Solderless Wrapped Connections

PART III — EVALUATION AND PERFORMANCE TESTS

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In the development of solderless wrapped connections the basic requirements of electrical and mechanical stability have been trans'ated into test requirements on laboratory samples of these connections and on the manufactured product. These tests have shown that the connections can withstand satisfactorily the effects of corrosion, humidity, vibration, and relaxation. The effects of terminal dimensions, materials, corner sharpness. wrapping tool construction, etc. are noted.

INTRODUCTION

The previous two articles have described the fundamental considerations involved in solderless wrapped connections. A description of these connections together with a rather detailed explanation of the forces which maintain them has been presented. This third article discusses the results of a number of tests where the actual fabrication and use of these connections have been simulated. From these results it will be seen that reliable performance can be expected over the central office life of these connections, and that the variations permissible in their fabrication will privide sufficient margin to make that process easy to control.

GENERAL REQUIREMENTS

The minimum physical requirements which a solderless wrapped connection must meet are:

1. Intimate contact between wire and terminal.
2. The points of contact should be gas-tight to withstand corrosion.
3. The minimum dimension of the gas-tight area should be great enough so that it does not decrease appreciably during the expected

life (forty years) because of corrosion or because of relaxation of the internal stresses in the wire or terminal.

4. The sum of the areas of intimate contact should be equal to or larger than the cross-section of the wire to prevent local heating.

5. The connection should be mechanically stable so that forces applied to the connection during shipment, installation and subsequent maintenance activities will not dislodge the wire and break the points of intimate contact.

6. The wire should not be embrittled during the wrapping operation so that it will subsequently break due to vibration, handling, or unwrapping.

TRANSLATION OF GENERAL REQUIREMENTS INTO TEST REQUIREMENTS

In order to evaluate the feasibility of solderless wrapped connections, extensive development studies were necessary so that a good estimate could be obtained as to whether these connections would meet these general requirements under a wide variety of conditions and with sufficient margin to provide for ease of manufacture. It was necessary to translate these requirements first into a set of development test requirements and second into a set of shop inspection requirements. These two translations of requirements will not necessarily be the same although there will be a large degree of overlap. In either translation they can be broken down into two distinct areas. These two areas of tests cover those tests which are related to evaluating (1) life and electrical stability of the connection and (2) mechanical stability.

A great deal of engineering judgment was used in the translation of the physical requirements into inspection requirements and this judgment took into account the special nature of conditions to be encountered in telephone offices. Consideration was given to the methods of handling the wire, the manipulations of installation and maintenance men when working on central office equipment, the effect of vibration, the effect of variation in tool dimensions and the like. Furthermore, a good deal of knowledge of the corrosion and relaxation process had to be developed before it could be judged on the basis of accelerated tests that the connections might be expected to have a satisfactory field life.

There may be applications where the translation of the physical requirements into test requirements may be different, perhaps quite different, from the translation made for the telephone apparatus which was in mind during this investigation. The use of other kinds and sizes of wire or terminals may require an evaluation quite different from the one presented here. Nevertheless, the test requirements herein established should have a wide application in many areas. In telephone practice they provide a reasonable latitude for variations in the process of making the connection, including tolerances in the parts, and at the same time guarantee a good product.

Most of the product tests which have been made so far apply specifically to connections which use Standard No. 24 tinned solid copper wire such as is used in 95 per cent of the telephone switching plant, and terminals having a rectangular cross-section punched from sheet nickel silver, brass or bronze and whose dimensions are one-sixteenth inch wide by the thickness of the stock (0.013″ to 0.062″). These terminals are typical of those which are or could be used on relays, switches, resistors, capacitors, terminal strips, etc. Studies with #20 and #22 wire have been made with results similar to those with #24 wire.

A similar investigation is under way on connections to terminals which are made from round silicon copper and nickel silver wire such as are used on the wire spring relay, and where the wire terminal had been prepared for connection by various treatments such as flattening, coining, serrating, annealing, etc.

AGING OF WRAPPED CONNECTIONS

Assuming that a connection can be wrapped with sufficient mechanical strength to withstand handling, vibration, etc., there appear to be two factors which might cause the connection to fail after a period of time. These factors are (1) relaxation of the internal stresses in the metals, and (2) corrosion of the metal surfaces. As Mr. Mason points out in his paper, it now appears that solid state diffusion of metal across the boundary between the wire and the terminal improves the connection as much or more than relaxation degrades it. Tests have been designed to relax the connections in a short time to the same degree that will occur in the normal forty-year life which is required. These tests will be described later.

Several investigators have studied the rate of surface corrosion in indoor atmospheres of metals such as are used in these connections.

Studies of corrosion* where oxidation is the primary factor indicate for example that the corrosion in zinc varies linearly with time and on copper it varies as the square root of the time exposed. The corrosion products are ZnO and Cu_2O. The corrosion rate for brasses fall between

* British Non-ferrous Metals Research Association, Investigation on the Atmospheric Corrosion of Non-ferrous Metals, First and Second Experimental Reports to the Atmospheric Corrosion Resistance Committee, May, 1924, and May, 1927, W. H. J. Vernon.

TABLE I—THICKNESS OF MATERIAL WHICH CORRODES IN FORTY YEARS

Zinc	0.00023″
Copper	0.000105″
Tin	Negligible

copper and zinc. There are very few data available on tin but its corrosion should be less than either copper or zinc. From the data presented the depth of metal which will corrode during a forty-year period in a central office for several metals is estimated* to be as shown in Table I.

