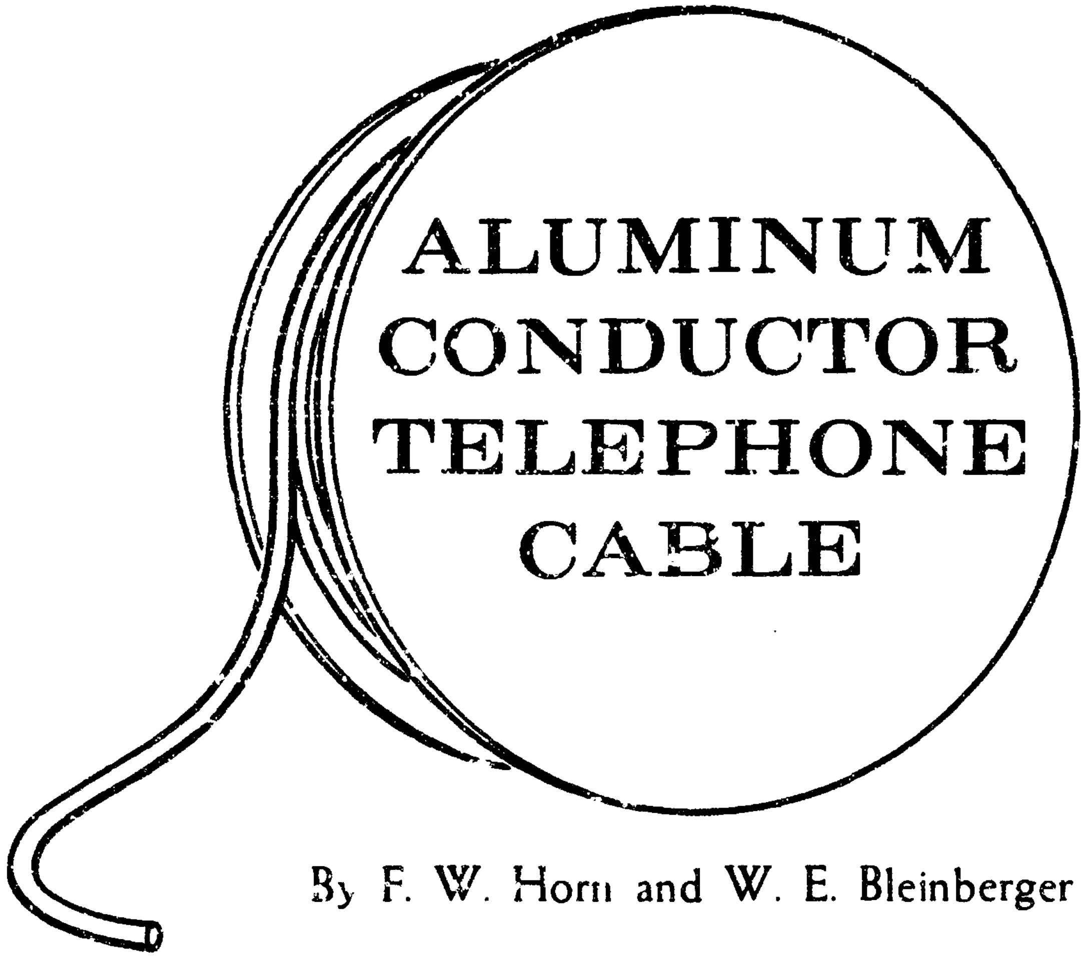
# DESIGN & MANUFACTURE OF PLASTIC INSULATED






By F. W. Horn and W. E. Bleinberger

**BTL and Western Electric**



## 15th ANNUAL WIRE AND CABLE SYMPOSIUM

ATLANTIC CITY, N. J.

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**December 7-8-9, 1966**

# DESIGN AND MANUFACTURE OF PLASTIC INSULATED ALUMINUM CONDUCTOR TELEPHONE CABLE

by

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Presented at
Fifteenth Annual Wire & Cable Symposium
U.S. Army Command, Fort Monmouth, N.J.

Shelburne Hotel
Atlantic City, N.J.
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# DESIGN AND MANUFACTURE OF PLASTIC INSULATED ALUMINUM CONDUCTOR TELEPHONE CABLE

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W. E. Bleinberger - Western Electric Company

Although the mining specialists insist that there is sufficient copper ore to take care of the demand for copper, periodically availability and price become unstable. As this article is being written we are in one of the most turbulent periods in copper history. Strikes, control of export and price by foreign governments help to keep the situation in constant turmoil.

Against such a background as this it is not surprising that the Bell System which uses something in the order of 200,000 tons annually felt the necessity for developing a usable substitute for copper. Exchange area telephone cable accounts for about half of this amount and this is the item to which we now want to focus your attention.

In the spring of 1965 the Bell Laboratories with the cooperation of Western Electric and the American Telephone and Telegraph Company launched a development project for the express purpose of finding a substitute for copper for exchange area telephone cable. It was realized from the beginning that just designing and developing methods and procedures for manufacturing aluminum conductor cable would not be a solution. A complete package must be available.

Besides cable manufacture ~~we must know~~ how to install the cable, splice the conductors, terminate the conductors, join cable lengths together, locate and repair trouble, always using suitable mitigating techniques to keep the ogre "corrosion" from destroying our project. In order to do this experts were drawn from all fields, the authors of this paper being responsible for cable development and cable manufacture.

Aluminum conductors in telephone cables is not a new subject. In fact, at the Wire and Cable Symposium in 1954 Mr. J. S. Herbert of the Western Electric Company delivered a paper entitled "Manufacture of Aluminum Conductor Telephone Cable" which summarized Western's experience with pulp insulated aluminum conductor cable. But, all projects do not survive, and this one unfortunately met its demise by way of corrosion problems.

We did, however, learn a great deal from our aluminum experience of over ten years ago. First of all, it was paper pulp insulation. This is normally kept dry and when dry, aluminum will not corrode. Cables do however get wet occasionally and with aluminum conductors the corrosion damage was catastrophic. Literally hundreds of conductors would corrode open before trouble was detected and repair operations could get underway. With pulp insulation much work was done, and some mitigating techniques were developed but none was of sufficient value to allow us to consider pulp insulated cable for the current development. Our present approach has therefore been directed toward plastic insulation only. The aluminum wire gauges under consideration for this development program are 17, 20, 22, and 24 gauge.

Re-vamping major production facilities for the substitution of aluminum for copper in telephone cables is not a simple matter as one can appreciate. Within Western Electric where production of plastic insulated conductor (PIC) for exchange area cable is approaching 100 billion conductor feet annually and divided between several plant locations the problems become more complex. In one manufacturing process area alone, that of tandem wire drawing, annealing, and insulating, Western has over 100 lines representing a sizeable investment.

Throughout the joint BTL and Western development program, with the support of the AT&TCo, one of our main objectives has been to design an aluminum conductor cable that will be compatible with existing manufacturing facilities.

To fully understand the problems associated with a tandem insulating line, Fig. 1 is shown to illustrate the various machinery components. It may be well to state here that during the course of this development serious consideration has been given to batch annealing of aluminum wire, but this would of necessity become a last resort. Even though the problem of "sticky wire" could be solved, reverting back to the older method of batch annealing would require Western to re-vamp their production facilities, procure additional annealing and wire drawing facilities, and in general increase the cost of producing cable.

After reviewing all of the information we had accumulated over the years, an exhaustive search was conducted of literature and the aluminum industry for new information concerning aluminum or aluminum alloys. We of course are basically concerned with conductivity and for any aluminum used, the size of the conductors must be adjusted to obtain the same conductivity of the copper conductor being replaced. The most commonly used aluminum for electrical application is EC grade which has a minimum of 99.45% aluminum. The conductivity of this material is around 62%, and aluminum conductors would have to be two gauge sizes larger than the replaced copper.

Other popular alloys are 5005 which contains 0.8% Magnesium and 6201 which contains 0.75% Magnesium and 0.7% Silicon. The mechanical properties are much more desirable than for the EC grade but conductivity is down to about 53% for both the 5005 and the 6201 alloys.

Alloys with intermediate mechanical properties, and conductivity not below 60% would be of interest but we of course would wish other than premium priced or proprietary materials. Our experience with aluminum so far indicates that EC grade may be satisfactory from a design and manufacture standpoint for 17 and 20 gauge, but not for 22 or 24 gauge. Wire with higher tensile and yield strength is required.

