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[33] Japan
[31] 43/21465, 43/83092 and 44/4722

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[54] HIGH FREQUENCY HEATING APPARATUS 4 Claims, 12 Drawing Figs.

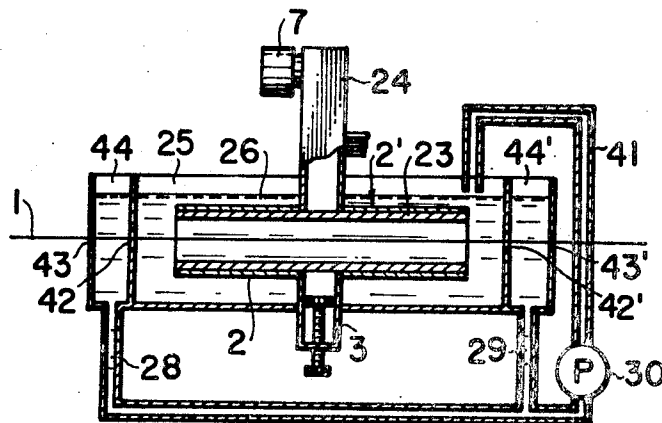
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219/10.61
[51] Int. Cl..... H05b 9/06,
H05b 5/00
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ABSTRACT: An apparatus for noncontact heating of a continuously running metal wire with microwave power, which consists of a high loss transmission line such as coaxial line, strip line, or slab line, or its resonator, with the wire serving as an inner conductor. A bare or insulated wire to be heated and a conductor surrounding the wire together constitute a high loss transmission line such as a coaxial line, a strip line or a slab line. Such a transmission line is shorted at both ends thereof to form a resonator. The transmission line or resonator is fed with a high frequency power from a high frequency power source such as magnetron through a waveguide system connected to the transmission line or resonator in noncontacting relationship to the wire. Heat that develops either by the resistance loss in the wire or by the dielectric loss in the insulation layer is used for annealing of the wire or curing of the insulation layer.