Samples of copper bus-bar taken from telephone exchanges where they have been exposed for periods up to forty years show that the tarnish is primarily Cu_2O and the actual rate of corrosion may be appreciably less than that estimated by the above figures.

Thus the depth of metal corroded is small enough to neglect when the metals are subject to indoor atmospheric exposure. When dissimilar metals are joined in a connection there is the possibility of electrolytic corrosion in addition to atmospheric corrosion. The particular metals involved here, however, are relatively close to each other in the electromotive force series of metals so that it is expected that this effect will be negligible especially as there is no condensation on these connections.

It is therefore expected that the most important factor in the aging of these connections is the relaxation of stresses internal to the wire and the terminal rather than corrosion. The test procedures and results in the following sections reflect that view.

DEVELOPMENT TEST PROCEDURE — ELECTRICAL REQUIREMENTS

General Requirements 1 through 4 are considered together. A set of tests has been designed to evaluate the degree to which these requirements can be met.

Since the tests which have been devised are destructive it is necessary to check connections in production on a sampling basis.

In determining whether a connection meets the General Requirements 1 through 4, Test Procedure I as follows was devised.

Test Procedure I for Solderless Wrapped Connections

1. Check connection for insulating barrier film between wire and terminal.

2. Measure the variation of the resistance of connection while producing movement between the terminal and connecting wire.

* Unpublished memoranda, D. H. Gleason, Bell Telephone Laboratories.

3. Chill for two hours at 0°F.
4. Heat for three hous at a temperature (175°C) which will relax the stresses as much as will occur during the expected life at the normal central office operating temperature.
5. Expose the connection to a suitable agent which will discolor all the non gas-tight area.
6. Remeasure the resistance variation as in 2.
7. Unwrap the wire and estimate the size of the gas-tight areas.

Items 1 and 2 are intended to show whether initially there is the intimate contact between wire and terminal demanded by the General Requirement No. 1. At present, the multiple terminal banks on step-by-step switches are connected together with a clinched solderless connection. Based on experience with these connections, together with an estimate of the noise produced (See appendix A) a resistance variation in excess of 0.002 ohms is considered to indicate a poor connection. Items 5 and 7 will show the existence of the gas-tight areas demanded by General Requirement No. 2, and the size estimate from Item 7, the area of contact demanded by General Requirement No. 4 can be evaluated. Items 3 and 4 are intended to simulate most of the aging which will take place during the life of the connection. It is believed, as described earlier in this paper, that relaxation of internal stress is the chief factor in the aging of these connections. The chill at 0°F puts the maximum initial stress in the wire by shrinking it at extreme operating

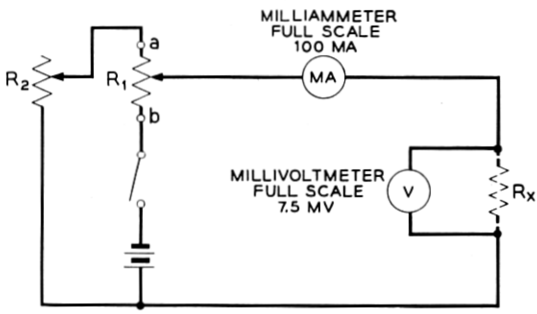

Fig. 1 — Test set for measuring resistance of solderless connection.

TEST PROCEDURE

(1) With R_1 set at "a" and switch SW closed, adjust R_2 so that the millivoltmeter reads 25 microvolts with R_x open.

(2) If millivoltmeter returns to zero with test connection across R_x, no barrier film is indicated and therefore connection is closed.

(3) All resistance measurements are made with R_1 set to give 100 milliamperes through R_x. Then R_x = millivolts/0.100.

(4) A variation of not more than 2 milliohms as the connection is moved or disturbed indicates a stable connection.

temperatures. The heating for three hours at 175°C produces the degree of relaxation expected over a 40-year period. By examining and estimating the size of the gas-tight areas after this process, the necessity for maintaining the intimate minimum gas-tight area demanded by General Requirement 3 is considered to be met. Item 6, the remeasurement of resistance is further confirmation of proper performance after relaxation.

For the measurement of resistance, and barrier films a circuit is used as shown on Fig. 1. With R_1 set at "a," R_2 is adjusted so that the voltage of about 25 microvolts is applied across R_x before the connection to be measured is inserted. This voltage is low enough to insure the absence of a film and at the same time gives a convenient reading on the test set. If the millivoltmeter drops to approximately 0 when the connection is inserted it indicates that no barrier film exists at the connection. The current is then increased to 100 milliamperes by means of the potentiometer, R_1, and the resistance is determined from the millivoltmeter reading. Since most of the measured resistance is in the wire rather than in the connection the important criterion of quality is the variation in resistance as the wire is moved relative to the terminal. If the variation in resistance of the connection does not exceed two milliohms when the wire is moved back and forth the connection is considered to be

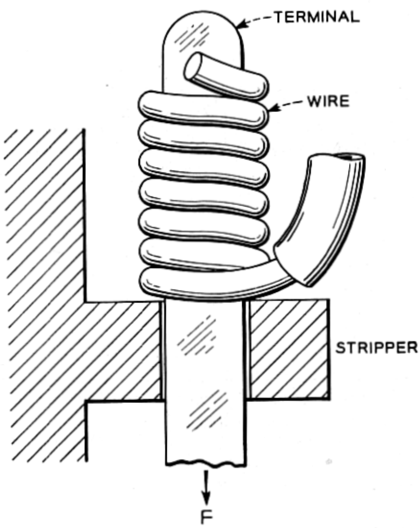

Fig. 2 — Stripping force test for solderless connection. (1) The connection shall consist of six turns minimum of which at least four are close wound. (2) The connection shall be capable of withstanding a stripping force, F, of at least 3000 grams applied as shown. (3) The wire shall be capable of being unwrapped from a terminal without breaking.

stable and the requirement for intimate contact between wire and terminal is considered met. In a typical local talking circuit this amount of resistance variation would correspond to a noise level of approximately -8 db where 0 db equals 10^{-12} watt and where anything less than $+26$ db would give no noise transmission impairment (See Appendix A).

