METHOD OF AND APPARATUS FOR HIGH-FREQUENCY DIELECTRIC HEATING

Filed June 26, 1942 3 Sheets-Sheet 1

FIG. 1.

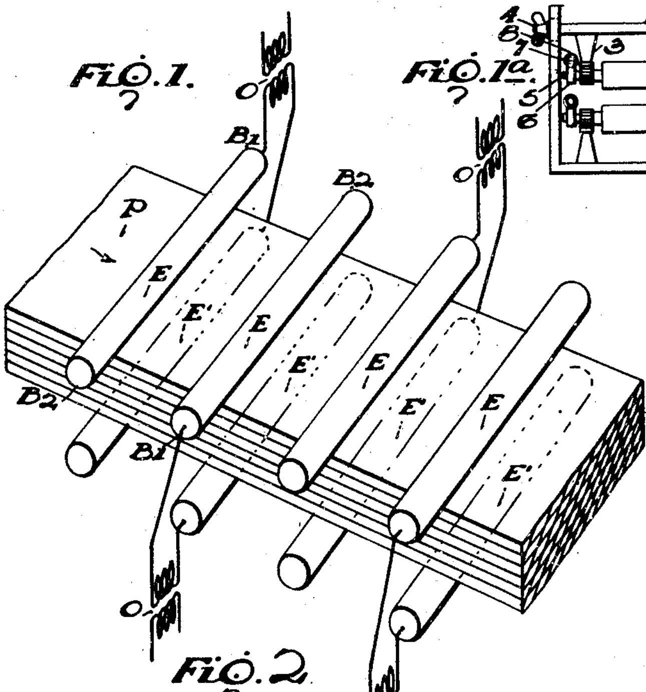


FIG. 1a.

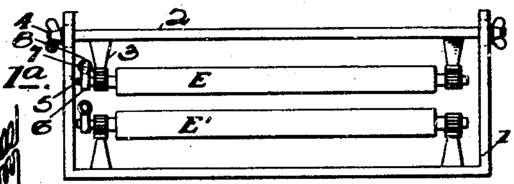


FIG. 1b.

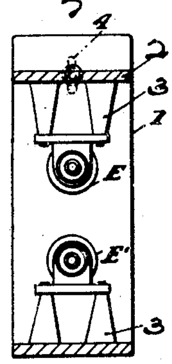


FIG. 2.

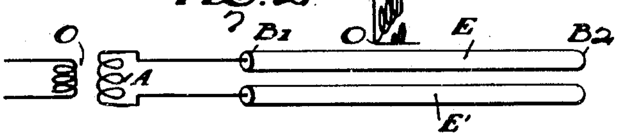


FIG. 3.

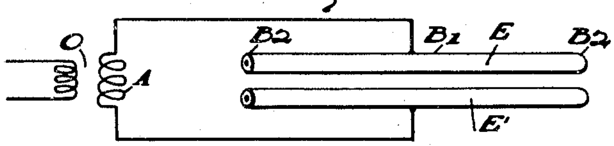
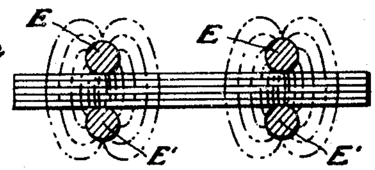


FIG. 5.



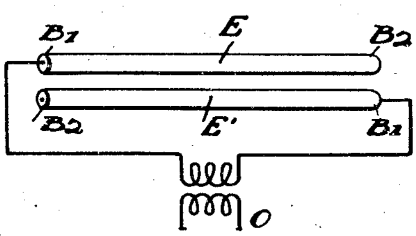


FIG. 4.

Inventor

George F. Russell.

By Cameron, Kerkam + Sutton.

Attorneys

Dec. 23, 1947. G. F. RUSSELL 2,433,067

METHOD OF AND APPARATUS FOR HIGH-FREQUENCY DIELECTRIC HEATING

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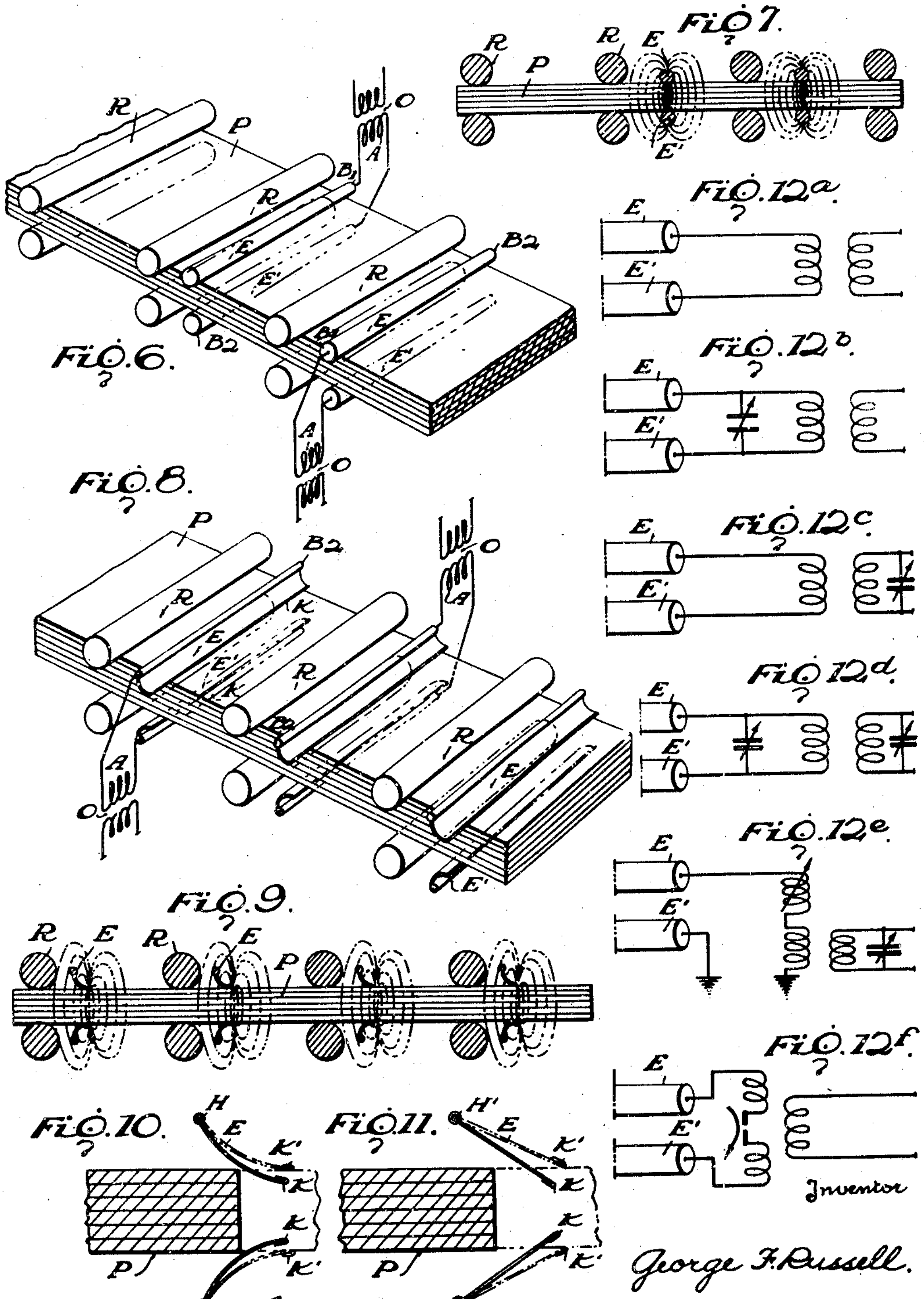