Therefore to initiate development effort it was decided to start with EC grade aluminum and a number of experimental cables were scheduled. These involved several gauges and pair sizes and a number of sheath constructions. Temper of the aluminum is also extremely important as the properties can be altered considerably by the anneal and strain hardening history of the material. Figure 2 shows the annealing curve for 17 ga. EC grade aluminum and 19 ga. ETP Copper.

Perhaps at this point it would be a good time to give a brief explanation of tandem wire drawing, annealing, and insulating facilities used by Western to manufacture plastic insulated copper conductor cable. The operations are as follows:

1. 13 Gauge hard drawn copper wire is payed-off the ends (the axis horizontally or at a slight angle) of large spools containing approx. 1,000 pounds of copper.

2. Wire is drawn down to 26, 24, 22, or 19 gauge before entering a resistance type strand annealer.

3. Cleaning of the wire is accomplished through a steam wiper ahead of the annealer with subsequent water cool and air wipe in the annealer.

4. Polyethylene insulation is applied in tandem with wire drawing.

5. The insulated wire is then quenched in a cooling trough and taken up on reels holding up to 39,000 feet for 26 ga.

6. A dual take-up with automatic cut-over completes the tandem insulating line. Insulating lines are normally operated on a 5 Day, 3 Shift basis and stop only when wire breaks occur, changes for gauge size, plastic color changes, or when maintenance requires a shutdown.

During the early stages of the aluminum conductor development program several annealed, half-hard, and hard drawn aluminum conductor cables were manufactured for Laboratory evaluation. Several of these cables were made with 24 gauge conductor - the smallest that we have contemplated using.

The net result of these early experimental cables has been to establish the fundamental differences between the extreme limits of our wire diameter range and to split the development into two distinct paths. One path which has been rated first priority is the development of a complete system for 17 and 20 gauge conductor. The second and final phase will be to develop a complete system for 22 and 24 gauge conductors.

Several cables with 50 pairs 17 ga. EC conductors were run and evaluations completed with the specific intention of getting a commercial field trial installed as soon as possible. The objective of a complete package was still the same. All associated items, and construction and maintenance techniques must be available and involve very little chance of trouble.

A discussion of the more important experimental cables leading up to the field trial design follows.

I. Batch Annealed (ECO), 17 Gauge

Properties:

| | |
|---|---|
| Elongation | 28% |
| Tensile | 10.7 KSI |
| Conductivity | 63% |

Attempts to insulate pre-annealed (ECO) 17 gauge aluminum conductor at speeds of 1000 FPM were very unsatisfactory. In paying off the wire from a horizontal position on Western Electric type reels the problems of low tensile strength and sticking (cold welding) of the wire prevented insulating more than a few hundred feet before a wire break would occur in the supply stand.

Only slight improvement was noted after several spools were carefully processed through a re-wind machine.

From this trial it was determined that it was impractical, if not impossible, to set up a high speed insulating production line using batch annealed wire.

II. "Strand" Annealed, 17 Gauge

<u>Properties</u>

| | |
|---|---|
| Elongation | - Variable (10-30%) |
| Tensile | - 12.3 KSI |
| Conductivity | - 63% |

After many start-ups to insulate pre-annealed conductor were unsuccessful, a trial run was made with the standard resistance type strand annealer starting with EC-H19 17 ga. wire. A combination of maximum annealer output and reduced wire speed (1000 FPM) enabled us to anneal in tandem and obtain physical properties of the wire comparable to the batch annealed wire.

Although the resistance type annealer served its purpose for the development experiment, the methods used to achieve the desired anneal are unsatisfactory and impossible to use for continuous high speed production. Aluminum oxide built up on the conducting sheaves after running no more than 50,000 feet, to such an extent that arcing was intolerable and reduced conductivity between the sheaves and wire caused wide variations in anneal.

III. Hard Drawn (EC-H19), 17 Gauge

Properties:

| | |
|---|---|
| Elongation | - less than 2% |
| Tensile | - 25.0 KSI |
| Conductivity | - 62.4% |

Insulating of 17 gauge hard drawn aluminum presented more problems than anticipated. One of the most significant items detected during the manufacture of this cable was the excessive "dancing" of the insulated wire between various sheaves at insulating, twisting, and stranding machines. The adverse effects of spring-like wire could probably be overcome by damping devices or machinery modifications at insulating, twisting, and stranding.

Although hard drawn aluminum conductor showed promise from a manufacturing view point, its death knell was sounded when several wires parted during the plowing tests at the Chester Outside Plant Laboratory in New Jersey. Examination of the wire breaks proved that they were tensile breaks.

With the results gained from the plowing tests it became apparent that the search must be continued for a better alloy or an EC grade aluminum wire that would exhibit improved mechanical properties.

These experimental cables were completely evaluated. Electrically they were found to be equivalent of a 50 pair 19 ga. copper conductor cable.

Splicing techniques for the 17 ga. conductors were also evaluated and it was determined that the "B" Wire Connector would make a reliable joint. The insulation must however be removed before insertion in the connector. (This is required for 19 ga. copper conductors as well). Fig. 3 illustrates the proposed joining of 17 ga. wires using the "B" Wire Connector.

At this point the results of a number of corrosion tests were summarized and a number of decisions made. These tests showed that in the presence of water and especially where a saline environment was involved "B" Wire Connectors and any of our terminating devices could not be used for aluminum conductor cable. This was not unexpected as these devices all are made of phosphorus bronze metal, some being tin plated.

It was decided then that all connections must be kept dry. In the case of terminals this is an almost impossible requirement. It was agreed therefore that the problem be converted to a splicing problem by using copper wire or stubs for any situations where terminating was involved. These wires or stubs would then be spliced to the aluminum cable.

Splices then must be made waterproof. A method of accomplishing this has been developed but admittedly it is more time consuming than desired and effort will continue toward a simpler waterproof splice. As mentioned previously the "B" Wire Connector will be used. As shown in Fig. 4 a group of connectors will be encased in polyurethane. Presumably we will not want even these to be immersed in water for indefinite periods of time.

Since Western could not at the present time run fully annealed wire on conventional equipment and full hard is unacceptable, intermediate characteristics were needed. These can be attained either by partial annealing which is a very critical operation or by fully annealing at an intermediate gauge and then drawing to attain the desired properties. We chose the latter technique and Fig. 5 shows the effect of various reductions on the tensile strength and elongation. Looking at the curve, 20% reduction after anneal, about one gauge number, appears to give the most desirable properties. For convenience we are calling this temper H-11.

When it was decided in early 1966 to proceed with a sizeable 17 ga. field trial cable, Western was not equipped to produce such a temper so it was decided to purchase the 17 ga. H-11 wire. This is not a commercial temper but two suppliers agreed to process 60,000 pounds for use in the field trial cable.

As mentioned previously it had to be an extremely conservative trial so we provided a moisture resistant APASP (aluminum w/plastic coat - polyethylene - aluminum - steel - polyethylene) sheath and an additional pair for an alarm circuit to detect water in the splices.

This scheme is shown in Fig. 6. A water detection element consisting of 2 bare conductors partially embedded in plastic is wrapped around the splice. A locking relay is also enclosed in the splice. When current passes through the detection element the relay locks closed and a simple resistance measurement discloses the short nearest the measuring set. If more than one relay closes, only the nearest will be detectable. However as soon as this splice is open another measurement can be made to see if other splices are wet.

The major field trial is being conducted in Northwestern Bell Telephone Company territory between Emmetsburg and Mallard, Iowa. Three sizes of cable 51, 76, and 101 pairs APASP were furnished for a run of about 20 miles.

The specification for the 17 gauge wire used was fully detailed but the basic requirements were as follows:

Chemical: Minimum aluminum content - 99.45%

Mechanical: Elongation: minimum of 2.4% in 10 inches
Tensile Strength: minimum of 13.0 ksi
Yield Strength: minimum of 10.0 ksi at 0.2% offset.

Dimensional: 0.0453" ± .0005"

Conductivity: 61.0% of IACS for minimum wire diameter.

Experience and observations made during the manufacture of early cables dictated that wire made from scalped billets would be required to minimize inclusion and surface problems. The surface photo-micrographs shown in Fig. 7 illustrate the typical surface condition of wire with and without processing from scalped billets or shaved rod.

Many of the procedures used for manufacture of the wire were left to the aluminum suppliers as long as they met the end requirements. Wire processed from shaved rod and scalped billets compared favorably. Surface conditions for the shaved rod type were better, as was expected. Consideration was given to using some continuous cast rod in the field trial but it was thought best to defer the use of this material until a later trial.