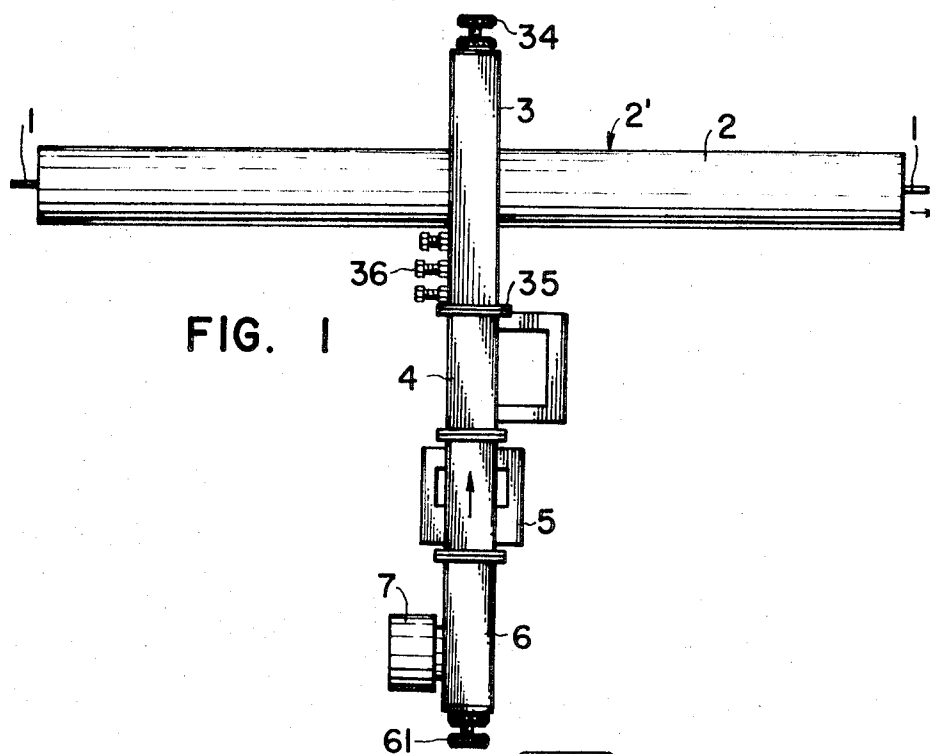


FIG. 1

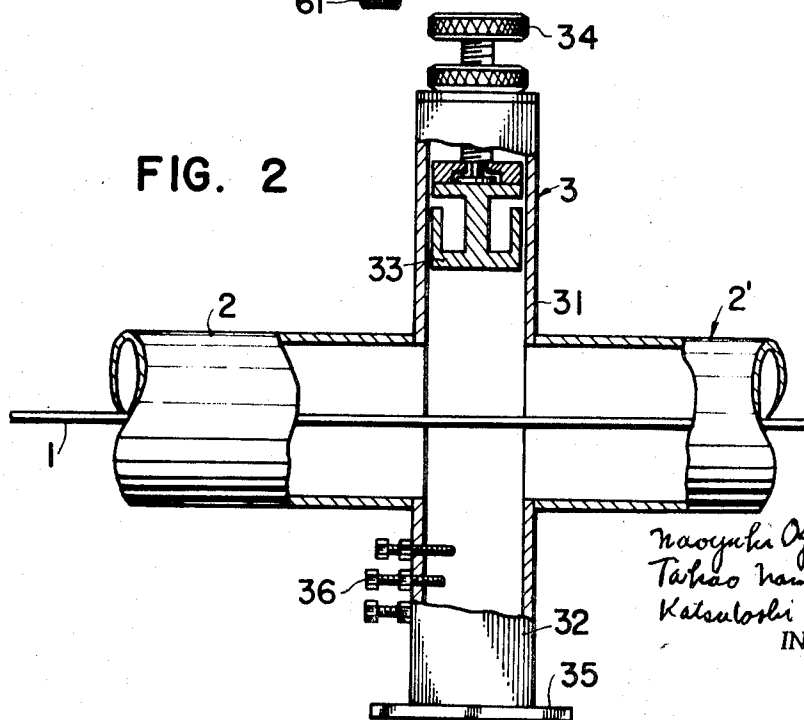


FIG. 2

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FIG. 3

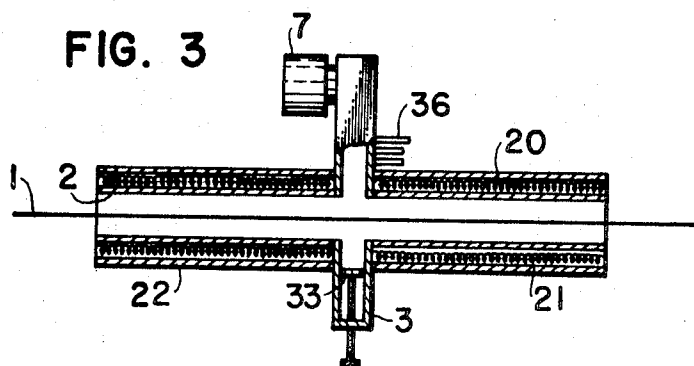


FIG. 4

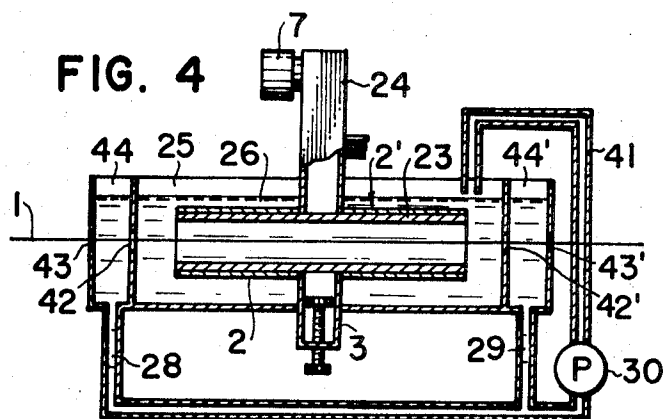
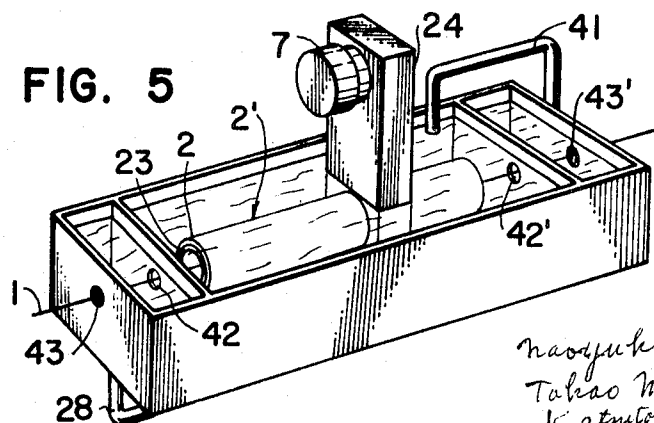