Inventor

George F. Russell.

By Cameron, Kerkam + Sutton.

Attorneys

Dec. 23, 1947. G. F. RUSSELL 2,433,067

METHOD OF AND APPARATUS FOR HIGH-FREQUENCY DIELECTRIC HEATING

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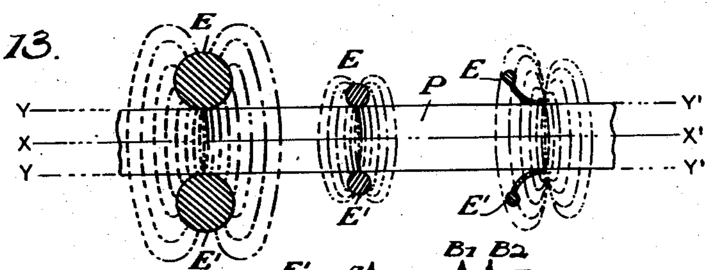
FIG. 13.



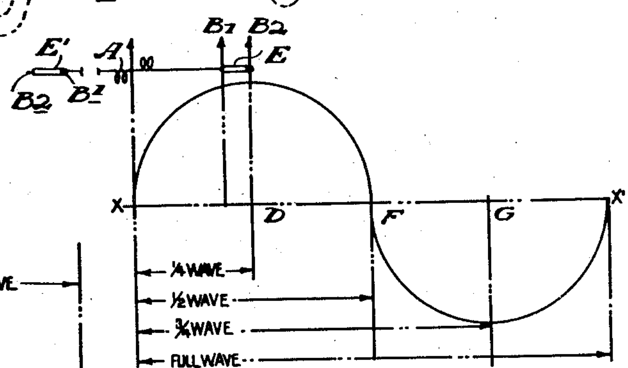


FIG. 15.

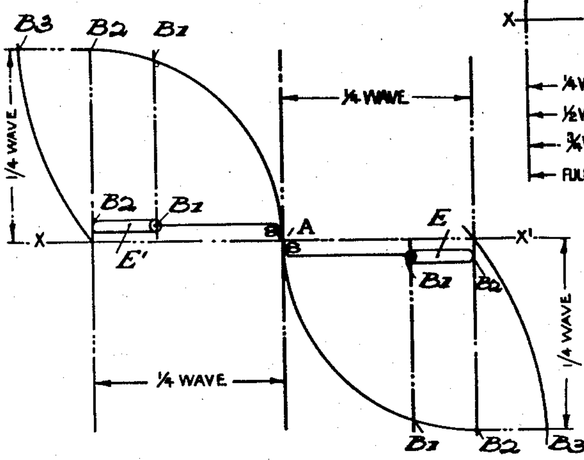
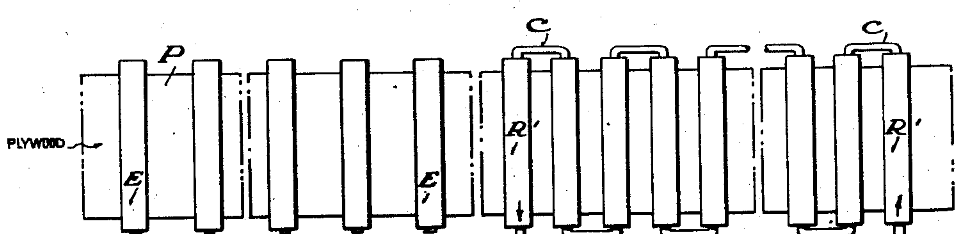
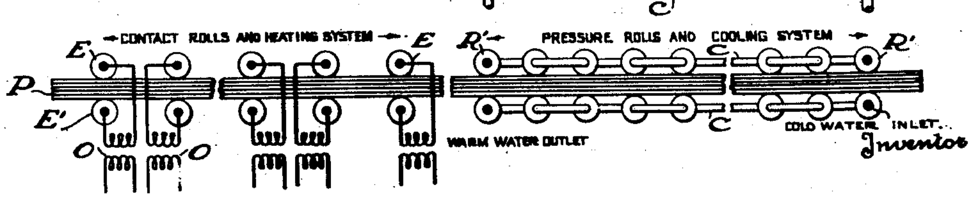


FIG. 14.

