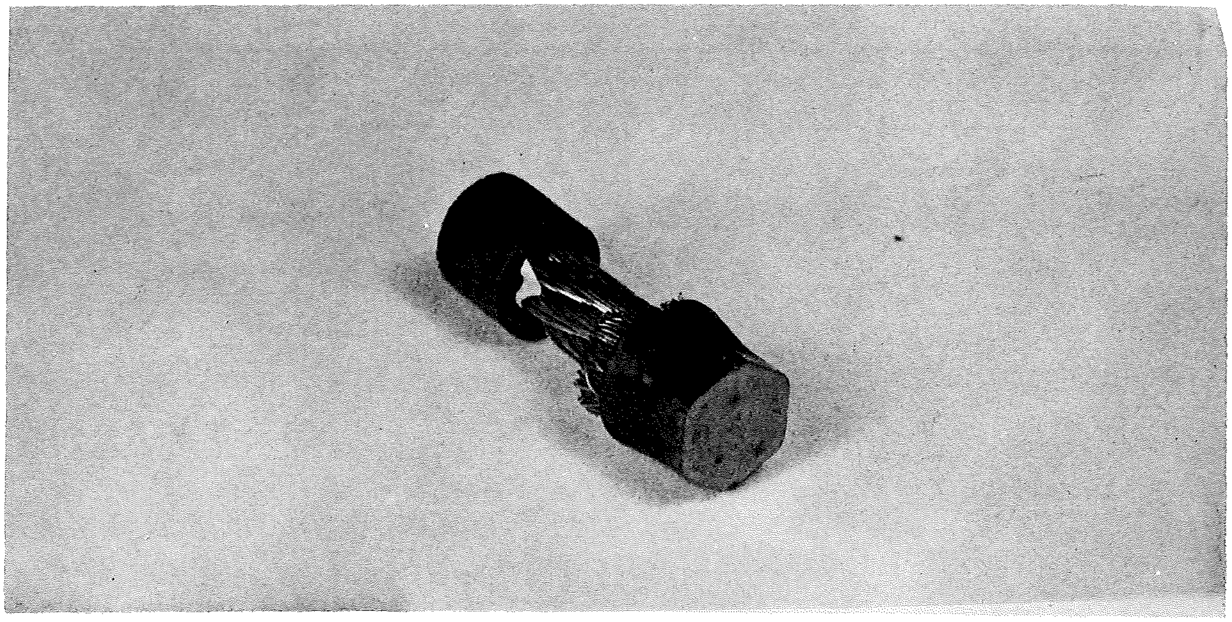


FIGURE 19

STRESS RELIEF DESIGN

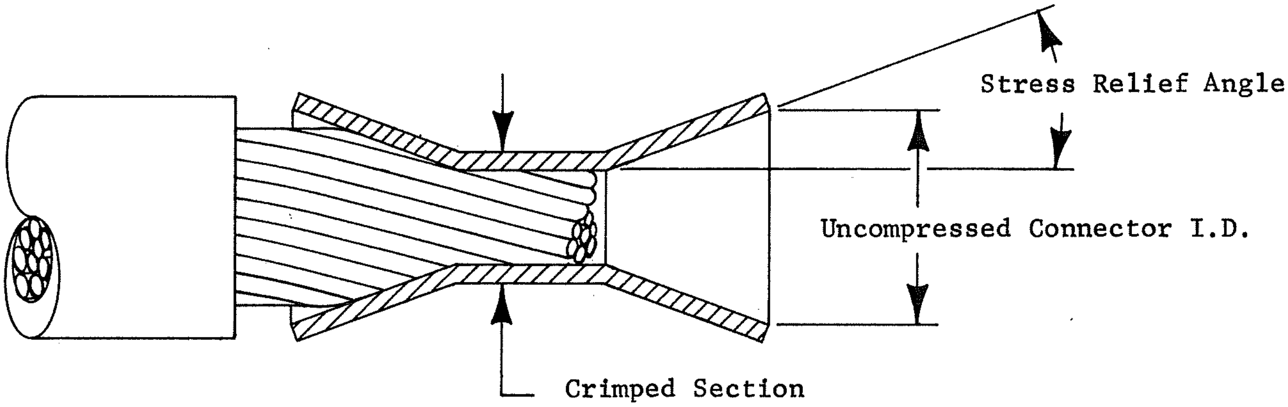


FIGURE 20

negating factors of increased compression were offset by the stress relief angle. As a result of this, the butt crimp contact length was reduced from .256 to .100. Table 'B' shows flex life and pullout data for various stress relief angles. From this data the 16° stress relief angle with a .100 crimp contact length and (-)7% compression below solid was selected as the optimum parameters for the #4 str. butt joint. (Group #2)

Similar reasoning was applied to the modified crowsfoot joint and Table 'C' shows flex life and pullout data obtained. From this data the 10° stress relief angle with a .150 contact length and (+)4.5% compression above solid was selected as the optimum parameters for the #4 str modified crowsfoot joint (Group #1).

The reasons for these selections are based on the following:

1) Consistency in meeting 1500 minimum flex angles
2) Consistency in meeting 650 pound minimum pullout
3) Minimum spread of values

TABLE 'B'
BUTT JOINT STRESS RELIEF ANGLE SUMMARY
#4 259 STR CONDUCTOR

				Flex Life		Pullout	
	Relief Angle	Crimp Contact	% Comp	Cycles	Summary	Lbs	Summary
Group 1	16°	.100	-5%	4056 5162 6720 4896	5208 Av 5388 Median 2664 Spread	510 434	N.G.
Group 2	16°	.100	-7%	3924 3824 3462 3510	3680 Av 3693 Median 462 Spread	724 837 851	804 Av 787 Median 127 Spread
Group 3	19°	.256	-5%	2650 2416 2000	2355 Av 2325 Median 650 Spread	662 732	697 Av 70 Spread
Group 4	30°	.100	-7%	5552 5858 3212 5914	5134 Av 4563 Median 2702 Spread	578 473 813	N.G.
Group 5	45°	.100	-7%	5206 7422 3070 3868	4891 Av 5246 Median 4352 Spread	468 643	N.G.
Group 6	60°	.100	-7%	5732 4404 2812	4316 Av 4272 Median 2920 Spread	472 528 497	N.G.

TABLE 'C'
MODIFIED CROWSFOOT STRESS RELIEF ANGLE CUMMARY
#4 259 STR CONDUCTOR

				Flex Life		Pullout	
	Relief Angle	Crimp Contact Length	% Comp	Cycles	Summary	Lbs	Summary
Group 1	10°	.150	+4.5	3944 3386 3538 3698	3641 Av 3665 Median 558 Spread	1038 1081 1021	1047 Av 1051 Median 60 Spread
Group 2	15°	.150	+4.5	3436 1986 4634 5322	3844 Av 3654 Median 3336 Spread	827 786 750	788 Av 788 Median 77 Spread
Group 3	20°	.150	+4.5	2222 1596 3194 2560	2393 Av 2395 Median 1598 Spread	852 797 727	792 Av 789 Median 125 Spread
Group 4	30°	.150	+4.5	6766 2952 2570 13612	6475 Av 8091 Median 11042 Spread	568 614 702	N.G.
Group 5	45°	.150	+4.5	2618 4884 1750 2486	2934 Av 3317 Median 3134 Spread	641 632 626	N.G.