DEVELOPMENT TEST PROCEDURE — MECHANICAL REQUIREMENTS

In determining whether a connection meets the General Requirements 5 and 6, Test Procedure II as follows was devised:

1. The connection shall be capable of withstanding a stripping force of 3000 grams applied as shown in Fig. 2.

2. The wire shall be capable of being unwrapped from a terminal without breaking.

These items are related directly to General Requirements 5 and 6. Experience has shown that under ordinary conditions of handling of connections as cables and frames are wired in the shop, or when a second connection is being made on an already wired terminal, a resistance to stripping in excess of about 3000 grams is required if the demands of General Requirement 5 is to be met. To insure adequate mechanical strength and current carrying capacity, a minimum of six turns is required. If the turns are close wound the strip-off force is readily met. If they are open wound they may strip off with a much lower force.

When the edge radius R (Fig. 3) of the wrapping tool is too small very high tension can be developed in the wire while wrapping. At very small radii the tension can be sufficient to break the wire. Although wrapping with high tensions in the wire produces a connection which will sustain very high stripping force, the wire is so embrittled that

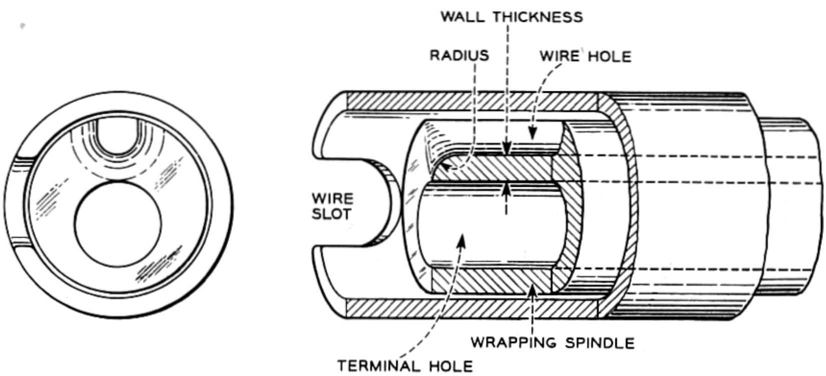

Fig. 3 — Solderless connection wrapping tool.

TABLE II — SOLDERLESS WRAPPED CONNECTION HUMDITY AND CORROSION EXPOSURE TESTS

Test Specimens					Exposure							Result
Terminal		Wire	No. of Wraps	Average Stripping Force	No. of Samples	Vibration	0° F.	180° F.	Corrosive Agent	Hours In Corrosive Agent	Months at 85°F 90% Rel. Humidity	Number of Connections Where Resistance Exceeded 0.002 Ohms
Material	Size											
	Inches	*Size*				*Hours*	*Hours*	*Hours*		*Hours*	*Month*	
Untinned brass	0.030 × 0.090	24 tinned	6	High†	24	50*	2	2	H_2S	½	21	None
	0.040 × 0.040	24 tinned	6	High	60	50	2	2	H_2S	½	7½	None
	0.020 × 0.060	24 tinned	6	High	60	50	2	2	H_2S	½	7½	None
	0.030 × 0.030	24 tinned	6	High	60	50	2	2	H_2S	½	7½	None
	0.040 × 0.090	24 tinned	6	High	48	50	2	2	H_2S	½	21	None
Brass-nickel plated and tinned	0.013 × 0.062	24 tinned	3	Low†	25	0	2	2	H_2S	½	9	25
	0.013 × 0.062	24 tinned	4	Low	25	0	2	2	H_2S	½	10½	5
	0.013 × 0.062	24 tinned	5	Low	25	0	2	2	H_2S	½	10½	1
	0.013 × 0.062	24 tinned	6	Low	25	0	2	2	H_2S	½	10½	None
Brass-nickel plated and tinned	0.013–0.031 × 0.047	24 tinned	6	High†	60	0	2	2	H_2S	½	15	None
	0.031 × 0.062	24 tinned	6	Low†	25	0	0	0	—	0	9	None
	0.031 × 0.047	24 tinned	6	Low	20	0	0	0	—	0	9	None
	0.031 × 0.062	24 tinned	6‡	5000 grams	25	0	0	0	—	0	9	None
	0.013 × 0.125	24 tinned	6	3100 grams	10	50	2	2	H_2S	½	2	None
	0.031 × 0.125	24 tinned	6	3400 grams	10	50	2	2	H_2S	½	2	None
	0.013 × 0.125	24 tinned	6	2100 grams	10	50	2	2	H_2S	½	2	None
	0.031 × 0.125	24 tinned	6	2600 grams	10	50	2	2	H_2S	½	2	None
	0.031 × 0.125	24 tinned	6	1800 grams	10	50	2	2	H_2S	½	2	None
Brass-nickel	0.020 × 0.063	24 tinned	6	7700 grams	50	50	2	2	H_2S	½	½	None

