"BUILD IT YOURSELF"

A 50 Watt High Quality Audio Power Amplifier

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There are many reasons why a person builds his own electrical and electronic equipment. The person may find that by so doing he can obtain a better quality of equipment at a lower overall cost. At the same time he may be learning something useful about the construction and principles of operation of the equipment. To an electrical engineering student the second of these reasons by itself is more than sufficient for undertaking such a project.

The purpose of this article is to describe a step by step procedure for building a high quality amplifier capable of delivering 50 watts of audio power with low distortion and good frequency response. An amplifier similar to this one has been described in:

(1) "A High Efficiency-High Quality Audio Frequency Power Amplifier", 1954 IRE Convention Record, Part 6, Audio and Ultrasonics, pp 18-24.

(2) "A High Efficiency-High Quality Audio Frequency Power Amplifier", IRE Transactions on Audio, March-April 1954, pp 49-60.

(3) "Fifty-Watt Amplifier for High-Quality Audio", Electronics, October 1954, pp 160-164.

More recently an amplifier of the same type, capable of delivering 3000 watts of audio power, was described in Vol. 4, Part 7 of the 1956 IRE Convention Record and in the March-April 1956 issue of the IRE Transactions on Audio.

The basic circuit of the Bereskin Power Amplifier is shown in Figure 1. Two beam power tubes are connected in push pull with their cathodes at common

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ground potential. The screens are fed from any suitable power supply which need not be derived from the plate power supply. The screen and plate supply voltages may therefore be chosen independently to suit best the particular application.

The dual triode acts as a direct coupled phase inverter and driver supplying enough bias and drive for Class B_1 operation of the beam power tubes. Class B operation of the output tubes requires that the output transformer primaries be bifilarly wound in order to avoid the conduction transfer notch. A feedback winding, closely coupled to the bifilar primary and to the secondary, and statically shielded from them, is connected in series with the input to the grid of the left hand section of the dual triode. Good coupling between the bifilar primary and the secondary is assured by dividing the primary into two sections and sandwiching the secondary between these two sections.

This type of circuit has produced stable operation with 40 db of feedback, but this amount of feedback requires an excessive amount of driving voltage so that a value closer to 25 db is generally used. Due to the large amount of feedback used, the circuit is relatively insensitive to screen and plate supply ripple and regulation. The input signal may be either transformer or impedance coupled to the phase inverter-driver. Resistance-capacitance coupled input has been found to be relatively unsatisfactory due to the large dc resistance introduced in the grid circuit of the input triode. Grid current flow in this resistance, tends to produce dc bias unbalance in the output tubes.

An appreciable amount of capacitance exists between the bifilar wound primaries of the output transformer. This capacitance tends to limit the high frequency power delivering capacity of the amplifier. This undesirable effect of the primary interwinding capacitance is reduced by operation at low plate signal voltage and high plate signal current. The capacitance itself can be reduced by approximately one third by transposing the bifilar winding at each turn.

In the complete amplifier, shown in Figure 2, the basic power amplifier has been combined with power supply circuits and a preamplifier. A single 5U4-G rectifier tube, operating within its ratings, is adequate for supplying the plate circuits of the 1614 tubes. One 6X4 tube is used to supply the power required by the preamplifier and the screens of the 1614 tubes, while another 6X4 tube is used to supply the negative voltage required by the 12AX7 tube. The voltages indicated at various locations on the diagram are the measured no-load and full load values.

The preamplifier consists of a two stage resistance-capacitance coupled amplifier with feedback between the second plate and the first cathode. This feedback provides good wave shape and low output impedance on the preamplifier. The preamplifier is coupled to the 12AX7 grid with a 1.25 µf capacitor and a modified Thordarson T20C51 choke. The modification consists in interleaving the laminations of this choke. This coupling circuit has a low Q resonance between 10 and 15 cycles per second.

Feedback from the secondary of the transformer is incorporated in a manner similar to that used before. Additional overall feedback, for use with the 8 ohm tap, has been incorporated in the form of the 20 µµf capacitor connected between the 8 ohm output tap and the first cathode of the preamplifier. This capacitor improves the transient response by providing a gradual roll off at high frequencies.

Figures 3 through 6 are experimental performance characteristics on an amplifier using the output and power transformers described in this paper.

The curves in Figure 3 show that the turn ratios have been properly chosen to match 8 ohms and 16 ohms on the respective taps. This figure also shows that while there is an optimum load impedance, the value of load impedance is not exceptionally critical. Less than 2% distortion will result over a 3 to 1 range of impedances at 1 db below the maximum power output.

The curve in Figure 4 shows that a good balance has been chosen between the feedback in the output stage and in the preamplifier. This is indicated by the fact that the distortion rises gradually with load until the peak clipping region is reached, above 50 watts, and then the distortion rises very rapidly. Over most of the useful range the distorion is considerably less than 1%. The oscillator used in these tests had 0.22% distortion.

The amplifier has a residual hum consisting of -67 db 60 cycle component, -91 db 120 cycle component, -76 db 180 cycle component, -87 db 240 cycle component, and -90 db 300 cycle component. All other components are more than 95 db below 50 watts. According to the Fletcher-Munson equal loudness contour curves the human ear has in excess of 20 db greater sensitivity to the 180 cycle component than to the 60 cycle component and the increase in the hearing sensitivity is less than the level decrease for the 240 and 300 cycle components. The effective residual hum is therefore for all practical purposes the 180 cycle component. Shielding of the T20C51 choke and the low level stages reduces the 60 cycle component of hum by as much as 6 db but has negligible effect on the other components. In any case when this amplifier is used in a quiet room with an RCA 515S2 Duo Cone loudspeaker, in a 10 cubic foot base reflex cabinet, the residual hum is essentially inaudible at distances from the cone in excess of 12 inches.

Several different frequency response characteristics are shown in Figure 5. The top curve shows the limit of power output for 2% distortion. Operation below this curve will result in less than 2% distortion. The power delivering capacity of this amplifier, for 2% distortion, is down 6 db at 22 cycles and at 22 Kilo cycles. This is more than adequate for all ordinary audio applications.

Proper loudspeaker damping requires low amplifier output impedance. The bottom curve in Figure 5 shows that this condition is adequately satisfied by the amplifier.

The transient response of an amplifier is to a large extent a function of its low level frequency response. A high frequency overshoot of this curve results in ringing with sharp rise time inputs. Too rapid a roll off at high frequencies results in poor high frequency response. Best performance is obtained with a gradual high frequency roll off which is free of positive slope regions. In Figure 5 curves A, B, C, and D are the low level frequency response characteristics for this amplifier. These curves are identical between 10 and 3000 cycles per second. The slight peak between 10 and 15 cycles per second is due to the series resonance between the 1.25 μf capacitor and the modified Thordarson T20C51 choke.

At the high frequency end curves A and B are for the 8 ohm tap, and curves C and D are for the 16 ohm tap. Slight differences are to be expected between the two taps since the secondary windings are not identical. Curves A and C are for the amplifier without any overall feedback while curves B and D are for the amplifier with a 20 μμf capacitor connected between the 8 ohm tap and the first cathode in the preamplifier. The 20 μμf capacitor improves the response on the 8 ohm tap but degrades it on the 16 ohm tap. The degradation on the 16 ohm tap involves moving the -3 db point from 42 kc to 28 kc. This is not a serious matter but the degradation can be eliminated by connecting a switch in series with the overall feedback so that the switch may be closed for 8 ohm operation and opened for 16 ohm operation.

The oscillograms in Figure 6a, b, and c were prepared at the request of the editor of the Student Quarterly. In Figure 6a the single square wave pulse shown at the top has been added to a 1 kc signal. The bottom curve is the amplifier output for this condition. The 16 ohm tap was used for this test and the rms value of the 1 kc signal was 10 volts. This makes the instantaneous peak power 112 watts. With steady state sine wave signal only 100 watts instantaneous peak power could be handled without peak clipping. The reason that more than 100 watts can be handled in this test is that the plate and screen supply voltages are nearer the no load values than they would be with a sustained full load signal.

Figure 6b shows the resulting output wave shape when the 1 kc signal is suddenly changed from a 50 to a 12.5 watt level.

Figure 6c shows the overload characteristics of the amplifier. In each of these cases the input has been adjusted for 3% distortion in the output. The character of the distortion is radically different at the different frequencies. At 20 cycles the distortion is due to the inability of the system to supply adequate magnetizing current for the output transformer. At 1 kc the distortion is due to hard peak clipping. At 20 kc the distortion is due to the inability of the system to supply the charging current required by the primary interwinding capacitance.

The oscillograms in Figure 6d show the 5 kc square wave response of the amplifier at both 40 and 10 watt output levels. The oscilloscope gain controls were left unchanged throughout this test. For each successive oscillogram the position controls were adjusted to shift the wave slightly downward and to the right so that the wave shapes could be observed with a minimum of interference.

Waves 1 through 4 are for a 40 watt output level and waves 5 through 8 are for a 10 watt level. Waves 1 and 5 are for direct connection of the input signal to the CRO. The input attenuation was adjusted to make the amplitude of these waves equal to the output on the 8 ohm tap for reference purposes. Waves 2 and 6 represent the output wave shapes on the 8 ohm tap when the 20 μμf overall feedback capacitor is omitted. The ringing associated with a rising low level frequency response characteristic is clearly evident in these waves. Waves 3 and 7 show the reduction in ringing obtained when the 20 μμf overall feedback capacitor is used on the 8 ohm tap. Waves 4 and 8 are for output taken on the 16 ohm tap. Since the input and the volume controls on the CRO were not changed, waves 4 and 8 have an amplitude approximately 40% greater than the previous corresponding waves. The 20 μμf capacitor was not used for these waves since the low level frequency response characteristic has a natural gradual roll off at the high frequency end.

The output transformer and the power transformer used in the complete amplifier are items that are not at the present time available commercially. The power transformer could be replaced with two or more commercially available transformers but there is no available combination that would satisfy the output transformer requirements. Cross-sectional views of the output and power transformers are shown in Figures 7 and 8. Most of the remainder of this paper will be devoted to a description of construction techniques which apply to these two transformers. The methods described will not necessarily be those that would be used for production purposes but will be quite satisfactory for the construction of these transformers in small quantities.

Coil Winding Equipment

Of course professional winding equipment would be by far the most satisfactory to use in making the required coils. This equipment will only be available to a relatively small number of people reading this article. A rather satisfactory substitute is a small bench lathe having provisions for slow speed operation and longitudinal feed. Rapid start-stop provisions, to permit inching of the work, are also highly desirable.

Figure 9a shows a set of coil winding parts which are used in conjunction with a lathe.

The arbor 1 is made in two parts which are held together with a pin. The manner in which the arbor head is attached to the lathe is shown in Figure 9b.

The revolution counter 4 is used to keep track of the turns. The bushing attached to the shaft of the revolution counter is the proper diameter to fit snugly in the spindle hole of the lathe as shown in Figure 9c. This arrangement eliminates most of the revolution counter vibration. The frame of the revolution counter is kept from turning by the rod 3 which is attached to it and which rests against the frame of the lathe. A revolution transmission link 2 is attached to the arbor head on one end and to the bushing on the revolution counter on the other end. Figure 9c shows that the bushing is long enough to permit access to both set screws when the bushing is in place. A simple reel, suitable for handling two spools of wire at the same time, is shown in Figure 9d. The advantage of this particular arrangement is that it can be assembled for use or taken apart in a matter of two or three minutes.

A simple wire guide, shown being used in Figure 11, can be frabricated out of a piece of cold rolled steel and a piece of hardwood. The cold rolled steel rod should be of the proper size to fit in the lathe tool holder. The piece of hardwood should be quarter rounded in the region where the wire is to pass over it. Suitable round or flat bottom slots can be cut in the quarter round section of the hardwood to accommodate the different wire sizes which will be used. These slots should be suitably sanded and burnished to eliminate all rough spots which might tend to bruise the wire insulation.

If neither a winding machine nor a lathe is available, some ingenuity will have to be exercised to fix up some other hand or machine driven coil winder.

A very crude arrangement, made of two by fours attached to a suitable plank, similar to the one shown in Figure 9d, and using a cold rolled steel rod bent to provide a handle, could be used in place of the lathe. This device can be clamped to a table or some other flat surface with a pair of C clamps and the motive power can be supplied by a friend having interest, patience, and a suitable amount of muscle. Turns can be counted either as the crank is turned, at the end of each row, or preferably by both methods. Considerable care should be exercised in this case to keep an accurate count of the turns.

In the case where only one amplifier is being made the total effort may be a minimum if the coil winding equipment is dispensed with and the coil is wound entirely by hand. One such case is known in which an output transformer with a trifilar winding, a driver transformer with a bifilar winding, and a power transformer were wound a layer at a time, during spare time intervals, with a total elapsed time of two weeks. In the succeeding discussion it will be assumed that a small bench type lathe, capable of slow speed operation, is available but the individual steps can be interpreted in terms of any winding system used.

Suitable wood blocks, of the type shown in Figure 10, will have to be prepared for the purpose of shaping and dimensioning the coil forms and the coils. The length of these blocks should be an inch or two longer than the final coils desired in order to avoid crowding during the winding process. The length of these blocks will probably be limited by the length of drill available for making the center holes. The center holes should be accurately centered and parallel to the longitudinal axis of the wood blocks to avoid wobble when the coils are being wound. The height and width of the wood blocks should be approximately 1/16 inch larger than the final corresponding dimensions of the cores. The output transformer will use a 2-7/8 inch stack of laminations having a 1-3/4 inch width center leg. The power transformer will use a 2 inch stack of laminations having a 1-1/2 inch width center leg. If only a few coils are to be made, pine can be used for making these blocks but if it is intended to make several coils over a relatively long period or time, better dimensional stability is attained by using maple or some other suitable hardwood.

Coil Forms

Coil forms for providing mechanical stability to the windings, can be made of gummed paper tape of the type used for sealing cardboard cartons. This tape in 5 mil thickness and 3 inch width is available in most stationery stores and in many 5 and 10 cent stores. In making the coil form a length of gummed tape, sufficient to go around the wood block ten to twelve times, should be cut. This tape should be trimmed in width to 1/16 inch less than the available core window length. This should be done carefully to avoid rough places and variations in the width.

Before starting to wind the coil form, two pairs of wood blocks should be prepared for the purpose of compressing the coil form while it is being dried. These blocks should be fairly smooth on the side that will be against the coil form and of dimensions suitable for some arrangement similar to that shown in Figure 10d. An arbor press and one C clamp are shown in this diagram but two C clamps would work equally well.

To wind the coil form:

(1) Wind two layers of wax paper around the center wood block and anchor the wax paper in place with a piece of cellophane tape, as shown in Figure 10a.

(2) Bend a length of the gummed paper tape, an eighth of an inch less than the circumference of the center wood block, back on itself gummed sides together.

(3) Moisten the two overlapping gummed sections liberally with a damp sponge and stick them together so that they are properly aligned.

(4) Place the overlapped piece of gummed tape around the wood block forming the first turn of the coil form. The gummed side of the remaining tape should face toward the coil form.

(5) Liberally, but not excessively, moisten the non-gummed side of the first turn and, pulling firmly on the loose end of the gummed tape, turn the ~~spindle~~ arbor through a turn while smoothing out the overlapping layers of paper. Insufficient moisture will not permit the first turn to be wound tightly with sharp corners while excessive moisture will make the first turn of the coil form slip around on the wood block. Insufficient tension on the gummed tape will not make a firm coil form while excessive tension will tear the gummed tape. A moderate amount of practice will make it possible to wind firm coil forms which are not excessively soggy.

(6) Proceed to moisten moderately two or three sides of the non-gummed side ahead and turn the ~~spindle~~ arbor while smoothing and firming the surface of the coil as shown in Figure 10b. Considerable care should be taken to insure that successive layers of the gummed tape are properly aligned.

(7) Cover the completed coil form, shown in Figure 10c, with two layers of wax paper and anchor the wax paper with cellophane tape.

(8) Thick metal plates and pieces of 1/2 inch bakelite have been used in Figure 10d in place of wood blocks. An arrangement of this type will squeeze out the excess moisture and insure adhesion at all points in the coil form.

(9) After approximately twenty-four hours remove the C clamps, the outside wood blocks, and the waxed paper. Allow the coil form to dry on the center wood block for an additional forty-eight hours. At the end of this time, if the weather has not been excessively humid, the coil form will have dried to a hardness which will be adequate for the purpose of winding the coils. A certain amount of time can be saved by drying the coil form in an oven but temperatures in excess of 150° F might produce dimensional changes in the wood block.

The Output Transformer

If a coil winder or a lathe is used it should be set to provide a 20 turn/in feed, and a guide slot, suitable for accommodating two #28 HFDC (Heavy Formvar Double Cotton) strands of wire side by side, should be provided on the feed mechanism.

To start the winding proceed as shown in the successive photographs in Figure 11. Place the two strands of wire side by side within 3/16" of the edge of the coil form and fasten them down with a piece of 3/4" electrical tape shown as item 1 in Figure 11. Bend the two wires at right angles as shown and fasten down with another piece of electrical tape 2 cut to extend about ~~three~~ four inches beyond the right hand side of the coil form. Place a third piece of electrical tape 3 underneath the two wires and the tape 2 placed over the wires previously. This piece of tape should be gummed side up and should extend approximately one inch inside the right hand side of the coil form and outward approximately four inches. The two pieces of gummed tape 2 and 3 should be kept from sticking to each other, in the region to the right of the coil form, by a piece of waxed paper or cellophane 4 inserted between them. The wire should be arranged to extend approximately six inches beyond the edge of the coil form.