FLARE ANGLE

As defined in the section "Pertinent Connector Design Terminology", the flare angle is an angle at the mouth of the connector to facilitate easy entry of all strands of the conductor.

In the case of the butt joint, tests indicate the flaring of the connector as shown in Figure 21 will allow easy entry of the #4-259 str conductor. Flaring for other size conductors should be proportionate.

The design of the flare angle should be such as to become part of the stress relief angle during the crimping process.

In the modified crowsfoot joint the connector is threaded over one of the conductors before fanning out the conductor ropes. Because of this and the fact that the connector I.D. is large enough to slide over both assembled conductors, a flare angle is not required on the modified crowsfoot connector.

SHROUD

Although a shroud (Figure 22) is usually used to seal the contact area from deteriorating environmental effects (i.e. moisture) it was investigated as a possible means of imparting stress relief to the conductor strands during flex cycling. It was felt that the shroud

FLARE ANGLE

BUTT JOINT #4 STR

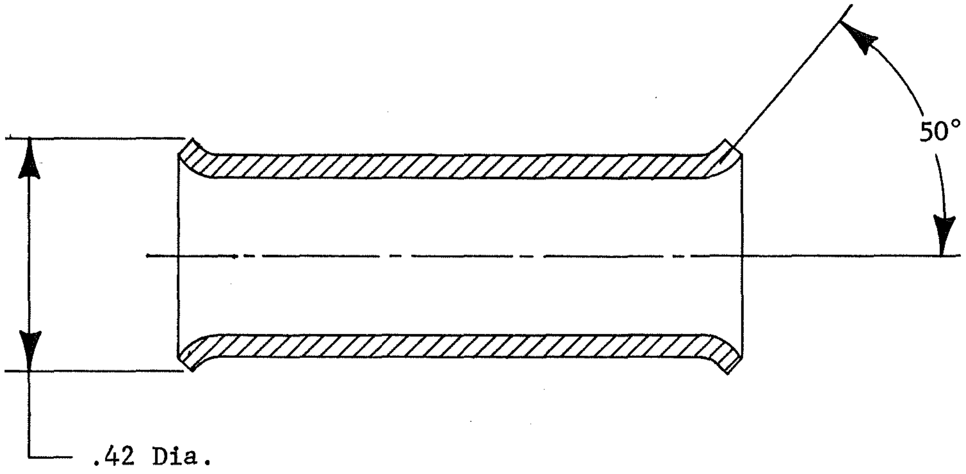


FIGURE 21

SHROUD

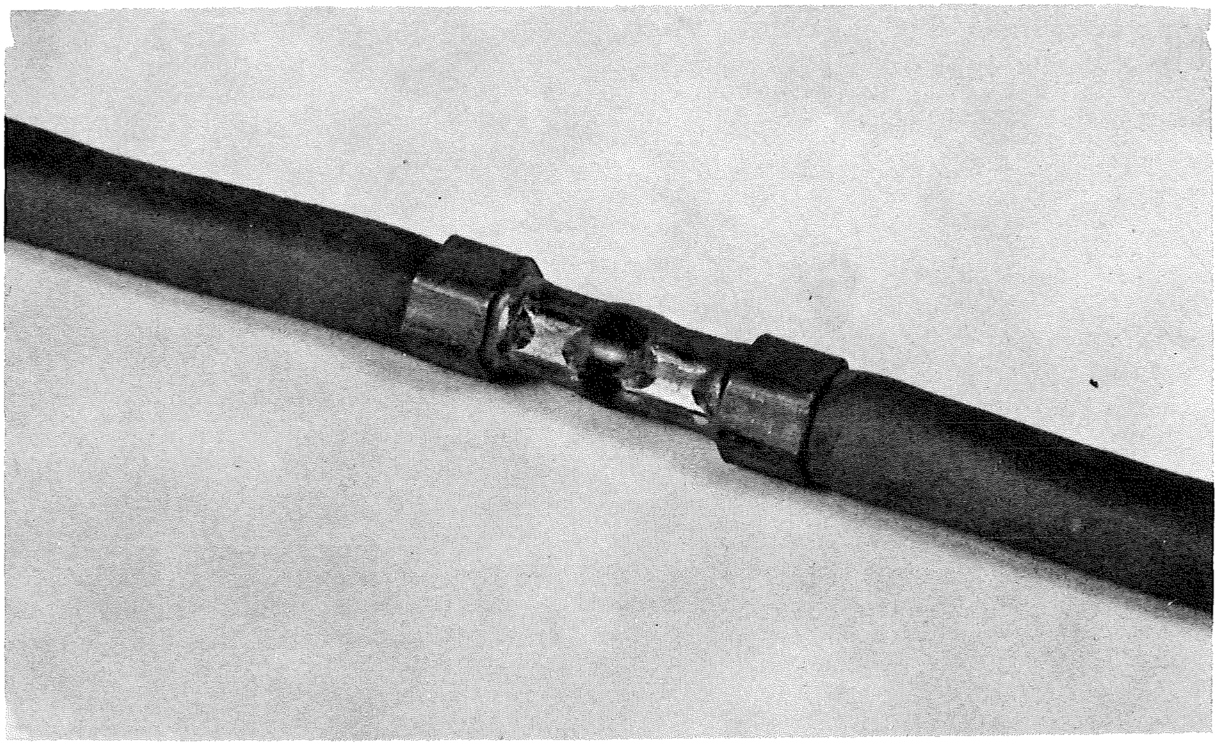


FIGURE 22

may relieve some of the conductor strand stress by transmitting the bending action to that part of the conductor which is insulated.

Since a modified crowsfoot joint is not suitable for a shroud because of the conductor-connector assembly sequence, the butt joint was used in this parameter investigation.

Flex cycle test results for different shroud lengths are shown in Table 'D'. The samples in Group 1 were extracted from Table 'B' (Group 2) for comparing connectors incorporating stress relief angles without shroud to the connector in Group 2 incorporating the same stress relief angle but with a shroud.

Since all connector crimp 'T' dimensions were equal, all percent compressions were equal. The 'T' dimension on the shroud represented a degree of compression necessary to grip the conductor insulation without overcompressing as would be indicated by longitudinal extrusion of the insulation. Figure 23 shows shroud-conductor cross section.

In comparing the shroud data of groups 2 and 3 (Table D) with that of no shroud group #1, no significant improvement in flex cycles is noticeable. In fact, the increased overall connector length resulting from the shroud may prove more of a liability. Because of this, the shroud as a significant contributory parameter was dropped.