nickel silver												
Untinned nickel silver	0.035 × 0.125	22 tinned	4	4000 grams	5	0	2	2	HCl	⅔	10	None
	0.035 × 0.125	22 tinned	4	4000 grams	5	0	2	2	SO_2	⅔	10	None
	0.035 × 0.125	22 tinned	4	4000 grams	10	0	2	2	—	0	10	None
	0.040 × 0.125	22 tinned enameled	4	5400 grams	10	0	2	2	H_2S	½	6½	None
	0.040 × 0.125	20 tinned enameled	4	High†	10	0	2	2	H_2S	½	6½	None
Steel-tin plated	0.035 × 0.125	22 tinned	4	Low†	50	0	2	2	H_2S	½	6½	None
Wire spring relay single wire	Flattened and solder dipped	24 tinned	6	3700 grams	25	0	2	2	H_2S	½	12	None
	Diamond shaped and solder dipped	24 tinned	6	4400 grams	25	0	2	2	H_2S	½	12	None
Twin wire	Solder dipped only	24 tinned	6	3700 grams	25	0	2	2	H_2S	½	12	None
	Diamond shaped and solder dipped	24 tinned	6	4400 grams	25	0	2	2	H_2S	½	12	None

* This was the time at which similar soldered connections began to show breakage.

† Estimated from wrapping tool dimensions.

‡ One turn insulated, five turns bare.

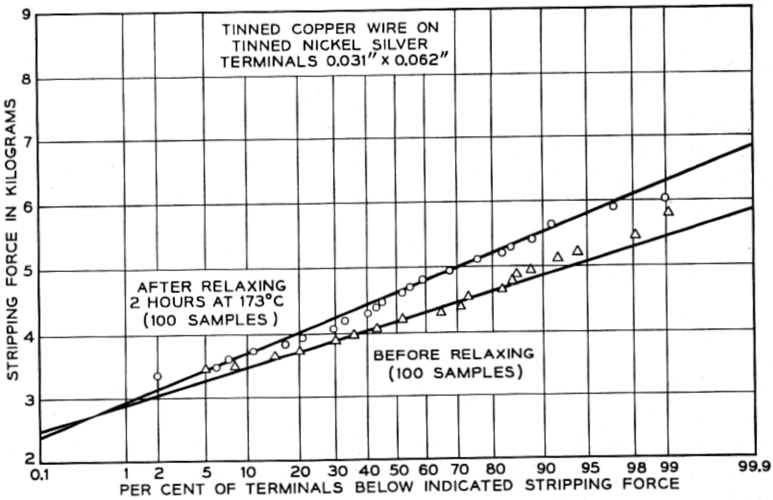

Fig. 4 — Effect of relaxation on stripping force.

under vibration and handling it may break easily. A practical and generally easily met requirement is that the connection be capable of withstanding unwrapping without wire breakage.

OTHER TESTS

A large amount of work has been done other than testing connections in accordance with the foregoing requirements. These tests (See Table II) include measurement of exposure to humidity, hydrogen sulphide corrosion, heating by internal electrical losses, vibration, etc. Many of these tests were made before any clear picture mechanism of deterioration of the connection was available so that they were not exposed to temperature high enough to cause very much relaxation. Therefore, there is no quantitative relation between these tests and the actual aging of connections, but they do indicate a general ruggedness which gives confidence in the reliability of the connections.

In measuring the effect of relaxation, connections have been tested in a preliminary way by subjecting them to sufficient heat sufficiently long to relax the stresses appreciably more than would be expected in a normal forty-year life. Upon unwrapping, the bright areas of contact were still present. Fig. 4 shows the result of a typical relaxation test on the stripping force. The rise in stripping force after relaxation is attributed to the solid state diffusion process described by Mr. Mason.

In order to compare how the solderless wrapped connection and soldered connections are able to withstand the effects of vibration over a period of time, several sets of terminals were mounted on a test table and wires from a cable were wrapped or soldered to the terminals. The cable was then oscillated through a small angle at 19 cycles per second and the elapsed time until lead breakage occurred was recorded. Some early similar tests indicated that soldered connections began to break at about fifty hours and the solderless connections lasted several times that long. In a more recent test where ten connections of each type were set up three of the soldered connections broke within six hours and all soldered connections broke within 1,000 hours. None of the wrapped connections had broken in that interval. In another test using ten soldered connections and twenty solderless connections, one of each broke at nineteen hours and after fifty-seven hours two more soldered connections broke with no further breakage of solderless connections. Further tests are being made of resistance to vibration under various conditions but the early indications are that the life of the solderless connections is as good as and perhaps better than that of the soldered connections.

The increased resistance of the wrapped connection to vibration breakage comes about because in the soldered connection the bending stresses are concentrated at the point of emergency of the wire from the solder, while in the wrapped connection the stresses tend to be distributed over the entire first turn of the connection. In order to obtain long life, it is important to avoid any exposed nicks in the wire at the first turn of the connection. Otherwise stress concentrations, perhaps as severe as those in soldered connections may be set up.

Incidentally, unless the wire has an enamel or similar coating it is unnecessary to clean the wire or the terminal before wrapping, since forces set up as the wire wraps on to the terminal shear off surface films and the resultant gas-tight areas are immediately established on clean surfaces. It is this intimate contact which also makes possible the diffusion process between the wire and the terminal.