FIG. 16.





Inventor

FIG. 17.

George F. Russell.

By Cameron, Kerkam + Sutton.

Attorneys

Patented Dec. 23, 1947

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UNITED STATES PATENT OFFICE

2,433,067

METHOD OF AND APPARATUS FOR HIGH-FREQUENCY DIELECTRIC HEATING

George F. Russell, Tacoma, Wash.

Application June 26, 1942, Serial No. 448,633

3 Claims. (Cl. 219—47)

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This application is a continuation in part of my application, Serial No. 367,147, filed November 25, 1940 (now abandoned), for a method of forming plywood.

The process is preferably of the continuous type in which sheaves of glue-spread veneers are passed between series of pressure rollers, heat being generated instantaneously in the glue lines to permit the desired uniting of the various layers.

Normally, plywood is formed by the "batch" method, that is, a number of glued veneer sheaves are placed in powerful hydraulic presses and heat is applied by means of plattens which are in most instances heated by live steam. Bonding agents are utilized whose bonding temperatures range from about 100° F. to 390° F., a temperature just below the flash point of the wood being bonded. The heat from the plattens passes through the wood veneers and acts on the bonding agent at the glue lines. The heat is naturally less intense in the interior of the sheaf, that is, on the glue lines of the interior plies of a multiple ply sheaf, than in the outside plies and a satisfactory bonding is not attained until the heat from the plattens has thoroughly penetrated the sheaf and raised the temperatures of the inner glue lines substantially to that of the outer glue lines.

Difficulty has been experienced in the past due to the necessity for raising the temperature of the veneer close to its flash point to provide quick penetration of sufficient heat at the interior glue lines for satisfactory bonding; moreover, due to the wide temperature variations between the outer and inner plies, great difficulty has been experienced due to the tendency of the veneers to buckle, split and check.

It has been suggested to form plywood sheets in a continuous process by passing glued veneers through a series of pressure rollers while applying heat by means of steam jackets and also by means of electrical resistance coils in the rollers themselves. So far as is known none of these continuous processes utilizing heated rollers have gone into commercial use due to the numerous difficulties attendant upon their operation, the high loss of heat due to radiation from the rollers being one of the major difficulties.

The present invention contemplates the formation of plywood by a continuous process, as opposed to the old batch process, in which the plywood sheaf is slowly passed between a series of adjustable pressure rollers. The novelty of the process lies in the manner of producing bonding temperatures at the glue lines between the veneers. The process contemplates the utilization of high frequency radio waves oscillating between suitable electrodes at opposite sides of the veneer sheaf to raise the temperature of the bonding agent sufficiently to permit of a suitable bond being formed between the sheets. It has been found through experimentation that this method of heating the glue lines obviates many of the difficulties attendant upon bonding methods heretofore in use. The old gradual heat penetration which existed in the hot platten methods has been eliminated and it is no longer necessary to pass extremely high temperatures through the wood veneers. The same desirable effect is created at the inner glue lines as is created at the outer glue lines and thus the long standing problem of unbalanced heat transfer is eliminated. The high frequency waves oscillating between the electrodes penetrate and result in action on all glue lines in almost identical fashion, except where the sheaf is very thick in which case the center glue lines become the hottest.

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In bonding veneer layers by the use of radio frequency waves, the waves pass through the veneer layers and have their effect on the glue lines between the layers. The resistance of the glue to the passage of the waves through the sheaf of veneer and glue causes a rapid increase in the temperature of the glue at the glue lines. The waves oscillate at a rate per second equal to the frequency at which the output circuit of the oscillator is tuned between electrodes representing two or more elements of the output circuit. These electrodes are placed in proximity to each other so that the passage of the radio waves alternating between them will be as concentrated as possible. The veneer sheaves pass between electrodes of the output circuit of the oscillator or oscillators and the glue is acted upon as a result of the waves passing between the electrodes.

The electrodes may be plates, bars, rollers, or metal strips. It has been found that upper and lower pressure rollers bearing directly on the veneer will act as electrodes when they are so isolated as to allow the output circuit to be matched with the oscillator frequency or vice versa. If the output circuit of an oscillator is tuned with two or more electrodes as output load elements of the circuit, standing waves are present in fixed shape or in fixed relation to the output circuit, based on the tuning and frequency thereof. For example, if an oscillator's output circuit load consists of two bar or roller electrodes, certain points on the electrodes will be surrounded by a greater field intensity than other points. This is evidenced by the existence of or lack of current at such points. When two electrodes are placed close together lengthwise and are each fed from the same end, the opposite or free ends possess a greater current field than the ends from which they are fed by the pickup system of the circuit.

The invention may be used for drying green veneers and similar materials as well as for creating heat in and bonding glue in plywood. In drying veneers the physical problem involved is not complicated. It is first necessary only to raise the wood and its water content to a temperature sufficient to cause total or partial evaporation of the water content.

Natural veneer, as it comes from the green log, varies in moisture content from 25 to 40%. The present method of drying is to subject the veneers to steam heat at temperatures of from 320 to 370° F. for from 5 to 11 minutes. The green veneer is usually carried between rollers the length of long dry kilns. Heat penetrates wood from the outside to the inside. The time cycle involved depends upon the amount of dehumidification desired.

Heat caused by penetration of high frequency radio waves is distributed through the wood with the greatest heat being created at the center of the material. This type of heating from the center out tends to drive the moisture out toward the surfaces where it may evaporate into the air. The reverse is true in the case of steam heating or other types of external heating. Heat applied externally to wood tends to overheat and cook the outer surfaces, injuring the fibres, in order to force enough heat to the center to produce drying at that point.