SHROUD-CONDUCTOR CROSS SECTION

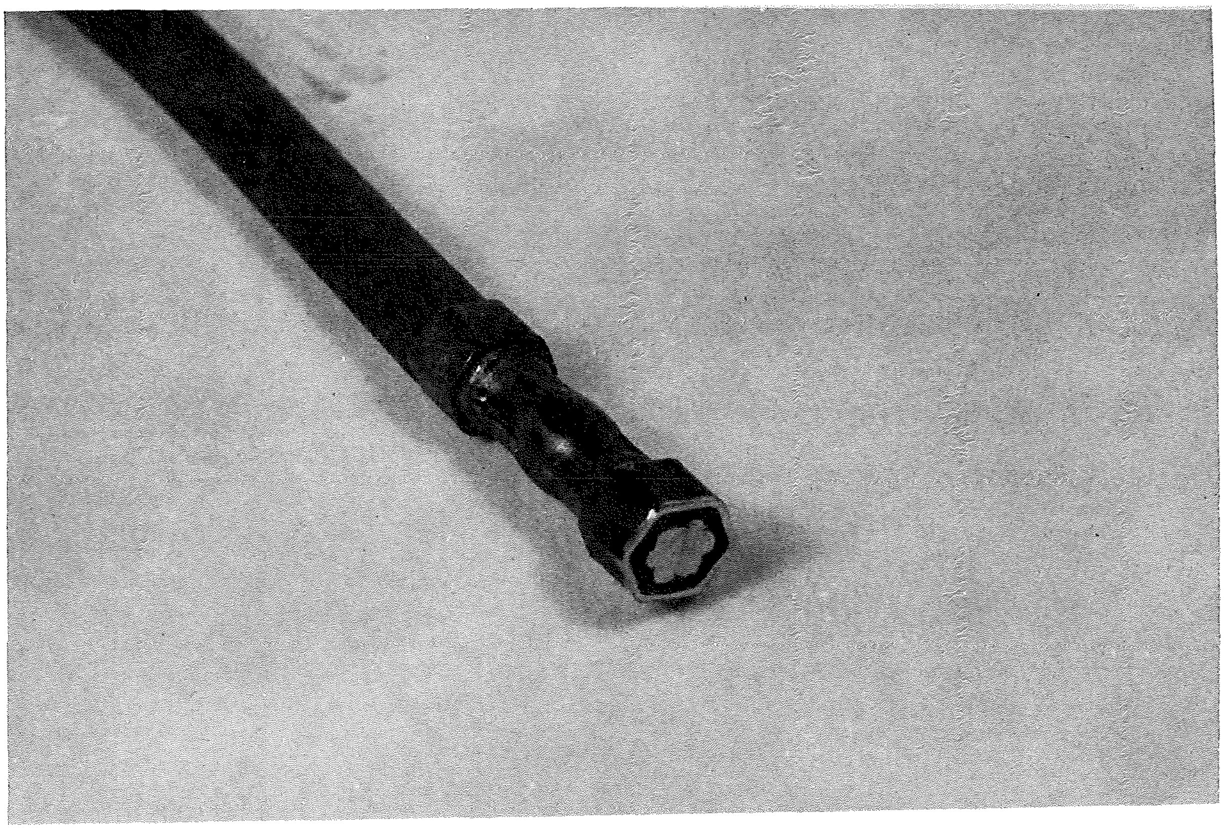


FIGURE 23

TABLE 'D'
SHROUD SUMMARY - BUTT JOINT
#4 259 STR CONDUCTOR

	Shroud Length in.	Stress Relief Angle	Crimp Contact Length	Shroud 'T' Dim	% Compression	Connector Overall Length	Flex Cycles
Group 1	None	16°	.100		(-) 7%	.811	3924
	"	"	"			"	3824
	"	"	"			"	3462
	"	"	"			"	3510
Group 2	.125	16°	.100	.396	(-) 7%	1.138	1238
	.187	"	"	"		1.254	2136
	.250	"	"	"		1.390	1246
	.375	"	"	"		1.628	1202
Group 3	.125	None	.100	.396	(-) 7%	.920	1238
	.250	"	"	"		1.182	3582
	.375	"	"	"		1.438	1456

#2 STR CONNECTOR PARAMETER DEVELOPMENT

Following a similar design approach, a #2 str modified crowsfoot connector was developed. It should be noted that some differences do exist between design parameters developed for the #4 str and the #2 str. Table 'E' shows a comparison of the optimum parameters. Where the parameter remains constant for both conductor sizes, it is felt that these will also remain constant for other conductor sizes. Where differences occur (crimp contact length and per cent compression) extrapolation is not advised in the development of other size connectors. Instead the development procedures outlined in Appendix I "How to Design" are recommended.

Table 'F' shows flex life and pullout test results on the #2 str modified crowsfoot connector design.

TABLE E

OPTIMUM PARAMETER COMPARISON

PARAMETER	#4 STR	#2 STR
JOINT TYPE	MODIFIED CROWSFOOT	MODIFIED CROWSFOOT
Connector Cross Section	1.75 X Cable Cross Section	1.75 X Cable Cross Section
Tool Max Crimping Force	9000 pounds	9000 pounds
Connector Metallurgy	Copper Annealed	Copper Annealed
Crimp Profile	Hex	Hex
Crimp Stress Relief	10°	10°
Crimp Contact Length	.150	.250
Percent Compression	+4.5% (Above solid)	+13% (Above solid)

TABLE 'F'

#2 STR MODIFIED CROWSFOOT CONNECTOR
PERFORMANCE SUMMARY

	Crimp Contact Length	Percent Compression	Stress Relief Angle	Flex Life		Pullout	
				Cycles	Summary	Pounds	Summary
Group #1	.250	+ 13% (Above Solid)	10°	1674 2208 2056	1953 Av. 1941 Median 534 Spread	1360 1315 1265	1313 Av. 1312 Median 95 Spread

SECTION VI

FIELD TESTING

A field test program was instituted for the purpose of determining the suitability of the developed connectors and their associated installation tooling for use in a mine environment. Also, an effort was made to monitor field connector performance for the purpose of confirming laboratory findings.

A mine located near Ebensburg, Pa. was selected for the field trials. The test plan was as follows:

1) #4 Str. and #2 Str. connectors incorporated the optimum design parameters listed in Table E (also see Figures 24, 25, 26)
2) #2 size connectors were tested in the South Mine and the #4 size connectors in the North Mine.
3) Installations were made on two shuttle cars in each mine.
4) A Burndy MD6-6 installation tool equipped with the proper crimping dies was used. (see Figure 27)
5) In order to minimize variables, the test cable used was from the same manufacturer as was used throughout the laboratory program.
6) Test cable lengths were approximately 100 feet long and were permanently spliced in the standard mine cable approximately 150 feet from the load center end. It was felt that this positioning would result in the most paying out and backspooling action.
7) All test cable was of the two conductor type without ground.

