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MANUFACTURE OF TRANSMISSION LINES

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2 Sheets-Sheet 1

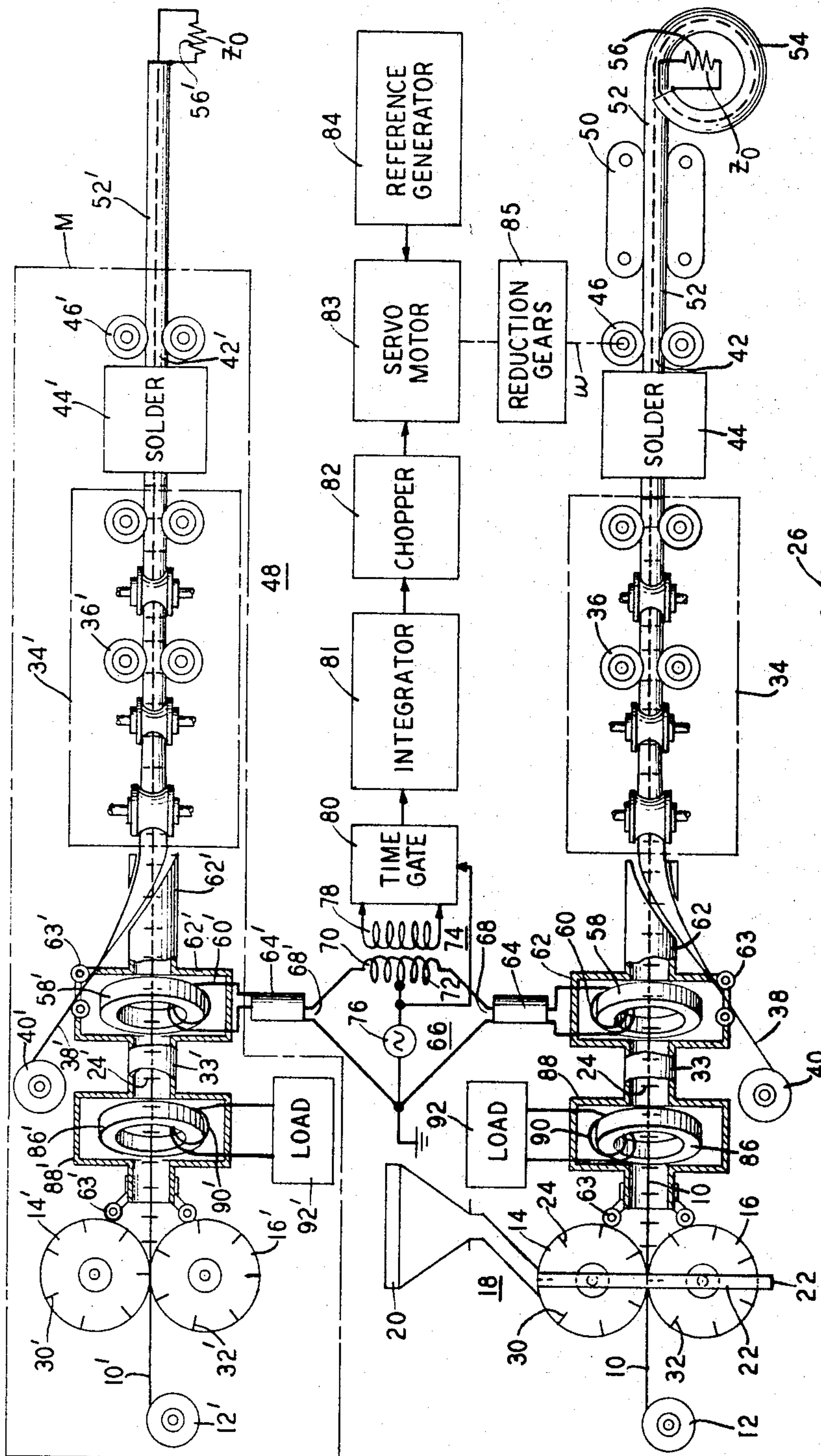


FIG. 1

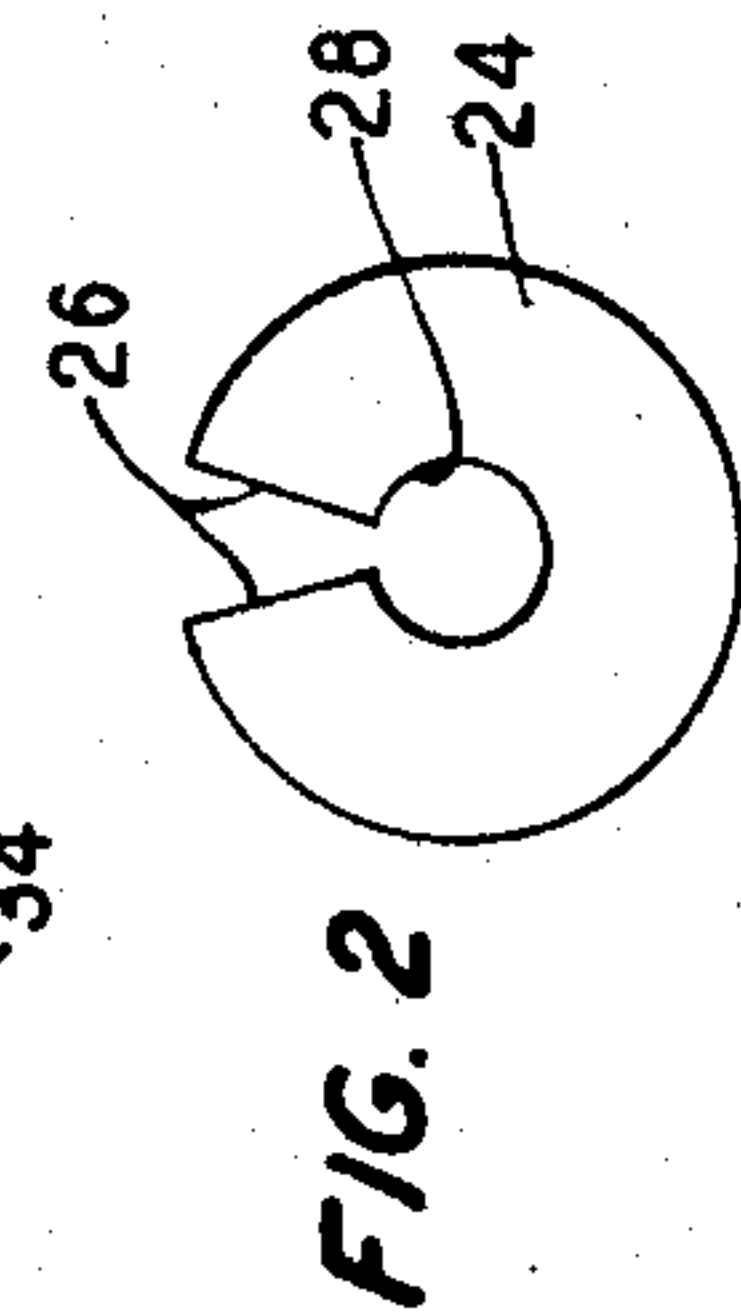


FIG. 2

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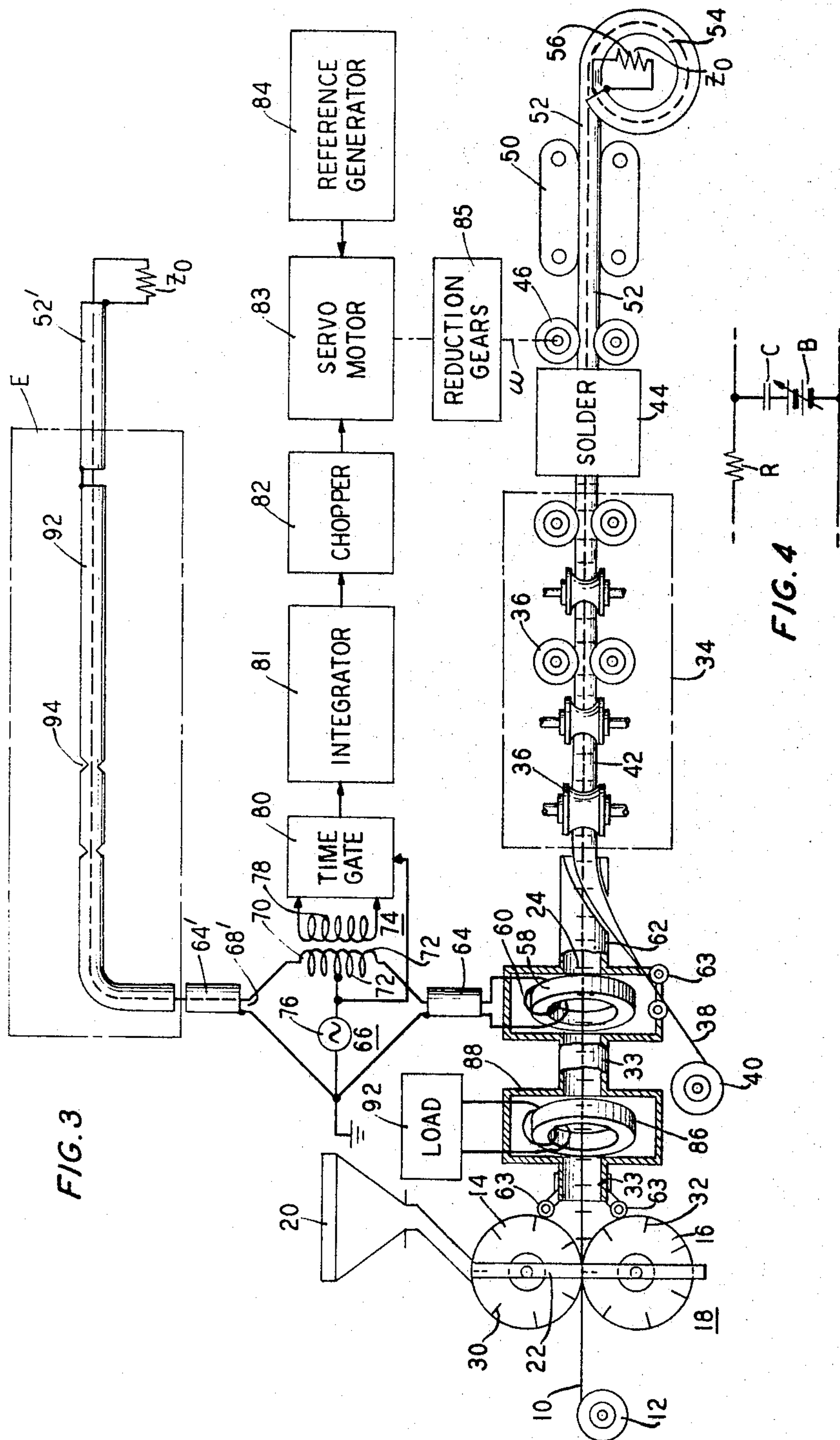
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MANUFACTURE OF TRANSMISSION LINES

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16 Claims. (Cl. 29—407)

This invention relates to the coaxial transmission lines, and particularly to the manufacture of coaxial cables having uniform characteristics.

Manufacture of coaxial transmission lines generally involves applying radial spacing means about a continuously moving central conductor, and then continuously forming an elongated cylindrical outer conductor around the spacing means from an elongated metal tape whose edges are soldered to form a longitudinal seam. The ultimate impedance of the coaxial line depends partly upon the sizes of the inner and outer conductors, as well as the spacing means. Its echo performance depends upon the uniformity of the impedance.