It is possible and feasible to eliminate the moisture from wood or other material exclusively by the use of internal heat induced by radio waves. It is, however, less expensive to start the drying with radio waves, i. e., bringing the mass up to a given temperature and then evaporating the moisture content by means of the cheaper steam heat.

The present method has been found to be particularly efficaceous in the drying of thick stock, which normally takes hours or even days to dry by the usual steam method.

In plywood manufacture many types of glues are used. Those employed in water-resistant plywoods differ from those used in non-waterproof plywoods. The glues used in the waterproof type differ from those used in the water-resistant type.

The exterior grade of plywoods, i. e., those whose glue lines are waterproof, are manufactured by the hot plate method, the bond being set with temperatures on the glue lines of above 212° F. This method of manufacture requires running the steam in the plattens to high temperatures, above 212° F. and frequently as high as 370° F., in order that the glue lines when set will withstand the boiling water tests without delamination.

The water-resistant grade of plywoods, i. e., those whose glue lines will resist water, but which are not waterproof, are usually made on hot plate presses with platten temperatures of from 180 to 240° F. The temperature penetrating to the center glue lines rarely exceeds 160–180° F. and will vary widely below 160° F., depending on the type of glue, the time cycle of heating, thickness and number of plies and other factors.

The non-waterproof and non-water-resistant grades, i. e., cold pressed, are formed without application of artificial heat. It requires from 2–8 hours to set a batch of cold pressed plywood at normal room temperatures.

In applying heat to the glue lines we are concerned mainly with the waterproof and water-resistant grades of plywood. This type of manufacture involves the setting of those types of bonds wherein heat on the glue lines is necessary to create solidification of the thermo-setting types of glues and the liquefaction of the thermo-plastic types. These two types of bonding materials will be further explained later in this specification.

It is therefore an object of this invention to evolve a continuous process for the formation of plywood from wood or other veneers in which a relatively uniform heating effect is produced on all of the glue lines between the veneers.

Another object of the invention is the provision of means whereby the oscillation of high frequency radio waves may be utilized to afford a relatively uniform heating effect at all glue lines throughout the veneer sheaf.

A further object of the invention is to reduce the temperatures and pressures previously necessary to provide a satisfactory bond between veneers and thereby to reduce the cost and waste attendant on prior methods of forming plywood.

Another object is to provide an improved method and apparatus for drying green veneers and similar materials.

Other and further objects of the invention will become apparent as this specification proceeds.

Referring to the drawings,

Fig. 1 is an elevation of one embodiment of a machine designed for use in the present method, showing pairs of driven pressure rollers, alternately connected at opposite ends in the output circuits of a series of oscillators and acting as electrodes;

Figs. 1*a* and 1*b* illustrate one method of mounting and insulating the driven pressure rollers or electrodes to isolate the electrodes from adjacent materials;

Fig. 2 shows one method of attaching electrodes E in the output circuit of the oscillator;

Fig. 3 is an alternative hook-up in which electrodes E are connected in the output circuit at their centers;

Fig. 4 shows an embodiment in which electrodes E are connected at opposite ends in the output circuit;

Fig. 5 is a section view showing in detail the electrical fields surrounding electrodes of the roller type;

Fig. 6 is an elevation of an embodiment of the invention in which sets of electrodes E are positioned adjacent to rollers R and separate therefrom;

Fig. 7 is a side elevation of the apparatus covered in Fig. 6, showing the field set up by electrodes E;

Fig. 8 is an elevation of another embodiment of the invention similar to that illustrated in Fig. 6 and in which the electrodes E comprise thin strips of metal whose extremity contacts the plywood sheaf;

Fig. 9 is a side elevation of the device illustrated in Fig. 8, showing the electrical fields surrounding this type of electrode;

Fig. 10 is a side elevation of a set of flexible electrodes as per Fig. 8;

Fig. 11 is a side elevation of a set of stiff metal electrodes as per Fig. 8;

Figs. 12*a* to 12*f*, inclusive, show various types of feeds between the output circuit of the oscillator and the electrodes;

Fig. 13 is a side section showing the various types of fields set up about the electrodes of Figs. 1, 6, 8, 10 and 11.

Fig. 14 is a pictograph showing a full standing voltage wave in its entirety, with nodes at X, F and X'.

Fig. 15 is a further pictograph illustrating the quarter wave heating effect; the full standing voltage wave on the electrodes broken down into its four component quarter waves.

Fig. 16 is a plan view of an apparatus for use with thermo-plastic bonding materials in which the plywood sheaf is first passed through heating electrode rollers and then through a series of pressure and cooling rollers which set the bond; and

Fig. 17 is a side elevation of the apparatus shown in Fig. 16.

In the drawings, Figs. 1–5, E indicates suitable driven pressure rollers. These rollers may be constructed of any suitable material, preferably of metal, and are preferably cylindrical in shape. They are so mounted in a suitable frame 1 as to allow for vertical adjustment with respect to lower rollers E'. The pairs of rollers may be spaced at any desired interval. Any suitable means for forcing rollers E toward rollers E', such as mechanical tension, hydraulic pressure, etc., may be utilized.

In Fig. 1*a*, for example, rollers E are shown suitably mounted on sliding frame 2 as by standoff insulators 3. Frame 1 is suitably longitudinally slotted to allow vertical movement of sliding frame 2. Sliding frame 2 is adjustable in frame 1 as by means of wing nuts 4. Rollers E are shown suitably mounted on standoff insulators. By varying the distance between the upper and lower rollers the pressure exerted by these rollers may be varied as desired.