The manner in which the wires are transposed at each turn is also shown in Figure 11d. The wires should be wound tightly with a minimum amount of space between them. There should be approximately 40 turns per layer, the wire not being wound any closer than 3/16 inch of the other edge of the coil form. Upon completing the first layer of wire a piece of 5 mil Kraft paper, cut to the width of the coil form should be wrapped around the wire with an overlap of about one inch at the position of the wire transposition and it should be anchored in place with a piece of cellophane tape. The paper is necessary to keep the succeeding turns of wire in a uniform layer. Succeeding layers of wire should be transposed on the same face of the coil form. Care must be taken not to transpose the wire on the core window faces of the coil form since ~~coil~~ window cross-section area is at a premium in these positions.

At the end of 7 layers there should be approximately 280 bifilar turns and it will be necessary to anchor the wire ends in place as shown in the successive photographs in Figure 12. When the winding is within approximately ten turns of the end of the last layer a piece of tape is placed gummed side up as shown by item 1 in Figure 12. The winding is then completed, and at the end the wires are bent at right angles and held in place by being pressed against the gummed tape. A strip of waxed paper 2 is placed over the gummed tape and another piece of gummed tape 3 is placed over the coil and the wire ends. The wire should again be trimmed to extend approximately six inches beyond the edge of the coil form.

The winding should now be covered with five layers of 5 mil Kraft paper to provide insulation between the primary and the secondary.

Since the end of the wire on the secondary winding will form the lead it is necessary to insulate this wire carefully and anchor it in place. The first layer of the secondary will be the 8 ohm section and will use #16 HF wire fed 18 turns/inch. To start this winding slip an 8 inch piece of vinyl insulating spaghetti over the wire and bend the wire at right angles to itself approximately 3/4 inch from the inner end of the spaghetti. Using the coil face opposite to that on which the primary winding was started, and with the wire coming out on the side opposite to that on which the primary winding started, place the wire within a quarter inch of the center of the coil face as shown in Figure 13a. Anchor the wire firmly in place with pieces of gummed insulating tape 1 extending over three faces of the coil and 2 across the full length of the coil. Care must be taken in making the first turn of wire to avoid pulling it loose. Before the first turn is completed arrangements must be made to provide an anchor for the last turn. To do this loop a piece of linen tape 3 over the first turn with the open end extending approximately three inches beyond the left edge of the coil form. If linen tape is not available a lengthwise folded piece of gauze bandage will work just as well. A piece of cellophane tape can be used to keep the loop end of the linen tape from flopping around while the secondary is being wound. After 20 turns of this layer have been completed fold the loose end of the linen tape 3 back on itself forming a loop which extends to the left hand edge of the coil form. Continue the winding over the folded section of linen tape. At the end of

35 turns of secondary wire, cut the wire long enough to permit an 8 inch lead when the coil is finished. Place the wire through the open loop end of the linen tape and then slip a 6 inch piece of vinyl insulating spaghetti over the wire so that the inside end of the spaghetti extends about 1/2 inch beyond the linen tape loop. The open ends of the linen tape should now be pulled firmly to close the open loop around the last turn of the secondary wire. Care must be taken not to pull the tape so hard that it tears. The wire end should now be bent at right angles so that it comes out parallel to the start wire on the coil. The loose end of the linen tape should be cut off even with the right hand edge of the coil form. Cover this winding with three layers of 5 mil Kraft paper anchored in place with cellophane tape.

The next layer of the winding will contain both the additional turns necessary to form the 16 ohm section of the secondary and the electrostatically shielded feedback winding. This section of winding will consist of 14 turns and the winding scheme will be the same as the previous layer except for the fact that the winding will be started 1-1/8 inch from the left hand edge of the coil on the same face as the previous layer and the looped linen will be under the full 14 turns of wire. The completed section of winding is shown in Figure 14.

In this amplifier the feedback information is derived from the magnetic circuit of the output transformer and any contamination of this information by capacitively coupled signals will be detrimental to the operation of the amplifier. The feedback is inserted at a relatively high impedance point and the feedback winding is physically close to the secondary and primary windings, both of which have relatively high signal potentials. To avoid capacitive coupling to the feedback winding, it must be statically shielded from both the primary and the secondary.

Any thin metallic material will serve as a static shield for the feedback winding. Copper foil of approximately 5 mil thickness is excellent for this purpose. Aluminum foil, while more readily available, can only be soldered by special techniques and is therefore not very satisfactory. The static shield must completely enclose the feedback winding without forming a short circuited turn on the transformer. This means that the ends of the static shield must both overlap and be insulated from each other.

To make the static shield, cut a strip of copper foil, of approximately 5 mil thickness, so that it is long enough to go completely around the right hand side of the coil form and overlap by approximately 1/4 inch. The width of the strip should be approximately 3/8 inch less than the space available between the exposed section of secondary and the right hand side of the coil form. Strip the insulation off of a 12 inch piece of #20 stranded thermoplastic (polyvinyl chloride) insulated wire to approximately 1/4 inch more than the width of the static shield. Carefully solder this wire to the static shield approximately 1/8 inch from the end of the shield as shown in Figure 14b. Place a 6 inch piece of insulating tape 1 gummed side up at the center of the coil form face as shown in Figure 14a. Fasten it down with a piece of insulating tape 2 gummed side down overlapping the first piece by approximately 1/4 inch. A piece of white electrical insulating tape 2 was used to show more clearly how it overlaps and anchors the piece of black insulating tape 1. Place the edge of the static shield 3 up against the edge of tape 2, as shown in Figure 14b, with its right hand edge within 1/8 inch of the right hand side of the coil form and press it firmly against the gummed side of tape 1. This must be done carefully so that the ends of the copper foil will line up when the turn is completed. Before completing the turn place a piece of waxed paper 4, over the portion of tape 1 extending beyond the edge of the coil form and then place a 4 inch piece of gummed tape 5 over the edge of the shield so that it is lined up with tape 1 as shown in Figure 14c. Take a piece of 5 mil Kraft paper 6, cut to the width of the distance between the exposed portion of the secondary and the right hand side of the coil form, and fold 1-1/2 inches of the end back on itself. Place the doubled section of this strip of paper over the starting end of the static shield and anchor the paper strip to the coil form with a piece of cellophane tape. Bring the copper strip around, maintaining a uniform edge with respect to the coil form and anchor it with a piece of cellophane tape to the Kraft paper. Bring the Kraft paper around for two complete turns and cut it off long enough so that it can be folded back on itself for a distance of 1-1/2 inches in the region of the static shield end. Bend the end under and anchor it down with another piece of cellophane tape as shown in Figure 14d. This completes the first section of the static shield and the insulation necessary to separate it from the feedback winding.

The wire size used for the feedback winding is not too important. It should be small enough to avoid making the coil bulky and yet large enough to reduce the danger of tearing the wire. The #30 H.F. used on the power transformer would be suitable for this purpose.

The sequence of operations required for the feedback winding is shown in Figure 15. The wire is first anchored in place by a piece of tape 1 approximately 1/4 inch to the right of the left hand edge of the static shield. The end of the wire is then bent at right angles to itself at a position far enough beyond the static shield insulation 5 to keep the two from interfering with each other. A 5 inch piece of gummed tape is slit lengthwise down the middle and the two strips are used to anchor and insulate the start of the feedback winding in a manner similar to that used with the primary. The upper strip of tape 2 and the waxed paper 3 used as a separator are clearly visible in the photographs. Forty turns of feedback winding are required and if #30 H.F. wire is used it should be fed

80 turns/inch. The end of the feedback winding is handled in a manner similar to that used for the end of the inner half of the primary except that in this case the gummed side up strip of tape should be inserted at the beginning of the winding. The upper strip of tape 6 and the waxed paper separator 7 are also clearly visible in these photographs. A piece of Kraft paper 8 is folded back on itself for a distance of 1-1/2 inches and the folded over section is placed at the position of the static shield overlap. After two turns of the Kraft paper it is cut off long enough to permit it to be folded under for a distance of 1-1/2 inches in the same section and it is then anchored down with a piece of cellophane tape. The piece of gummed tape 5 is now folded back, trimmed to the edge of the secondary winding, and anchored down with the piece of gummed tape 9 which overlaps tape 5 by 1/4 inch. Waxed paper 4 and gummed tape 5 are identical in Figures 14, 15 and 16. Figure 16 shows how the outer static shield is anchored to gummed tape 5 in the same manner that the static shield was handled in Figure 14. Notice that the two leads from the static shields are now between the same two pieces of gummed tape with only wax paper 4 between them. The outer static shield is finished off in exactly the same manner as the inner static shield. The outer section of the secondary and the feedback winding assembly are approximately the same height on the coil form and should be covered with 5 layers of full width 5 mil Kraft paper.

In order to avoid bringing out too many leads the ends of the inner primary are spliced to the starts of the outer primary as shown in Figure 17. Items 1 and 3 in Figure 12 and 17 are the same. In Figure 17a tape 3 has been folded back and held in place by tape 2. The two wires are folded over, skinned, and spliced to the new wires coming off the spools. A strip of tape 4 is placed over the upper splice in such a manner that its edge comes up to but does not cover the lower splice. Then a piece of tape 5 is placed over the lower splice in a similar manner. This insures that the two splices will never be able to slip sufficiently to touch each other. An additional two strips of tape are now placed uniformly over both splices and finally tape 1 is folded back and the various tapes are all trimmed even with the left hand edge of the coil. One more piece of tape 6 is used to keep the two wires from pulling loose and the outer primary is wound in exactly the same manner as the inner primary with a final 5 turns of 5 mil Kraft paper.

The wires used on the primary and feedback winding are too fragile to be used as transformer leads. It is now necessary to splice them to suitable flexible leads such as #20 stranded polyvinyl chloride hook up wire, and to anchor these leads in place. In Figure 18 strips of gummed insulating tape 2 and 3 are the same as those in Figure 11. Strips of tape 4 and 5 come from the finish of the outer primary in a manner similar to pieces 3 and 1 in Figure 12, which shows the finish of the inner primary. In Figure 18a pieces of tape 2 and 4 have been folded back over the coil and are held in place by two other pieces of white electrical insulating tape 6 and 7. The four wires are also folded back and are anchored in place with a piece of insulating tape 8 which keeps them from being pulled out of the coil during the skinning operation. Figure 18b shows these wires skinned and soldered to the flexible leads. The wires have been folded in such a manner that when the vinyl sleeving is slipped over them in Figure 18c, the cotton covered sections of wire are about as far apart as it is possible for them to be. This section is now finished off as shown in Figure 18d by folding pieces of tape 3 and 4 over the flexible wires and sleeves. Notice that tape 3 was mistakenly cut too short originally and does not go all the way to the left edge of the coil. If several different colors of flexible leads are available it is convenient to use some color coding convention to keep track of the individual wires. A similar procedure has been used to bring out the feedback windings as shown in Figure 19a. The flexible leads are now held tightly in place and the outside of the coil is finished off by wrapping two layers of insulating tape around the outside of the coil as shown in Figures 19a and b.

The wood block has now served its purpose and must be removed. This is done as shown in Figure 19c. A pair of blocks with a 90° edge are held firmly against the wood block and then the wood block is tapped lightly with a hammer to make it come out of the center of the coil. A very dangerous procedure is to hold the outside of the coil in one hand while tapping the wood block with a hammer since this may result in a separation of the winding and require that the transformer be wound over again from the beginning.

The completed transformer winding, with the wood block removed, is shown in Figure 19d. If the coil has been rightly wound, in accordance with the previous description, the laminations will fit with a slight amount of surplus room in the windows. ~~Two~~ All transformers wound according to these exact specifications have had adequate clearance for the laminations. Notice that the wires have all been brought out at the same end of the winding. The primary wires have been brought out at one face of the winding while all the other wires have been brought out at the other face.

Before any more work is done on this coil it is desirable to increase its mechanical stability by tying it in various locations with linen tape as shown in Figure 20a. Notice that on the long sides the knots in the linen tape have been placed at the edge of the coil where the paper can be squeezed inward. If these knots are placed anywhere else they will interfere with the stacking of the laminations.

This transformer has been designed for use with grain oriented EI laminations such as the Thomas & Skinner EI - 1-3/4 inch H Orthosil laminations. Notice in Figure 20b that the holes in these laminations are not centrally located in the corners but have been moved so that their centers are 1/4 inch from each edge of the lamination. This is an important factor and has a considerable bearing on the low frequency operation of the amplifier. This point will be covered more thoroughly later.

For best low frequency performance the laminations are 100% interleaved and tapped together with a hammer to produce minimum air gap. Protective pieces of 10 mil fish paper insulation have been inserted as shown in Figure 20b and c. The complete output transformer with mounting brackets, before being dipped in insulating material, is shown in Figure 20c.

Moisture absorption by the cotton insulation on the primary wire will increase the primary interwinding capacitance and thereby interfere with the high frequency power delivering capacity of the amplifier. The presence of moisture will also tend to rust the laminations in a relatively short time. Both of these undesirable factors can be avoided by dipping the complete transformer in a suitable insulating material. Several good commercial products are available for this purpose but the minimum sale quantities are usually considerably in excess of the amount necessary for this application. The ~~cost of the minimum quantity of~~ insulating material, with a total cost of a little over a dollar, can be made by dissolving polystyrene in toluol in the proportion of 4 cubic inches of polystyrene to a quart of toluol. A 4" x 8" x 1/4" sheet of polystyrene costs thirty-nine cents while a gallon of toluol costs approximately $1.65 and can be purchased in most paint stores. The rate at which the polystyrene dissolves in the toluol depends to a large extent on the particle size of the polystyrene.

With relatively large particles it may take as much as 48 hours for the polystyrene to be completely dissolved. The amount of solution that will be required will depend on how close a fitting can is used. With the can shown in Figure 20d a little less than a quart of mixture was necessary to cover the transformer including the laminations.

Before the transformer is dipped it should be baked to drive all of the moisture out of the insulation. If a temperature controlled oven is available, then baking for approximately 12 hours at 70° C. will suffice. If a temperature controlled oven is not available then the same thing can be accomplished by shorting the primary windings and exciting the full 16 ohm secondary winding with 2.5 volts of 60 cycle power. The excitation transformer could be a center tapped 5 volt filament transformer but it must be capable of delivering continuously a load current of 10 ampere. This is to some extent a more satisfactory system of baking since the heat is generated uniformly throughout the structure. A 24 hour bake by this method has been found to be adequate to drive the moisture from the insulation.

While the transformer is still hot from the baking operation it should be inserted upside down in a can, as shown in Figure 20d, and the previously prepared insulating fluid should be poured into the can until it completely covers the transformer laminations. Since the solvent used is toluol, which is inflammable, a considerable amount of caution should be exercised in the handling of this material. To insure complete penetration the transformer should be left immersed in the insulating fluid for approximately one-half hour after it ceases bubbling. Surface evaporation of the solvent may be reduced during this time by placing a cover over the can or by placing the whole system inside a pan which has a tight fitting lid.

When the transformer is removed from the can it should be allowed to drip back into the can until the free running material has ceased to flow. It should then be subjected to the same baking procedure that was used to drive out the moisture. The dip and bake process should be repeated, leaving the transformer in the dip only long enough to stop the bubbling, three or four more times to seal the pores through which moisture might penetrate the coil at some later time.

Output Transformer Variations

An equally good output transformer could have been made on the basis of a pair of 2" x 1" grain oriented C cores. If the C cores had been used the total weight of core material would have been reduced from 14.5 lbs. to 11.2 lbs. but the cost of the core material would have increased from $5.50 to $8.00. The mechanical problems of mounting the C core transformers are somewhat greater than those encountered when EI laminations are used.

The magnetization curves in Figure 21, for the various types of iron indicated, were obtained experimentally. Grain oriented EI laminations suffer from the fact that a portion of the flux path must of necessity be at right angles to the grain orientation. The position of the mounting hole, in the corner of the lamination, also has an appreciable effect on the magnetization properties at high inductions. Since all of the EI laminations tested were 100% interleaved they behaved at low inductions as though they had exceedingly small air gap. In the case of the C cores a butted joint is unavoidable and it is very difficult to get a total air gap of less than .001 inch with such a joint. This requires an appreciable amount of magnetizing ampere turns at low values of induction although the iron does not start saturating until it gets to considerably higher values of induction. As a matter of fact in the region below the knees of the curves for the grain oriented EI laminations, the ampere turns required for the

C cores can be approximated very closely by adding the ampere turns of the .001 inch air gap to the ampere turns of the EI laminations, making a small correction for the fact that the C core flux path is longer than the EI flux path.

Operation at 30 cycles and 40 watts would require 0.093 ampere peak magnetizing current for both the C core and the EI - 1-3/4 inch H Orthosil 3X designs. The use of EI - 1-3/4 inch HS Orthosil 3X laminations would boost this magnetizing current to 0.210 amperes while the use of non-grain oriented EI - 1-3/4 inch laminations would require 0.350 amperes peak magnetizing current. The greater the peak magnatizing current required for magnetization the less is available for supplying the load and therefore low frequency distortion becomes evident. The EI - 1-3/4 inch HS Orthosil and non-grain oriented laminations are clearly unacceptable if good low frequency performance is desired.

The #16 HF wire used for the secondary of the output transformer was a little heavier than it needed to be. This wire size was specified because it is also used for the filament windings in the power transformer and it is desirable to use as few different wire sizes as possible.

If impedances other than 8 and 16 ohms are desired it is simple enough to compute the number of turns and the wire size that must be employed. Transformers of this type have been made for as low as 4 ohms and as high as 500 ohms output impedance. Values outside these limits could also be used.