To obtain the best possible echo performance it has been customary to pass the line, just before the solder seam hardened, through sizing rolls or dies that were intended to produce a uniform outer diameter. However, it has been discovered that wear of the sizing rolls or dies produces a small drift impedance of the lines. This results in the need to allocate the coaxial singles in ascending impedance levels in each multicoaxial cable and to install reel lengths in sequence of manufacture. Aside from the persistent impedance-varying shift in the outer diameter size of the line there are other factors causing variation of impedance quite apart from the uniformity or lack of it in the sizing dies. These may be due to changes in the central conductor diameter, the electrical properties of the spacing means, or other causes. Present manufacturing systems fail to consider these.

A general object of the invention is to improve the echo performance of coaxial transmission lines.

Another object is to manufacture coaxial transmission lines having a uniform impedance whereby the difficulties associated with present line manufacturing procedures are eliminated in whole or in part. Still another object is to manufacture a high echo performance coaxial line that takes into account the changes in parameters of portions other than the outer conductor.

These ends are achieved during the manufacture of coaxial transmission lines by launching into the moving central conductor, as it combines with the outer conductor, a series of pulses coming from a toroidal core that surrounds the moving conductor, and then controlling the opening of the sizing rolls or dies on the basis of the impedance measured on the completed moving line near the sizing rolls as indicated by echo reflections returning at predetermined times.

The invention has the advantage of adjusting the outer conductor diameter to many of the parameters affecting the high echo performance cable, without, however, requiring conductive access to the moving central conductor near its conjunction with the outer conductor. Preferably, suitable shielding means limit the effect of the pulses prior to this conjunction.

According to a more particular aspect of the invention, the pulses are launched and sensed by the toroidal core from a winding that forms an arm of a hybrid coil bridge in which a second arm launches identical pulses in an electrical equivalent of the manufacturing apparatus with a reference coaxial line, and wherein the sensed echoes are compared so as to control the sizing rolls or dies.

These and other features of the invention are pointed out in detail in the claims. Other objects and advantages

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of the invention will become obvious from the following detailed description when read in light of the accompanying drawings, wherein:

FIG. 1 is a somewhat schematic block diagram of an apparatus for manufacturing cable according to the principles of the invention;

FIG. 2 is an elevation of a spacer in the cable manufactured by the system of FIG. 1;

FIG. 3 is another embodiment of the apparatus in FIG. 1; and

FIG. 4 is a schematic diagram of an integrator in FIG. 3.

In FIG. 1 wire forming a central conductor 10 feeds off a supply roll 12 and between the two wheels 14 and 16 of a disc applicator 18. The latter includes two feed devices 20 and 22 that furnish insulating spacer discs 24 such as shown in FIG. 2 and having each a single radial slot 26 and axial bore 28. The wheels 14 and 16 grasp an unslotted edge of each disc in successive peripherally-spaced axial slots 30 and 32 of their respective edges. The turning wheels 14 and 16 advance the conductor 10 translatorily and circularly advance the discs 24 until one and then the other wheel slides successive discs onto spaced positions of the conductor 10 by means of the slots 26 and bores 28. The bores 28 are small enough so that the discs 24 fit snugly about the conductor 10. Examples of such disc applicators appear in U.S. Patents 2,404,782, 2,579,468, 2,579,486 and 2,579,487.

The longitudinal passage of the now disc-carrying conductor 10 continues through a plastic guide tube 33 until it reaches a roll former 34 whose individual roll elements 36 successively increase the transverse curvature of a metal tape 38 feeding off a reel 40 until they form a complete cylindrical outer conductor 42 embracing and holding the spacer discs 24. The cylindrical outer conductor 42 has a longitudinal overlap. A solder pool 44 longitudinally spaced from the roll formers 34 applies a liquid solder seam to the overlap. Located adjacent the solder pool 44 at a point where the applied solder on the outer conductor has not solidified are adjustable sizing rolls 46 that further reduce the diameter of the outer conductor to a point determined by a control system designated 48. A capstan 50 draws the completed transmission line 52 by its outer conductor 42. A take-up reel 54 stores the cable. An impedance 56 equal to the desired characteristic impedance Z_0 of the line 52 terminates the cable.