#4STR DESIGN PARAMETERS

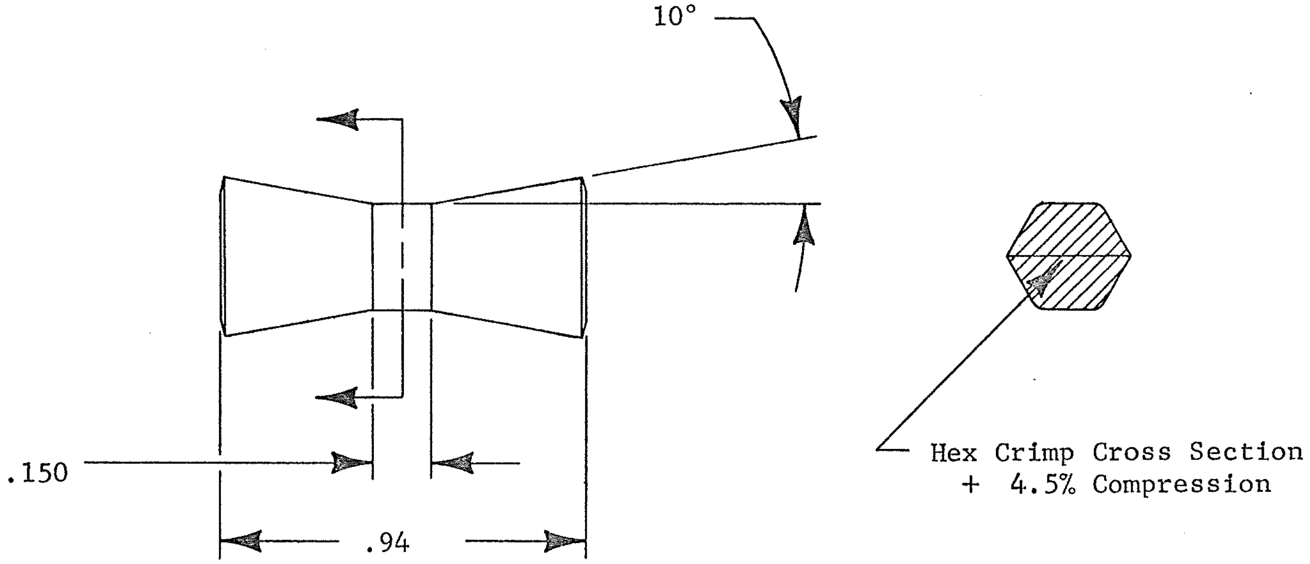


FIGURE 24

#2STR DESIGN PARAMETERS

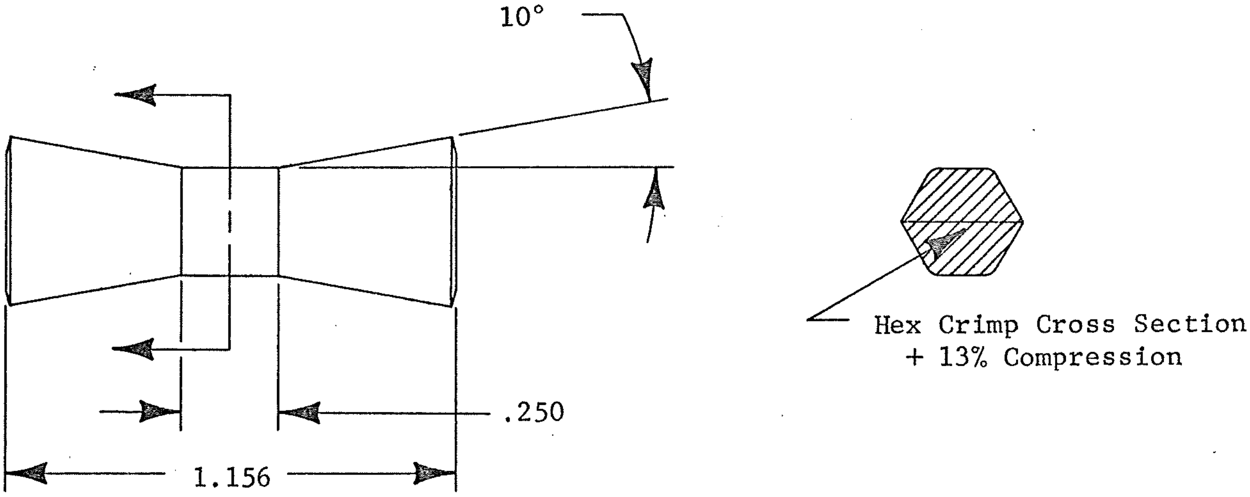


FIGURE 25

#4STR & #2STR TEST CONNECTORS

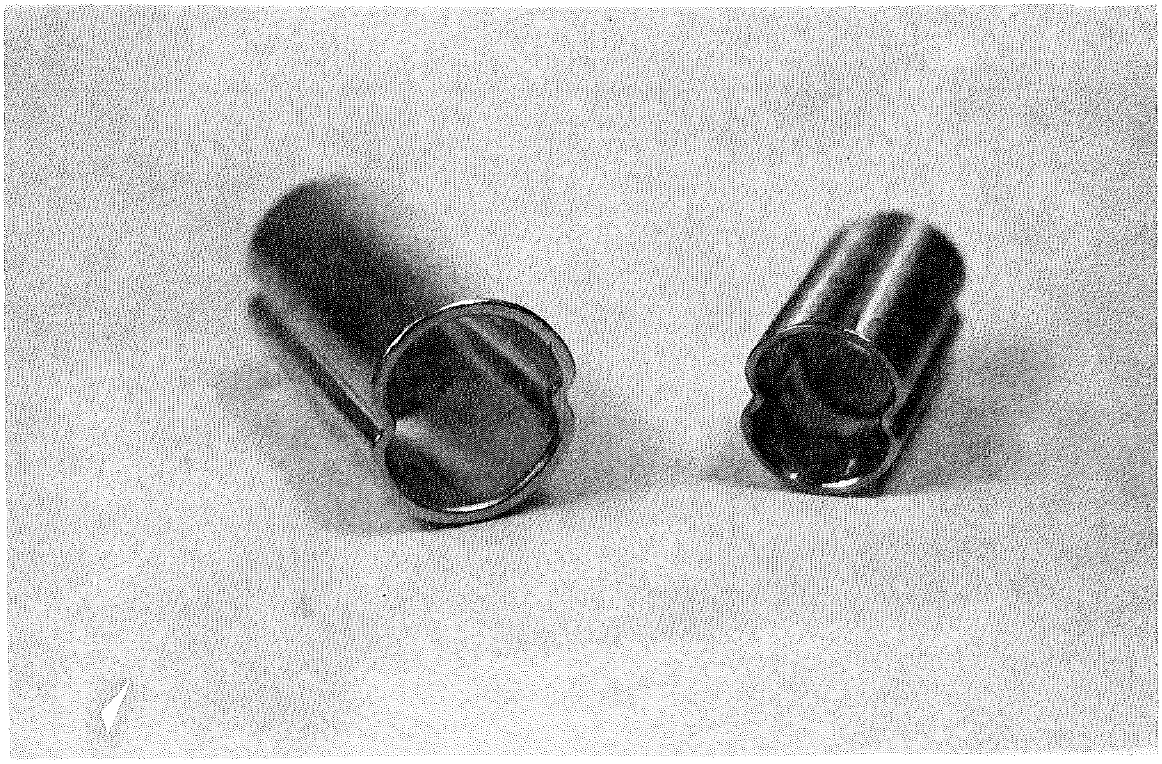


FIGURE 26

MD6-6 INSTALLATION TOOL

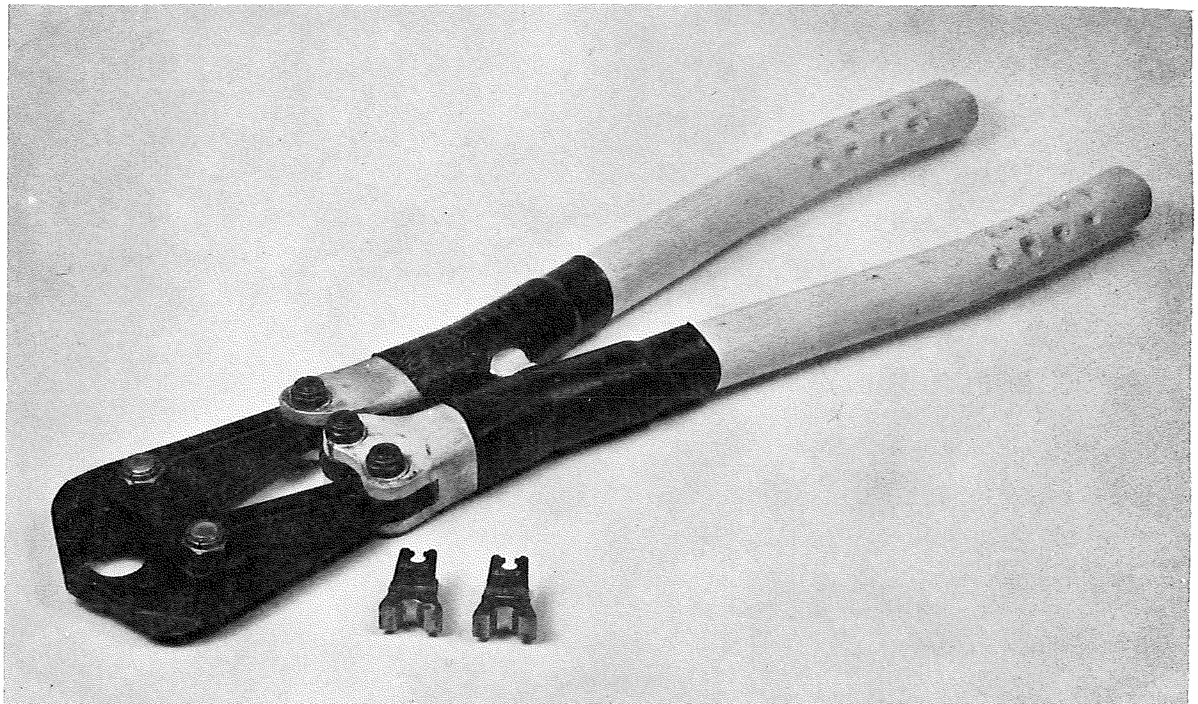


FIGURE 27

8) Since this mine used a cold splice insulation kit, this same kit was used to insulate all test splices.
9) Splices were made above ground in workshop like conditions, as well as underground in what was considered a severe environmental condition. (42" seam height with wet and muddy floors)

Over 100 connector installations (both #4 and #2 str.) were made during this test program. This included training of the mine mechanics in the proper use of the connectors and installation tool. As a result, it is felt that the developed connectors and installation tooling is suitable for trailing cable splicing.

It should be noted that an attempt to accurately correlate field test results with laboratory work proved unsuccessful due to the following reasons:

1) Difficulty in accurately monitoring splice longevity.
2) Difficulty in controlling connector installation technique which can also result in a very wide spread of results.
3) Difficulty in controlling insulation technique which can also result in a very wide spread of results.
4) The type of insulation used may not produce maximum splice life.

However, from the performance data gathered it is concluded that when the proper installation procedure is followed, a significant increase in splice longevity may be expected. Appendix II describes the connector installation procedure recommended during this test program.

The insulation procedure described in this appendix is one that the mine was familiar with and used throughout the test program. Its inclusion in this report does not constitute a recommendation as a means for obtaining maximum splice life.

SECTION VII

CONNECTOR PARAMETER DEVELOPMENT CONCLUSIONS

1. Based on the connector design parameter study, the modified crowsfoot connector design was selected as the optimum type connector for the following reasons:

   1.1 Shortest overall length (conducive to good flex life).

   1.2 Less compression required to obtain minimum pull out requirements (also conducive to good flex life).