The Power Transformer

The plate and screen supply voltages have been carefully chosen to keep both the plate and screen dissipation within the rated values for maximum power output. There is no single commercially available power transformer that supplies the specific voltages required. Two separate power transformers could be purchased, one to supply the plate power requirements and the other to supply the screen, preamplifier, and bias power requirments. The filament burden could be taken by either one or shared between them. The plate supply transformer would have to supply a maximum rectified current of 175 m.a. while the screen supply would have to furnish a maximum rectified current of ~~25~~ 35 m.a.

A better and less expensive solution to the problem would be to make a suitable power transformer as described below. The design that follows is for a 2 inch stack of 100% interleaved EI - 1-1/2 inch #26 Radio 4 laminations. If grain oriented laminations are used the stack and the number of turns can be suitably modified in conformity with the information presented in Figure 21.

A cross sectional view of the power transformer is shown in Figure 8. The general manner in which the coil form is made and the windings are started and finished is the same as that used for the output transformer. Taps are brought out by combining the finishing and starting techniques at the same location as shown in the photographs of Figure 22. In Figure 22a, at the beginning of a layer requiring a tap, a piece of tape 1 is placed, gummed side up, at the position at which the tap is going to be taken out. White electrical tape was used in these windings in order to make visible the thin wire that is used. This piece of tape should be 1/4 inch wide. The layer is then wound up to the position of the tap as shown in Figure 22b. The wire is brought up to the center of the gummed tape, bent at right angles and pressed against gummed tape 1 along its length. The wire is then bent back on itself and returned along the same piece of gummed tape and again bent at right angles to itself, this time in the direction in which the coil is being wound. Pressing the wire against the gummed tape will tend to hold the wire in place. Another piece of tape 2 is placed gummed side down over tape 1 with waxed paper 3 between the two pieces of gummed tape as shown in Figure 22c. The wire is now only lightly held by the pieces of gummed tape and therefore the first two turns, following the tap, must be made very carefully to avoid pulling the wire loose at the tap. The layer of wire is then completed as shown in Figure 22d. Tape 1 is now cut off even with the left edge of the coil and a layer of paper is placed over the wire.

The high voltage winding has been placed on the coil form first because it uses the smallest wire and will go around the sharp corners most easily. The primary is wound next in order to keep it close to both the low and high voltage secondaries. The two filament windings using the heaviest wire are put on the transformer last. The two filament windings are wound in a single layer as shown in the photographs of Figure 23.

Figure 23a shows the completed 6.3 volt filament winding. This winding is handled in the same manner as the secondary of the output transformer with the single exception that a piece of twisted linen tape is inserted in the linen tape loop before this loop is pulled closed. The twisted linen tape is then brought around one complete turn and is fastened in place by being slipped under the finish wire of the 6.3 volt winding. The piece of twisted linen tape is necessary to maintain physical separation between the two windings which have an electrical potential difference of about 600 volts. Before starting the 5 volt filament winding two thicknesses of electrical insulating tape should be placed over the length of the coil, covering the two leads of the 6.3 volt winding. The start of the 5 volt winding is carried out in the conventional manner and is anchored in place with pieces of tape 1 and 2. Tape 2 is placed over all three lead wires in such a manner that it covers the previous two pieces of tape that covered the leads of the 6.3 volt winding. As the 5 volt winding is now completed, as shown in Figure 23d, there will be a piece of vinyl sleeving and three thicknesses of vinyl tape between it and the leads of the 6.3 volt winding. This is adequate insulation for the voltage that will exist between the two windings. The two center lead wires are for the 6.3 volt winding and the two outside lead wires are for the 5 volt winding.

The transformer is finished by wrapping 5 layers of 5 mil Kraft paper around the outside, bringing out all leads on the same end of the transformer, and anchoring the leads with an outside tape wrap as was done with the output transformer. It is convenient to bring out the five high voltage leads on one face of the transformer and all the other leads on the opposite face of the transformer. In order to keep the magnetizing current low the laminations for this transformer should be 100% interleaved and carefully hammered together to obtain as small an air gap as possible.

After assembly the complete transformer should be dipped in the insulating solution used for the output transformer. The probability is that by this time the solution has become appreciably thickened through solvent evaporation. This thickening is desirable for the later output transformer dips since it seals the pores more readily than a thin solution. The power transformer, however, has many closely packed layers of fine wire and the solution will have to be relatively thin in order to penetrate to the center of this winding. The insulating solution should therefore be thinned down to its original consistency before dipping the transformer. Two dips, or three at the most, will be adequate for this transformer since interwinding capacitance is of no particular importance. The transformer should be left in the solution for at least an hour more than the time required to stop bubbling. Suitable baking may be accomplished by shorting the terminals of the two filament windings and exciting the outside terminals of the high voltage secondary with 120 volts. The primary must be left open in this case.

The manner in which the various items are placed on the chassis is not critical. A convenient arrangement for this purpose is shown in Figure 24. Other chassis sizes and arrangements would work equally well.

The output transformer connections must be made properly in order to insure correct feedback polarity for both the basic amplifier and the 20 uuf overall feedback. One of the two primary "start" wires must be connected to the plate of the bottom 1614 tube. The "finish" of this winding and the "start" of the other primary winding must be connected to the cathode of the 5U4-G. The "finish" of the other primary winding must be connected to the plate of the top 1614 tube. The "start" of the feedback winding must be connected to the grid of the left section of the 12AX7. The "finish" of the feedback winding must be connected to the junction of the 1.25 mfd capacitor and the modified T20C51 choke. Of course this assumes that the transformer was wound exactly as described in this paper. If any free-lance deviations were attempted the proper polarity may have to be determined experimentally.

Only two operational adjustments need to be made on this amplifier and they are both concerned with the bias supplied by the 12AX7 tube to the 1614 tubes. The 33 ohm resistor in the bias-divider circuit of the 12AX7 may have to be modified to produce approximately equal dc voltages at the two plates of the 12AX7 tube. The 4.7 k resistor in the plate supply circuit of the 12AX7 may have to be modified to produce a total plate current of 20 to 30 ma for the two 1614 tubes. The circuits involved are basically stable and it will be found that new 12AX7 and 1614 tubes can be plugged in without appreciable change in the total 1614 tube plate current.

The net prices shown in the "List of Material" were obtained from a late catalog but may be subject to some variation depending on where the material is purchased. Most of these items are available from your local radio parts or electrical supply distributor. If you live in an area that does not have these distributors the parts may be purchased from one of the several mail order houses that operate on a national scale. If you have not previously purchased materials of this type, consult your faculty adviser for the most convenient procedure for your particular location.

The Belden Manufacturing Company and Thomas & Skinner, Inc. have graciously consented to furnish the first three items in the list of material. These items are not normally available for across the counter sales in the quantities required for this amplifier.

Orders for the laminations should be sent to:

Thomas & Skinner, Inc.
1120 East 23rd Street
Indianapolis 7, Indiana

Orders for the two one pound spools of #28 HFDC wire should be sent to the Cleveland Warehouse of the Belden Manufacturing Company:

Complete-Reading Electric Co. of Ohio
1437 St. Clair Avenue
Cleveland, Ohio

The Belden Manufacturing Company has stated that this wire would be shipped on a freight collect basis.

Since the material not specifically required in the construction of the transformers is readily available on short notice its purchase may be postponed until after the two transformers are completed.

In order to give the author of this article some indication of the number of people interested in building this amplifier ~~he~~ it would be appreciated ~~it~~ if ~~they would send~~ a postcard were sent first to indicate interest and second when the amplifier is made operational to:

Professor A. B. Bereskin
University of Cincinnati
Cincinnati 21, Ohio

Those who carry out the amplifier construction described in this paper will have an excellent audio frequency power amplifier in addition to having gained a considerable amount of experience in the construction of transformers. They should now be ready to experiment with modifications to provide different amounts of power, use different tubes, or have different frequency characteristics.

LIST OF MATERIAL

Transformer Material

Quantity	Item	Total Net Cost
220	Lamination sets - Thomas & Skinner - Orthosil 3X EI - 1-3/4" H at $25.10/M (for output transformer)	5.52
115	Lamination sets - Thomas & Skinner - 26 gauge Radio 4 - EI - 1-1/2" at $15.60/M (for power transformer)	1.80
2	1 pound spools of #28 HFDC (Heavy Formvar Double Cotton) wire	3.20
1	1 pound spool #16 HF (Heavy Formvar) or #16 Heavy Nylclad Wire	1.06
1	1 pound spool #20 HF wire or #20 Heavy Nylclad wire	1.14
1	1 pound spool #30 HF wire or #30 Heavy Nylclad wire	1.73
1	20 ft. roll of 3/4" plastic insulating tape (Scotch No.33)	.54
1	Roll of 3/4" linen tape (only 15 feet required)	
1	25 ft. roll of 3 inch gummed paper tape	
1	Roll of 3/4" cellophane tape	.39
2	36" x 36" sheets of 5 mil Kraft paper	
1	4" x 8" x 1/4" piece of polystyrene	.39
1	Gallon of toluol	1.65
	Thermoplastic (Polyvinyl Chloride) #20 stranded hook up wire - may be purchased in various colors at $0.44 for a 25 ft. roll	
1	Vinyl sleeving for #16 wire - 25' roll	.53
1	Vinyl sleeving for #14 wire - 25' roll	.53
1	Strip of .005" Copper foil	

Other Material

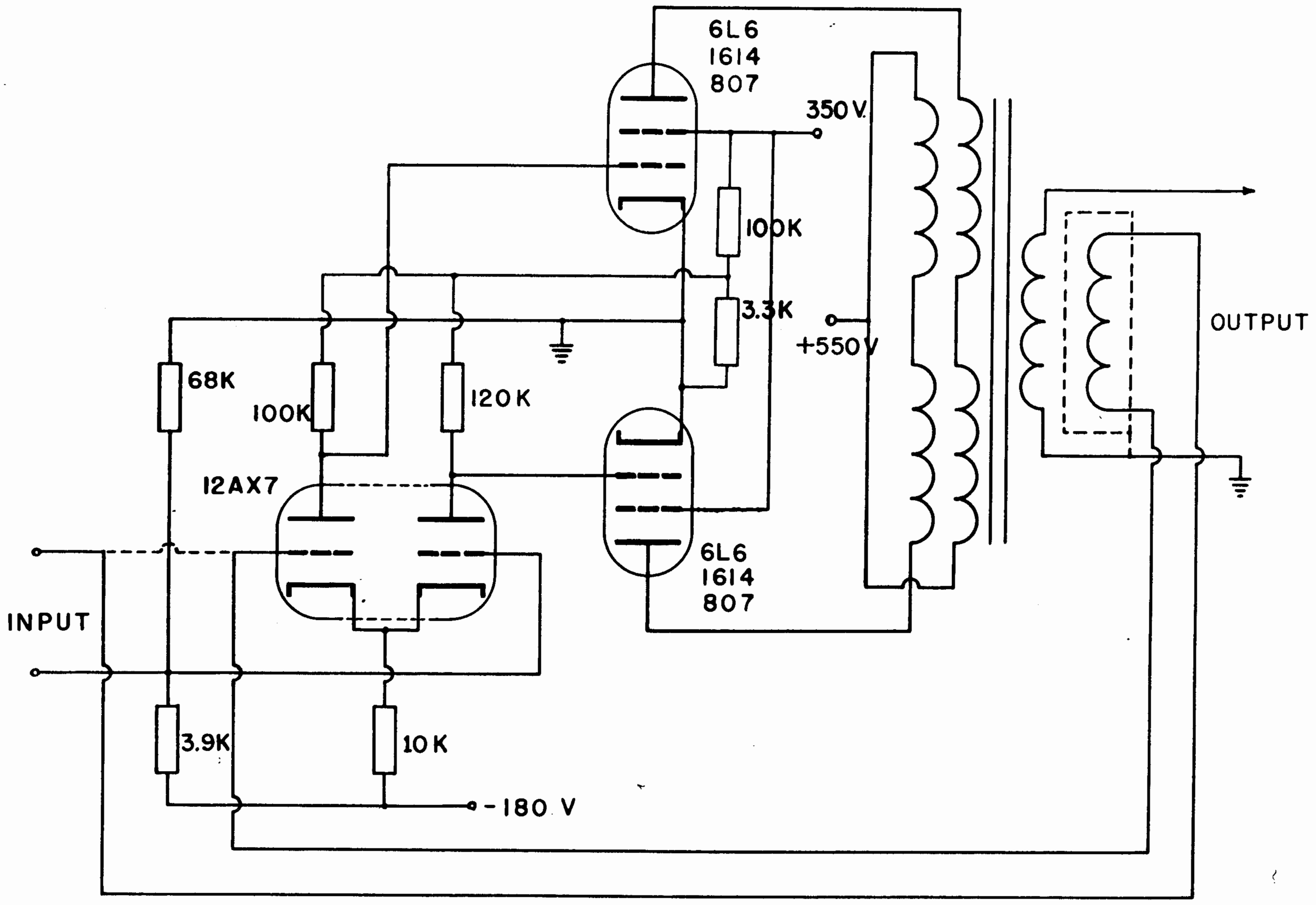
Quantity	Item	Total Net Cost
1	5U4-G tube	.95
2	6X4 tubes	1.56
2	1614 tubes	4.00
1	12AX7 tube	1.29
1	6BK7A tube	1.62
2	60 mfd - 350 volt cardboard covered metal tubular electrolytic capacitors for below chassis mounting	2.30
1	20 mfd - 450 volt cardboard covered metal tubular electrolytic capacitor for below chassis mounting	.91
1	20 mfd - 250 volt cardboard covered metal tubular electrolytic capacitor for below chassis mounting	.79
1	20-20-20 mfd at 450 volt and 100 mfd at 50 volt metal can electrolytic for above chassis mounting	2.68
1	.05 mfd - 600 volt paper capacitor	.24
1	.25 mfd - 600 volt paper capacitor	.32
1	1.25 mfd - 600 volt paper capacitor (1 mfd - 600 volt paper capacitor would work equally well)	1.05

LIST OF MATERIAL (Cont.)

Quantity	Item	Total Net Cost
1	Thordarson T20C51 Choke (This choke must be modified by 100% interleaving of laminations)	1.65
3	Octal sockets - saddle type with 4 ground lugs	.24
2	9 pin miniature saddle type socket with 4 ground lugs	.44
2	7 pin miniature sockets	.28
1	SPST power switch 6A - 125 volt	.49
1	On-Off plate	.04
1	Line cord	.35
1	Pilot light assembly	.44
1	Duplex power outlet or 2 single power outlets	.40
1	Phono Jack	.09
1	50 K potentiometer	.73
6	3 terminal (1 ground) solder terminal strips	.18
1	14" x 10" x 3" aluminum chassis	2.62
4	2 watt resistors (see cct. diagram for values)	.80
4	1 watt resistors " " " " "	.60
11	1/2 watt resistors " " " " "	1.10