FIG. 5

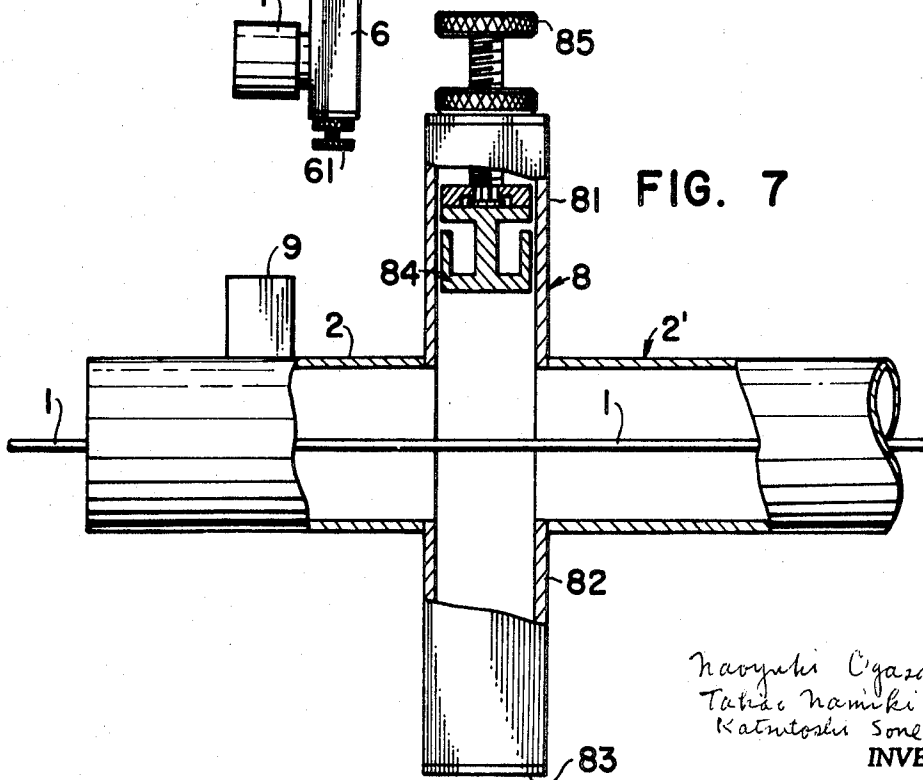
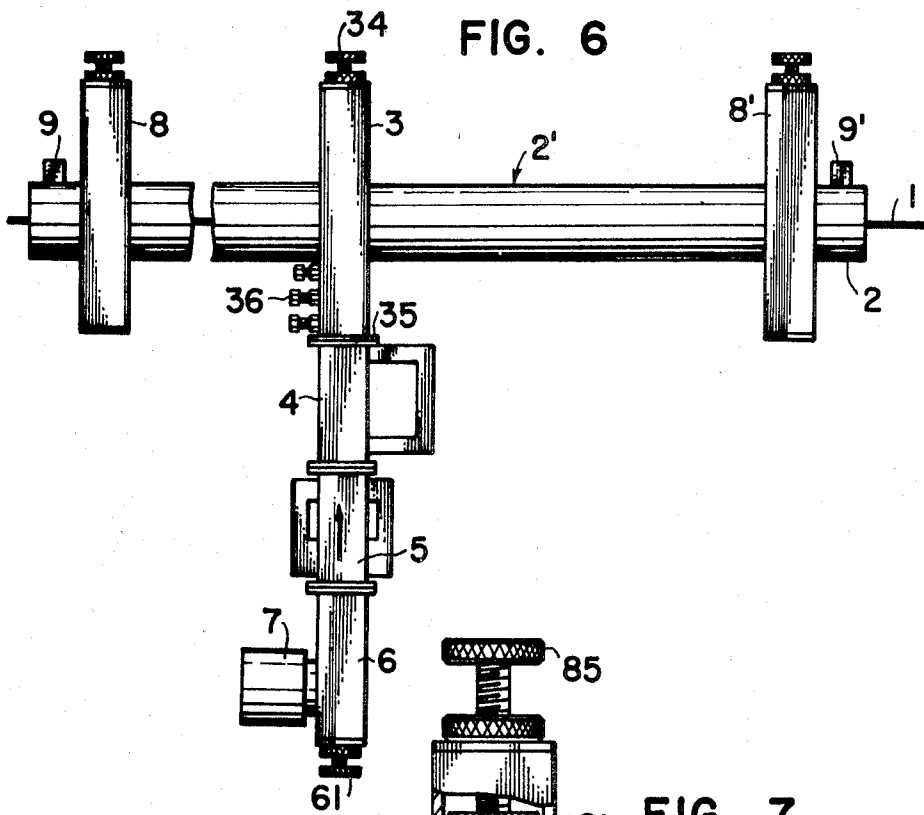


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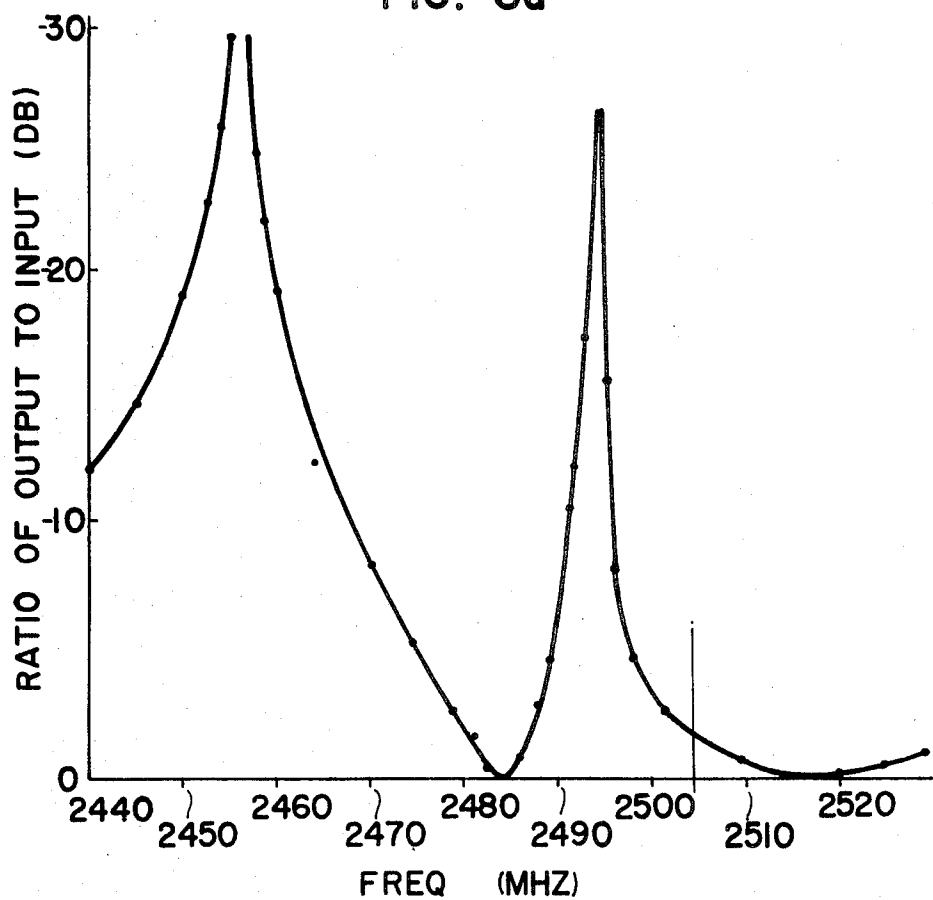