   1.3 One crimp to make complete installation (facilitates easy field installation).

   1.4 Easy threading of connector on conductor. (Facilitates easy field installation.)

   1.5 Easy longitudinal alignment of conductors for tensile load equalization (conducive to good flex life and easy field installation).

   1.6 Electrical tests indicate relative resistance levels less than 100% which means the connections result in resistances less than equivalent lengths of conductor. Heat run tests also indicate connector temperatures equivalent to or less than conductors at 60°C, 75°C and 90°C levels.

In addition, the modified crowsfoot connector design appears to be less sensitive to pullout performance changes as a result of different manufacturers' conductors as discussed in the section entitled "Other Factors Affecting Splice Performance".

2. Based on the design procedures outlined in this report, a minimum pull out requirement of 650 pounds and a minimum flex life of 1500 cycles can be met for #4 strand applications. A 950 pound minimum pull out and a minimum flex life of 1500 cycles can also be obtained for #2 str applications.

Table 'G' shows typical flex and pull out values. The flex values represent an improvement by at least a factor of three over present commercially available connectors and square knot method. The pull out values meet proposed requirements not consistently achieved by any of the commercially available connectors tested.

TABLE 'G'

MODIFIED CROWSFOOT CONNECTOR
PERFORMANCE SUMMARY

	Connector Developed Per Contract		Commercially Available Connectors		Square Knot	
Size	Flex Cycles	Pullout-Lbs	Flex Cycles	Pullout-Lbs	Flex Cycles	Pullout-Lbs
#4	3642 Av.	1070 Av.	968 Typical	562 Typical	798 Typical	719 Typical
#2	1953 Av.	1313 Av.	1286 Typical	1362 Typical	464 Typical	1065 Typical

3. As a result of the design parameter study, Appendix I lists a step by step connector design procedure. It must be noted that in addition to this procedure, final design approval must be dependent on the following performance tests:

Pullout
Flex life
Relative Resistance
Heat Run

Variations in contact lengths from those listed in this report may be acceptable providing that proper changes in compression are made to insure meeting the required performance criteria.