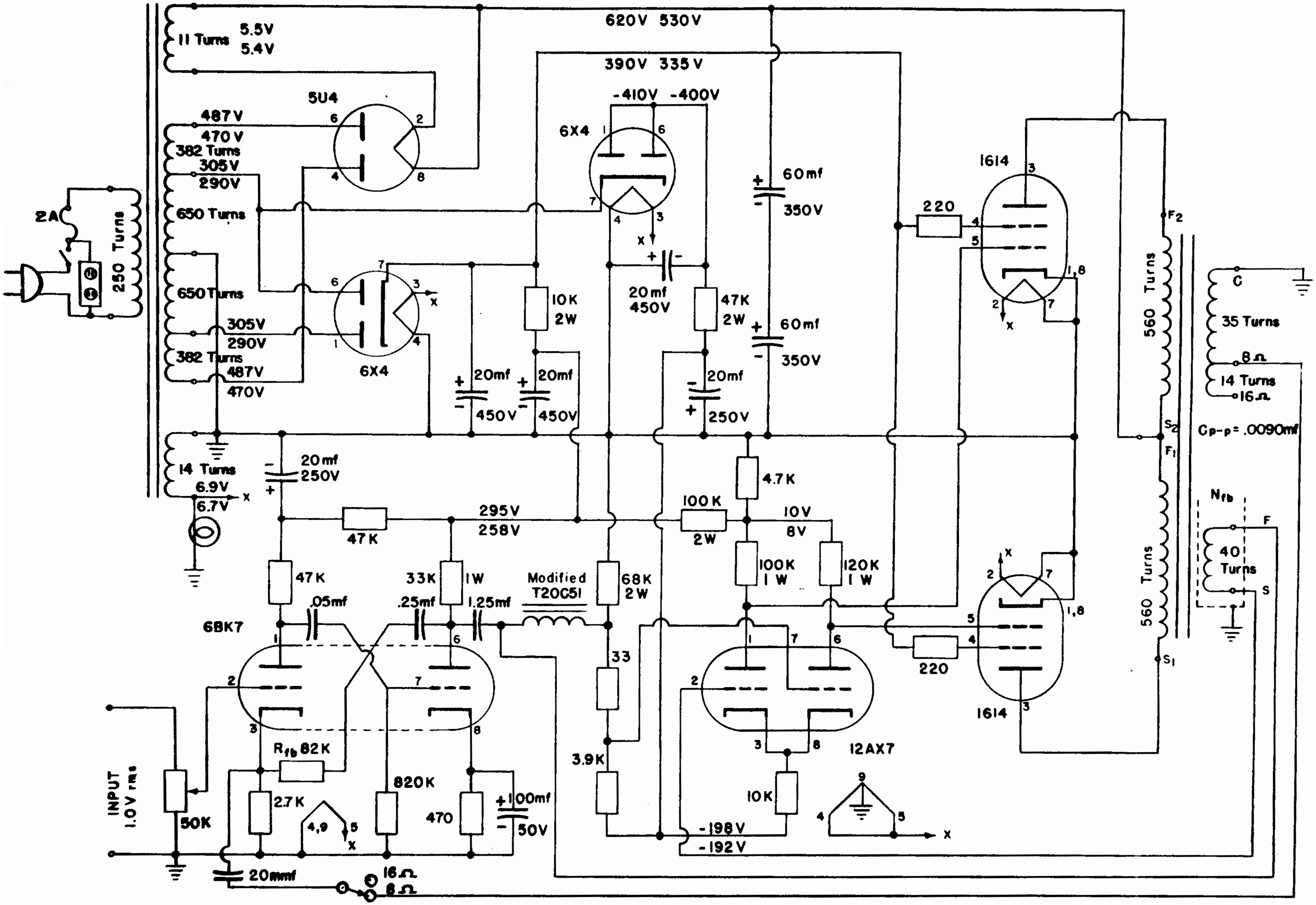
LIST OF ILLUSTRATIONS

~~Fig 24~~



BASIC BERESKIN POWER AMPLIFIER CIRCUIT

Fig. 1



BERESKIN 50 WATT 1614 TUBE POWER AMPLIFIER

Fig. 2

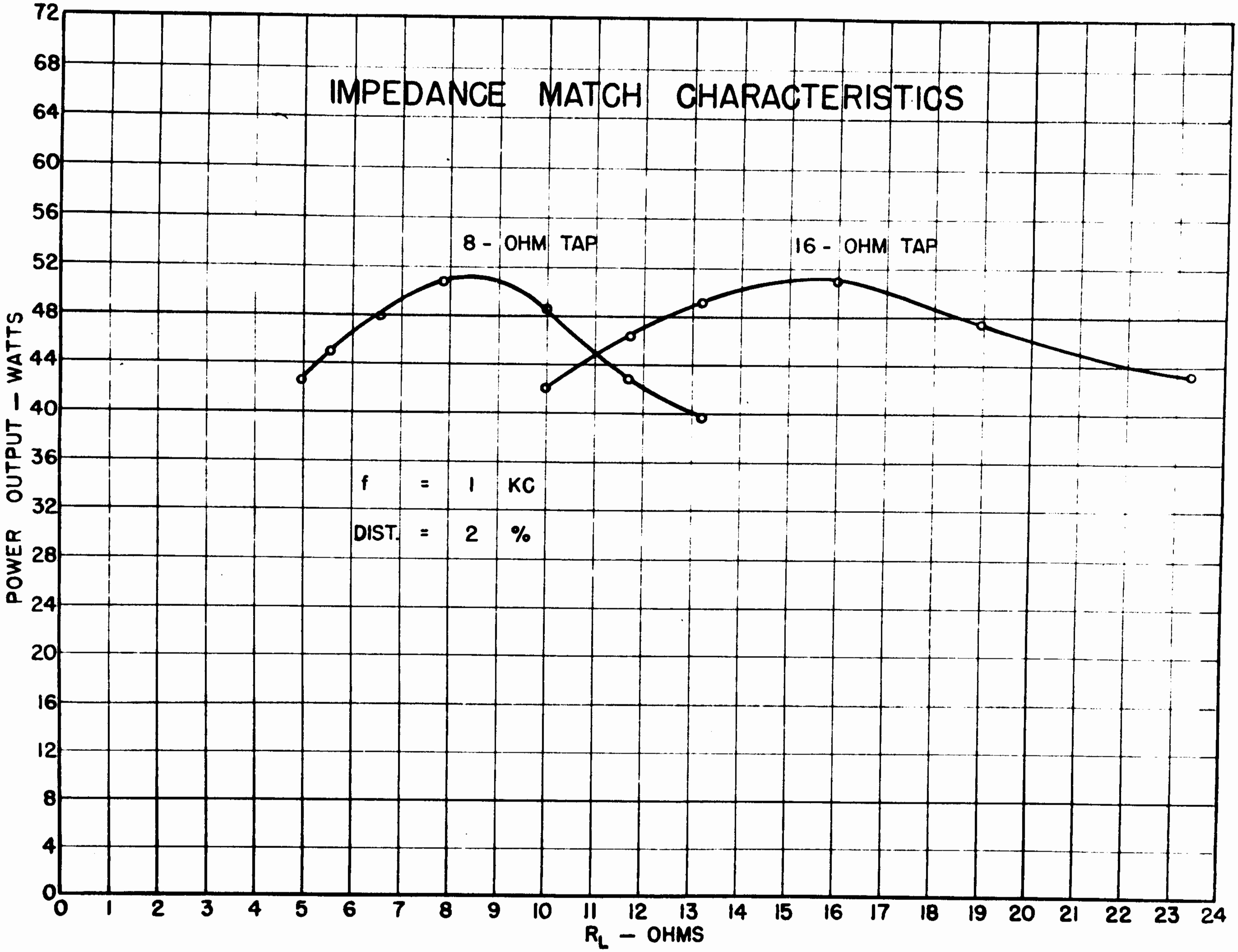

IMPEDANCE MATCH CHARACTERISTICS
8 - OHM TAP
16 - OHM TAP
f = 1 KC
DIST. = 2 %
POWER OUTPUT — WATTS
0
4
8
12
16
20
24
28
32
36
40
44
48
52
56
60
64
68
72
R$_L$ — OHMS
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24

Fig-3

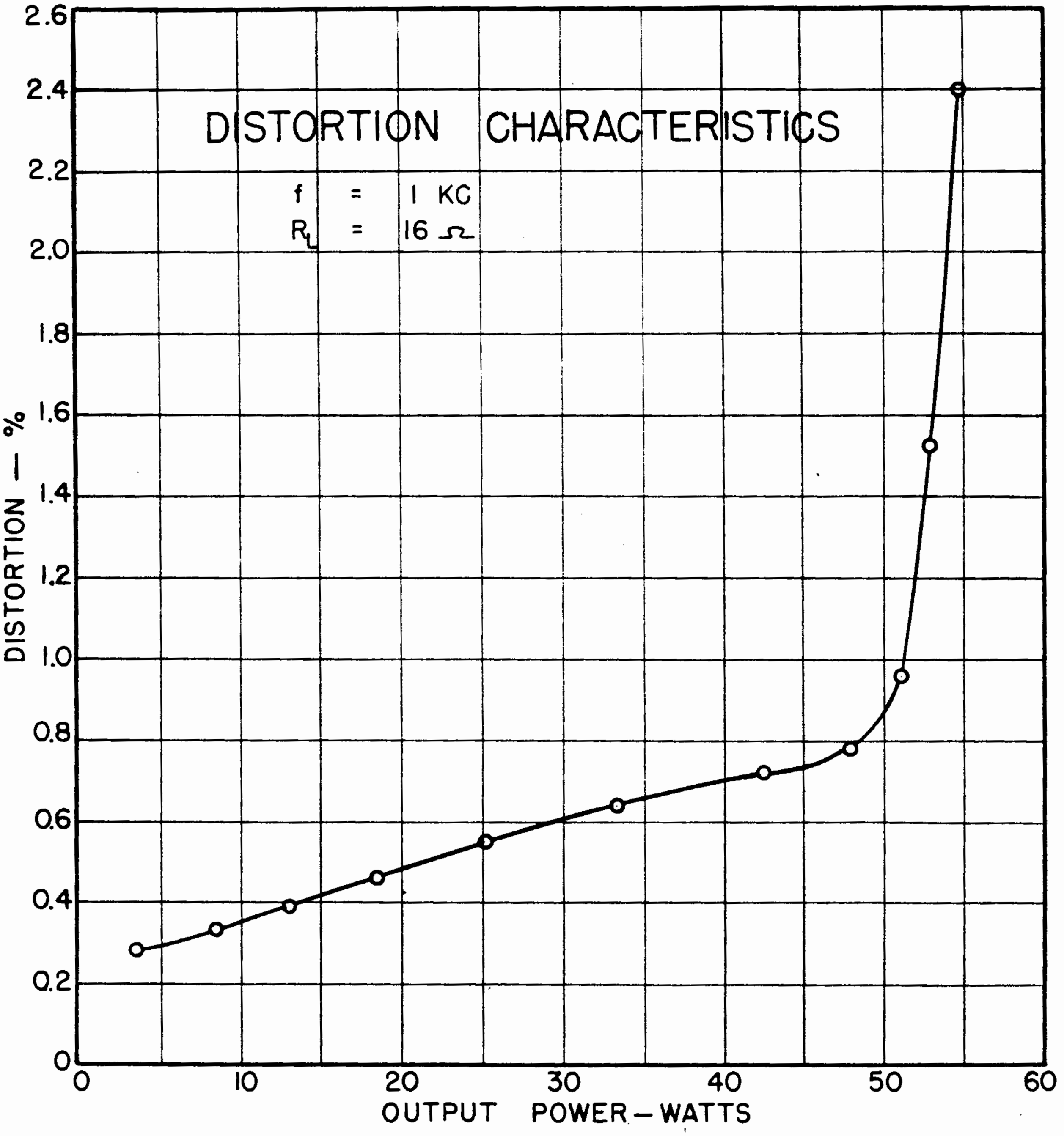

DISTORTION CHARACTERISTICS
f = 1 KC
RL = 16 Ω
DISTORTION — %
OUTPUT POWER — WATTS
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
0
10
20
30
40
50
60

Fig. 4

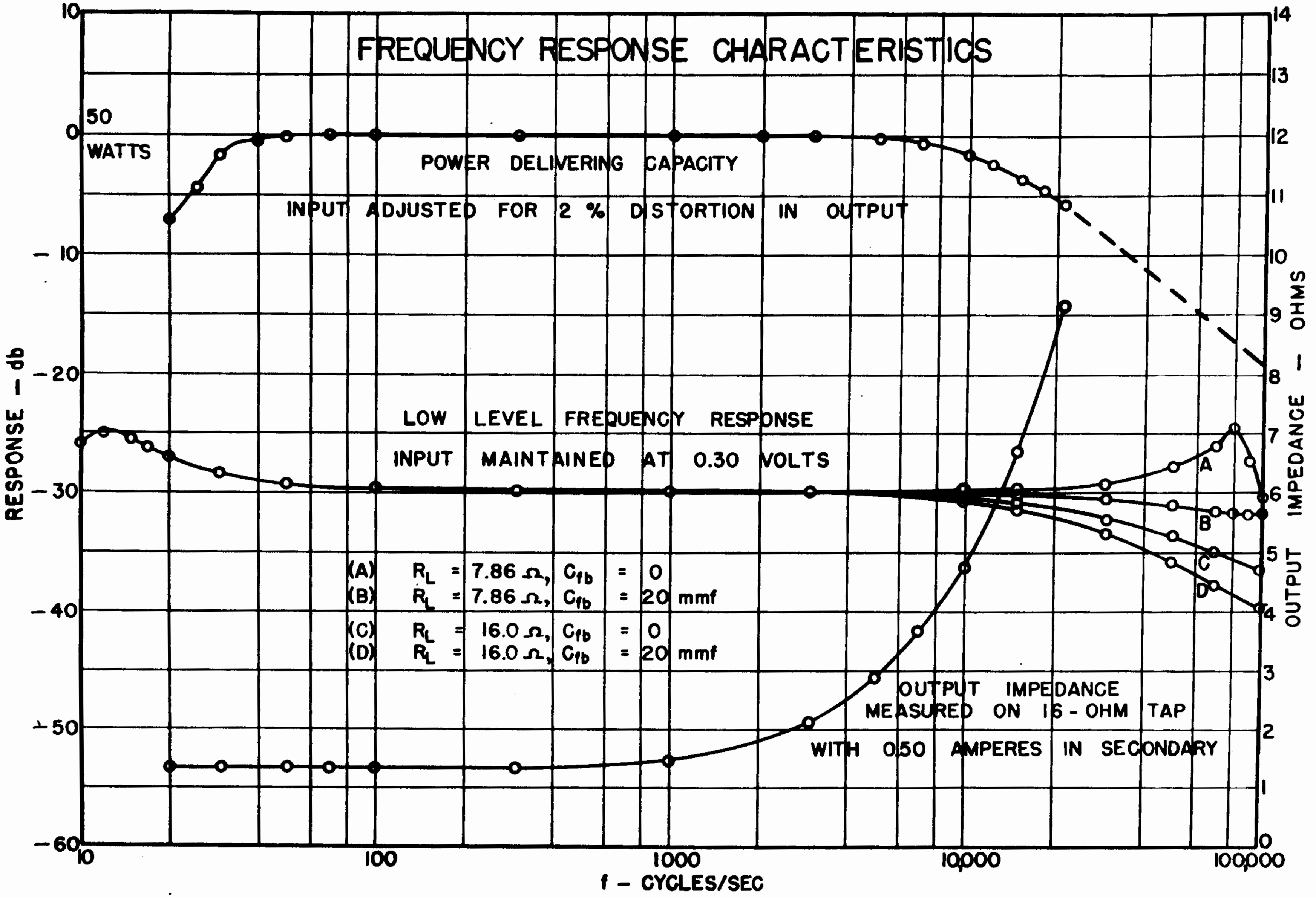

FREQUENCY RESPONSE CHARACTERISTICS
50
WATTS
POWER DELIVERING CAPACITY
INPUT ADJUSTED FOR 2 % DISTORTION IN OUTPUT
LOW LEVEL FREQUENCY RESPONSE
INPUT MAINTAINED AT 0.30 VOLTS
(A) R_L = 7.86 Ω, C_{fb} = 0
(B) R_L = 7.86 Ω, C_{fb} = 20 mmf
(C) R_L = 16.0 Ω, C_{fb} = 0
(D) R_L = 16.0 Ω, C_{fb} = 20 mmf
A
B
C
D
OUTPUT IMPEDANCE
MEASURED ON 16 - OHM TAP
WITH 0.50 AMPERES IN SECONDARY
RESPONSE – db
10
0
– 10
– 20
– 30
– 40
– 50
– 60
OUTPUT IMPEDANCE – OHMS
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
10
100
1000
10,000
100,000
f – CYCLES/SEC