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FIG. 8a



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FIG. 8b

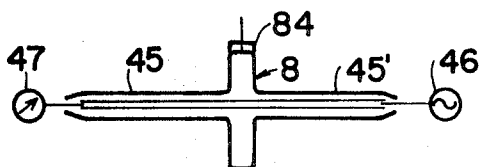
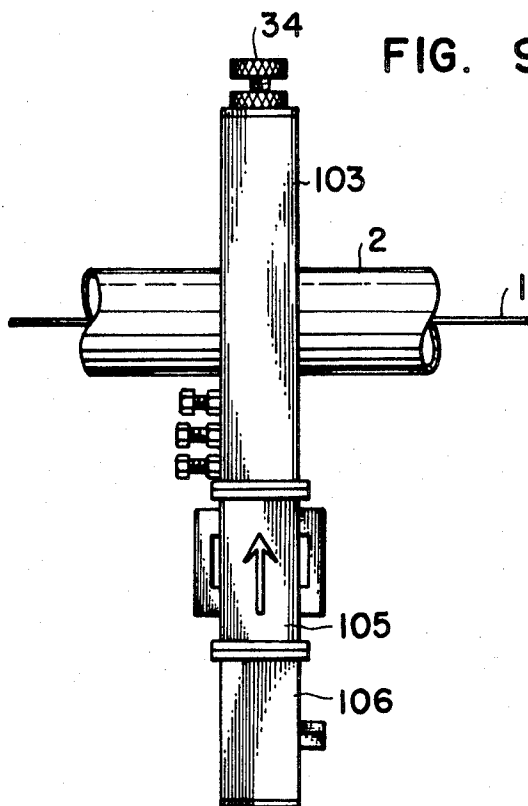


FIG. 9



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FIG. 10

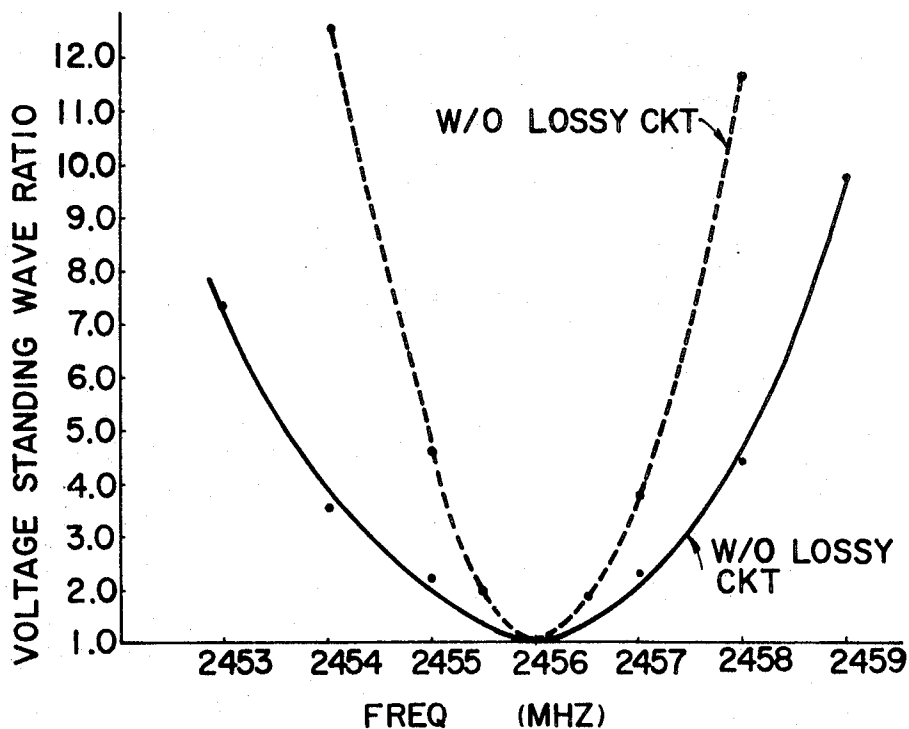
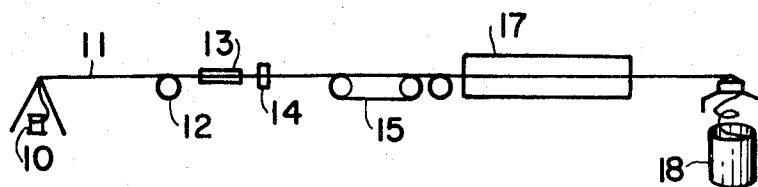


FIG. 11



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HIGH FREQUENCY HEATING APPARATUS

BACKGROUND OF THE INVENTION

The present invention relates to a high frequency heating apparatus, and more particularly to an apparatus for noncontact heating running object of continuous length hereinafter called "heating object" such as a metal wire, an insulated electric wire, tube or the like, for continuous annealing of metal wires or heat treatment of insulating layers.