In Fig. 1 a plywood sheaf P is shown suitably disposd between the sets of upper and lower rollers. As illustrated the plywood sheaf consists of six veneer layers with five glue lines therebetween. Suitable caul or backing sheets may be applied, if desired, on either side of the sheaf prior to insertion between the rollers to distribute the pressure more evenly. Oscillator coils O are illustrated. Rollers E and E' are shown connected as electrodes in the output circuits of oscillators O in such fashion that oscillating high frequency waves generated in oscillator coils O will alternate between rollers E and E' so as to pass through that portion of the plywood sheaf lying between and adjacent to them. The pairs of pressure rollers may be driven by any suitable means. As illustrated in Fig. 1*a*, roller shafts 5 carry gears 6 which are driven from drive shaft 7 and worm gears 8. Worm gears 8 are separated electrically from each set of the rollers by insulated couplings. They may be rotated at any desired speed to pass the veneer sheaf through the press at whatever speed may be required to produce complete bonding thereof.

Fig. 2 illustrates schematically a series-fed output circuit connected to rollers E and E' as electrodes. It will be noted that rollers E and E' are preferably in close proximity to each other and disposed parallell to one another. Fig. 5 illustrates schematically the field between the electrodes. The greatest field concentration between the electrodes occurs at points B2, the extremity opposite the center of pick-up coil A. The wave form standing on circuit A—B1—B2 on rollers E and E' is such that B2 is the point where exists the greatest electrostatic field intensity and therefore heat will be concentrated in the sheaf passing between the electrodes. At points B1 on the rollers there will be less heat due to lower field intensity between these points. At point A, the center point of the pick-up coil, there will be the least possibility of heat, as point A is the electrical center of the circuit, i. e., the current antinode or voltage node under no-load condition. These wave forms will be further explained in the portion of the specification relating to Figs. 14 and 15. The standing wave on the electrodes is evidenced by the varying amounts of voltage and current at different points in the circuit. The electrostatic field intensity between the electrodes is greatest at B2, the free end of the electrodes. It will therefore be seen that the greatest heating effect on the glue lines of a plywood sheaf will be exerted at and about the free end B2 of the electrodes. Thus, if each set of electrodes was fed from the same side there would exist at the opposite side a much more intense electrostatic field than at the feeding side. This would cause an intense heating of the glue lines at one side of the sheaf and a lower heating of the glue lines at the other side of the sheaf and would result in an uneven lateral bonding of the plywood. To avoid such a result it is proposed that the sets of electrode rollers be fed alternately from opposite sides. This hookup is illustrated in Fig. 1. As illustrated, the first set of electrode rollers E and E' are fed from their right-hand extremities by oscillator coils O, creating an electrostatic field of greatest intensity about their left extremities and thus about the left portion of the plywood sheaf P. The next set of electrode rollers are fed from oscillator O' from their left extremities, creating the greatest electrostatic field intensity about their right extremities and thus about the right portion of plywood sheaf P. As the roller electrodes rotate slowly, passing the plywood sheaf in the direction indicated by the arrow, it will be seen that first the left-hand side of the sheaf is subjected to an electrostatic field of great intensity and that subsequently the right-hand side of the sheaf is subjected to such a field. This alternate subjection of the opposite sides of the sheaf to intense electrostatic fields causes uniform activity on the glue lines on each side of the sheaf and tends to produce a perfectly balanced bond therein.

In Fig. 3 there is illustrated an alternative hookup in which rollers E and E' are fed from their central points B1, instead of from their extremities. The pick-up coil of oscillator O is illustrated connected to the electrodes at central points B1. The greatest electrostatic field intensity will therefore exist about terminal points B2 at the extremities of electrodes E and E'.

In Fig. 4 another hookup is illustrated. This hookup is another method of equalizing field intensity on the electrodes. As illustrated, the pick-up coil of oscillator O is connected to opposite ends of electrodes E and E'. Thus, as greatest field intensity exists about points B2 on each electrode and least intensity about points B1 the field intensity about the electrodes will be equalized. The hookup shown in Fig. 2 is more satisfactory than that of Figs. 3 and 4 since by its use it is possible mechanically to equalize differences in potential in the field on the rollers by adding rollers fed in the opposite direction. This is not possible with the hookups of Figs. 3

and 4. Both Figs. 3 and 4, however, have their own distinct advantages and are to be preferred as compared to the Fig. 2 method for many uses other than that illustrated in Fig. 1.

Fig. 5 shows in detail the electrostatic field between electrodes E and E', and illustrates that field intensity is greatest directly between the electrodes.

Fig. 6 shows another embodiment of the invention in which electrodes E are placed adjacent driven pressure rollers R and separate therefrom in pairs above and below the sheaf. Electrodes E are preferably cylindrical in shape and are preferably formed of metal or of any other suitable conducting material. They are preferably of much smaller diameter than pressure rollers R. The reduced diameter and the lessening electrical capacity of these smaller electrodes make it possible to use lower wave lengths and therefore higher frequencies on the operating oscillators, resulting in greatly increased heating effect.

Electrodes E may be in the form of small rollers; they may be stationary tubes or bars or in any other suitable form. They preferably bear directly on the material being passed between them to provide the most effective application of the high frequency field existing between them, but need not touch the material if such a condition is desirable, due to extremely wet material passing between them which might be apt to short out the field.

It will be noted that pairs of electrodes E are fed alternately from opposite ends to balance the heating effect on the material P, the greatest field intensity being about points B2 at the extremity of the electrodes E.

Fig. 7 is a side elevation of the apparatus shown in Fig. 6, showing the nature of the fields set up about pairs of electrodes E. It will be noted that the greatest field intensity occurs directly between the electrodes, the intensity decreasing away from the electrodes.