Essentially all the wire was drawn from 3/8" rod down to 16 gauge - fully batch annealed - and then processed through a wire drawing machine for the final 20% reduction to 17 gauge - cleaned - and wound on Western Electric type reels which hold approx. 100 pounds of aluminum wire. Special packaging procedures were used to prevent damage to the wire during shipment or storage. Fig. 8 shows the distribution curve of tensile, yield, and elongation for wire used in the 17 ga. field trial. Curves were extrapolated from data obtained from 100 samples. Presumably the process capability will improve with process refinement.

All aluminum conductor for the trial cable was insulated on slightly modified PIC insulating lines at 1500 feet per minute. Continuous operation was obtained by cold-welding the wire tail of one spool to the outside end of another spool. Cold welding of the 17 ga. wire was very satisfactory and no wire breaks could be assessed to this operation.

Polyethylene was extruded on the wire at room temperature without problems. On one occasion the wire on several reels had not been cleaned adequately and caused rough insulation. This wire was removed from the process and insulating returned to normal. This, and other experiences gained from running experimental cables points out the fact that aluminum wire entering the extruder must be free of oil.

Twisting of EC-H11 17 gauge wire proved to be equivalent to running copper conductor except for a higher percentage of breaks. Most of these defects have been analyzed and traced back to the raw material. Hopefully these problems can be solved in the raw material used for ultimate production.

Stranding, Cabling, and Sheathing operations were performed as expected with the exception of a few opens showing up in the stranding operation. One hundred per cent testing of the field trial cable was used throughout the manufacturing and final testing operation.

Pair sizes of 51, 76, and 101 were successfully completed in September, 1966 and shipped to Iowa (Northwestern Bell) for standard plowing operations. A photograph of the three sizes of 17 gauge field trial cable is shown in Fig. 9. The table shown in Fig. 10 gives typical values for the 51 pair 17 ga. aluminum conductor field trial cable and an equivalent copper conductor cable.

Although the field trial cable was insulated on commercial equipment it was realized from preliminary development work that an experimental pilot line would be required to develop the necessary techniques for wire drawing, annealing and insulating in tandem. To expedite and assure the successful development of aluminum conductors for telephone cable, a tandem wire drawing - annealing - and insulating pilot line has been installed at the Baltimore Works of the Western Electric Company. The acquisition of this laboratory and pilot line, shown in the photograph and layout of Figs. 11 and 12, will greatly assist Western and Laboratory engineers to experiment, evaluate, design, and develop processes and machinery to produce economical telephone cable of the highest quality.

The pilot line will be fully instrumented and have the capability to insulate wire from 200 - 4000 feet per minute. Machinery will be similar, or simulate that presently installed at several Western cable manufacturing locations. A 3 1/2" - 24:1 l/d ratio extruder (vented) rated at 300 pounds per hour has been installed to give maximum flexibility for present and future development work.

This extruder, although large in comparison to our 2 1/2" extruders used in production, will give us the capability to perform experiments in both polyethylene and expanded polypropylene. Provision has been made to utilize capacitance monitor control of the insulating process and the cooling trough has been so designed to enable us to simulate various designs of installations.

A special wire drawing compound tank will enable us to experiment with and develop a good drawing compound that is compatible with our cleaning and extrusion process. Services to the experimental annealing and wire drawing area include natural gas, steam, water, compressed air, and 440 volt power. The pilot line is completely enclosed, and the room is air conditioned. Contamination from copper particles produced in the surrounding copper cable shop should be virtually eliminated as a possible source of trouble.

If H-11 becomes the specified temper, it will be necessary from a production basis to anneal on the extrusion line and then draw one gauge size. Space has been allocated for this operation. Fig. 13 illustrates the machinery as we now visualize it. In-line high speed annealing will be one of the major problems and much development effort is being allocated to this problem. The ability to continuously strand anneal aluminum wire and guarantee a surface free from pits with the desired mechanical properties has historically been something less than completely successful, especially with wire in the 24 to 17 gauge range. Aluminum oxide build-up and arcing at the wire and sheave contact are the major problems.

After considerable exploratory work and evaluation in detail of numerous annealing methods, the most feasible and practical annealing processes suited to our continous process were selected for further investigation. Many factors were considered including cost, development time required, safety, efficiency, and ease of operation. The types of annealers selected for further investigation and development are as follows:

1. Electric Resistance Systems
    a. Induction at 60 cycles

2. Convection Heating System
    a. Direct flame - high velocity gas

3. Conduction Heating System

Figures 14 and 15 illustrate schematically the basic concept of two of the three annealing processes. Fig. 14 shows the Induction Heating or "short-circuited secondary" process. In this equipment the conductor is heated by an electrical current induced into the wire by a toroidal inductor without the use of slip rings or brushes. The power input to the transformer is controlled by a saturable core reactor in the primary circuit. Due to the many advantages of an induction type system, including the possibility of incorporating a wire temperature feed back control into its electrical system, heavy development effort is being expended on this method. A commercial induction type machine with a capacity of 65 KVA has been procured for experimental purposes.

A direct flame method similar to that shown in Fig. 15 has the best heat transfer properties, but from our experience will have the disadvantage of being the most difficult process, out of the three under study, for controlling wire temperature. Systems of this type also have the undesirable characteristics of a very high noise level. At the time this paper is being prepared the direct flame heating for continuous annealing of conductors is in the design stage.

Several conduction heating systems are being considered but it has not as yet been decided which of these processes will be developed.

Most of Western's development effort has been directed toward the induction type process since it has many advantages over the other two and it appears feasible to anneal 17 and 20 gauge wire by this method. Parallel development effort will be made on the other methods to assure that at least one production process will be available. There is also the possibility that one process may be better adapted to a particular wire gauge or specific aluminum alloy. From results of early experimental work it does not appear impractical to expect at least two methods to be used in final manufacturing operations.

In order to consider commercial production of 17 ga. it will be necessary to develop the wire drawing and annealing process. Hopefully this will be accomplished by the end of 1967. In the meantime work will be done on 20 ga. wire aimed at early laboratory and field approval.

To give some idea of our plans to develop manufacturing techniques and facilities for aluminum conductors the following summary of operational sequences and problems has been prepared.

## Wire Drawing

### Rod Breakdown to 10 or 12 Gauge wire:

Only exploratory development work has been done in this area up to now. Present plans call for active development of procedures and facilities to begin in early 1967. Wire drawn to our specified requirements and size has been supplied by several aluminum companies.

Our goal is to use 5,000 pound reel-wound packages of 3/8" rod and draw on Western Electric No. 1 machines at speeds over 6,000 FPM.

### Tandem Wire Drawing

A sufficient quantity of aluminum wire has been drawn on presently installed tandem wire drawing machines to indicate that these machines with the correct mineral type wire drawing compound and associated dies will produce satisfactory product. Wire breakage has been small. The speed of wire drawing will be governed by the speed of the insulating line which could approach 5,000 feet per minute.

Some work will be required to develop the optimum shape and dimensions for dies, but to date the standard dies used to draw copper have performed remarkably well. According to discussions we have had with experienced aluminum wire drawing personnel, it may be possible to substitute tungsten carbide in place of the diamond dies. The wire drawing machine and associated experimental compound tank installed in the aluminum conductor pilot line will enable us to obtain the optimum combination of machinery, tools, and wire drawing compound before design specifications are written for production facilities.

In Western's present tandem wire draw - anneal - and insulating lines the problem of removing residual wire drawing compound from copper is taken care of in a convenient manner. A steam wiper removes the water soluble compound from the wire and the small traces of steam condensate are burned off in the final passes of the resistance type annealer. Cleaning aluminum conductor presents an entirely different and more difficult problem in that a mineral based oil cannot be readily cleaned by a steam wiper. Present development effort is centered around the use of solvents with the possible use of ultra-sonic transducers to facilitate the best cleaning in the minimum space.

Annealing and Insulating

This has already been discussed in connection with the Aluminum Conductor Pilot Line.

Twisting

Individual conductors are twisted into pairs on Western Electric designed high speed twisters before they are stranded into cable. Experimental cables manufactured to date have used designs covering a complete range of twist lengths from 2.0 to 6.1 inches. Twisting was performed at 1035 RPM at lineal speeds of 345 to 1050 feet per minute. Twisting of plastic insulated aluminum conductors has presented problems, but none that cannot be corrected through minor machinery modifications or instituting controls for more evenly distributed wire or better raw material. One particular item that appears to be more critical than any other in the twisting of plastic insulated aluminum wire is the proper distribution of wire on the single conductor reels. The lower tensile and yield strength of aluminum wire have an adverse effect on this operation.