Fig. 5

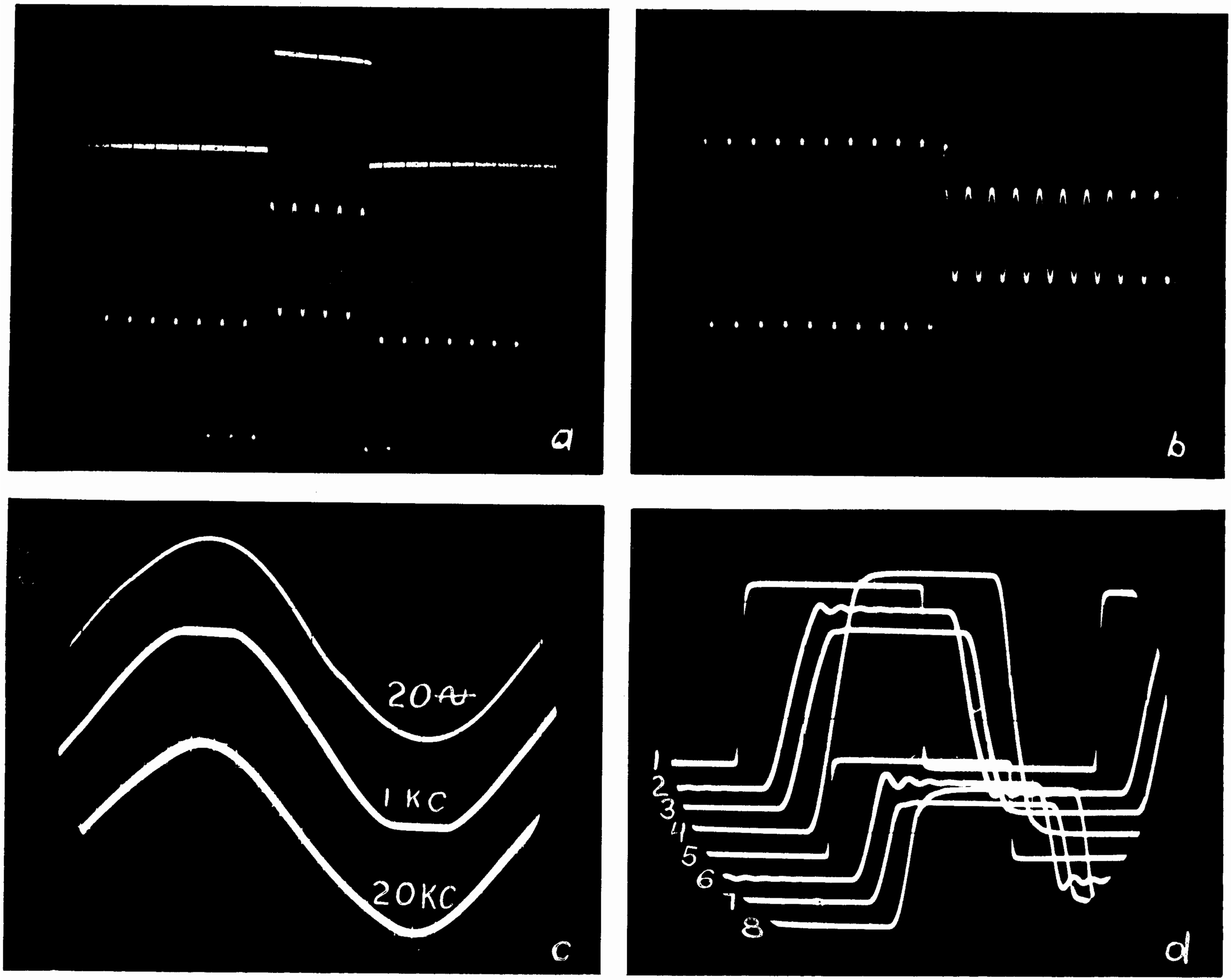
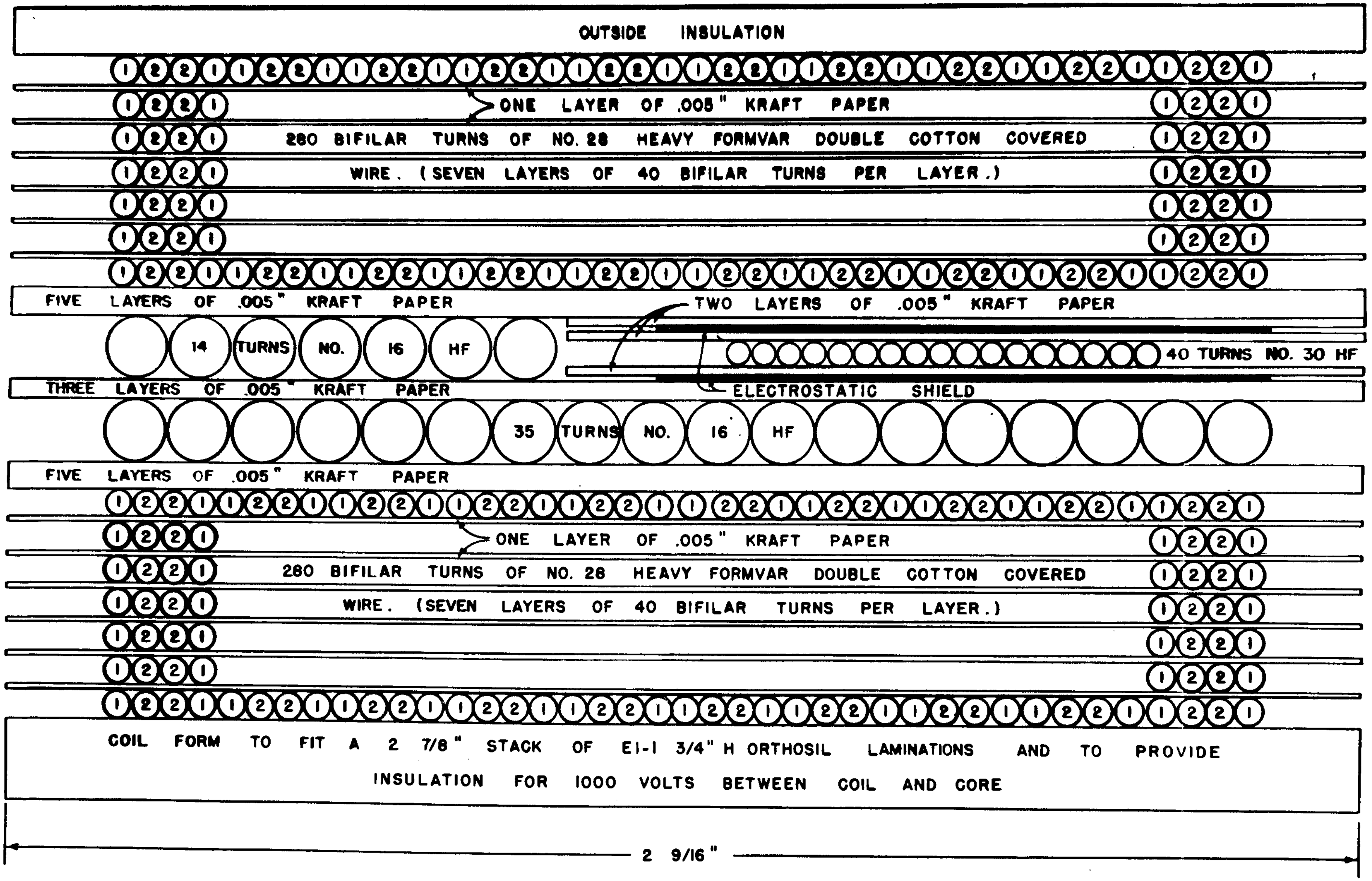


Fig. 6



PROPER PROPORTIONS ON
VERTICAL SCALE ONLY

OUTPUT TRANSFORMER COIL BUILDUP
FOR BERESKIN 50-WATT, 1614-TUBE POWER AMPLIFIER

Fig 7

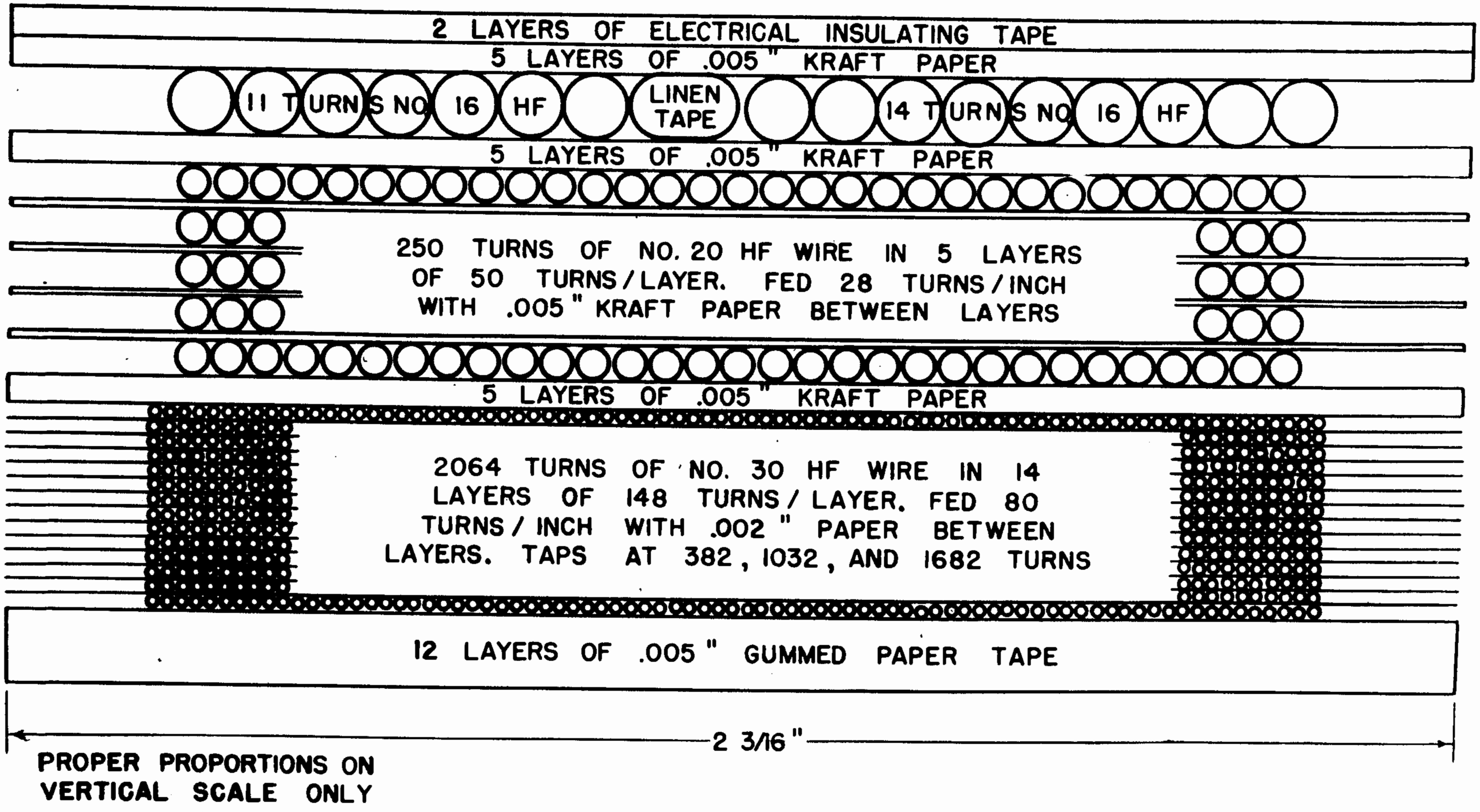

2 LAYERS OF ELECTRICAL INSULATING TAPE
5 LAYERS OF .005" KRAFT PAPER
11 TURNS NO 16 HF
LINEN TAPE
14 TURNS NO 16 HF
5 LAYERS OF .005" KRAFT PAPER
250 TURNS OF NO. 20 HF WIRE IN 5 LAYERS OF 50 TURNS/LAYER. FED 28 TURNS/INCH WITH .005" KRAFT PAPER BETWEEN LAYERS
5 LAYERS OF .005" KRAFT PAPER
2064 TURNS OF NO. 30 HF WIRE IN 14 LAYERS OF 148 TURNS/LAYER. FED 80 TURNS/INCH WITH .002" PAPER BETWEEN LAYERS. TAPS AT 382, 1032, AND 1682 TURNS
12 LAYERS OF .005" GUMMED PAPER TAPE
2 3/16"
PROPER PROPORTIONS ON VERTICAL SCALE ONLY