Fig. 8 is a plan view of another embodiment of the invention, similar to that shown in Fig. 6, but utilizing a different type of electrode. In this embodiment, as in the embodiment shown in Fig. 6, the smaller electrical capacity of pairs of electrodes E allows the use of shorter wave lengths and therefore higher frequencies of the operating oscillators feeding the electrodes. Electrodes E, in this embodiment, preferably consist of thin strips of stiff or flexible metal suspended in the output circuits of the oscillators in such position that their extremities K bear directly on material P passing between electrodes E. Portion K of this type of electrode is its contact foot. It will be noted, from Figs. 10 and 11, that contact feet K of electrodes E are farther apart when material is passing between them than when no material is present. This arrangement is designed to insure a firm contact at all times between the electrodes E and the material being heated, resulting in an extremely even and efficient heating effect.

As shown in Figs. 10 and 11, curved spring metal electrodes may be used, which are fixed at points H or, as in Fig. 11, stiff strips of metal may be used, which are pivotally mounted at points H' to allow passage of material P.

It will be noted that in this embodiment also, the sets of electrodes E are fed alternately from opposite sides from oscillator coils O, to equalize the heating effect in the plywood sheaf. Here again, the area of greatest field intensity is about points B2, at the extremities of electrodes E.

Fig. 9 is a side elevation of the apparatus shown in Fig. 8, showing the electrical fields surrounding electrodes E. It will be noted that the point of maximum field intensity lies directly between contact feet K of the electrodes E.

Figs. 10 and 11 illustrate two types of strip electrodes. In Fig. 10 the electrodes E comprise flexible metal strips fixedly mounted at points H in such fashion as to be forced to position K' by the passage of the sheaf between them. In Fig. 11 electrodes E comprise stiff metal strips which are not curved and which are mounted to oscillate about points H' to enable the passage of the sheaf therebetween. It will be noted that both types of strip electrodes illustrated maintain a constant contact with the surfaces of the sheaf at all times, but may be fixed so as not to make direct contact under circumstances, one of which was described above.

Figs. 12a to 12f, inclusive, illustrate some of the various types of feeds which may be utilized between the output circuits of the oscillators and the electrodes E.

The particular feed utilized depends upon the nature of the material being processed, the type of processing done, the type of field desired and the type of radio frequency generator used.

Fig. 12a shows a straight feed to the electrodes without any variable capacity either in the output tank or the pick-up circuit, connecting electrodes E.

Fig. 12b shows variable capacity in the pick-up circuit and none in the output tank circuit.

Fig. 12c shows a variable capacity in the output tank circuit and none in the pick-up circuit.

Fig. 12d shows variable capacity in both circuits.

Fig. 12e shows grounding one electrode and one side of the pick-up circuit, while the other side of the pick-up circuit has both variable capacity and the only line connection.

Fig. 12f illustrates variable capacity between two elements of the pick-up circuit.

Fig. 13 is a side view showing the types of fields set up between the various types of electrodes, i. e., roller, small bar, and metal strip. The figure illustrates that field intensity is greatest perpendicular to line X—X' between the center of electrodes E and least perpendicular to lines X—X' at the other points between the electrodes. The point of greatest heat will be at the current antinode, which lies halfway physically between the two electrodes, when the current curve lags voltage by 90 degrees, as described later. The outside surfaces are subject to atmospheric radiation of heat, while the interior is not subject to radiation. Other factors also contributing to the nature of the heating effect are the thickness of the material being processed, the density of this material, the distance of the electrodes apart, etc.

Fig. 14 is a pictograph showing a standing voltage wave in its entirety, with voltage nodes at X, F and X'. The current curve of this wave will lag. in a push-pull, self-excited oscillator of half wave rectifier type by 90 degrees behind this voltage curve. The points of zero voltage or potential (voltage nodes), therefore, will be the same on line X—X' as the points of maximum current, or current anti-nodes. The pictograph illustrates that a standing quarter wave eliminates superfluous current anti-nodes between X and D. Such points are wasteful of energy.

As was stated in the descriptions of Figs. 12a to f, inclusive, the method of feeding electrodes E, regardless of whether they are roller, bar or strip electrodes, as per Figs. 1, 6 or 7, has a substantial bearing on the type of wave standing on the electrodes. In the case of the roller electrodes it is desirable to feed as much energy as possible into the rollers to get the maximum effect on the material passing between them. The consequent elimination of current antinodes in the circuit is most highly desirable as superfluous current antinodes dissipate heat in the circuit. Any heat discharged in the electrical factors is wasted as far as the heating effect on the processed material is concerned.

On a full standing current wave, there will be two current antinodes therein. These are the points at which the current wave form is farthest away from the zero line X—X'. It is, therefore, most highly desirable in the present instance to establish a circuit which has a full standing wave on the entire output circuit instead of a quarter wave or half wave.

In Figs. 2, 6, and 8 it will be noted that the center point of the pick-up coil connected to each end of the electrodes, is marked A. A is shown in Fig. 14 as a line drawn perpendicular to base line X—X' and passing through the center of the pick-up circuit as shown above the wave form. The extremities of the electrode, B2, opposite the center of the pick-up coil, are shown as B2 in the pictograph, resting on the crest of the wave form at a point directly above D on base line X—X'. Point B1, on the electrodes is shown to be at the extremity of the electrode where it is fed from the pick-up coil. The total pick-up circuit, as described, will be split into two parts, namely from A to B2 on the upper electrode and from A to B2 on the lower electrode. It will be seen, therefore, from the pictograph, that since X—D on line X—X' is one quarter wave, the point of greatest voltage will be the crest of the voltage wave form shown in Fig. 14, directly above D, or the voltage antinode.

Fig. 15 is a further pictograph of the voltage wave form as shown in Fig. 14, but dealing with the wave from points X to D of Fig. 14, increasing its size, and superimposing on this section of the wave form both electrodes E in the output circuit of the oscillator, and completing the cycle of the full standing wave from B2 back to the zero line X as shown in Fig. 14 from D to F on line X—X'. It will be noted that point A is halfway between X—X' in Fig. 15 and is the voltage node and the current antinode of the half wave voltage form shown. Points B2 on the curve of the wave form are the current nodes and voltage antinodes of this half wave form. Center line X—X' is the same electrical depiction of line X—X' as shown in Fig. 14, halfway between the electrodes E. It will, therefore, be seen that there is a quarter standing wave on that portion of the electrical circuit containing the upper electrode and there is another quarter standing wave on that portion of the electrical circuit containing the opposite electrode.