4. As a result of the laboratory testing on flex life and pullout, Figure 28 shows a matrix of connector design parameters and the effect of one parameter by varying the other. This comparison is the result of an analysis of the connector design parameter study.

5. Field tests indicate the connector and associated installation tooling to be suitable for installation in a mine environment. Field tests also indicate that proper installation techniques as described in Appendix II should result in a significant improvement in splice longevity and thus correlate with the laboratory work.

6. As a result of the laboratory work and field testing completed and in the interest of preserving the intent of this contract, the following minimum mechanical requirements extracted from Grant #GO-133077 are considered good and should be maintained. In addition, the minimum electrical requirements listed are also recommended as important design criteria.

	Mechanical Req'ts.		Electrical Req'ts.	
Size	Min. Flex Cycles	Min. Pullout Lbs.	Max. Relative Resistance	Heat Run
#4 Str	1500	650	100%	Note 1
#2 Str	1500	950	100%	Note 1

Note 1: Connector temperature must run equal to or cooler than the conductor temperature at rated current levels when tested in a controlled environment.

FIGURE 28

	VARYING PARAMETERS											
Constant Parameters	Connector cross section	Crimping force	Connector metallurgy	Joint type	Conductor overlap	Insulation strip distance from connector	Crimp contact length	Percent compression	Crimp profile	Crimp stress relief	Flare angle	Shroud
Connector cross section	X	N	P	P	N	N	N	P	P	N	N	N
Crimping force	P	X	P	P	N	N	P	P	P	P	N	N
Connector metallurgy	P	P	X	N	N	N	P	P	P	P	P	P
Joint type	P	P	P	X	P	P	P	P	P	P	P	N
Conductor overlap	N	N	N	P	X	P	P	N	N	N	N	N
Insulation strip distance from connector	N	N	N	P	N	X	N	N	N	N	N	P
Crimp contact length	P	P	P	P	P	N	X	P	P	P	N	N
Percent compression	P	P	P	P	N	N	P	X	P	N	N	N
Crimp profile (geometry)	N	P	P	P	N	N	P	P	X	N	N	N
Crimp stress relief	P	P	P	P	N	N	N	P	P	X	N	N
Flare angle	N	N	P	P	N	N	N	N	N	P	X	Note 3
Shroud	N	N	P	P	N	P	N	N	N	N	Note 3	X

NOTES

1) P means constant parameter will probably be affected by a change in varying parameter.
2) N means constant parameter will probably not be affected by a change in varying parameter.
3) Does not apply.
4) A change is defined as affecting flex life, pullout, electrical resistance or combination of.
5) Fixed dimension crimp tooling assumed (not pressure sensitive).
6) Crimp profile refers to different plane geometrical shapes (not similar shapes).

SECTION VIII

OTHER FACTORS AFFECTING SPLICE PERFORMANCE

As previously mentioned the scope of this contract only covered a study to develop optimum design parameters for splice connectors. However, cursory examinations not covered by the scope of this contract have resulted in uncovering other areas of splice design which may have equal importance on splice longevity (flex and pullout) as does the connector design. These areas include the following:

1. Performance differences between cable manufacturers: As previously stated, one cable manufacturer was used throughout the design parameter study in order to minimize variables. Supporting this practice were the significant differences in pullout values noted when using different manufacturers'conductors. Differences varied by at least a factor of 3 with all other design parameters equal.

2. Installation Method: Although all studies were run on core conductors, some flex tests were run on complete cables (2 core conductors). Extremely wide variations in results were obtained leading us to believe that equalization in tensile loading of the individual conductor is important for maximum flex life of the complete splice. This was substantiated by running flex tests on single core

conductors with test tensile loads of 175 pounds (for total cable p174 Grant No. GO-133077) instead of 100 pounds for single core conductor. The higher tensile loads resulted in lower flex life by a factor of approximately three, indicating the need for conductor tensile load equalization when making complete cable splices.

3. Insulation Components: Cursory flex life tests on completely insulated cable splices indicate that the type of insulating means used can either significantly deteriorate or significantly enhance splice flex life. This applies to the insulation of the individual core conductors as well as the overall insulation of the completed splice. Varying the types of insulation, while holding all connector design parameters equal, and carefully assuring tensile load equalization between core conductors during installation, resulted in a wide variation of flex life. This indicates the importance of selecting insulation components that will provide maximum flex life.

Although these investigations were by no means of a comprehensive nature, they do illustrate the importance of additional splice parameters. It is also evident that any one or combination of these areas will have a profound effect upon a MESA testing procedure. Because of this, it is felt consideration should be given to the undertaking of indepth studies on these important parameters which were not part of this contract.

APPENDIX I

SUGGESTED "HOW TO" DESIGN PROCEDURE

As a result of the connector design parameter study the following example is offered as a guide on a design procedure to meet pullout requirements while achieving maximum flex life and stable electrical performance. Pullout flex and resistance tests must be run to insure a properly designed connector.

Problem: Design a splice connector for #1 strand mine cable. 1500 minimum flex cycles and 1300 pounds minimum pullout (requirements as listed on p174 & 175 Grant No. GO-133077).

Step #1: List optimum parameters:

Connector Type - Modified Crowsfoot
Connector Metallurgy - High Conductivity Annealed Copper
Crimp Profile - Hexagon
Crimp Stress Relief - Between 10° & 20°
Connector Cross Section - 1.5 to 2.0 x cable cross section

Step #2: Develop connector cross section

Connector cross section = 1.5 to 2.0 x #1 strand conductor cross section (Ref. Step #1)

Step #3: Develop Connector ID. This is done by arranging the conductors in a modified crowsfoot joint and measuring the resulting O.D. with a caliper or similar measuring device. The I.D. should only be large enough to allow the connector to slip over the conductors. Excess clearance will result in a larger connector O.D. The appropriate 'IPCEA' specification should also be consulted for conductor dimensional information.

Step #4: With I.D. and connector cross section known, O.D. can be derived from the following relationship:

$$A = \pi/4\ (D^2 - d^2) \quad *$$

Where:

A = Connector cross section in sq. inches

d = Connector I.D. in inches

D = Connector O.D. in inches

Step #5: Percent compression

Work under the contract has indicated maximum flex life performance obtained with the following percent compressions:

#4 str - (+) 4.5%

#2 str - (+) 13%

With only these two reference points, extrapolation is not recommended, however, since the #1 strand conductor under consideration is close in dimension to #2 strand, a percent compression value in the area of 13% is considered a good starting point. Since our work indicates less compression is likely required as conductor size increases, a value of 15% is selected as a good start for the #1 strand conductor.

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Step #6: Design crimped cross section and crimping die profile

6.1 Add the copper cross section of two #1 strand conductors. (2 conductors are crimped together in a modified crowsfoot joint) to the connector cross section.

I.E. Conductor + connector = total copper cross section.

6.2 Calculate 15% larger than total copper cross section. This is the required crimped cross sectional area which should be used in conjunction with the desired crimp profile.