A large number of parameters have an effect on the level of stripping force which a given connection will withstand. Among these are the number of wraps, tension on the wire during wrapping, sharpness of the corners of the terminals, the elastic properties of both the terminal and the wire, the size of the terminal, the hardness of the terminal and wire, the presence or absence of tin plating, taper of the terminal, aging, tool design, etc. Tests have been run showing the effect of variations in these parameters on the stability of the connections. Typical results of these

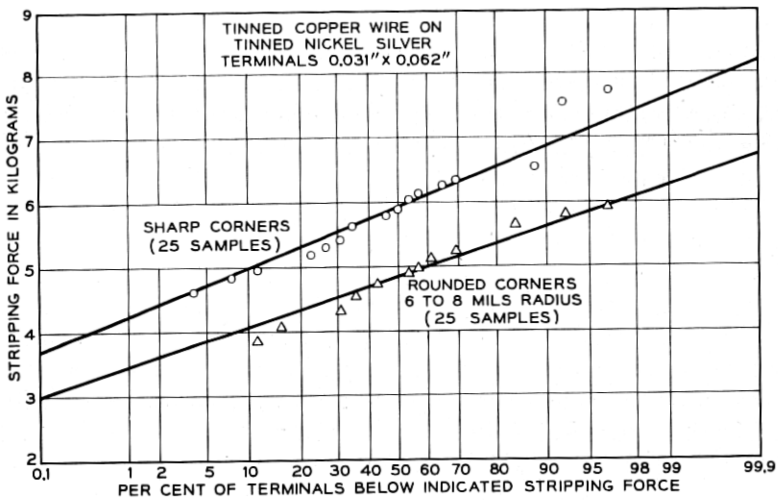

Fig. 5 — Effect of terminal edge sharpness on stripping force.

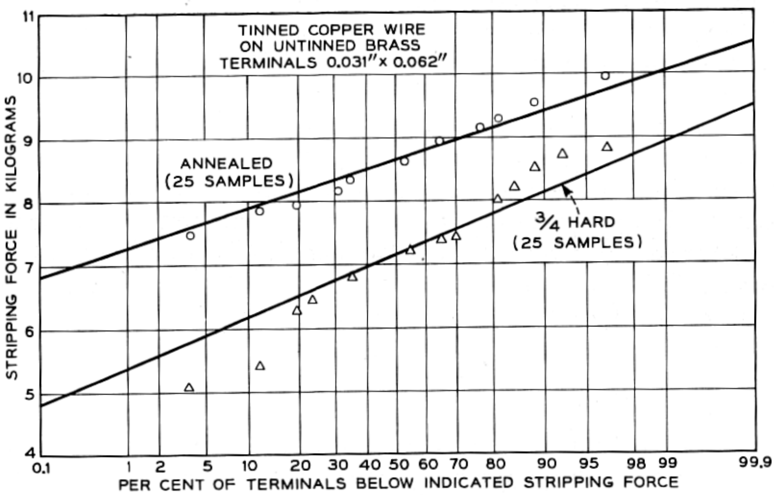

Fig. 6 — Effect of terminal hardness on stripping force.

tests are shown on Figs. 5 to 9 inclusive. These charts show a plot on arithmetic probability paper of stripping force against the cumulative per cent of the sample below the indicated stripping force. The straight lines shown there are actually drawn through the average and average minus 3σ points where σ is the standard deviation of the observed readings. In the cases shown, and in fact in practically all the tests made to date the results have come out so that the experimental values fit very well on the straight line drawn through these points, thereby indicating good normal statistical distributions of the data.

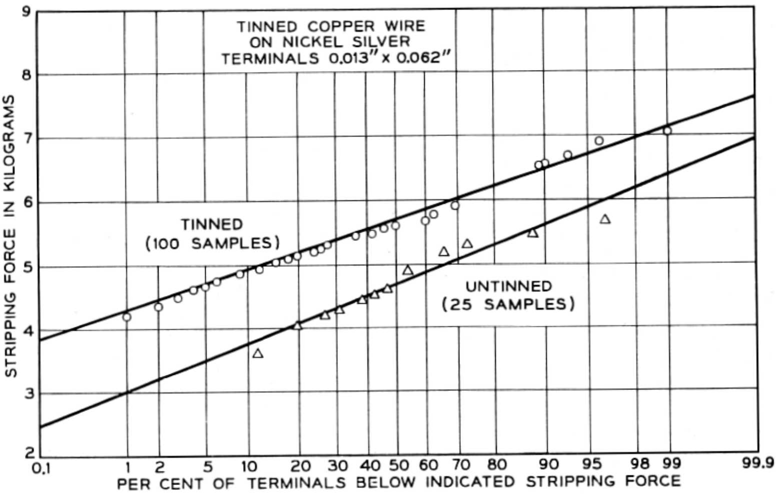

Fig. 7 — Effect of terminal plating (tin) on stripping force.

For example, Fig. 5 shows the effect of stripping force of rounding the corners of the terminal. These curves are for a typical tinned nickel silver relay terminal 0.031″ by 0.062″ in crosssection. The terminals represented by the upper curve were punched from sheet nickel silver stock and the corners were sharp as is usually the case where shearing operations are used. The lower curve represents connections where the corners were rounded off to a 0.006″ to 0.008″ radius. It is seen that on the average the stripping force using the sharp corners is about 1,000 grams higher than with the rounded corners, although both sets of terminals met the 3,000 gram requirement for mechanical stability.