From our limited experience, the paired wire defects ran higher than normally experienced with equivalent copper conductors. An analysis of wire breaks that occurred during the manufacture of the 17 Ga. field trial cable indicated that a majority of the breaks were caused by imperfections in the raw material.

Development work will continue on 1035 and 1200 RPM machines for all gauges sizes to determine the optimum tensions and machine design.

Stranding and Cabling

The stranding and cabling of aluminum wire into cable units and cores has been done on the same machinery used to process copper conductors. Stranding of 17 gauge conductor on flyer stranders at 300 FPM has been satisfactory. Running at higher speeds may require some development and modification to supply and take up tension machinery.

Cabling appears to present the smallest problem to the successful substitution of aluminum conductor for copper. Regardless of the hardness of the aluminum wire the cabler has operated at a speed of 120 FPM without producing a single defect. Some cable has been made in Strander-Cabler machinery with problems comparable to those encountered with the flier-strander.

Sheathing

Because of the trend toward more and more buried exchange cable plant, this development project has concerned itself mainly with buried plastic composite sheath designs. Several novel sheath designs have been tried on experimental cables to produce a moisture barrier. No difficulty has been experienced in the forming or polyethylene extrusion operations when sheathing aluminum conductor cable.

Buoyancy of the cable in the water cooling troughs made it necessary to install submerging rolls to provide uniform sheath cooling and prevent sheath damage.

Factory Conductor Joining

All factory welds have been made with commercially available cold pressure type welding equipment. The results have been very encouraging but more development work is required on the optimum tooling and flash removal techniques.

Future Direction

The 22 and 24 ga. sizes represent an entirely different problem. Here tensile strength of EC aluminum is marginal and it is entirely possible that intermediate conductivity alloys will have to be developed. This may take considerable time.

We believe aluminum is here to stay and the balance between copper and aluminum will be dictated strictly by the market fluctuations of the two metals.

F. W. HORN

BA-5443-FWH-WEB-PAT

W. E. BLEINBERGER

Att.
Figures 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14 and 15

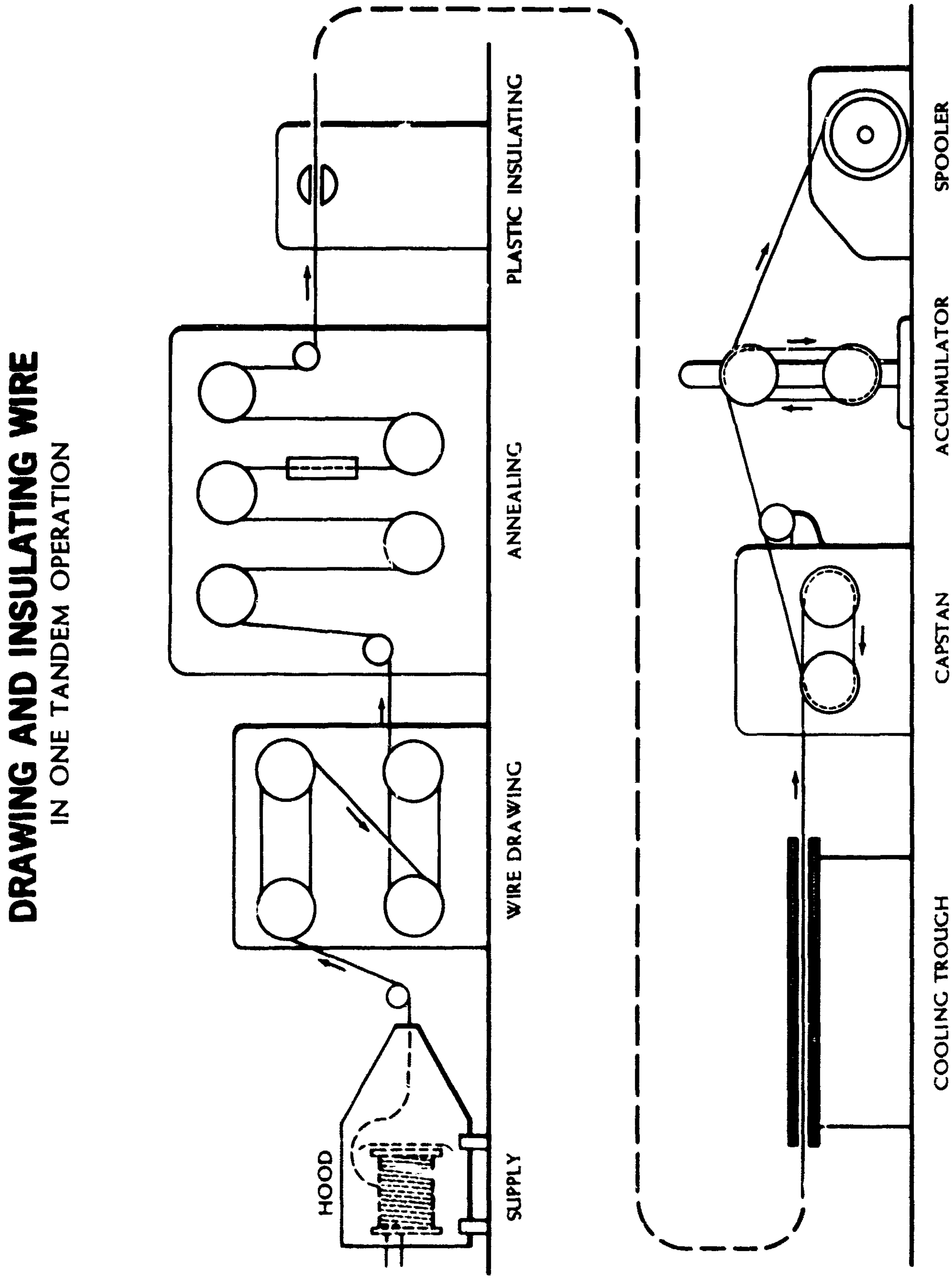
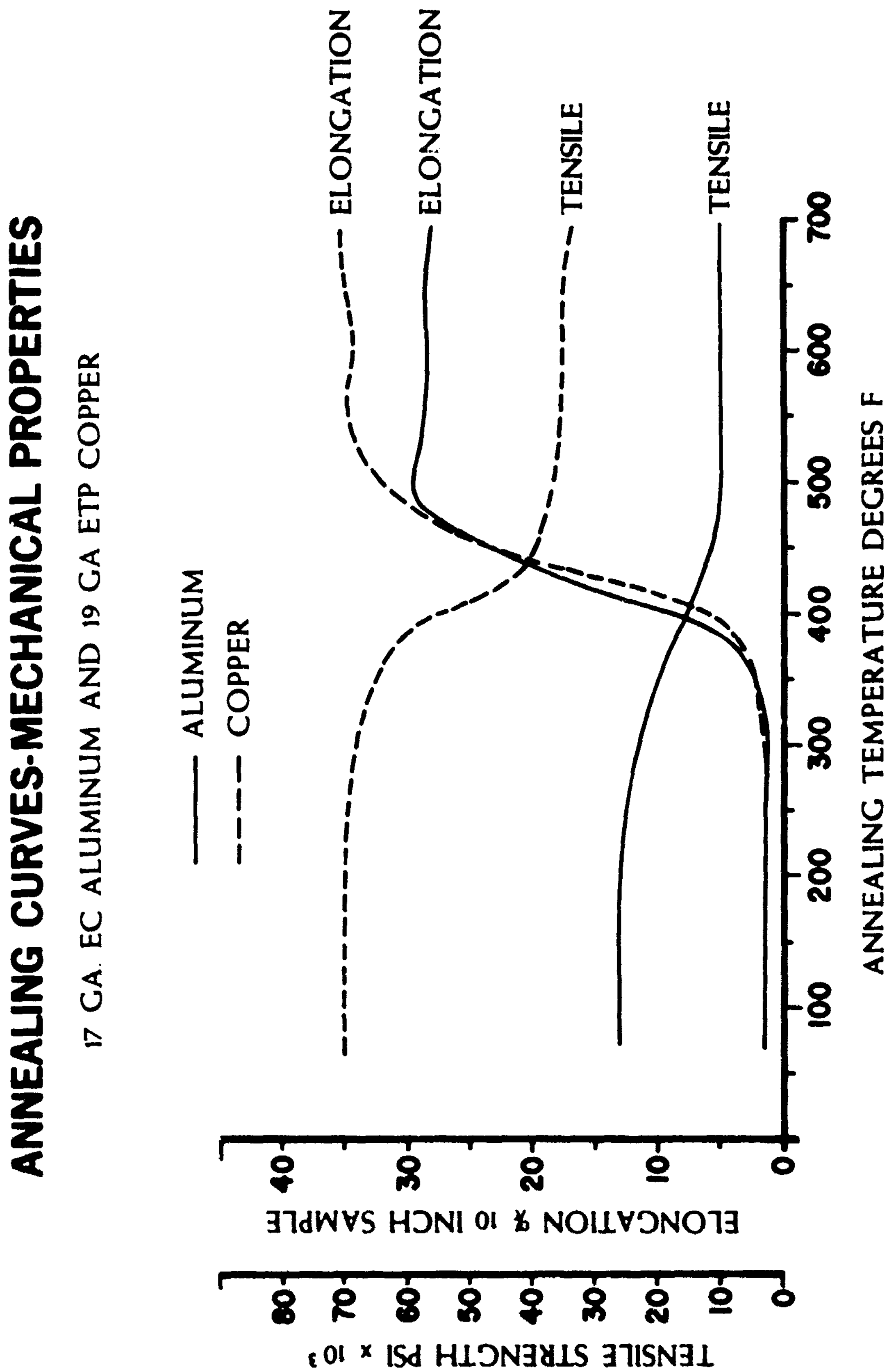