Feeding information to the control system 48 is a high permeability coupling toroid 58 that coaxially surrounds the conductor 10 just before the roll former 34 and launches pulses induced by a winding 60, into the conductor 10. The tube 33 forms a radiation shield 62 by virtue of having a metallized outer coating. It conserves the energy of the launched pulses and protects them from excessive noise. It is connected to the wheels 14 and 16 and to the moving tape 38 by suitable rollers 63 and surrounds the conductor 10 between the disc applicator 18 and the roll former 34. The shield 62 is enlarged in a section to receive the toroid 58 and winding 60. Effectively the shield also extends the electrical length of the outer conductor 42 on complete transmission line 52.

The winding 60 on the toroid 58 and a shielded connector cable 64 form an arm 68 of a hybrid coil bridge 66. A second arm 68' of the bridge 66 comprises a cable 64', identical with cable 64 and terminating in an exact mock-up M of the heretofore described manufacturing apparatus, from the supply roll 12 to the sizing rolls 46, and including the winding 60 on toroid 58. The mock-up members are designated with the primes of their counterparts, for example, 14', 16', 18', 34', 36', 44', and 62'. They operate upon an ideal prefabricated coaxial line 52'

of uniform impedance having a central conductor 10' and an outer conductor 42'. The line 52' terminates in an impedance 56' equal to its characteristic impedance and that of the line 52, namely Z_0 . The line 52' represents the reference line which the apparatus according to the invention is to duplicate.

The two halves 70 and 72 of a center tapped hybrid coil 74 form the two other arms of the bridge 66. A pulse generator 76 from the center tap of coil 74 to ground energizes the respective toroids 58 and 58' and launches equal pulses in the lines 52 and 52' as well as in the cable portion formed by the conductors 10, 10' and shields 62, 62'. The toroids 58 and 58' relay the echoes from the lines to the coil halves 70 and 72. If the echoes are equal the coil 74 cancels them. If they are unequal the coil 74 induces into a secondary winding 78 a signal which a time gate 80 allows an integrator 81 to apply across a constituent capacitor. The gate 80 responding to pulses from generator 76 permits only the echoes arriving from the time of each initial pulse at generator 76 to the time they can return from the end of cable 52'. This end corresponds to the first few feet of the cable 52. The gate 80 blocks other echoes arriving from the effects of the main pulse traveling beyond the first few feet of cable 52. A chopper 82 converts D.C. signals at the integrator 81 to A.C. output signals, whose phase depends upon the polarity of the D.C. signals. These A.C. signals activate a servo motor 83 that receives a 90° reference signal from a reference generator 84 to increase or decrease the size of the outer conductor 42 established by the sizing rolls 46. This is done through suitable reduction gears 85 and a worm W.

In the apparatus of FIG. 1 it is essential that the reflections to the left of the toroid 58 do not interfere with the measuring reflections from the right. For this purpose the shields 62 and 62' connect through the rollers 63 and 63' to the wheels 14, 14' and 16, 16' that contact the conductors 10 and 10'. This short circuits the transmission line to the left of the toroid 58. The short circuit reflects pulses at the toroid 58. However, by limiting the distance from toroid 58 to wheels 14 and 16, the echo appears to be part of the pulse.

While a predictable electrical contact to the central conductor 10 from the wheels 14 and 16 is contemplated, the construction of many wheels 14 and 16 is such as to make such predictable contact unlikely without considerable additional equipment. Thus, in the embodiment of the invention shown in FIG. 1 a terminating toroidal core 86 surrounds the central conductor 10 within an enlargement 88 in the shield 62. A winding 90 upon the core 86 connects to a suitable matching termination 92. The distance between the coupling toroid 58 and the terminating toroid 86, and the character of the termination 92, is such as to prevent the pulse from being reflected. In still another embodiment of the invention, the core 86 itself comprises a lossy ferrite material sufficient to absorb the pulses and thus makes the winding 90 and termination 92 unnecessary.