Fig. 8

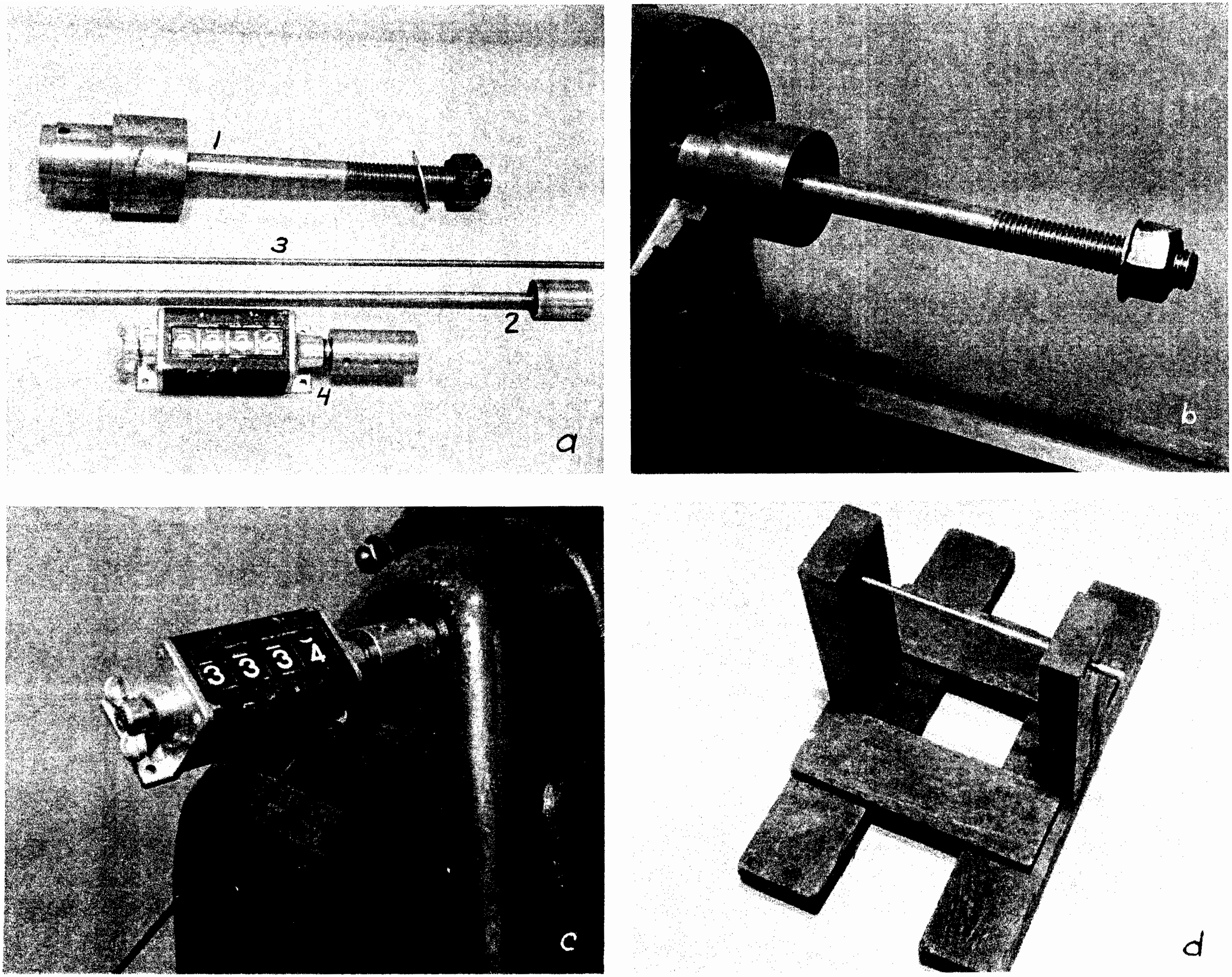


Fig. 9

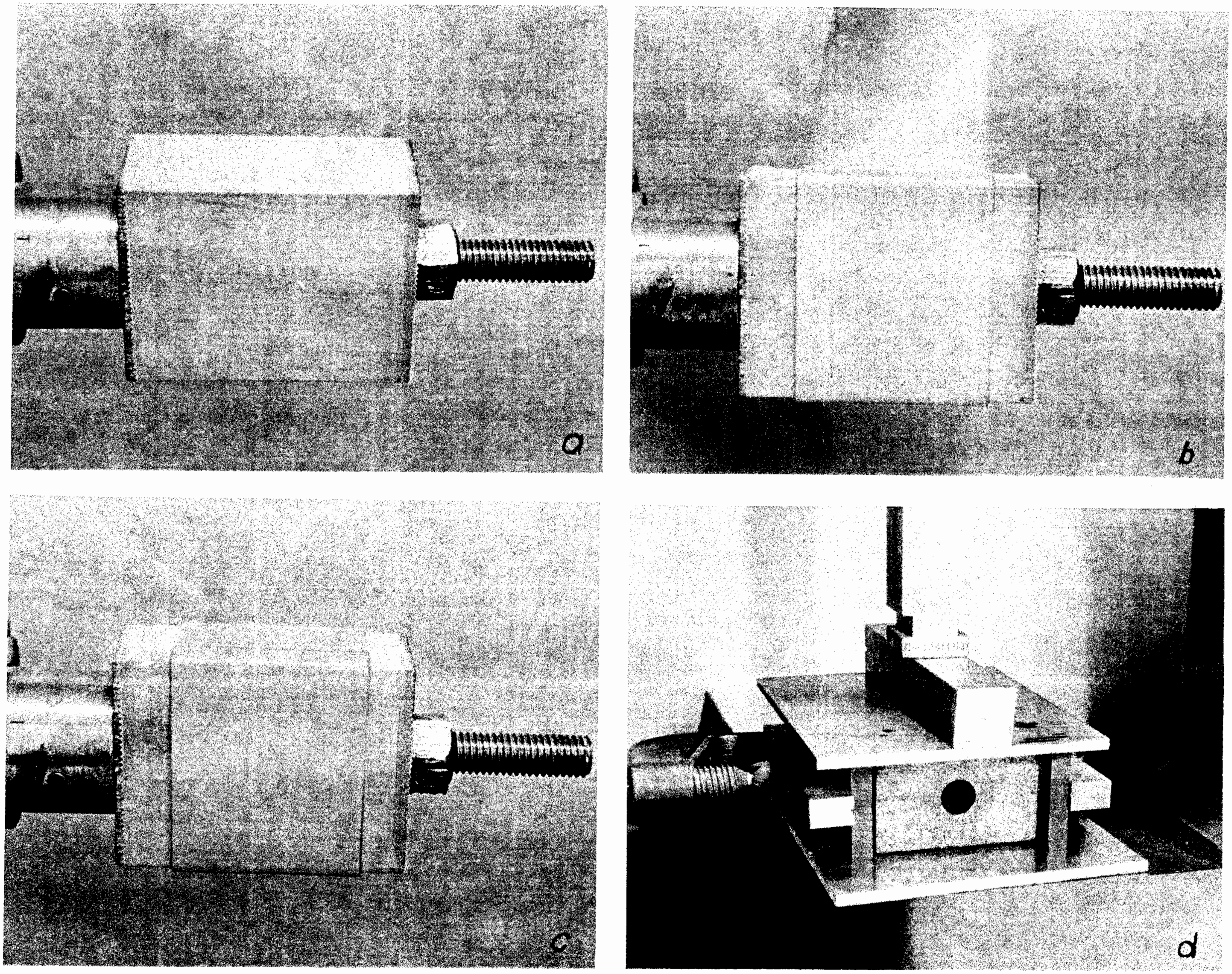


Fig.10

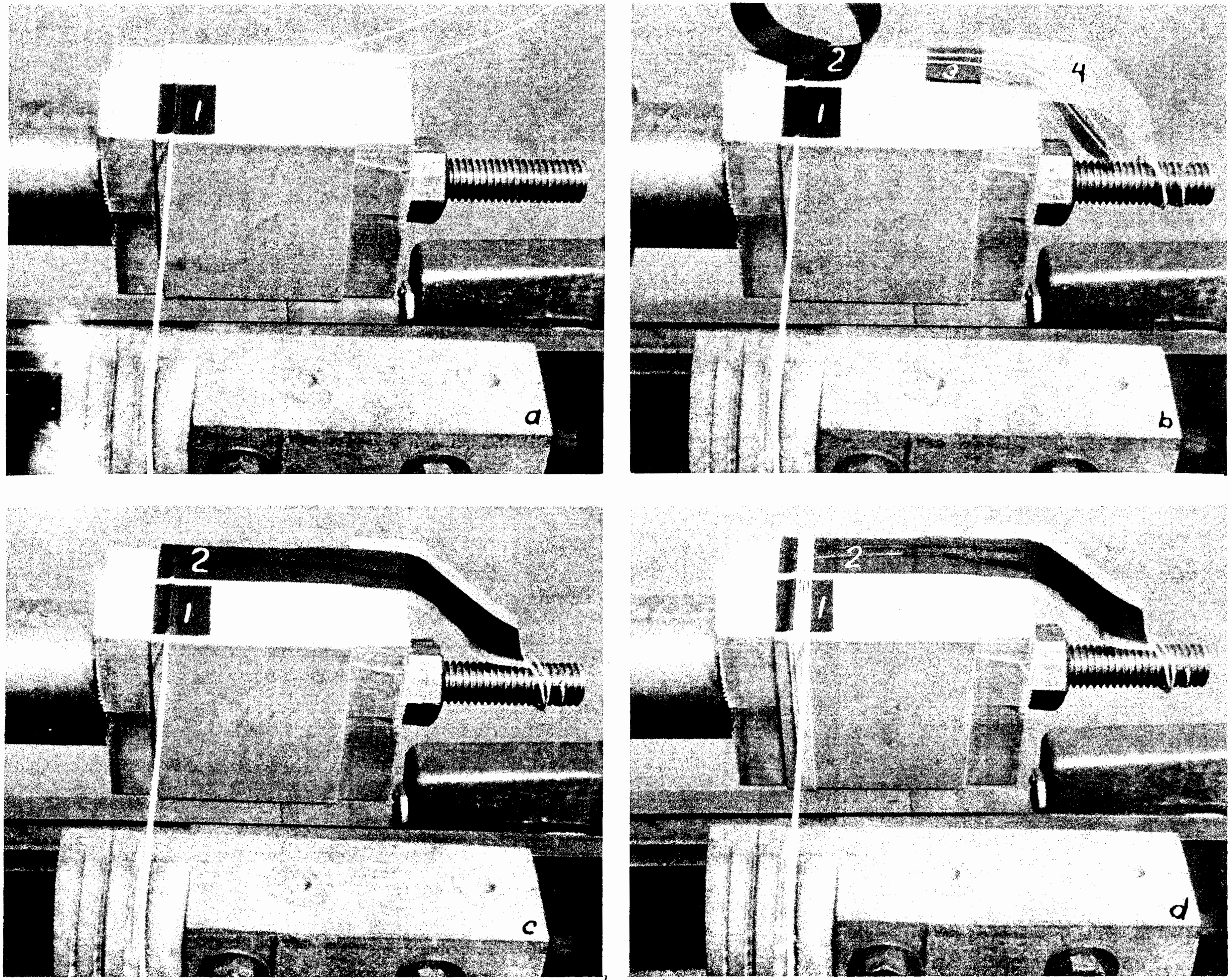


Fig. 11

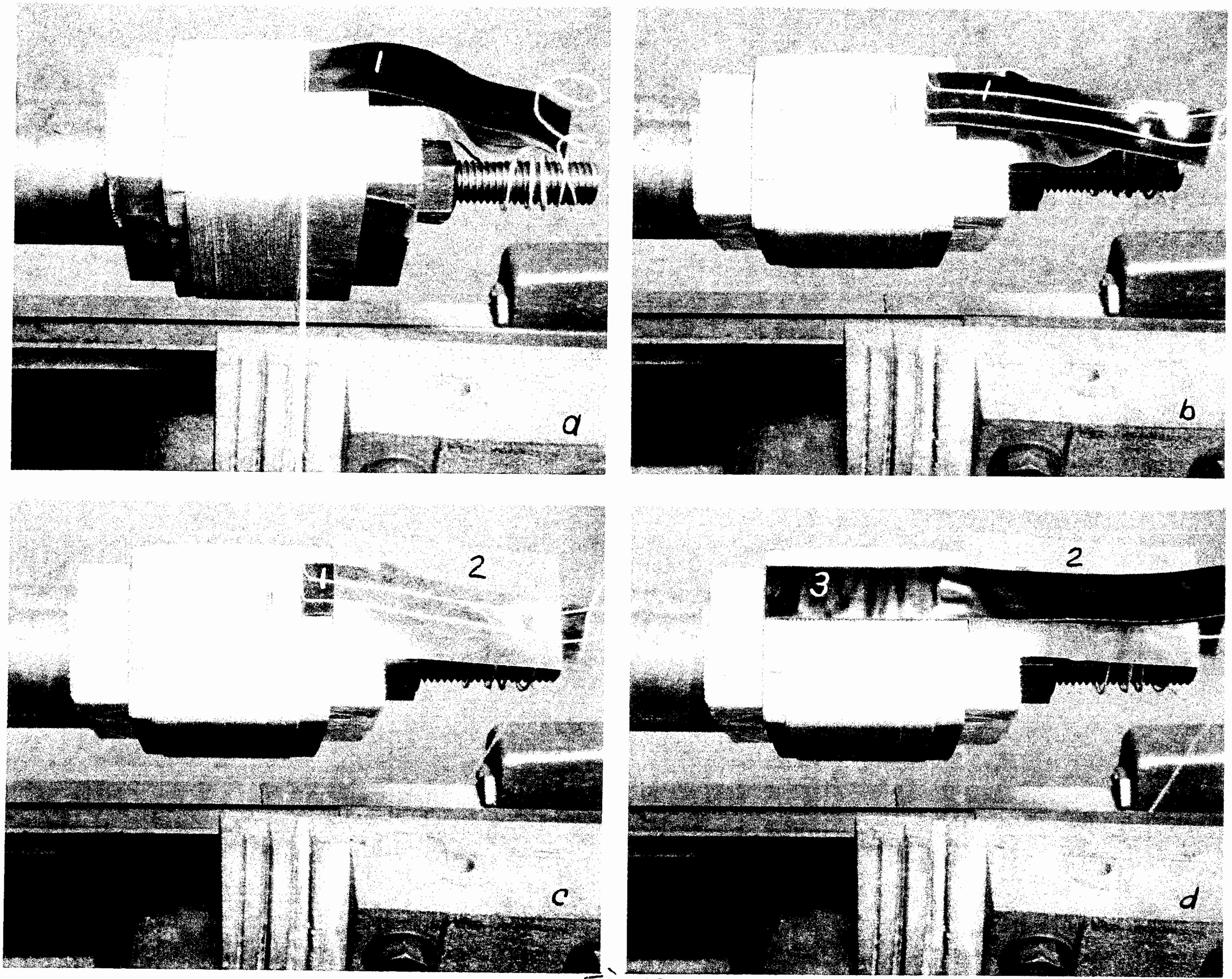


Fig 12