DRAWING AND INSULATING WIRE
IN ONE TANDEM OPERATION
HOOD
SUPPLY
WIRE DRAWING
ANNEALING
PLASTIC INSULATING
COOLING TROUGH
CAPSTAN
ACCUMULATOR
SPOOLER

Figure 1


ANNEALING CURVES-MECHANICAL PROPERTIES
17 GA. EC ALUMINUM AND 19 GA ETP COPPER
ALUMINUM
COPPER
ELONGATION
ELONGATION
TENSILE
TENSILE
ELONGATION % 10 INCH SAMPLE
TENSILE STRENGTH PSI x 10³
ANNEALING TEMPERATURE DEGREES F
100
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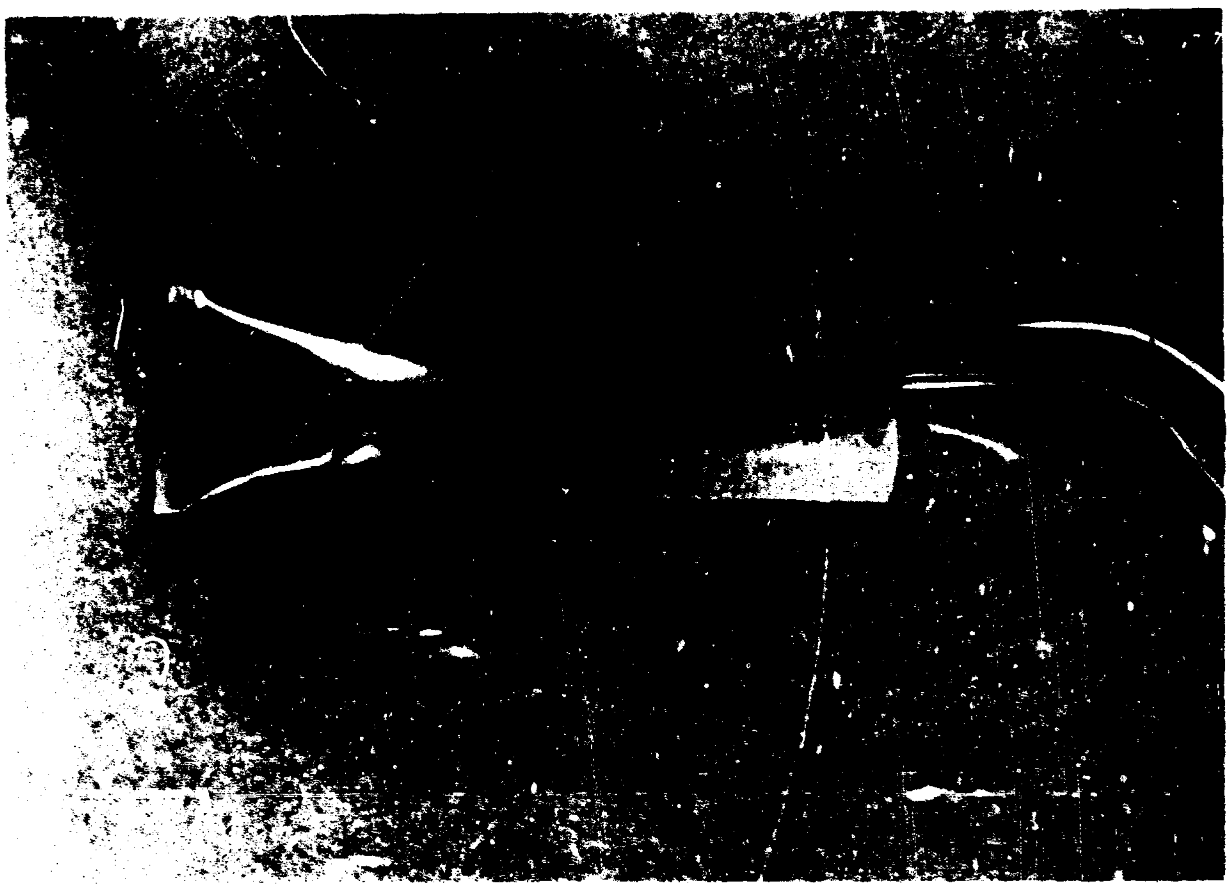
80