According to the embodiment of the invention, shown in FIG. 1, the mock-up M includes a toroid 86' identical to the toroid 86 within an enlargement 88' in the shield 62'. A winding 90' about the toroid 86' terminates in a termination 92'. Again as before the members designated by prime numerals in the mock-up are identical to the corresponding unprimed members in the coaxial line manufacturing device. Where the invention is embodied in a machine having the lossy ferrite toroidal core, the mock-up core 86' is of identical material.

In operation, the wheels 14 and 16 draw the central conductor 10 off the reel 12 and apply the necessary spacers on a one by one basis around the conductor 10 in a snug fit so that they travel with the conductor. The discs 24 and the conductor 10 pass through the shield 62 and the toroids 86 and 58 until they meet the tape 38 coming off the reel 40 and being formed into a tubular outer conductor by the roll formers 34. A solder pool 44 forms a seam

along the longitudinal overlap in the outer conductor 42. Prior to the hardening of the solder the sizing rolls 46 compress the outer conductor to a smaller diameter into its desired size of coaxial line 52. The tape and the line generally are drawn during this operation by capstan 50 and taken up by the reel 54.

During the manufacturing process the pulse source 76 passes sequential and equal pulses through the connector cables 64 and 64' to the windings 60 and 60' on the toroids 58 and 58'. The pulse induced into the toroids 58 and 58' are inductively transferred to the central conductors 10 and 10' and travel in both directions. From the toroid 58 the pulse travelling to the left is absorbed by the toroid 86 and its accompanying winding 90 and termination 92. The pulse passing to the right passes through the shielded wire until echoes are reflected by the end of the shield 62 and the beginning of the outer conductor 52. The pulse continues through the coaxial line 52, partially completed, and other echoes occur at the last roll former. Additional echoes occur at the sizing rolls.

A similar pulse and echoes occur in the mock-up at the roll formers 34' and the sizing rolls 46' as well as at the end of the shield 62'. Each of the toroids 58 and 58' sense the echoes that occur at each of the positions along the line being manufactured. Since the members in the mock-up are substantially identical to the corresponding roll formers 34, the echoes cancel each other within the hybrid coil 74. Only when a difference exists in the impedances of the lines 52 and 52' at the exit of the sizing rolls 46 and 46' does a difference exist in the echoes. This difference is sensed by the secondary winding 78 in the hybrid coil bridge 66. It is used by and passed to the members 80, 81, 82, 83, 84 and 85 to adjust the sizing rolls 46 to eliminate the error signal.

The signal accumulated at integrator 82 over a cycle of generator 76 represents the difference between total echo voltages due to accumulated changes from the impedance Z_{64} of the preselected reference cable 64 to the impedance Z_{52} of the cable 52 being manufactured on the one hand, and total echo voltages due to accumulated changes from the impedance $Z_{64'}$ of preselected reference cable 64' to the impedance $Z_{52'}$ of the reference cable 52' on the other. However, the impedance changes along the path from cable 64 through former 34 are identical to the changes of mock-up M. Thus the total signal of integrator 81 represents the departure of the impedance Z_{52} of cable 52 from the ideal value $Z_{52'}$. It is this departure which controls the servo motor sizing rolls 46.

Since the impedance changes along the mock-up M are identical to the changes in its counterpart unprimed members, the voltage stored at integrator 81 is proportional to $(Z_{64'} - Z_{52'}) - (Z_{64} - Z_{52})$. The identity of the echo signals in mock-up M and its unprimed counterparts affects this value because each impedance change causing an echo depletes the energy of the propagating and echo-producing signal pulse. Therefore, when a depleted signal pulse reaches a new impedance change the new echo it produces is somewhat less than it might have been had no prior echo occurred. Thus the total echo from an impedance change of $Z_{64'}$ to $Z_{52'}$ is greater than from the same change with intervening steps, namely from $Z_{64'}$ to Z_a and then Z_a to Z_b and then Z_b to $Z_{52'}$. Nevertheless the effects in intervening changes are comparatively small and constant. It is possible therefore to furnish a total echo voltage from a cable 64' connecting directly to a cable 52' equal to the total echo voltage from the mock-up M and also equal to the desired echo voltage from the components manufacturing cable 52, by adjusting the new cable to produce extra echoes equal to the echoes due to the mock-up M.