The effect of terminal hardness on stripping force is shown in Fig. 6. Here brass terminals were used and it is evident that the softer terminals give considerably higher stripping force than the harder ones. Both

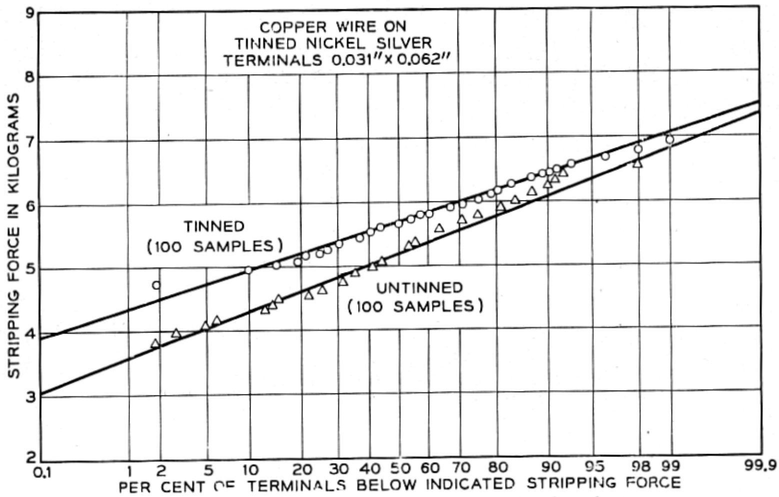

Fig. 8 — Effect of wire plating on stripping force.

curves run higher than the curves for the harder nickel silver in Fig. 5. Fig. 6 shows that the presence of tin plate on a 0.013″ by 0.062″ terminal increased the minimum expected stripping force by more than 1,000 grams. Figure 8 shows that on a 0.031″ y 0.062″ terminal that while the effect of the tin plate on the wire was to raise the stripping force as before, the increase was not as great as that in Fig. 7. It is also clear that the thicker terminal of Fig. 8 results in a higher stripping force than that for the corresponding thinner terminal of Fig. 7.

In analyzing the effect of tool variations it has been convenient to take a series of curves like those in Figs. 5 to 8, and from each curve select two points, namely one for the average stripping force and one for the average minus 3σ where σ is the standard deviation of the observed values of stripping force. Using these two points for each of several sets of curves a plot may be obtained of the average and minimum expected stripping force as one or another of the parameters of the tool design are changed. In this manner curves of the type shown on Fig. 9 were obtained. By preparing curves of this type for any given application, the permissible range, Z, of variation of tool radius, R, can be obtained. This range includes those values of R which are above that value which results in wire breakage and below that for which the minimum expected stripping force falls below the stripping force limit.

Table II summarizes the results of many of the tests which have been run on a large number of samples in which the materials and dimensions of the terminals, wires, tightness of wrap, etc., were varied. All of sample connections originally met the initial test requirements outlined above for resistance variation. They were then subjected to the indicated exposures including being kept in the Humidity Room at 85°F and 95 per cent relative humidity for periods up to two and one-half years, following which they were remeasured. In no case was any barrier film found which did not break down at 25 microvolts nor was any resistance variation in excess of 0.002 ohms observed. Some of these terminals are shown in the photographs of Figs. 10 and 11. Upon unwrapping some of these connections there were still considerable areas which were bright (See Fig. 12), indicating that they were still gas-tight. This would seem to indicate a life expectancy of many years. Since connections

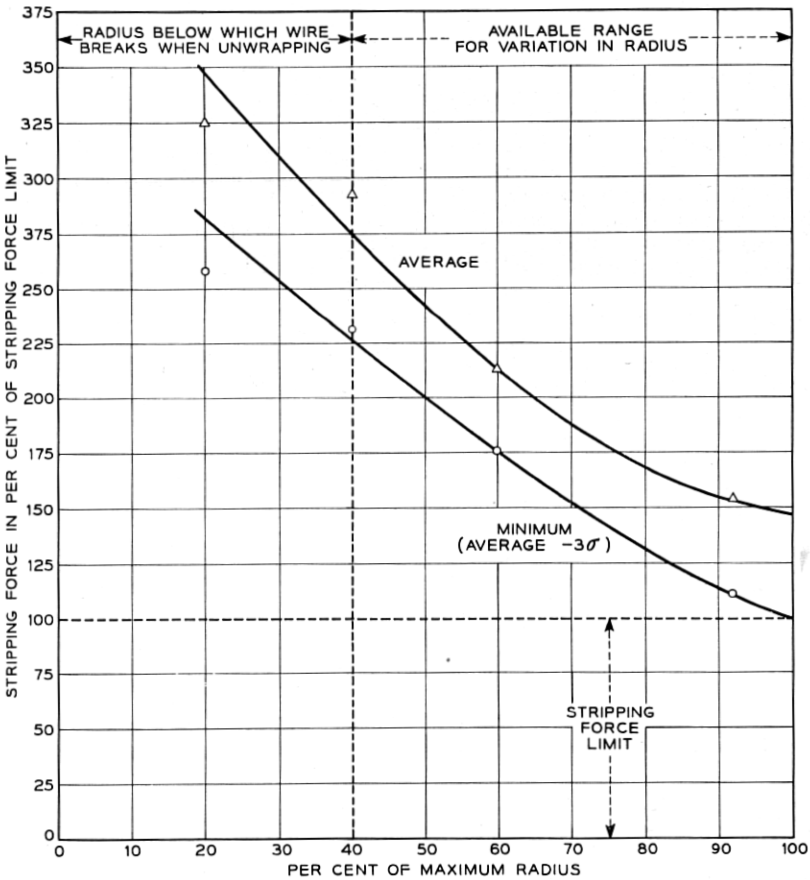

Fig. 9 — Stripping force as a function of radius of wrapping tool.