**Figure 2**


Figure 3



ENCAPSULATED "B" WIRE CONNECTOR

Figure 4

# EFFECT ( ̄ COLD WORK ON MECHANICAL PROPERTIES

17 GA. EC GRADE AL (0.0453")

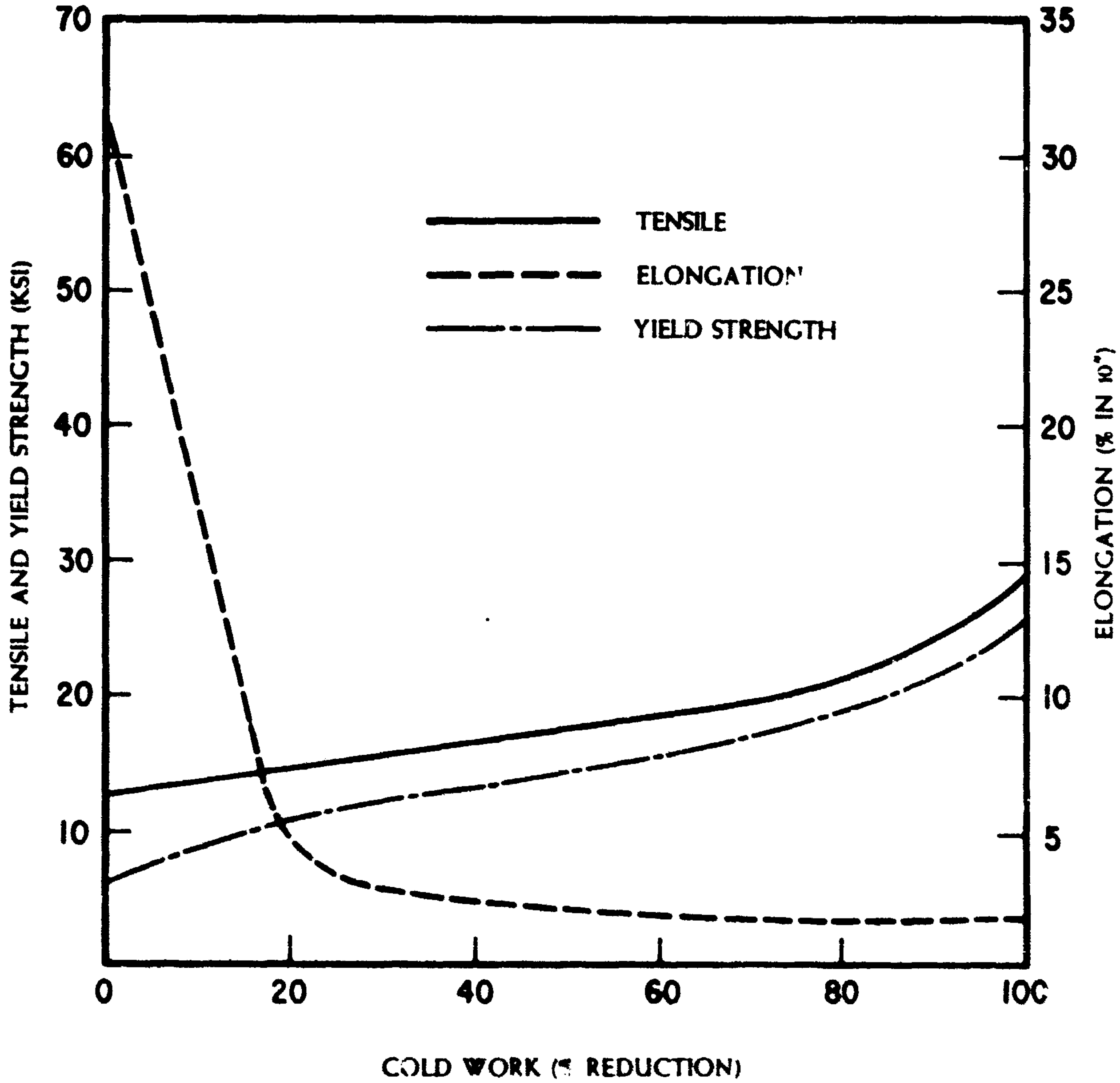



Figure 5

# LATCHING RELAY AT EACH SPLICE POINT

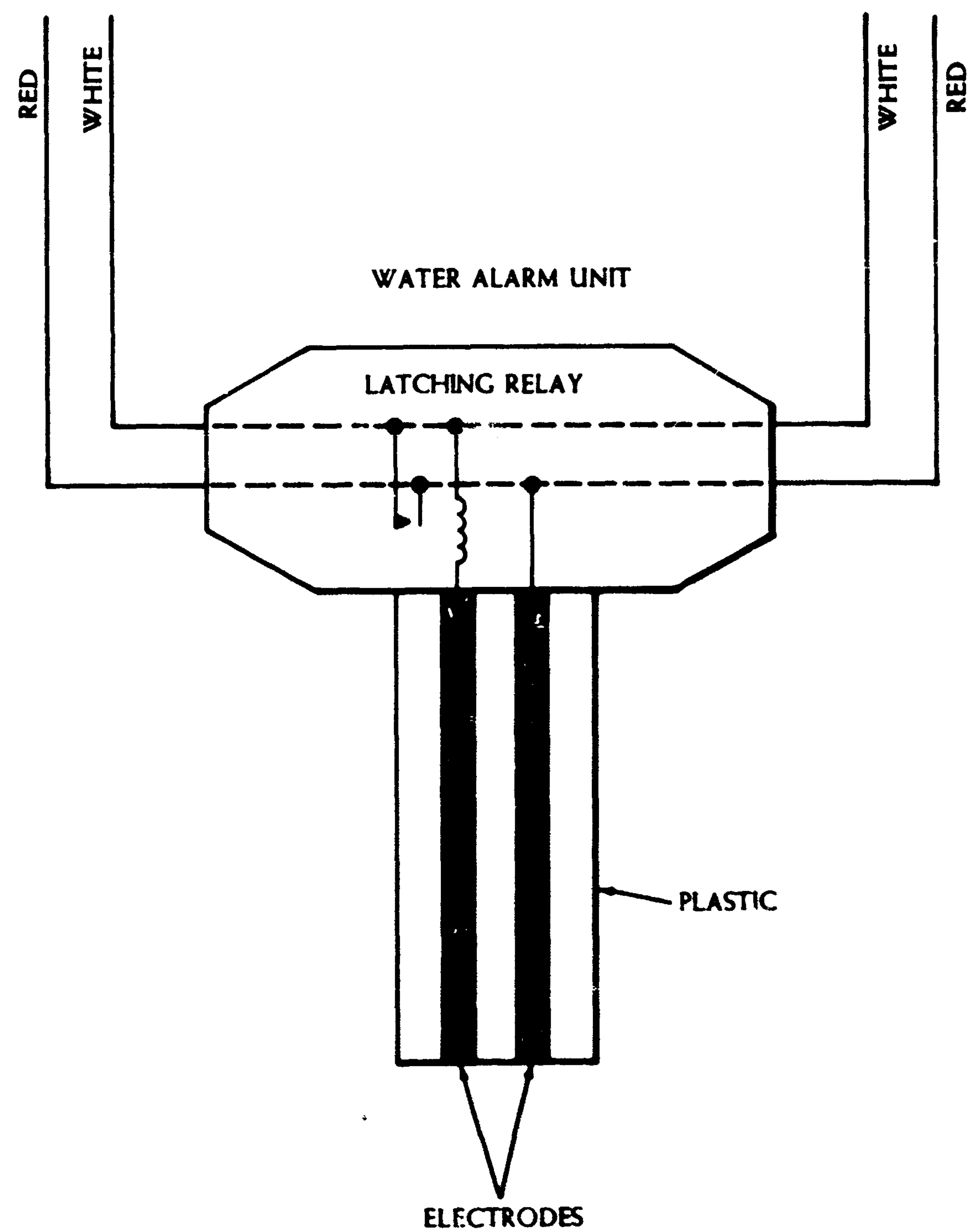



Figure 6

# COMPARISON OF TYPICAL ALUMINUM CONDUCTOR SURFACES

PHOTOMICROGRAPHS of 17 GA. AT 200X

STANDARD

SCALPED

SHAVED

Figure 7

# 17 GA. EC-H11 ALUMINUM WIRE FOR FIELD TRIAL

RAW MATERIAL INSPECTION RESULTS

TENSILE, YIELD, ELONGATION VS FREQUENCY

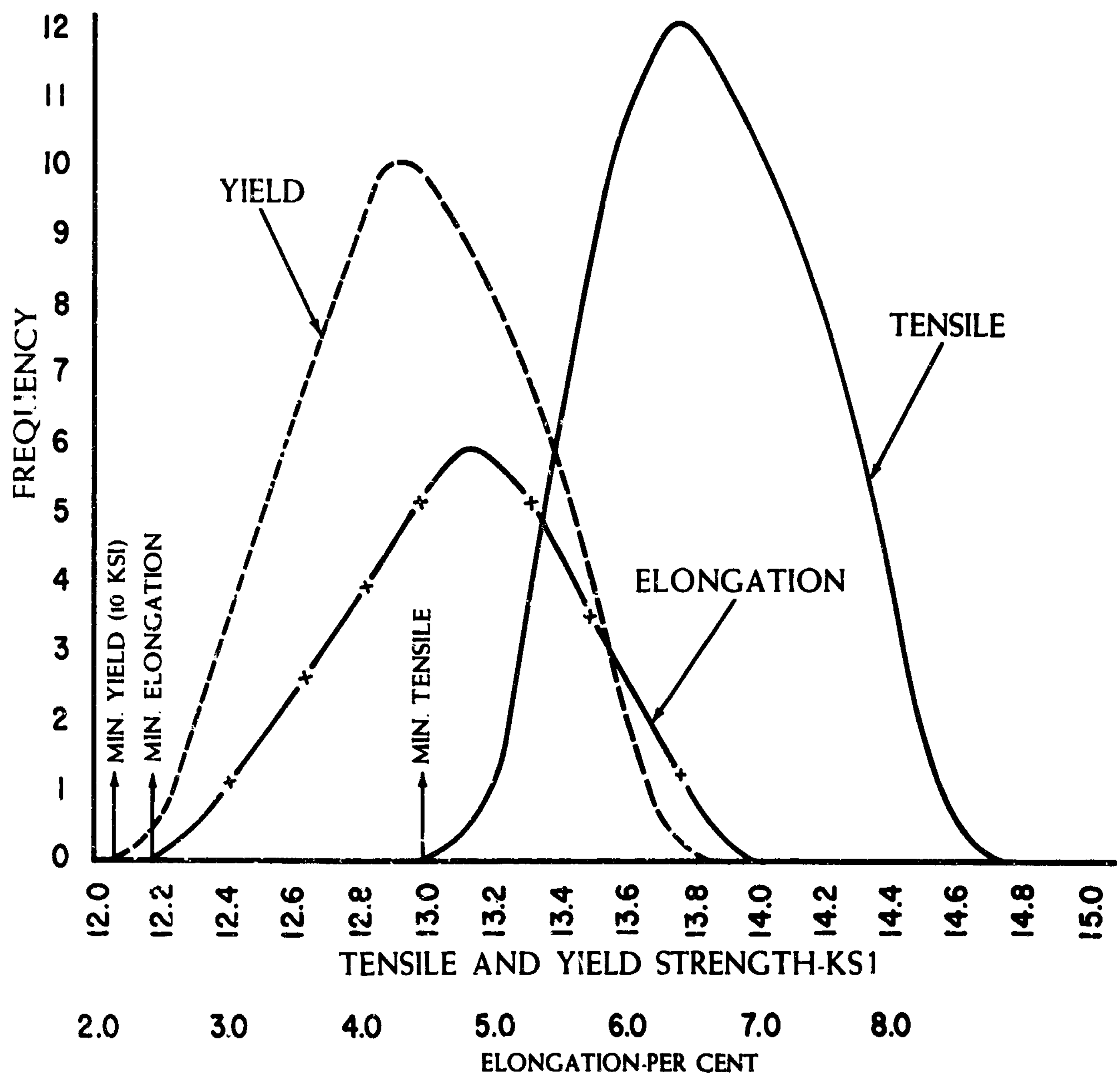
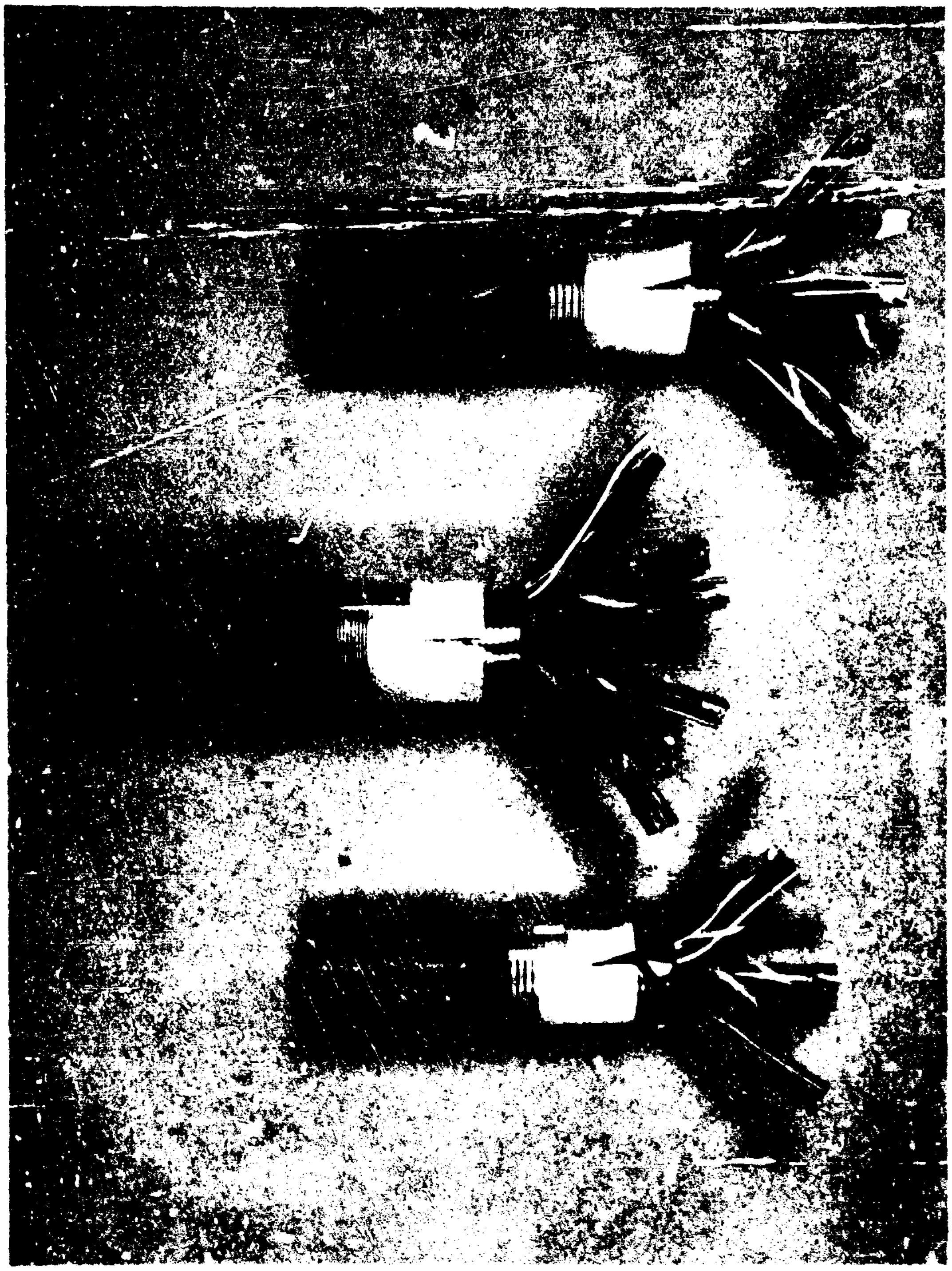



Figure 8



FIELD TRIAL CABLES

Figure 9