6.3 Since a hex crimped profile has been previously selected, the following relationships may be used to calculate the hex crimped cross section and in turn the required hex crimping die:

$$S^2 = \frac{A}{2.598} \quad *$$

Where:

A = required crimped cross sectional area

S = side of hex

$$r = .866S \quad *$$

Where:

S = side of hex

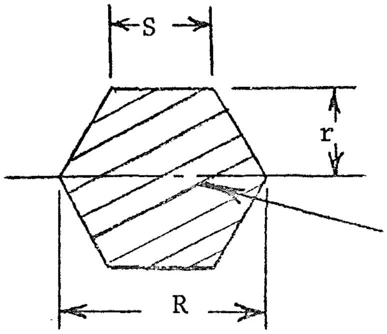
r = 1/2 of across flat dim. ('T' dimension)

$$R = 2\left(\frac{r}{.866}\right) \quad *$$

Where:

r = 1/2 of across flats dim.

R = Across corners dim.



Required Crimped Cross Sectional Area

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Step #7: Crimp contact length

Work under this contract has resulted in crimp contact lengths of .150 and .250 for #4 strand and #2 strand conductors respectively. Extrapolation of this information to the #1 strand conductor size under consideration has questionable reliability due to the change in percent compression between conductor sizes and only having two reference points from which to extrapolate. However, it has been found that utilization of a direct proportion of pullout requirements to contact length will give a good starting point.

I.E. $\frac{.250}{950} = \frac{X}{1300}$

Where:

.250 = #2 strand contact length developed per contract

950 = pounds pullout requirement for #2 strand

1300 = pounds pullout requirement for #1 strand

Step #8: Crimping Force

As previously mentioned, the scope of this contract did not include development of installation tooling. Existing suitable Burndy tools were used throughout the laboratory and field test program. However, these were selected on the basis of their known output or crimping forces (9000 pounds) and the compressive strengths of the connector and conductor combination. This same procedure should be used when selecting appropriate tooling for installing the #1 strand connector under consideration. By utilizing the simple stress relationship P= AS (P= tool output force, A = crimp plane area, S = connector/conductor compressive strength), the crimp contact length and number of crimps can be varied for a given tool output force.

Step #9: Stress relief angle. Stress relief angles were derived on both #4 and #2. Similar work should prove acceptable on the #1 str conductor. The stress relief should originate from the compressed cross section and run for a length until meeting the I.D. of the connector (resulting in zero stress).

Step #10: The proposed connector should first be subjected to pullout tests. If necessary, crimp contact length and/or percent compression should be altered so that the minimum pullout required can be consistently met. Excessively high pullouts must be avoided in order to minimize over compression and maximize flex life; the objective being to minimize contact length and percent compression as much as possible.

Step #11: After acceptable pullout, the connector is now subjected to flex testing. As mentioned in the section Development of a Test Procedure, flex testing should be done on single core conductors and the connector should not be insulated. This will minimize variables, making analysis of results more accurate.

Step #12: When acceptable pullout and flex life is obtained, the installed connector should be subjected to a resistance test and relative resistance computed. Relative resistance levels of 100% or less are considered acceptable. (See Development of a Test Procedure)

Step #13: Installed connector should be subjected to a heat run test to insure that the connection will run at a temperature level equal to or cooler than an unconnected conductor. (See Development of a Test Procedure)

In summary, the design of an optimum performing connector for trailing cable applications is the judicious balance of design parameters which will provide the minimum pullout required consistently. This coupled with the proper stress relief and shortest possible connector overall length will provide maximum flex life and optimum splice longevity.

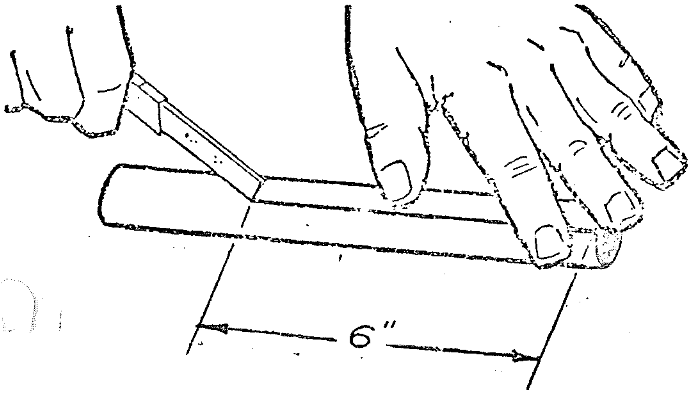
APPENDIX II

MINE SPLICE INSTALLATION INSTRUCTIONS
4-2 CONDUCTOR W FLAT

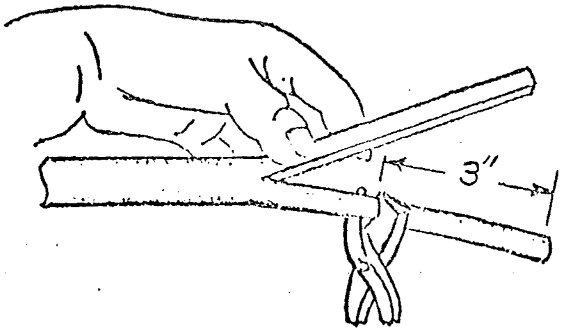
1. CUT OUT DEFECTIVE AREA COMPLETELY.

2. SLIDE INSULATING OUTER JACKET OVER END OF ONE CABLE, AWAY FROM WORK AREA.

3. CUT BOTH ENDS OF CABLE DOWN CENTER FOR A LENGTH APPROXIMATELY 6"
<u>IMPORTANT</u>: DON'T CUT INTO CONDUCTORS.

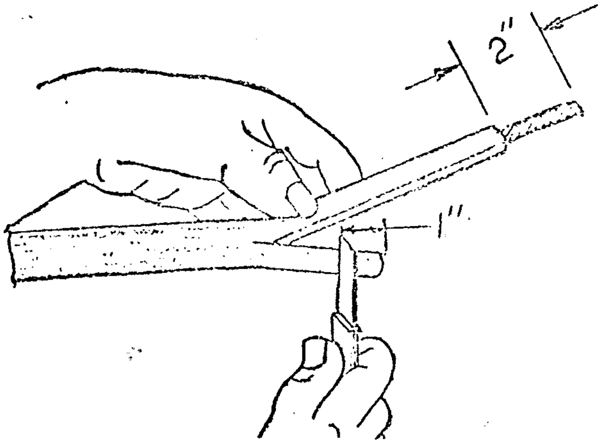


4. CUT WHITE CONDUCTOR BACK APPROXIMATELY 3" AND SAVE CUT OFF PIECE.

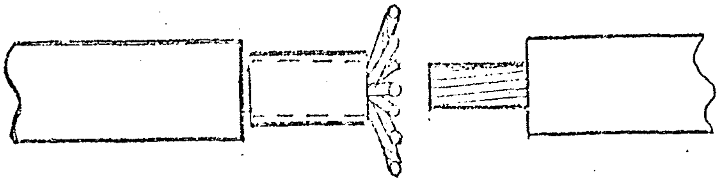


5. USING CUT PIECE FROM STEP (4) AS GAGE, CUT OFF BLACK CONDUCTOR ON OTHER CABLE END.
<u>IMPORTANT</u>: BLACK PIECE OF CUT CONDUCTOR MUST BE EQUAL IN LENGTH TO WHITE PIECE TO INSURE EQUAL TENSILE LOADING OF BOTH CONDUCTORS WHICH IS IMPORTANT TO SPLICE LIFE.