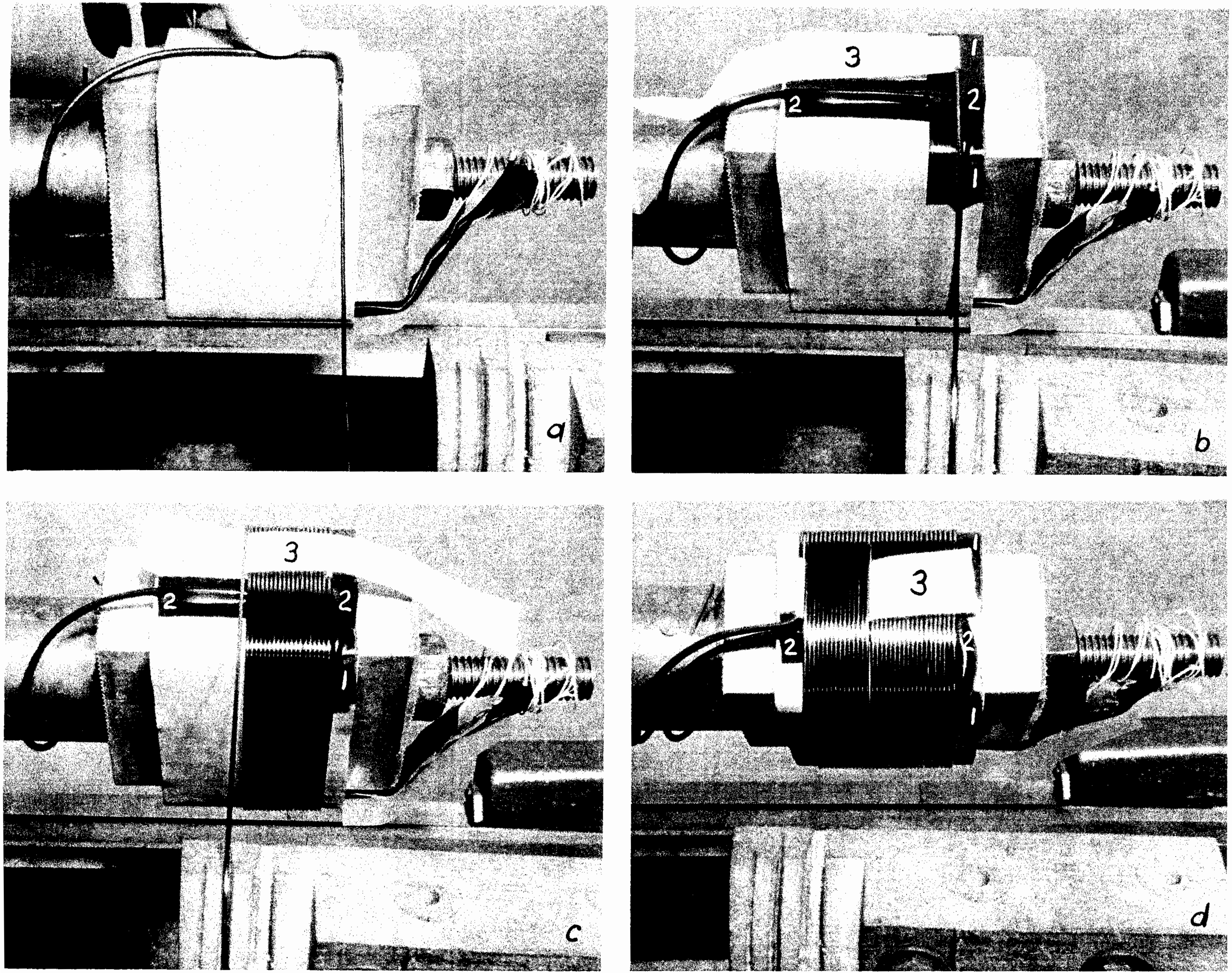


Fig. 13

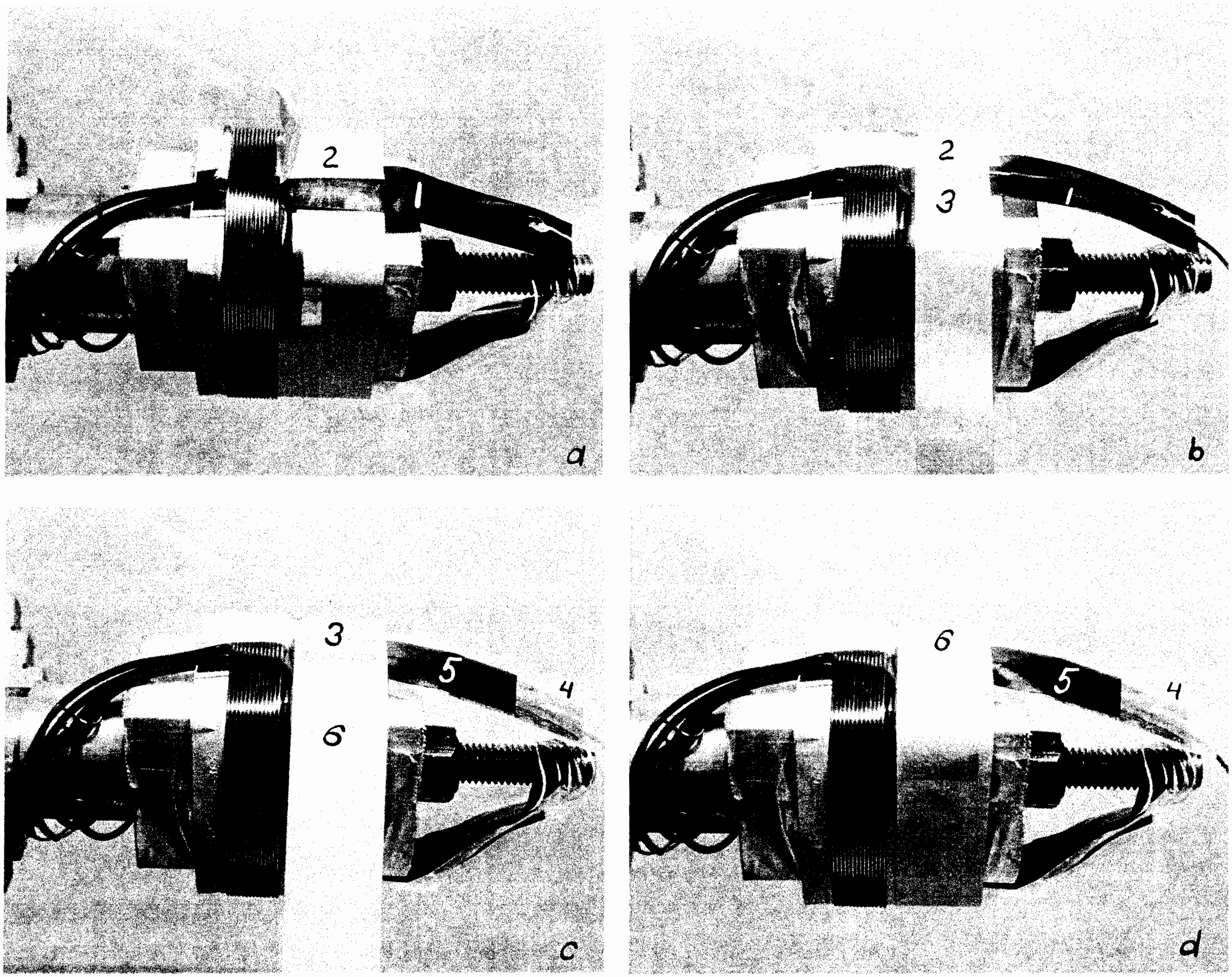


Fig. 14

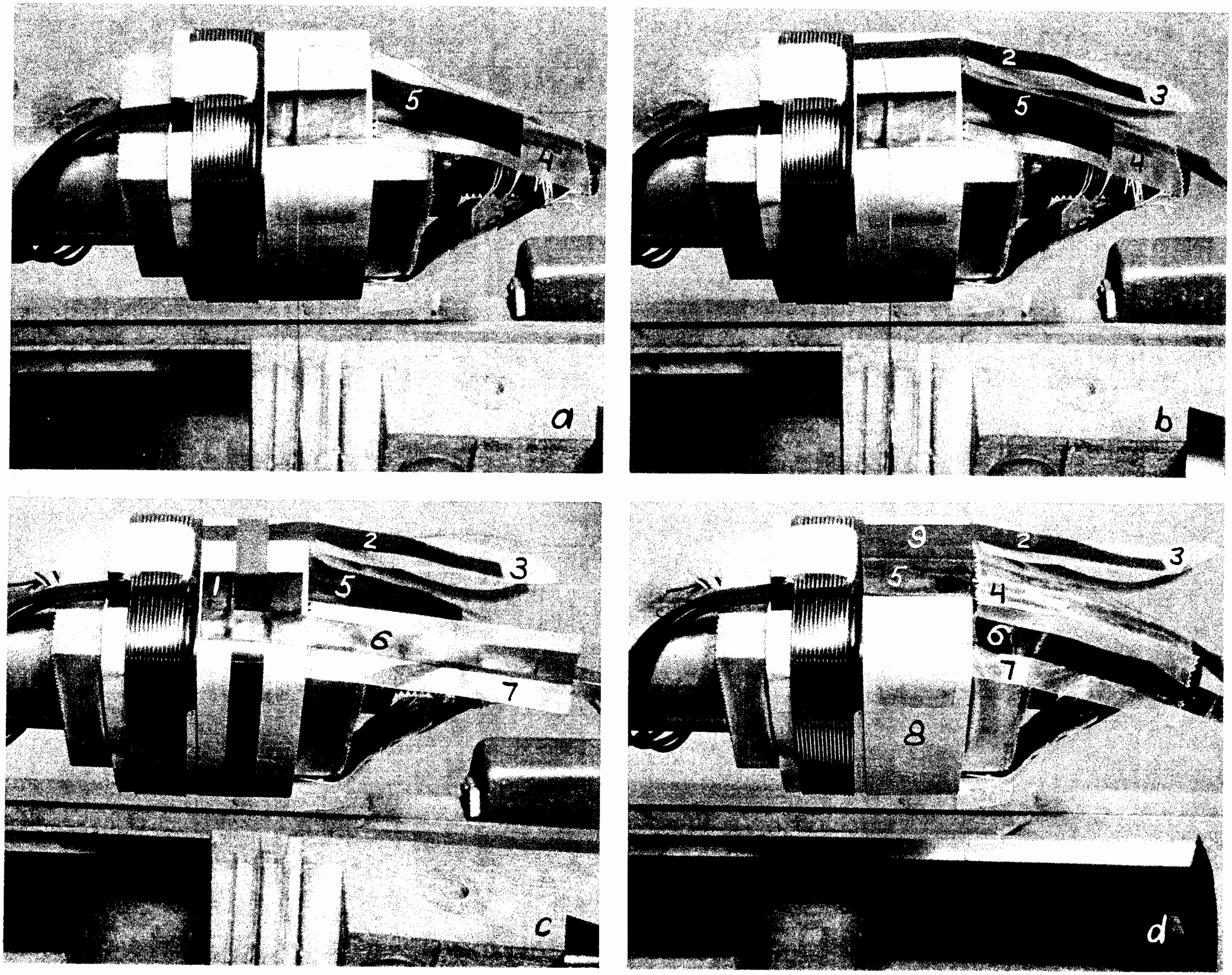


Fig 15

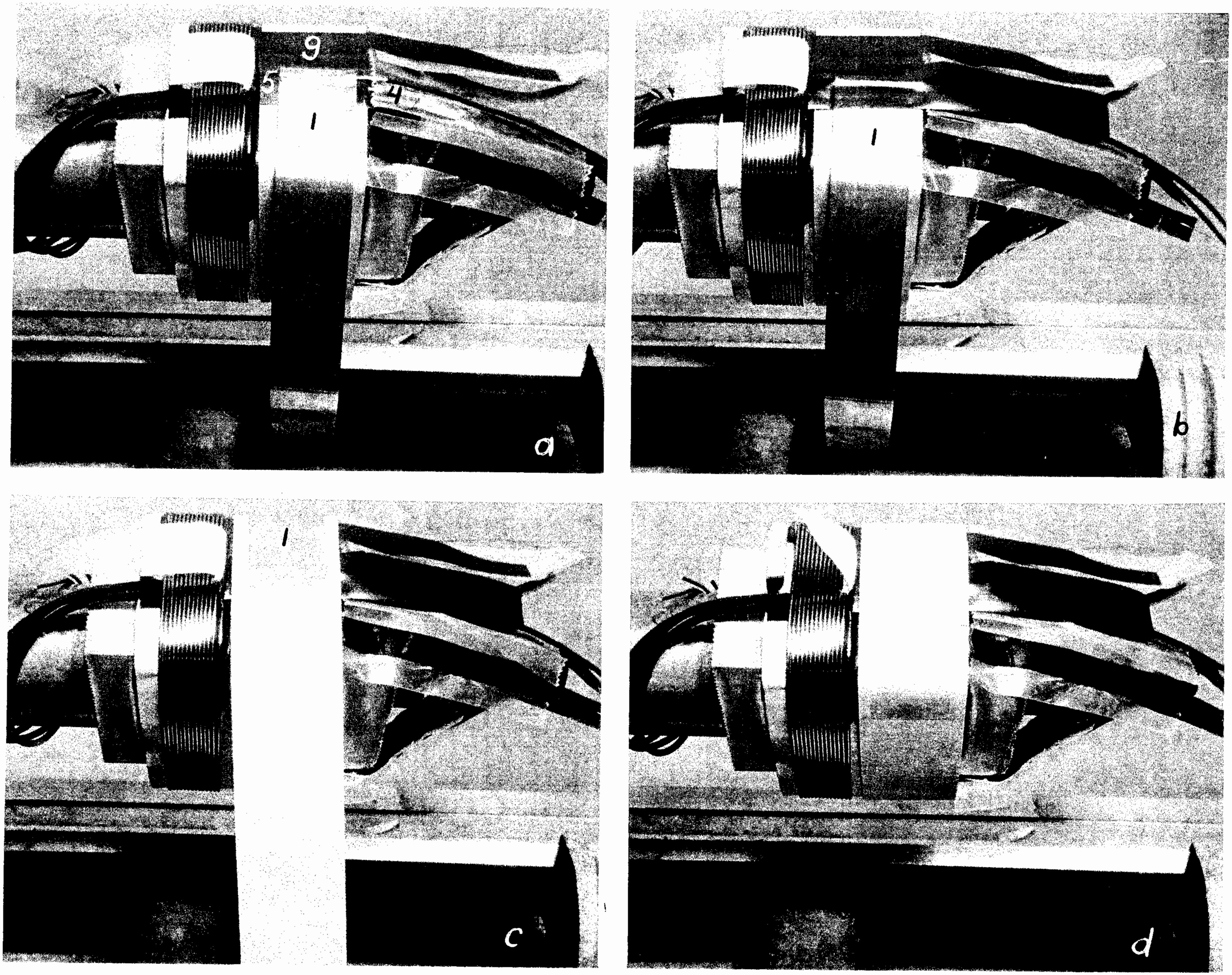
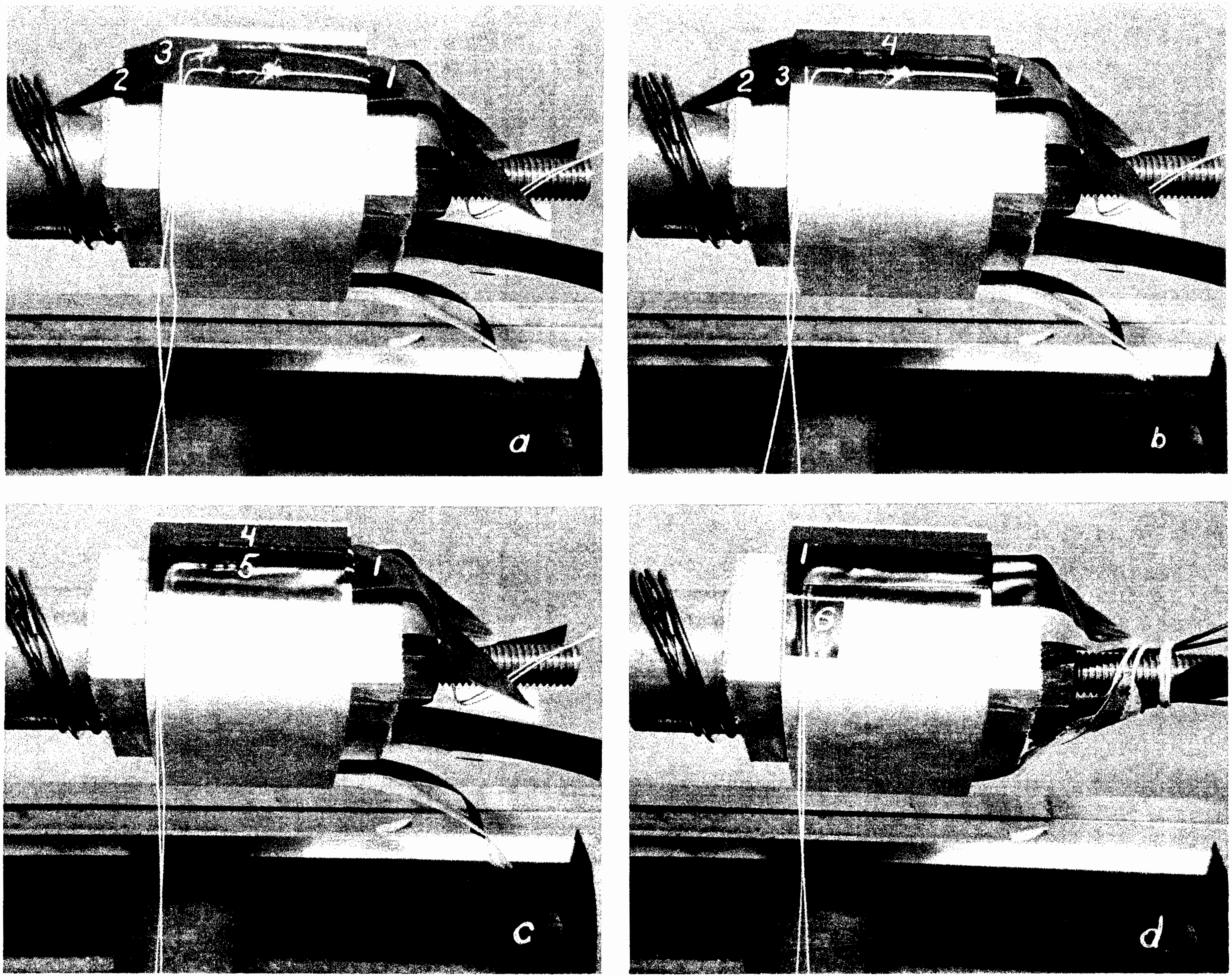