There have been several conventional methods of continuously heating a running metal wire such as a bare copper wire, a synthetic resin insulated electric wire, an enameled wire or the like; that is, radiation heating using electric heaters or infrared ray heater, conduction heating using heated liquids, heating by direct passage of electric current, and induction heating. The radiation heating and the conduction heating are defective in that their thermal efficiency is very low because other objects than the heating object must also be heated and that their thermal response is slow because the heating furnace used has a large thermal capacity. A large size heating apparatus will therefore be required if such heating must be done at a high speed. The slow thermal response means the impossibility of rapid temperature control and therefore of uniform heating.

On the other hand, heating by direct passage of electric current requires electrodes for power supply and the induction heating requires contact members for constituting a secondary circuit. Therefore, an object heated by these methods will be injured by friction or spark discharge that develops between it and the electrodes or contact members.

In the wood, synthetic fiber and food industries there has been employed dielectric heating. For example, the so-called microwave oven having a cavity resonator for generating microwaves, has been put to practical use. Such technique, however, is based on the dielectric loss and therefore unsuitable for heating a rapidly running wire. It is also difficult to use such technique for heating object with metallic conductors embedded therein such as insulated electric wires.

The principal object of the present invention is to provide a novel high frequency heating apparatus free from the above disadvantages of the conventional heating apparatus.

Another object of the invention is to provide a high frequency heating apparatus capable of continuously heating either or both of a metallic conductor and a dielectric material provided thereon.

A further object of the invention is to provide a high frequency heating apparatus adapted for heating a metallic conductor covered with a dielectric material such as an insulated electric wire, which allows not only dielectric heating of the dielectric material but heating of the conductor by ohmic loss at the same time, utilizing the microwave technique.

A further object of the invention is to provide a high frequency heating apparatus in which high frequency power is concentrated on and absorbed by the heating object in noncontact relationship thereto, without electrodes, contact members or the like for feeding power.

A further object of the invention is to provide a high frequency heating apparatus having a high power efficiency, with a high concentration of high frequency power on the heating object and little leakage of the power.

A further object of the invention is to provide a high frequency heating apparatus, small in size and capable of rapid temperature control with quick thermal response.

A further object of the invention is to provide a high frequency heating apparatus in which a cavity resonator is made in the form of coaxial line, strip line, or slab line with a heating object serving as the inner conductor, the apparatus having a wideband coupling with the cavity and being free from spark in the cavity.

A further object of the invention is to provide a high frequency heating apparatus that can be applied to foaming process in the manufacture of an electric wire insulated with foamed synthetic resin.

A still further object of the invention is to provide a high frequency heating apparatus suitable for continuous annealing of a metallic wire.

SUMMARY OF THE INVENTION

In accordance with the invention, there is provided a high frequency heating apparatus comprising (1) a high loss, high frequency transmission line composed of a running object, which serves as an inner conductor, and an outer conductor surrounding the running object, (2) a high frequency power source for feeding high frequency power to the transmission line; and (3) a waveguide system for coupling the transmission line and the power source with each other in noncontacting relationship to said inner conductor.

In accordance with another aspect of the invention, near the ends of the outer conductor of the above transmission line there are provided shorting elements in noncontacting relationship to the object to be heated, both the shorting elements and the transmission line together constituting a high frequency resonator.

Other features and advantages of the invention will be apparent from the following description taken in connection with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings:

FIG. 1 illustrates a high frequency heating apparatus embodying the invention;

FIG. 2 is a view, partly in section, of a feeder for feeding high frequency power to a coaxial line in noncontacting relationship to a heating object as an inner conductor;

FIG. 3 is a longitudinal sectional view of another embodiment of the invention;

FIG. 4 is a longitudinal sectional view of another high frequency heating apparatus;

FIG. 5 is a perspective view of the apparatus in FIG. 4;

FIG. 6 illustrates a further high frequency heating apparatus;

FIG. 7 is a view, partly in section, of a shorting element in noncontacting relationship to a heating object as an inner conductor;

FIG. 8a is a diagram showing the frequency of the shorting element;

FIG. 8b is a schematic longitudinal view of a measuring apparatus used for obtaining the characteristics shown in FIG. 8a;

FIG. 9 illustrates a lossy circuit structure;

FIG. 10 is a diagram showing input voltage standing wave ratio (as function of frequency) of a cavity resonator with or without the lossy circuit in FIG. 9;

FIG. 11 illustrates an application of the high frequency heating apparatus of the invention to the manufacture of an electric wire insulated with a foamed synthetic resin.