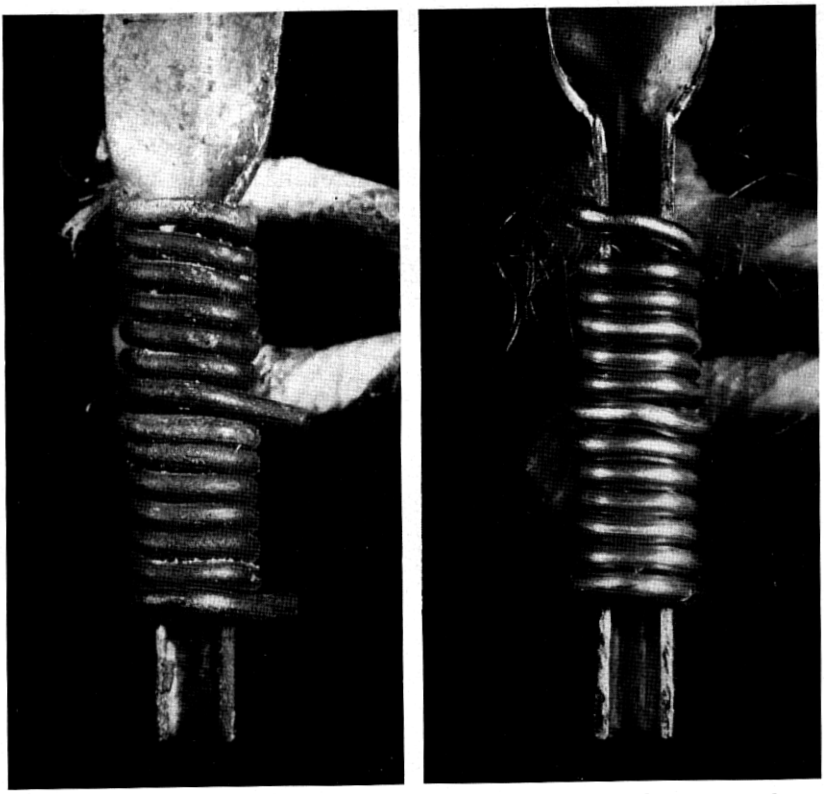

Fig. 10 — Terminal at left exposed to H_2S for 14 hours and then 30 months at 85°F 90%RH. The connections did not develop resistance variation in excess of the 0.002 ohm limit. Corresponding new terminal is shown at right.

which meet the 3,000-gram strip-off requirement appear satisfactory on the other tests, the strip-off test used on a sampling basis has been standardized as the shop control of the wrapping tool and indirectly of the quality of the connections themselves.

FIELD TRIALS

A number of equipment units using these connections is currently on field trial. At Tonawanda, N. Y., one trunk unit using wire spring relays of an early design and 300 solderless wrapped connections has been in service successfully since 1951. At Elmhurst, L. I., a sender frame comprising five senders with about 7,500 connections has been in use about a year and a half with no troubles reported to date. At Boston, Mass., an outgoing sender frame for the No. 4 crossbar office comprising three

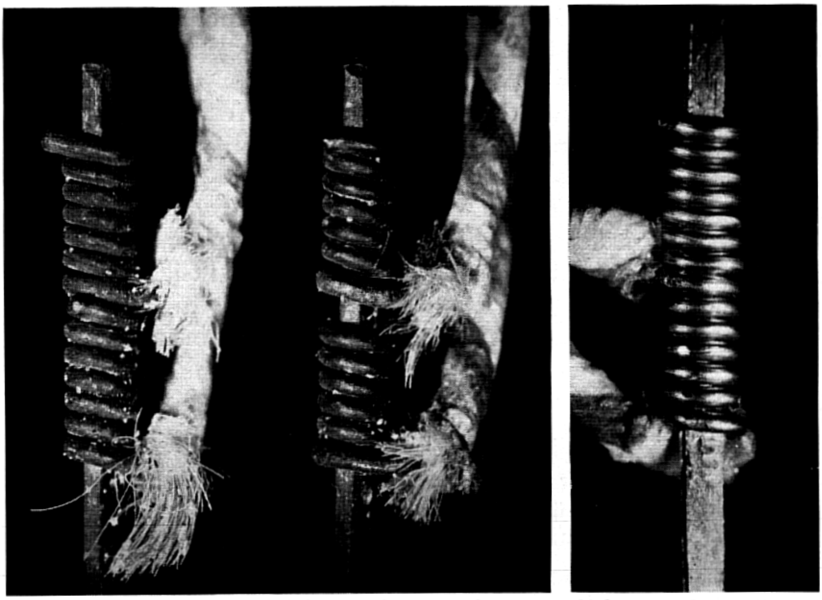

Fig. 11 — Terminals on left exposed to H_2S for one-half hour and 85°F 90 per cent RH for seven and one-half months without development of excessive resistance variation. Corresponding new connection is shown on right.

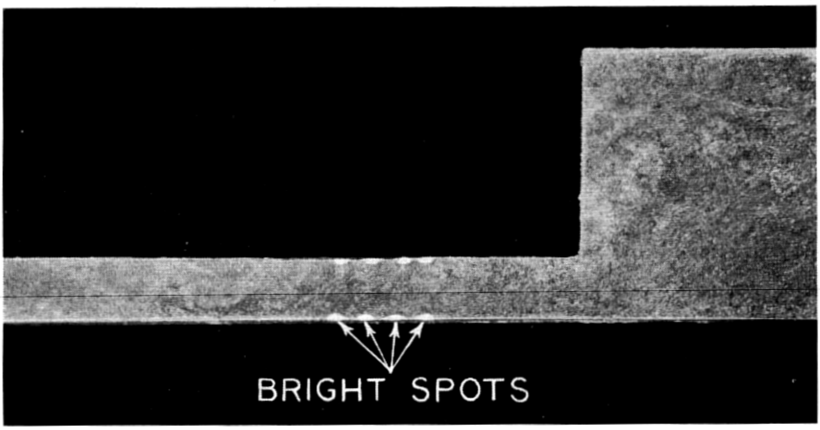

Fig. 12 — Corroded nickel silver terminal after unwrapping connection. Note the bright spots where the wire was in contact with the terminal.

senders with 6,000 solderless connections has been in service about nine months, again with no troubles reported.