An apparatus utilizing this principle appears in FIG. 3. Here the electrical circuit E substitutes for the mock-up M in an apparatus otherwise identical to that of FIG. 1. The circuit E simply comprises a cable coaxial 92 between the cable 64' and 52' having a sufficient number of

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discontinuities 94 such as holes in the outer conductor and interior baffles to produce echoes equal to those in the mock-up M. To calibrate the cable coaxial 92 an operator terminates the cable 52 at a position comparable to the sizing rolls 46 with a length of ideal cable 52' and a terminating impedance Z_0 and then adds discontinuities to the coaxial 92 until the integrator exhibits a zero output. Instead of adding discontinuities an operator may calibrate the entire system merely by biasing the integrator with a variable voltage while performing the above test. In that case the integrator has the structure shown in FIG. 4, using a variable source B with a capacitor C and resistor R.

The round-trip transmission losses through the hybrid coil bridge 66 are equal approximately to 6 db. If the bridge is matched to the toroid 58 reasonably well the circuit loss at this point is approximately 2 db. A termination by the toroid 86 either with or without the winding 90 and termination 92 introduces an additional round-trip loss of 6 db. To detect a difference in impedance of .1 percent between the mock-up and the original system, an additional loss of 66 db would have to be measured. This amounts to a total loss of about 80 db. The pulse generator then must produce a 50 volt input to produce a detector signal level of 5 millivolts. For the launching system employing a short circuit instead of a toroid 86 immediately to the left of the toroidal coupler 58 the required pulse generator voltage could be reduced to 24 volts.

The pulse generator 76 is of the composite type capable of producing pulses of varying length as determined by the operator or at predetermined intervals. The short pulses precisely locate the spot where the impedance of the coaxial transmission path actually changes. Such short pulses are in the nanosecond range.

The apparatus and method according to the invention are applicable not only for forming coaxial lines having a simple central conductor and cylindrical outer conductor but are equally suitable for corrugated outer conductors. In the past, corrugated conductors had presented a particularly difficult situation because only the outer diameter could be made constant while the size of the corrugations might vary. Here, because all the parameters affecting the impedance of the wire are simultaneously measured by varying one parameter, it is possible frequently to compensate as closely as possible for all variations that may occur. This, of course, applies to all coaxial transmission lines manufactured according to this invention. The manufacturing system according to the invention is particularly useful in fabrication of L-type coaxial lines having serrated seam coupled outer conductors. The serrated seam coupled outer conductor normally is wrapped with two helically applied steel tapes to hold the seam together and provide low frequency shielding. The steel tape necessarily deforms the coupling tube dependent on the tension adjustments of the tape applicator. In such a device the servo motor 84 instead of controlling sizing rolls 46 would control the tension adjustment of the tape applicator.

While embodiments of the invention have been described in detail it will be obvious to those skilled in the art that the invention may be embodied otherwise without departing from its spirit and scope.

What is claimed is:

1. Apparatus for manufacturing coaxial cable comprising, feeding means for guiding an inner conductor in a direction along a given path, supply means near said path for furnishing outer conductor tape near the path, shaping means along the path for forming from said tape a cylindrical conductor surrounding the inner conductor, drawing means for drawing the conductors along the path, sizing means in said shaping means for varying the diameter of the outer conductor, magnetic means in inductive relation with inner conductor and located between said feeding means and said shaping means, elec-

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trical means connected to said magnetic means for furnishing pulses to said magnetic means and simultaneously receiving signals inductively sensed by said magnetic means as appearing on said inner conductor, and control means responding to predetermined ones of the sensed signals for regulating said sizing means.

2. Cable making apparatus comprising, forming means for combining bare inner conductor wire with material that forms an outer conductor to produce coaxial cable, magnetic means inductively related to the bare wire for applying electric pulses thereto and for sensing echo signals, control means connected to said magnetic means for varying the diameter of outer conductor issuing from said forming means in response to echo signals occurring at predetermined times.