In the drawings the corresponding parts are designated with the same reference numerals.

Referring now to FIG. 1, the reference number 1 designates a wire to be heated, such as a bare copper wire, a synthetic resin coated electric wire, an enameled wire or the like, which, driven by a suitable device not shown, runs in the direction shown with an arrow. A pipe-shaped outer conductor number 2 is arranged so as to surround coaxially the wire 1, and both constitute a high loss coaxial line 2'. Coupled with the outer conductor 2 is a power feeder 3 in noncontacting relationship to the wire 1 as an inner conductor. The feeder 3 is a coaxial line waveguide transducer with the wire 1 as the center conductor of coaxial line. Its coupling degree can be adjusted by means of a movable shorting plate 33 with an adjusting screw 34 in a waveguide section 31 and matching stubs 36 screwed into another waveguide section 32. The waveguide section 32 is connected in series to a directional coupler 4 and an isolator 5.

The isolator 5 in turn is connected to a magnetron mount consisting of a magnetron tube 7, a waveguide 6, and a short plunger 61. The feeder 3, directional coupler 4, isolator 5, and waveguide 6 together constitute a waveguide system for carrying high frequency power from the power source 7 to the coaxial line 2'. The directional coupler 4 is equipped with a detector and a galvanometer (not shown), and serves to monitor the incident power to the coaxial line 2' and the reflected power from the feeder 3. The isolator 5 absorbs reflected power from the coaxial line to keep power source stable.

Waveguide 6 is provided with a movable shorting plate (not shown) actuated by an adjusting screw for matching the waveguide system with the power source 7. As the high frequency power source 7 there may be employed a microwave oscillator of high power such as magnetron which oscillates microwave power, in frequency of 2,450 MHz.

In the above arrangement, the high frequency power which has been generated in the power source 7 is excited in the waveguide 6 and supplied to the coaxial line 2' through the waveguide system. Almost all of the power from the power source 7 may be fed to the coaxial line 2' by proper adjustment of the shorting plate 33 and the matching elements 36. Since the coaxial line 2' is constructed as high loss transmission line as described above, the high frequency power fed thereto is well concentrated on the wire 1, which is heated by ohmic loss in the case of bare wire and, in addition, by dielectric loss in the case of insulated wire. Furthermore if the inner wall of the outer conductor 2 is lined with a appropriate lossy material such as ferrite or polyiron, the wire will receive the radiant heat from the lining, in addition to the heat generated by itself.

The microwave power of the coaxial TEM mode is most suitable for concentrating high frequency power on the inner conductor and dissipating it mostly therein. The TEM mode is also stable against mechanical vibrations of the running wire 1.

The heating apparatus shown in FIG. 3 is provided with an electric heater 20 wound on the outer conductor 2. The heater 20 is embedded in a heat insulating material 21 such as asbestos and covered with a protecting metal tube 22. In such a structure, the wire 1 may be heated up not only by ohmic loss and dielectric loss but by radiation heat supplied from the surrounding electric heater 20. Such a structure of heating apparatus, especially when utilized for the foaming process in the manufacture of foamed synthetic resin insulated electric wires, as described later, permits high speed production of foamed plastic insulated wires of good quality.

In FIGS. 4 and 5, the coaxial line system 2' is immersed in a dielectric liquid 26 in which case high frequency power heats not only the wire by its ohmic loss and dielectric loss but also the liquid 26 by its dielectric loss. For this purpose, the outer conductor 2 is internally lined with a heatproof dielectric tube 23 such as a fused quartz tube, which prevents the liquid 26 in the coaxial line 2' from flowing out into the waveguide system 24. The dielectric liquid 26 must have such permittivity and loss factor as will permit it to be heated by dielectric loss to a predetermined temperature. As such liquid, water or glycerine may be preferably used. The wire 1 runs through the apertures 43 and 42, the tube 25 and apertures 42' and 43', and is heated in the coaxial line 2' by its ohmic loss and dielectric loss and additionally by the heated liquid 26. The liquid 26 is circulated by a pump 30 through a feed pipe 41, receptacle chambers 44 and 44' having opening 42 and 42' and return pipes 28 and 29. This heating apparatus may also be utilized for foaming process in the manufacture of foamed synthetic resin insulated electric wires, and permits high speed production of foamed plastic insulated wire of good quality.

In order to ensure higher thermal efficiency of a high frequency heating apparatus and less leakage of high frequency power therefrom, a resonator is formed in the apparatus by shorting the inner and outer conductors at both ends of the above high loss transmission line. This helps reduce the overall size of the heating apparatus. Since the wire 1 must be kept

noncontact with any part in an exciting section and other sections in the whole apparatus, noncontact short elements and a noncontact exciting section must be provided to make such a coaxial resonator. The noncontact short elements may be constructed by utilizing the effect of detuned short of a cavity resonator, which is a tunable waveguide cavity provided with a couple of tubes to permit the wire to run through as shown in FIG. 7. As regards the noncontacting exciting, the coaxial line-waveguide transducer may be used as shown in FIG. 2, where the movable shorting plunger serves not only to adjust the coupling with a cavity but to adjust the resonant frequency without changing the length of the coaxial cavity.