# Characteristics of 51 Pr. - 17 Ga. Plastic Insulated Field Trial Cable and Equivalent 50 Pr. - 19 Ga. Copper Cable

| | Aluminum | Copper |
|---|---|---|
| Average Mutual Capacitance M. F. per mile | 0.079 | 0.083 |
| Average Conductor Resistance Ohms per loop mile | 42.32 | 43.0 |
| Diameter over Insulated Wire | 0.078 ± .002 | 0.060 ± .002 |
| Cable Core weight Pounds per TLF | 322 | 461 |
| Diameter over Core | 1.10 | 0.85 |

Figure 10

ALUMINUM CONDUCTOR PILOT LINE

Figure 11

## ALUMINUM CONDUCTOR PILOT LINE

FLOOR LAYOUT

20 x 95 FEET

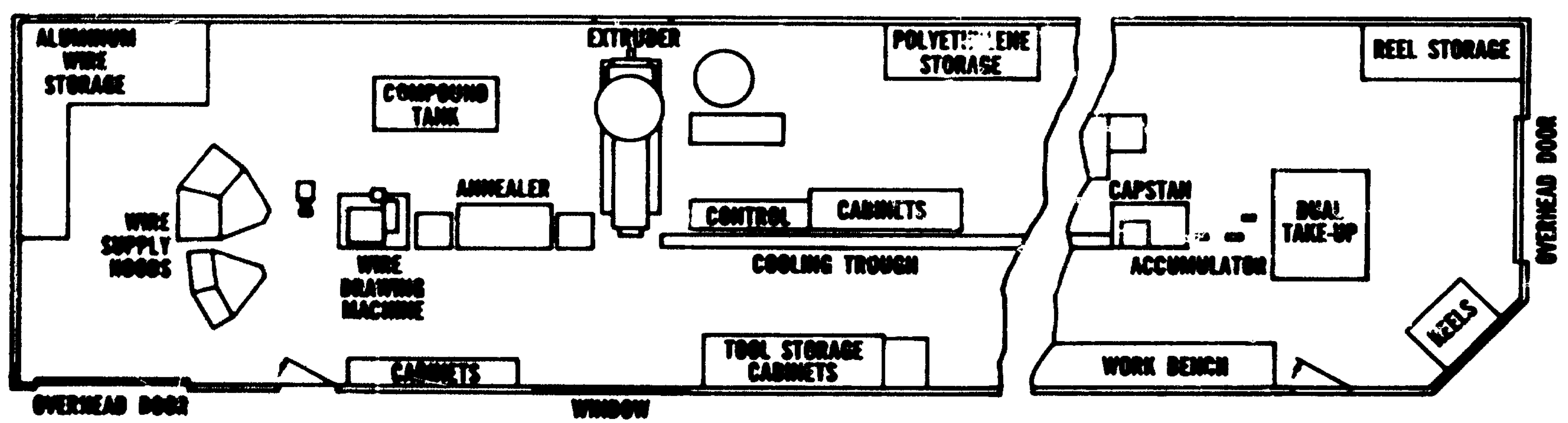



Figure 12

# TANDEM WIRE DRAW, ANNEAL, DRAW & CLEANING OPERATIONS

(CONTINUOUS MANUFACTURE OF EC-H II ALUMINUM WIRE)