3. Cable making apparatus as in claim 2, wherein said magnetic means comprise a core inductively linking said wire and a coil on said core, and wherein said control means comprise electric means connected to said coil for applying electric pulses thereto and simultaneously sensing signals induced from said wire into the coil.

4. Cable making apparatus, as in claim 2, further comprising shielding means surrounding said bare wire and said magnetic means and contacting said material of the outer conductor for forming a pulse propagating transmission line section with the bare wire, and means for effectively terminating the propagating character of said section on the side of said magnetic means opposite the forming means.

5. Cable making apparatus as in claim 2 wherein said magnetic means comprise a core inductively linking said wire and a coil on said core, and wherein said control means include electric means connected to said coil for applying electric pulses thereto and simultaneously sensing signals induced from said wire into the coil, and further comprising shielding means surrounding said bare wire, said core, and said coil and contacting said outer conductor for forming a transmission line on both sides of said core and having pulse propagating characteristics with said bare conductor, and terminating means for terminating the pulse propagating character of said line on the side of the core opposite the forming means.

6. Cable making apparatus as in claim 5 wherein said electric means include a four-arm hybrid coil bridge having one arm connected to said coil and source means for applying electric pulses to the coil and simultaneously sensing signals induced from said wire into the coil.

7. Cable making apparatus as in claim 5 wherein said electric means comprise a four-arm hybrid coil bridge having connected in one arm said magnetic means, an electrical equivalent of said forming means and said magnetic means as well as said wire and outer conductor, said equivalent being connected in another arm of said bridge, pulse generator means in said bridge for applying pulses to said bridge, said bridge having two arms for comparing echo signals from said magnetic means with those appearing in said equivalent for producing a series of comparison pulses, and means for responding to predetermined ones of said comparison pulses.

8. Cable making apparatus as in claim 5 wherein said terminating means comprise rolling means for contacting said inner conductor on the side of the core opposite the forming means.

9. Cable making apparatus as in claim 5 wherein said terminating means comprise a load device inductively linked to said inner conductor on the side opposite said forming means.

10. Cable making apparatus as in claim 9 wherein said load device comprises a lossy core surrounding said inner conductor.

11. Apparatus as in claim 9 wherein said load device comprises a load core surrounding said inner conductor, a load coil on said load core, and a load connected to said load coil.

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12. Cable making apparatus as in claim 7 wherein said equivalent includes a structure forming wire and tape into cable of predetermined characteristics, all in respective corresponding relations, and means in said control means responding to said electric means for varying the diameter of outer conductor issuing from said forming means in response to signals from said electric means at predetermined times.

13. Cable making apparatus as in claim 12 wherein said control means include regulating means responding to said electric means for varying the diameter of outer conductor issuing from said forming means in response to signals from said means at predetermined times, said control means including gate means for selecting signals at predetermined times to utilize in establishing the size of said cable.

14. The method of producing cable which comprises the steps of forming cable by moving bare wire and moving conductive material toward the wire and surrounding the wire with the material to form an outer conductor, inductively launching pulses in the wire so that they travel through the cable and produce echoes as impedance changes occur, inductively sensing the echoes, and controlling the diameter of the outer conductor on the basis of the characteristics of the sensed echoes.

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15. The method of producing cable as in claim 14 which further comprises the step of simultaneously shielding a portion of the exposed moving wire by surrounding the wire with stationary shielding material and inductively terminating the transmission line formed by the shielding material.

16. The method of producing cable as in claim 15 wherein the step of controlling the diameter of the outer conductor comprises inductively launching pulses in a device corresponding electrically to the means by which the wire and the material are formed into a cable and wherein the cable characteristics are predetermined, inductively sensing the echoes in the wire and mock-up, comparing the echoes from the mock-up with the echoes from the cable, and controlling the diameter of the outer conductor on the basis of the comparison of the sensed echoes.

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