Such a heating apparatus of resonator type is illustrated in FIG. 6. Near the ends of the coaxial line 2, there are mounted noncontact short elements 8 and 8'. The short element 8 and 8', as shown in detail in FIG. 7, are each composed of (1) two waveguide members 81 and 82 connected transversely to the outer conductor 2 of the coaxial line, (2) a metallic plate 83 for shorting the free end of the waveguide member 82, and (3) a movable shorting plate 84 with an adjustment screw 85 mounted to the free end of the waveguide 81. The noncontact short element 8 and 8' serve as a cavity filter. FIG. 8a shows an example of the short characteristic of noncontact short elements 8 and 8', ascertained by the use of a measuring circuit shown in FIG. 8b. In FIG. 8a the abscissa represents the frequency applied and the ordinate represents the ratio of output to input level. As the short element shown in FIG. 8b, a rectangular waveguide having inner dimensions 34.0 mm. $\times$ 72.1 mm. was used while the input and output lines 45 and 45' were each composed of a coaxial line having an inner conductor of 16.9 mm. and an outer conductor of 38.8 mm. in diameter. The reference numeral 47 designates a high frequency oscillator and 47' an output level detector line 45'. The input and output line 45 were matched with the oscillator 46 and the detector 47 respectively. As is evident from FIG. 8a, the short element in FIG. 8b has the shorting effect at the frequencies of 2,456 and 2,493 MHz. The shorting frequency may be changed by means of the movable shorting plate 84 in a desired manner. The shorting frequency, of course, must agree with the frequency of the high frequency power source. The reference numerals 9 and 9' in FIG. 6 designate each a monitor for power leakage from the coaxial resonator, in which a loop of suitable form or a probe is inserted.

It is better to make Q_0 of the resonator somewhat smaller in view of the spark discharge and the wideband coupling with the resonator. The reduction of Q_0 may be easily achieved by loading lossy materials such as polyiron or ferrite in the coaxial cavity or by coupling lossy circuits with the coaxial cavity. The lossy circuit used in one embodiment of the invention consists of a noncontact coupler 103, an isolator 105, and a waveguide transducer 106 as shown in FIG. 9. The improvement of Q_0 is evident from the graph in FIG. 10, in which the abscissa represents the frequency applied while the ordinate represents the input voltage standing wave ratio to the coaxial cavity.

In the foregoing, the description has been referred to a high loss transmission line and a resonator of a coaxial line. Such a high loss transmission line or a resonator may naturally be made of a strip line or a slab line.

The application of the high frequency heating apparatus described above to the foaming process in the manufacture of an electric wire insulated with a foamed synthetic resin will be described with reference to FIG. 11. A conductor wire 11 fed from a supplier 10 is led into a coating tank 14 through a payoff capstan 12 and preheating furnace 13, where it is coated at a high temperature with a solution of crystalline synthetic resin melted in an organic solvent. The conductor wire with the solution is then stored temporarily in a wire stored temporarily in a wire storing machine 15, in which the crystalline resin in the coating while being cooled and dried segregates from the solvent so that the coated layer which has been transparent becomes cloudy. Such a step, which is indispensable for foaming, will be referred to as "clouding"

hereinafter. The wire coated with such a cloudy resin layer will be called as a clouded wire. The clouded wire is then led to a high temperature foaming furnace in which the coated layer thereof is foamed. When the high frequency apparatus of the present invention is used as the foaming furnace 17, the coated layer is not only heated by dielectric loss that develops in the layer itself but heated from inside by the resistance loss of the conductor wire. Additional heat is given from outside to the coated layer when the heating apparatus as shown in FIG. 3 or 4 is used. The resin-coated wire is finally wound up by a winding machine.

Several examples of the manufacture of a synthetic resin insulated wire by the use of the heating apparatus of the invention will be described in the following:

Now, when the high frequency heating apparatus shown in FIGS. 1, 3, and 6 are given such construction as described in examples 1, 2, and 3, the foamed synthetic resin insulated electric wires produced by them have the characteristics as shown in the columns of examples 1, 2, and 3 of table 1.

EXAMPLE 1

A heating furnace using a high loss coaxial line as shown in FIG. 1 was used. The outer conductor of the coaxial line was 53.5 mm. in inner diameter and 6.6 mm. in length. A rectangular waveguide having the inner dimensions 34.0 mm. $\times$ 72.1 mm. was employed as the waveguide system for feeding high frequency power to the coaxial line. The high frequency power source was a magnetron having a power of 1.2 kw. at 2,450 MHz. The conductor wire was a soft copper wire of 0.32 mm. in diameter. A coating solution was made of one part by weight of high density polyethylene (density: 0.949, melt index: 0.32) mixed with two parts by weight of xylene as a solvent. The solution at 130° C. was coated on the copper wire.

EXAMPLE 2

A heating furnace using a high loss coaxial line and a connectional heater as shown in FIG. 3 was used. The outer conductor of the coaxial line was 53.5 mm. in inner diameter and 3.3 m. in length. The heater having a power of 10 kw. was wound on the outer conductor. The heating temperature of the outer conductor was set at 500° C. The other conditions were the same as in example 1.