Fig. 16



Fig, 17

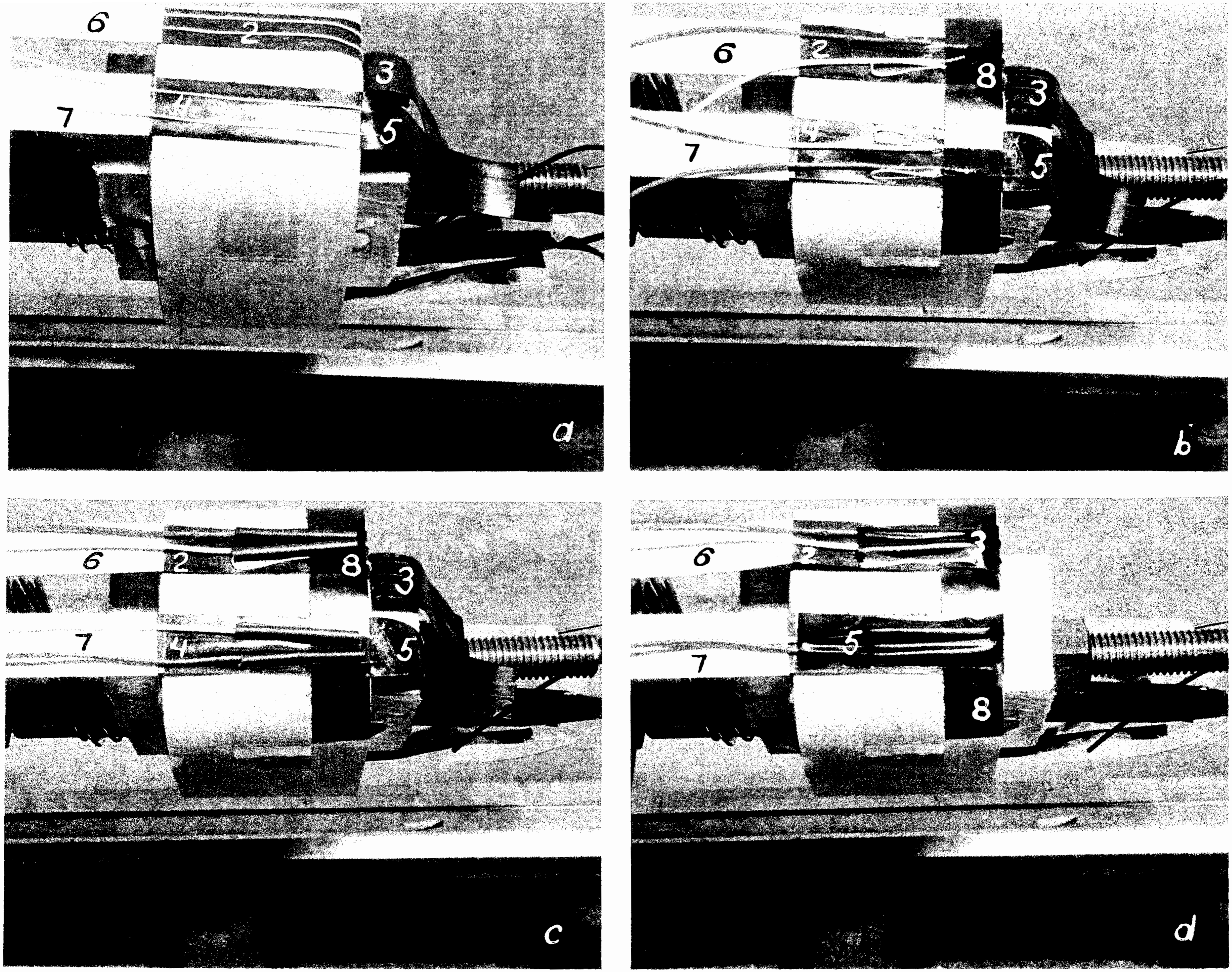


Fig. 18

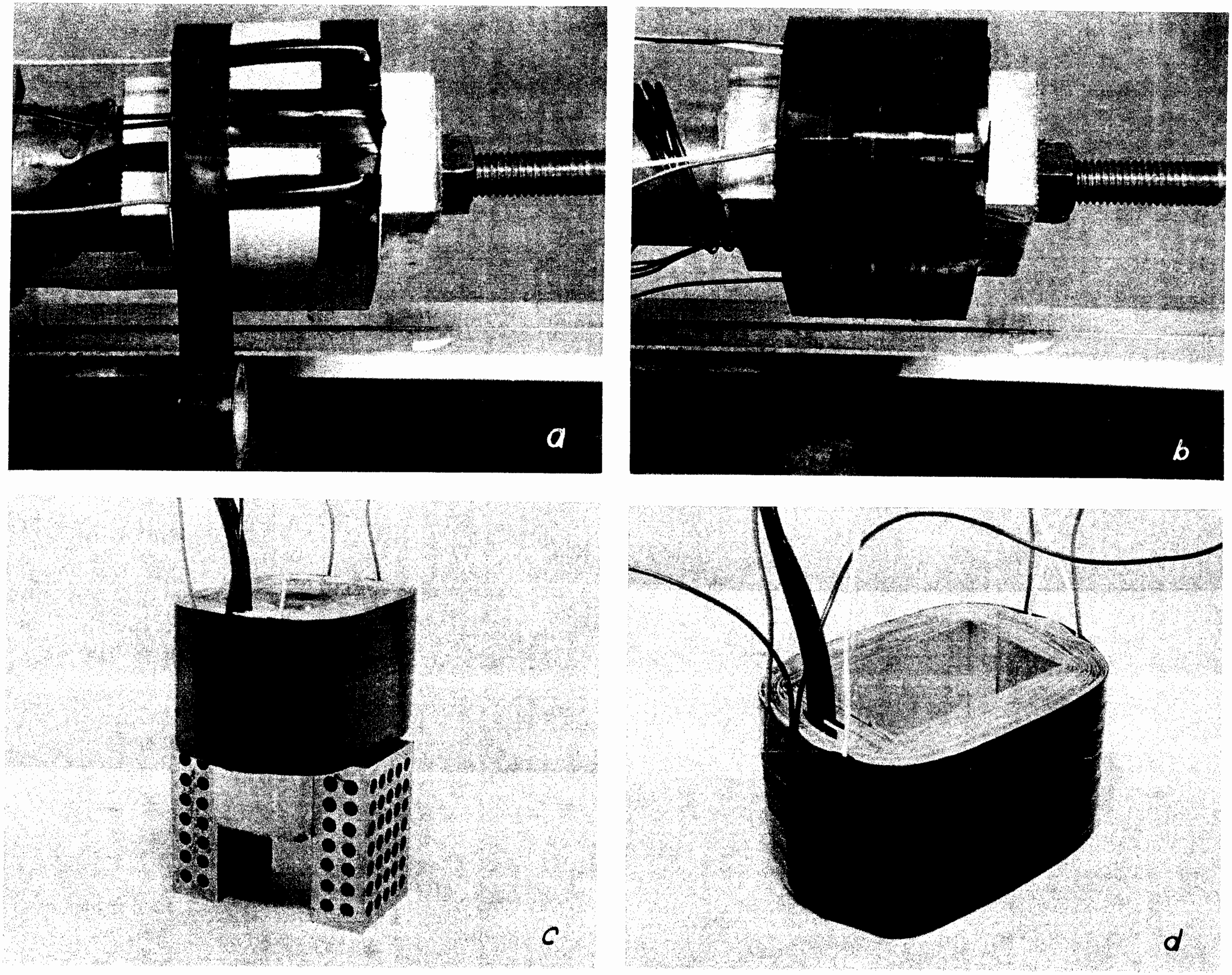


Fig. 19

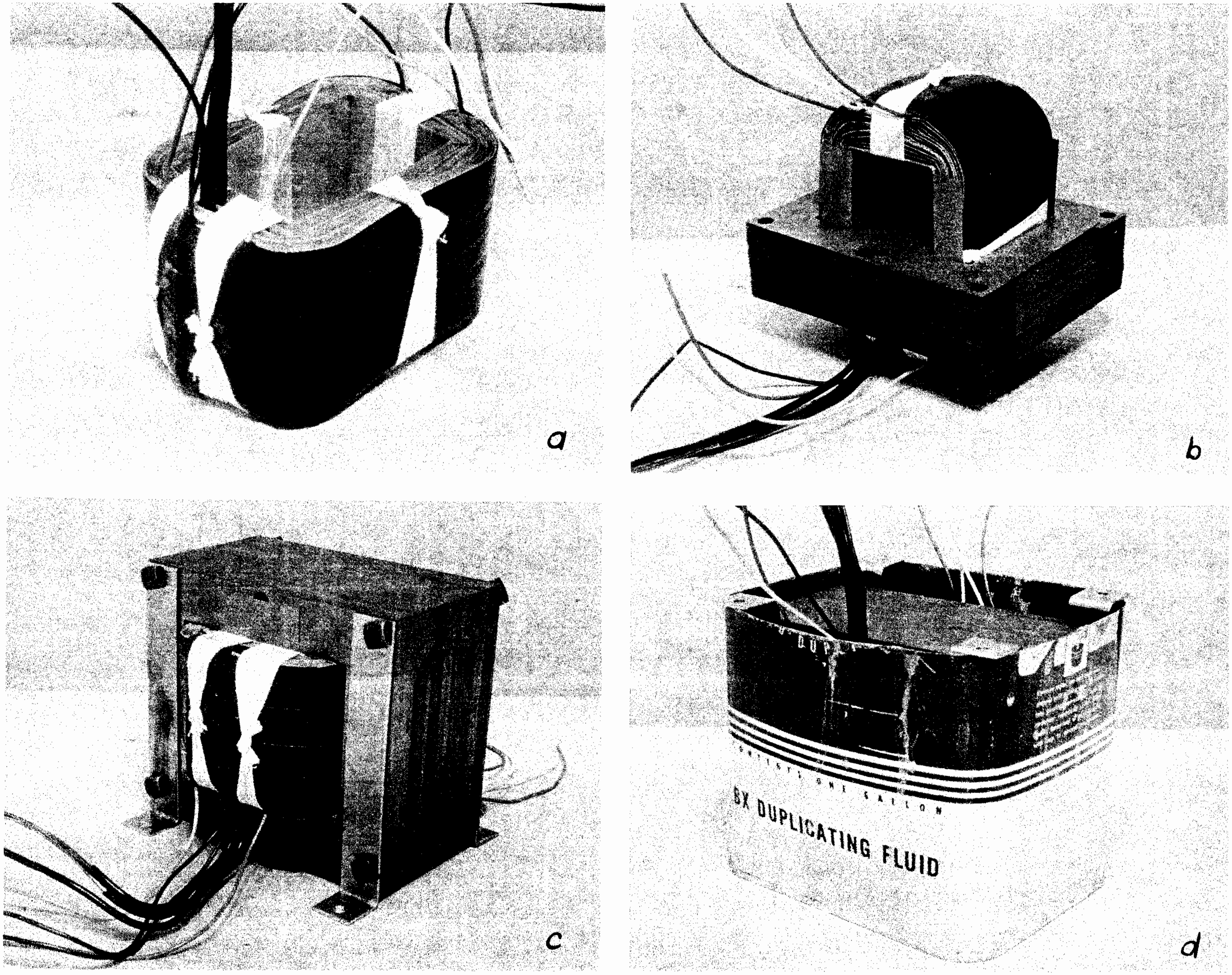
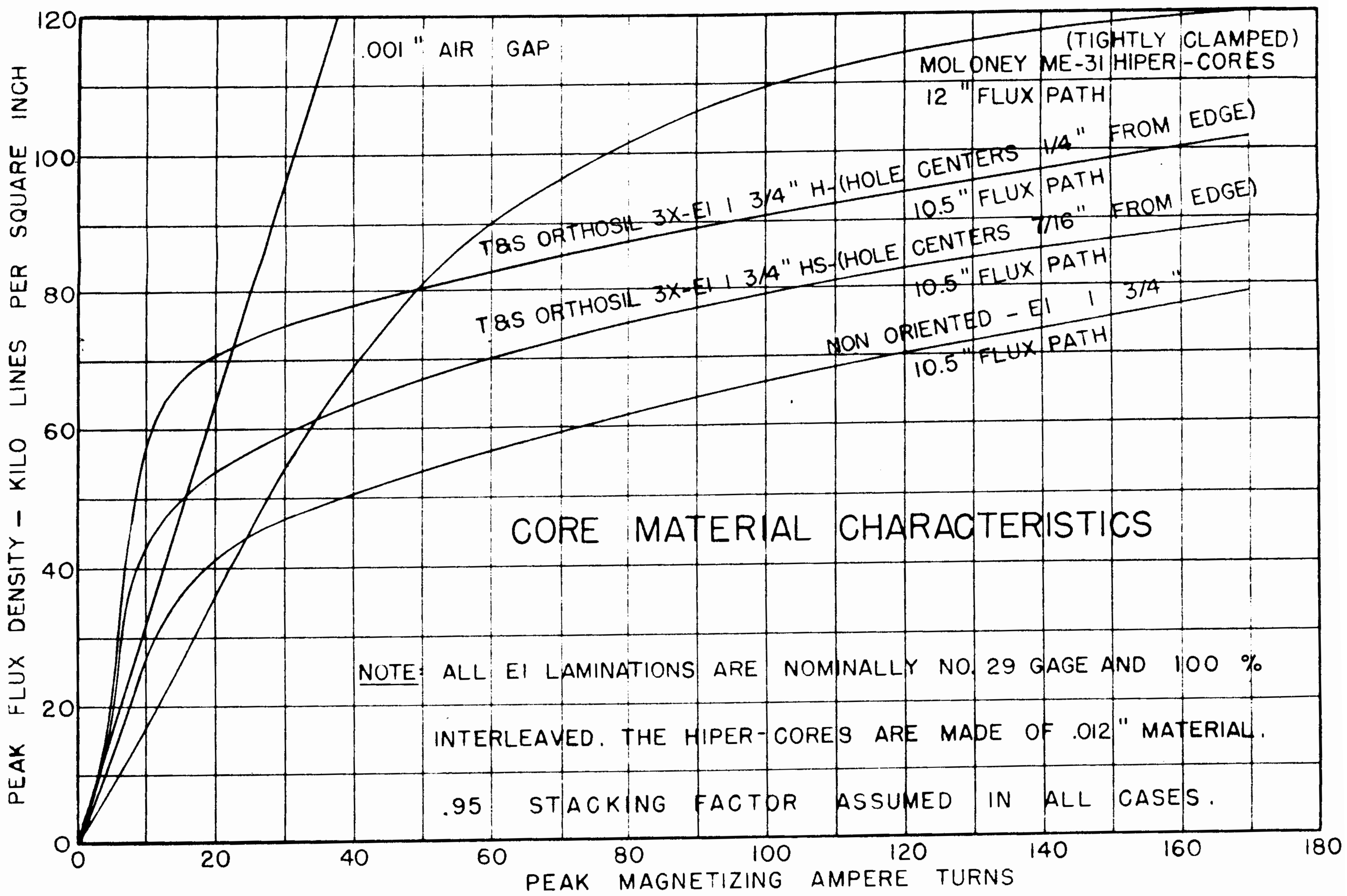


Fig. 20



CORE MATERIAL CHARACTERISTICS

NOTE: ALL EI LAMINATIONS ARE NOMINALLY NO. 29 GAGE AND 100 % INTERLEAVED. THE HIPER-CORES ARE MADE OF .012" MATERIAL. .95 STACKING FACTOR ASSUMED IN ALL CASES.

Fig. 20

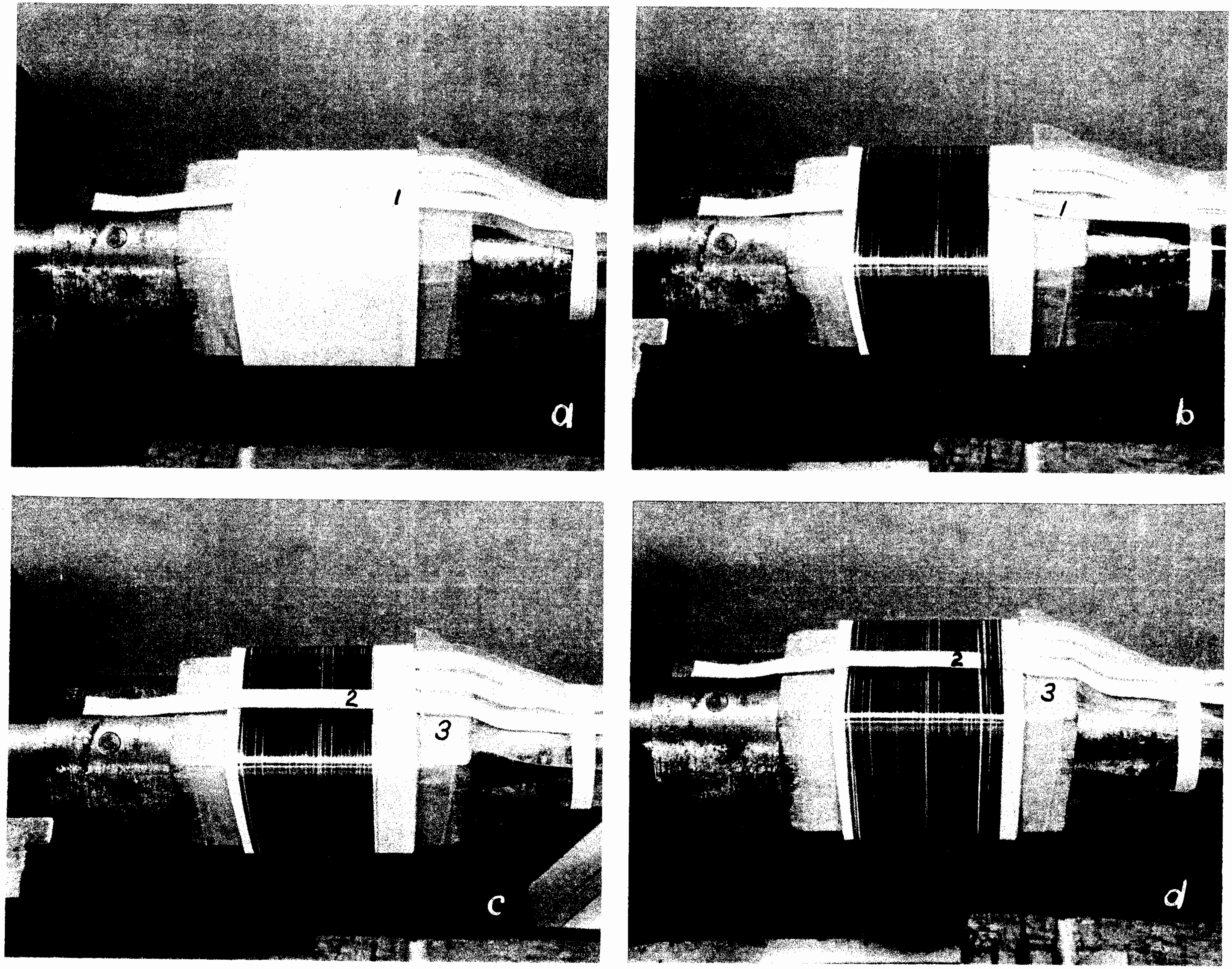


Fig. 22

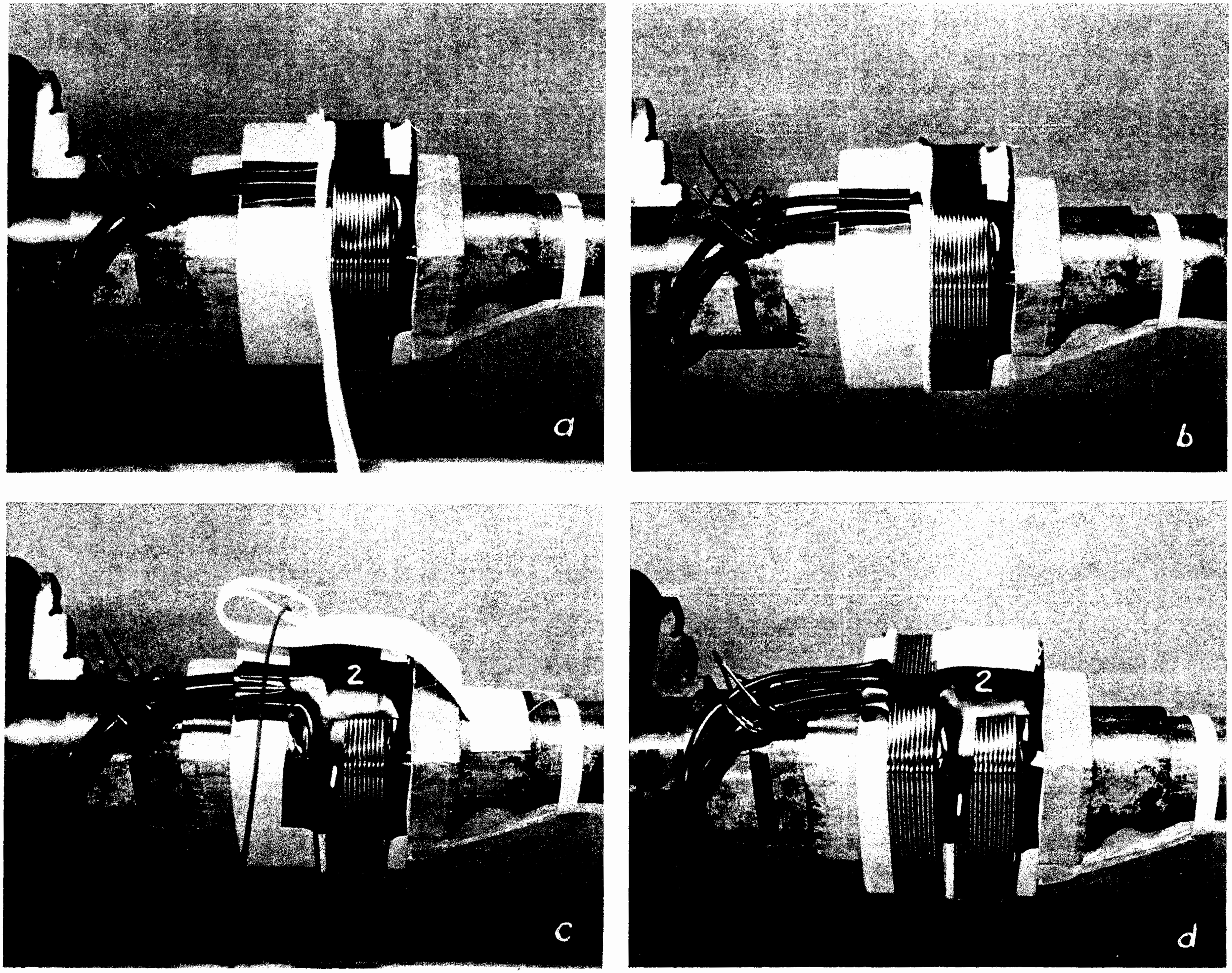


Fig. 23

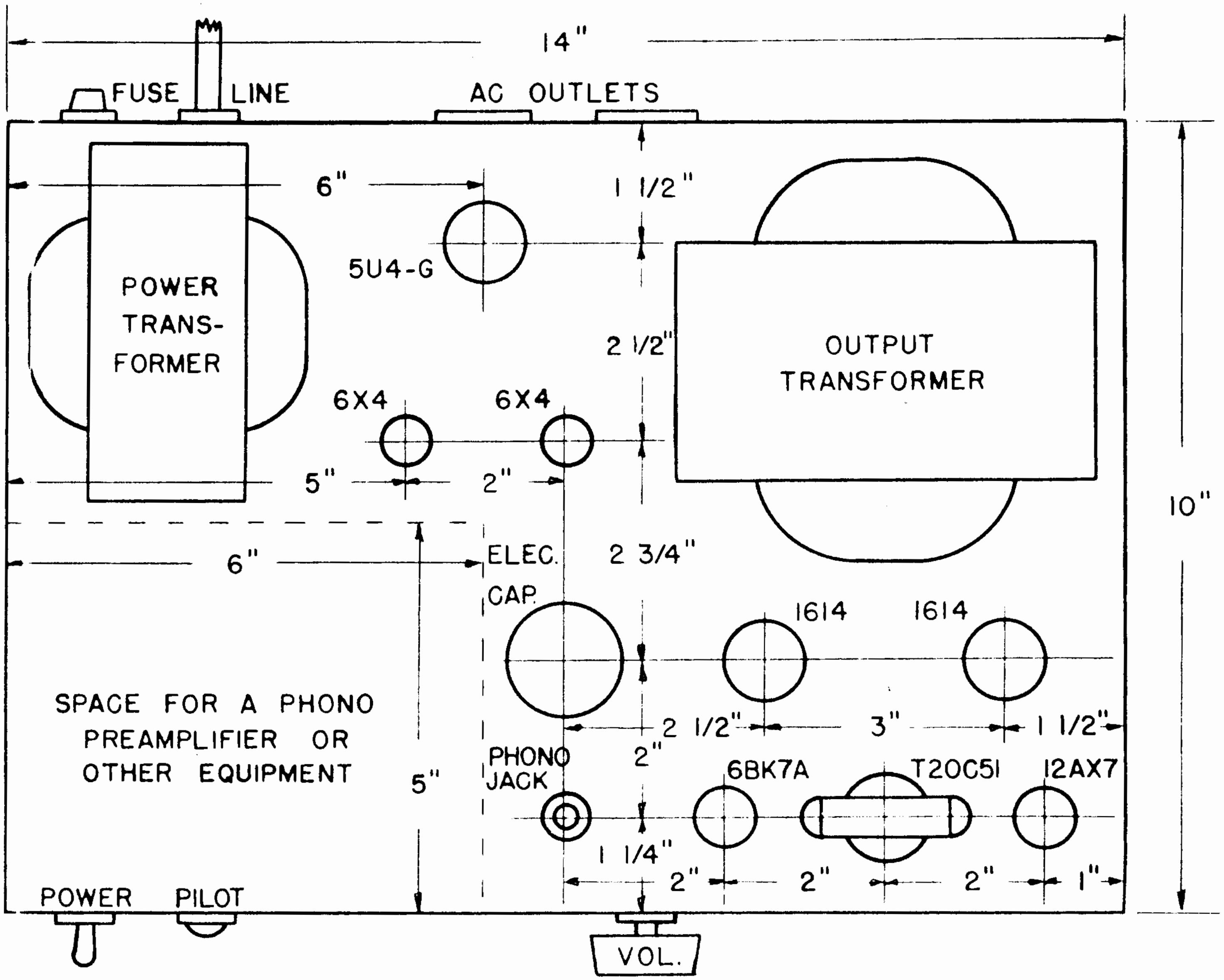

14"
FUSE
LINE
AC OUTLETS
10"
6"
1 1/2"
5U4-G
POWER TRANS-FORMER
2 1/2"
OUTPUT TRANSFORMER
6X4
6X4
5"
2"
6"
ELEC. CAP.
2 3/4"
1614
1614
SPACE FOR A PHONO PREAMPLIFIER OR OTHER EQUIPMENT
2 1/2"
3"
1 1/2"
PHONO JACK
2"
6BK7A
T20C51
12AX7
5"
1 1/4"
2"
2"
2"
1"
POWER
PILOT
VOL.

Fig. 24