The line X—B3 represents the distance between B2 on electrode E and the center line X—X' between the electrodes. A quarter wave X—B3 is bunched between B2 and X and returns the wave form to the zero point, X. There is, therefore, a quarter standing wave from A to the end of the electrode E and another quarter wave from that point to the center line, or a half wave from A to X.

Since the intensity and penetrating effect are greatest at the current antinode, or voltage node, where current lags voltage by 90 degrees, it will be seen that at B1 there will be less electrical effect on the material being processed than at B2 as B1 is closer to A than is B2 and the form of the wave is a pure sine curve.

Fig. 16 is a plan view of an apparatus designed specifically for use with the thermo-plastic types of bonding agents, as distinguished from the so-called thermo-setting bonding agents. It will be seen that the apparatus disclosed in Figs. 16 and 17 comprises a combination of pairs of heating roller electrodes E, and pressure rollers R', so arranged that the sheaf first passes through electrode rollers E, where the thermo-plastic bonding agent between the plies is raised to liquification temperature. The sheaf then passes through sets of pressure rollers R', where the bond is set by pressure and cooling. Electrode rollers E are preferably cylindrical in shape, of any suitable conducting material, and are of any desired size. They may be driven from any suitable source by worm gearing or other means and they are suitably insulated as by standoff insulators or other means from the frame of the machine. As illustrated, electrodes E are preferably arranged in pairs and are preferably alternately fed from opposite sides from oscillator coils O so as to equalize heating effect. Any desired number of electrode rollers E may be utilized, depending upon the thickness, density and nature of the plies being processed.

Pressure rollers R' are shown. They are preferably arranged in pairs at any desired interval, and are preferably cylindrical in shape and of any suitable material and size. They are preferably so mounted that the distance between rollers may be adjusted to regulate the pressure exerted. They may, for example, be mounted as in Fig. 1.

Pressure rollers R' may be driven from any suitable source, as by worm gears, etc. As illustrated, cooling pipes C are provided connecting the upper and lower pressure rollers. Cooling pipes C carry a suitable cooling medium, i. e., water, brine or other refrigerant and are so arranged as to cool pressure rollers R' internally. As illustrated, the cold refrigerant is introduced into pressure rollers R' at the end of the apparatus opposite to the heating exit. Thus the rollers nearest the heating electrodes will carry the warmest refrigerant and those at the end will carry the coldest. This arrangement tends to supply a gradual cooling to the thermoplastic bonding agent as it is subjected to pressure, resulting in a perfect bond. The cooling agent, as it leaves the warm end outlet, can be recooled in a suitable refrigerating plant and then recirculated.

The roller electrodes E and the pressure rollers R' may be driven at any desired speed, depending upon the nature of the ply sheaf, its thickness, and the bonding agent used. The speed is also regulated depending upon the moisture content of the veneers, the bonding point of the thermoplastic used, and other factors.

If desired, an endless belt may be provided over the rollers E and R', or cauls may be utilized above and below the sheaf.

The heating section of the apparatus illustrated in Figs. 16 and 17, namely that composed of electrodes E above and below the material passing there-between may be supplemented, in another application by a hydraulic flat bed press, the plattens of which are cooled either by water or brine or some other cooling media, and substituted in the process illustrated above for the pressing rollers R′ and the cooling coils C illustrated as the second part of the apparatus shown in Figs. 16 and 17, respectively. In this method of operation, the package being heated through the section comprising electrodes E would pass from the effect of the radio frequency fields and be pressed by a stationary hydraulic platten press, the heat being withdrawn from said package and the bond being set therein by the action of simultaneous pressing and cooling in the said hydraulic press. This method as differentiated from that illustrated graphically in Figs. 16 and 17 will prevent any possibility of warpage of the veneer, strain, checking, cracking or other such finishing difficulty.

Nothing in this specification should limit, therefore, the application of this method of using a thermo-plastic bonding agent to strictly the methods shown in Figs. 16 and 17. The method equally applies to the batch press method, when it is used in conjunction with the continuous heating section above described, namely the first section of Figs. 16 and 17.

So far as thermal setting resin bonds are concerned the hydraulic press may be used without a cooling agent when the cycle is so timed as to allow the bond to set when the package being treated has been run through the heating section composed of electrodes E and subsequently placed for pressing between hydraulic press plattens.

The apparatuses illustrated in Figs. 1, 6 and 8 are designed for bonding veneers with the thermo-setting types of bonding agents. The phenols, ureas, seed meal and other formaldehydes, blood albumen and Bakelite glues and others comprise the thermo-setting agents. Thermo-setting synthetic resins are the ones most commonly used as a base for plywood glues. They exhibit the characteristic of "setting" or becoming hard on a rise in temperature. A thermal setting resin having a critical setting temperature of 160° F. will set at about that temperature when treated for a given length of time. Once set they will not reliquify on the application of additional heat.

It is necessary, when bonding plywood with thermo-setting materials, to apply heat and pressure simultaneously. The heat is necessary to set the glue, the pressure is necessary to keep the fibres of alternate layers in intimate contact to make a satisfactory wood bond when the glue sets up.

The thermo-setting agents are difficult to control in a high frequency field as they create a very low resistance path between the electrodes when an excess is used, as the excess squeezes out in a blob from between the layers of veneer and contacts the electrodes. The blob carbonizes on contact and forms a flash or arc between the electrodes. This arc reflects back into the oscillator, varying the frequency and unbalancing the circuit.