In order to test these connections in a transmission circuit one channel of the K-1 carrier system between Newark and Atlanta was selected. Rather than wire a regular equipment unit with solderless wrapped connections, four units were built consisting of two groups of 320 connections in series. Each unit was exposed to 15 weeks at 85°F 90 per cent relative humidity and then inserted in the system. One unit was located at each of the following places: New York, Philadelphia, Baltimore, and Richmond. No troubles or adverse service reactions have been received to date, more than six months after installation.

SUMMARY

The tests described indicate that solderless wrapped connections are practical when wrapping No. 24 solid tinned copper wire on flat punched terminals of brass or nickel silver where the width is one-sixteenth inch and the thickness varies from 0.010″ up to one-sixteenth inch. Similar tests with heavier wire, (No. 20 to No. 23) such as would be used in distributing frames and tests with No. 24 wire on flattened, coined, or otherwise treated wire spring relay terminals have also been successful. These connections are mechanically stable, and have less tendency to break due to handling and vibration than solder connections, and will

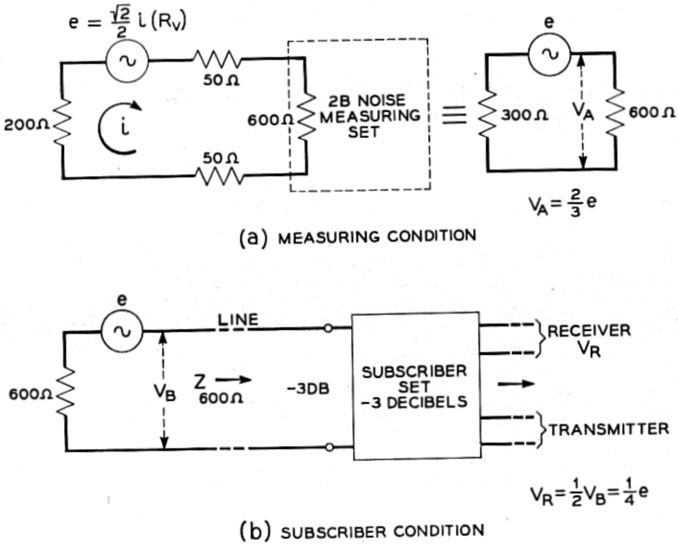

Fig. 13 — Comparison of noise measuring circuit with subscriber circuit.

probably have a central office life of more than fifty years without developing objectionable resistance variation. Tests on other terminals and using wires heavier than No. 20 and on wires smaller than No. 24 are to be made.

ACKNOWLEDGEMENT

The author acknowledges that this paper reflects largely work done under the supervision of D. H. Gleason whose recent retirement prevented his authorship.

Appendix A

NOISE LEVEL ARISING FROM VARIABLE CONTACT RESISTANCE

The measurement of contact resistance noise in a telephone central office has been standardized, and the estimate of the effect of a given resistance variation has been made in accordance with the standard technique.

In this measurement, a 2-B noise measuring set is connected as shown in Fig. 13 (a) where the voltage, e, is that due to a variation in contact or connection resistance. If a dc current i is flowing and the resistance variation is $(\Delta R)_0 \sin \omega t$, then

$$e_{\text{eff}} = \frac{\sqrt{2}}{2}\, i \cdot (\Delta R) \tag{1}$$

and

$$V_A = \frac{2}{3}\, e. \tag{2}$$

In the subscriber condition (Fig. 13 (b)) there is a 3 db loss in the subscriber's loop and a 3 db loss at the subset so that the voltage at the receiver

$$V_R = \tfrac{1}{2}\, V_B$$

and

$$V_b = \tfrac{1}{2}\, e$$

It therefore follows that

$$\frac{V_A}{V_R} = \frac{2e}{3} \div \frac{1}{4}\, e = \frac{8}{3}$$

and

$$20 \log \frac{V_A}{V_R} = 9\ db \text{ (to the nearest decibel).}$$

Extensive tests have shown that a level of 17 db at the receiver where 0 db = 10^{-12} watts will produce no noise impairment of transmission. The corresponding level at the input to the noise meter in the measuring condition is 17 + 9 or +26 db.

Currents in talking circuits may vary from 0.025 amperes in many central office circuits to approximately 0.150 amperes in short subscriber's loops. At a current of 0.025 and assuming $\Delta R = 0.002$ ohms the noise voltage will be

$$e = \frac{\sqrt{2}}{2} \times 0.025 \times 0.002 = 35.4 \times 10^{-6} \text{ volts}$$

and the voltage at the input to the noise measuring set will be $\frac{2}{3}\, e = 23.5 \times 10^{-6}$ volts. The power into the set will be

$$\frac{23.5 \times 10^{-6}}{600}$$

or 1×10^{-12} watts or 0 db. The noise measuring set is equipped with a weighting network which takes into account the relative interfering effect of different noise frequencies on received speech. For random noise, the effect of this network is to reduce the measured noise level by about 8 db as compared with the reading that would be observed without the network. Accordingly the noise produced by the above 23.5×10^{-6} volts would measure -8 db.