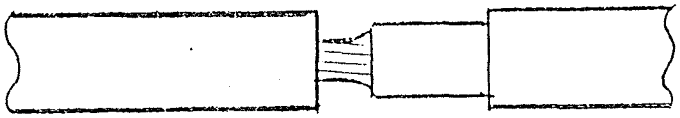
6. REMOVE INSULATION FROM THE LONG CONDUCTOR ENDS FOR 2" AND FROM THE SHORT CONDUCTOR FOR 1".
<u>IMPORTANT</u>: DON'T CUT ALL THE WAY THROUGH INSULATION TO PREVENT CONDUCTOR DAMAGE. FIRST CIRCLE CUT AND THEN WITH PLIERS TEAR OFF THE INSULATION SO THAT IT COMES OFF IN ONE PIECE.



7. PUT <u>BURNDY</u> CONNECTORS ON LONG CONDUCTORS AND SPREAD OUT THE 7 ROPES INTO "CROWS FOOT".



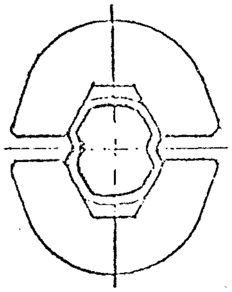
8. PUSH SHORT CONDUCTOR FROM OTHER CABLE INTO CROWS FOOT AND SLIDE CONNECTOR AND THE ROPES OF THE LONG CONDUCTOR ALL THE WAY OVER AGAINST THE INSULATION OF THE SHORT CONDUCTOR. REPEAT WITH OTHER COLOR CONDUCTORS.
<u>NOTE</u>: CONNECT BLACK TO BLACK AND WHITE TO WHITE.



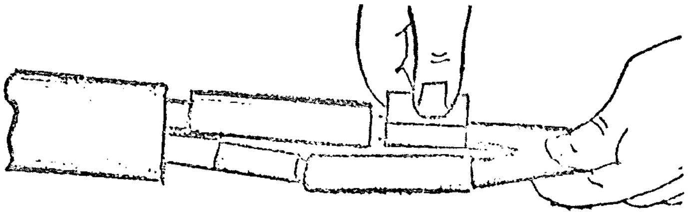
9. CRIMP CONNECTORS MAKING CERTAIN THE STRANDS OF THE LONG CONDUCTOR BUTT AGAINST THE INSULATION OF THE SHORT CONDUCTORS.

IMPORTANT

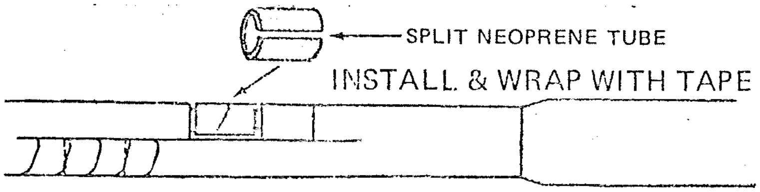
POSITION CONNECTOR IN CRIMPING TOOL SO THAT DIMPLES ARE PARALLEL TO CRIMPING-DIE BUTTING-SURFACE AS SHOWN.



10. USING SELF VULCANIZING TAPE WRAP ENOUGH AROUND THE EXPOSED BARE CONDUCTOR TO MAKE IT EVEN WITH THE OUTSIDE DIAMETER OF THE CRIMPED CONNECTOR.



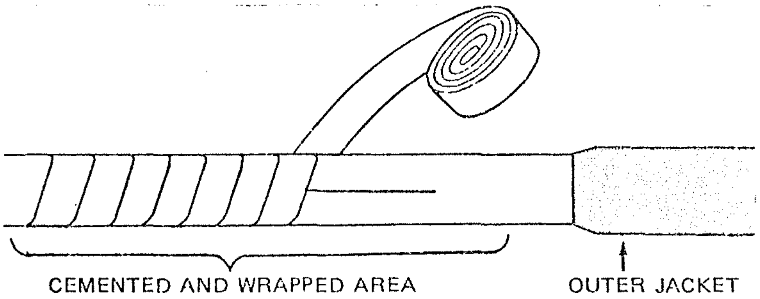
11. CUT SPLIT NEOPRENE TUBE (INSULATION) TO PROPER LENGTH TO FIT OVER CONNECTOR & TAPED CONDUCTOR. APPLY 1 OR 2 WRAPS OF TAPE TO KEEP TUBE IN PLACE.



12. CLEAN CABLE JACKET WITH CABLE CLEANER AND ROUGHEN ENDS OF CLEANED CABLE JACKET WITH ABRASIVE CLOTH AND REMOVE LOOSE MATERIAL.

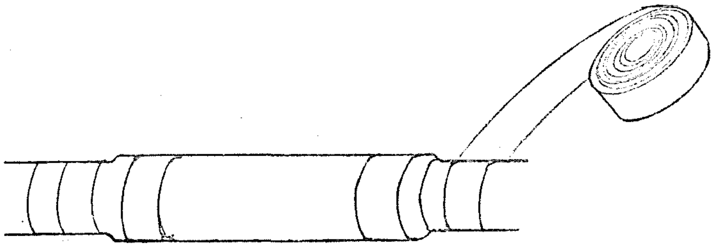
13. APPLY A LIGHT COAT OF CEMENT ON THE CABLE SPLICE AREA SLIGHTLY LONGER THAN THE LENGTH OF THE OUTER JACKET. ALLOW TO DRY UNTIL TACKY (APPROXIMATELY 1 1/2 MINUTES).

14. APPLY A LAYER OF RUBBER TAPE OVER THE CEMENTED SPLICE AREA, SLIGHTLY LONGER THAN THE OUTER JACKET. WRAP TAPE TOWARDS OUTER JACKET, AS ILLUSTRATED. APPLY A DOUBLE LAYER OF TAPE APPROXIMATELY 2" WIDE IN AREA WHERE THE ENDS OF THE OUTER JACKET WILL BE POSITIONED IN THE COMPLETED SPLICE. (THIS INSURES A GOOD SEAL).



15. APPLY A HEAVY COAT OF THE RUBBER SPLICING CEMENT OVER THE TAPED AREA.

16. IMMEDIATELY SLIDE OUTER JACKET IN PLACE BY GRASPING END OF JACKET AWAY FROM SPLICE AREA AND PULLING JACKET INTO POSITION. CEMENT AND TAPE ENDS OF SPLICE TO EXCLUDE DIRT AND MOISTURE.



17. THE SPLICE IS COMPLETE AND READY FOR IMMEDIATE USE.