In working with thermo-setting compounds the pressure must be applied at the right time. If the bonding agent solidifies without enough pressure, an open or porous bond results and the glue line and bond will be unsatisfactory. Critical setting temperature and speed of passage of the sheaf are of primary importance when working with these agents.

The thermo-plastics, on the other hand, exhibit the property of setting on cooling, and will reliquify on the application of sufficient heat after

setting. No thermo-plastics are being used commercially at present in plywood manufacture as no equipment is at present available which is adaptable to such use. I have found, however, that with a machine of the type shown in Fig. 21 the use of thermo-plastics as bonding agents is feasible. I have used one of the thermo-plastics with marked success on a machine of this type. The thermo-plastic used is a synthetic commercial product made with vinyl as a base. I have found that it is possible to create any type of plywood desired by varying the critical melting temperature of the thermo-plastic. For example, a thermo-plastic whose critical liquefying temperature is above 212° F. will withstand all water tests and is 100% waterproof both as to soaking and boiling. A thermo-plastic whose critical temperature is 160° F. will withstand soaking without delamination but will not withstand boiling temperature, namely, 212° F. This bond will be water-resistant at temperatures below its critical temperature.

The problem of arcing, as discussed in connection with thermo-setting bonding agents, i. e., the ureas, formaldehydes, etc., is non-existent when using some thermo-plastic bonding agents in an apparatus similar to that shown in Fig. 16.

The new process is preferably carried out as follows: A sheaf of either green or dry veneers is assembled with a suitable bonding agent between each veneer. It has been determined that either wet or substantially dry bonding agents may be utilized, as the heat created at the glue lines is sufficiently intense to raise either type to binding temperature. The head of the assembled sheaf is then inserted between the first pair of pressure roller electrodes and the rollers are set in motion. The pressure exerted by the rollers may be regulated gradually to increase from the entering end of the machine to the terminal end thereof, or a constant pressure may be exerted. Satisfactory results have been obtained with each type of adjustment. The temperatures generated at the glue lines may vary from about 140° F. to about 390° F. depending upon the thickness of the sheaf and the binding agent used. The pressure exerted by the rollers may vary from a few pounds per square inch to many hundreds of pounds per square inch depending upon the nature of the sheaf and the degree of bond therein desired, or whether the wood is natural or resin impregnated.

Greater activity in the glue lines is created by radio waves of a frequency of twenty million cycles per second than by radio waves of an order of two million cycles per second. Successful operations by radio frequency penetration have been conducted on frequencies of an order of fifty million cycles per second and as low as one million cycles per second. The field intensity between electrodes in the output circuit of an oscillator operating with an input power of 1,500 watts and tuned to resonance at a high frequency of the order of fifty million cycles per second is such as rapidly to raise the temperature of the glues currently used in hot plate methods to well beyond the bonding point. The point to which the temperature is raised may be regulated by varying the intensity of the field, the power of the radio frequency generator, tuning the circuit off of peak resonance, varying the speed of passage of the veneers through the area of radio frequency activity and by varying the factors contributing to the bonding temperature of the glue. The flash point of fir veneer is something over 390° F. and the increase in the heat of the glue line should be kept below this temperature so as not to injure the wood fibre.

With the present process it is possible to utilize green, undried veneers and a substantially dry binding agent and procure excellent results. Due to the extremely high temperatures generated in the glue lines and in the wood by the oscillations of the high frequency waves it is possible to create a satisfactory bond while using pressures far below that of 150 pounds per square inch normally required in the manufacture of plywood.

Satisfactory results can be obtained by numerous alternative applications of this method. For example, the glue-spread veneers may be passed between slowly driven roller electrodes until the glue line temperature is raised to the binding point. The plies may then be placed in a hydraulic press and subjected to pressure until the bond is complete. As an alternative method of pressing the sheaf it may be passed through a series of pressure rollers which complete the bond. Another method is to place the glue-spread veneers between flat plate electrodes which are then pressed together and move on a continuous track until the glue lines have been heated to the binding point and the bond completed.

In any of these methods the frequency of the oscillations between the electrodes may be varied so that the temperatures at the glue lines will build up rapidly or slowly. The bond may be set at peak temperature or on a declining temperature, depending upon the veneer used, the glue, and the frequency of the wave oscillations between the electrodes.

The advantages of this new method of heating and bonding plywood are numerous. For the first time, a simultaneous effect on all of the glue lines, both interior and exterior is produced. No difficulty has been experienced with buckling or warping of the veneers and waste is reduced to a minimum. It is possible to produce uniform stock continually and the savings in labor and processing are great. Lastly, due to the action of the high frequency waves at the glue lines, and due to the high permeation of the binding agents it is possible to create high grade plywood with a small fraction of the glue formerly used.

The invention is susceptible of many embodiments and adaptations. Nothing in this specification is intended to limit its scope. Attention is directed to the appended claims for this purpose.

What is claimed is:

1. The method of heating dielectric materials

which comprises passing such material through a heating zone and subjecting it during its passage therethrough to a plurality of successive high frequency fields of force established between successive pairs of electrodes extending transversely across the path of the material, and feeding the electrodes of each pair of electrodes from the same end and successive pairs of electrodes from opposite ends to more evenly balance the heating effect on said material throughout said zone.

2. An apparatus for heating dielectric materials comprising successive pairs of electrodes between which the material to be heated passes and providing a heating zone comprising the successive fields of force between said electrodes, and high frequency oscillator means for feeding said electrodes, the electrodes of each pair extending transversely across the path of said material and being fed from the same end and successive pairs of electrodes being fed from opposite ends for more evenly balancing the total heat distribution in the material throughout said zone.

3. An apparatus as claimed in claim 2 wherein said oscillator means comprises a plurality of high frequency oscillators, each pair of electrodes being connected to the output of one of said oscillators to establish a high frequency field of force through the material.

GEORGE F. RUSSELL.

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