EXAMPLE 3

A heating furnace using a coaxial resonator as shown in FIG. 6 was used. The outer conductor thereof was 53.5 mm. in inner diameter and 2 m. in length. The short element was a rectangular waveguide having inner dimensions 34.0 mm. $\times$ 72.1 mm. Other conditions were the same as in example 1.

TABLE 1
Apparatus of the invention

Characteristic	Example 1	Example 2	Example 3	Conventional apparatus
Running speed of the wire (m./min.)	250	400	350	150-200.
Amount of residual solvent immediately after foaming of the coated wire (percent).	15	10	12	20.
Foaming degree (percent)	20-25	28-30	27-30	15-17.
Feature of foaming as seen in the cross section	Foamed cells are concentrated mean the conductor so that the equivalent dielectric constant may be reduced.			Foamed cells are scarcely concentrated in the vicinity of the conductor.
Burst of foamed cells towards the conductor	No burst.	No burst.	No burst.	Burst frequently.
Mechanical property of the insulation layer				
Elongation	Medium	Large	Large	Small.
Adhesion to conductor	Strong	Strong	Strong	Weak.

As is evident from the above table, the foamed synthetic resin insulated wire manufactured, using the heating apparatus of the invention, has excellent features as enumerated below:

1. The insulation layer is uniformly foamed and well cured so that the amount of residual solvent may be reduced.
2. Because the optimum foaming condition can easily be obtained, the foaming degree is remarkably improved.
3. The insulation layer, which is well cured, has excellent mechanical properties, that is, a good elongation and a

high mechanical strength.

4. Since a well-cured thin annular layer forms in contact with the conductor, foamed cells never burst toward the conductor.
5. The insulation layer is well foamed near the conductor so that the electric property thereof is improved. (In case of equal foaming degree, the equivalent permittivity of the insulation layer well foamed near the conductor is smaller than otherwise.)
6. The high speed and high efficiency production of the insulated electric wire will be possible.

Although heating of the insulation of an insulated electric wire has been described, the heating apparatus of the invention may be applied to heating of a metal wire without insulation, for example, to continuous annealing of a bare copper wire. Examples of continuous annealing of a bare copper wire will be described in the following:

EXAMPLE 4

An annealing furnace using a high loss coaxial line as shown in FIG. 1 was employed. The outer conductor of the coaxial line was 53.5 mm. in inner diameter and 3.6 m. in length. The waveguide system for feeding high frequency power to the coaxial line was a rectangular waveguide having inner dimension 34.0 mm. $\times$ 72.1 mm. As the high frequency power source is used a magnetron having a power of 1.2 kw. at 2,450 MHz. A hard copper wire was 0.4 mm. in diameter.

EXAMPLE 5

An annealing furnace using a coaxial resonator as shown in FIG. 6 was used. The outer conductor thereof was 53.5 mm. in diameter and 2 m. in length. The short element was a rectangular waveguide having inner dimensions 34.0 mm. $\times$ 72.1 mm. Other conditions were the same as in example 4.

The results obtained are shown in table 2.

TABLE 2

Sample Number	Example 4			Example 5		
	1	2	3	1	2	3
Running speed of the wire (m./min.)	100	154	183	300	400	500
Mean elongation (percent)	21.2	17.78	5.12	20.5	18.1	8.4
Mean tensile strength (kg./mm. ²)	22.77	26.44	35.85	23.7	25.3	30.0

The present invention may naturally be applied with advantage to the using process of enameled wires or the vulcanizing process of rubber- or plastic-insulated wires.

Further changes also may be made without departing the scope and spirit of the invention as set forth in the appended claims.

We claim:

1. A high frequency heating apparatus comprising:
 1. a high frequency coaxial transmission line wherein a running wire to be heated, serves as an inner conductor, and an outer conductor surrounding coaxially said inner conductor;
 2. shorting elements which short the inner and outer conductors in noncontacting relationship to each other near both ends of the outer conductor of said coaxial;
 3. a high frequency power source for feeding high frequency power to said coaxial line; and

4. a waveguide system for coupling said coaxial line and said power source with each other in noncontacting relationship to said inner conductor, said coaxial line and said shorting elements together constituting a high frequency coaxial resonator, said coaxial resonator being immersed in a dielectric liquid. 5
2. A high frequency heating apparatus as claimed in claim 1, wherein a bare copper wire, an enameled wire, or a synthetic resin coated wire is used as an inner conductor.
3. A noncontact coaxial resonator type high frequency heating apparatus for heating a running metal wire comprising: 10
 1. a high frequency coaxial transmission line immersed in a dielectric liquid wherein said running wire to be heated serves as an inner conductor and a tubular outer conductor;
 2. detuned cavity resonator elements for short circuiting

- said wire and said outer conductor in a noncontacting relationship to each other near the ends of said outer conductor;
3. a T-shaped junction for joining said coaxial transmission line to a waveguide to excite said wire with a high frequency power in noncontacting relationship to said wire; and
4. means for feeding a high frequency power to a noncontact type coaxial resonator composed of said coaxial line, detuned cavity resonator elements and T-shaped junction.
4. A high frequency heating apparatus as claimed in claim 3, wherein a bare copper wire, an enameled wire, or a synthetic resin-coated wire is used as an inner conductor. 15

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