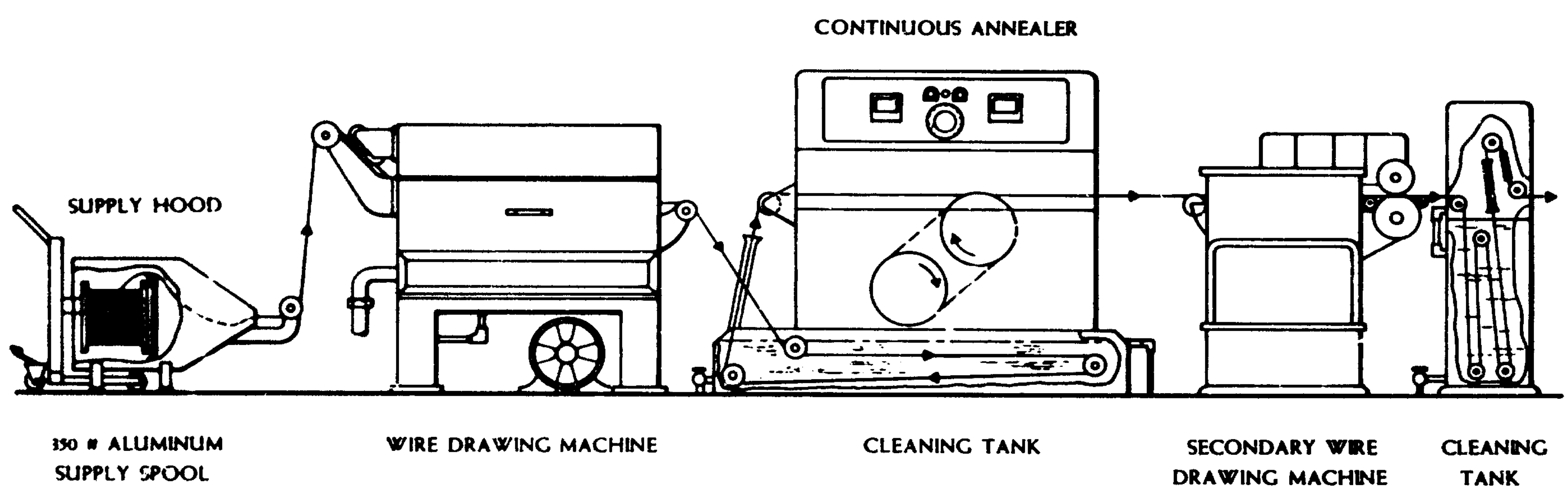



Figure 13

# INDUCTION HEATING

(SHORT CIRCUITED SECONDARY)

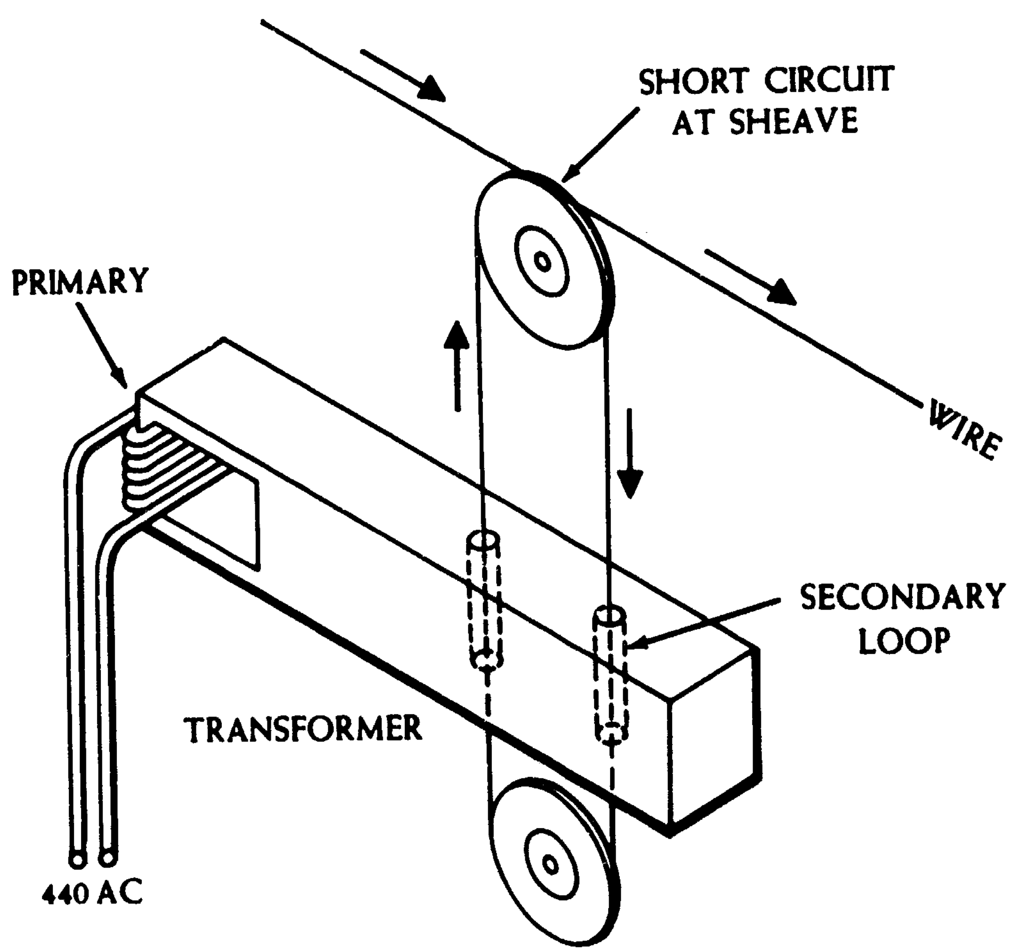



**Figure 14**

# DIRECT FLAME HEATING

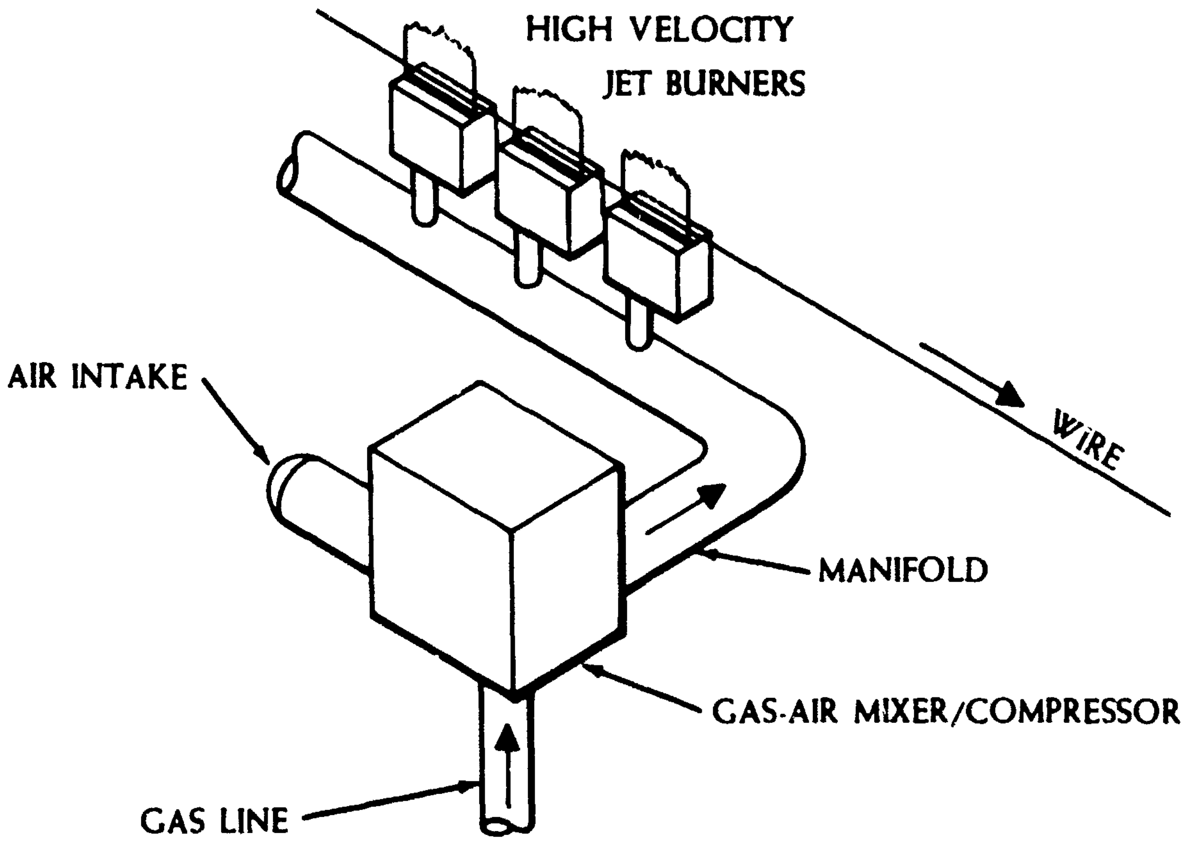



Figure 15