200KW HIGH FREQUENCY PRESS FOR DIELECTRIC HEATING

J. Tomljenovic

Plustherm Point GmbH
Seminarstrasse 102, 5430 Wettingen, Switzerland

ABSTRACT

After initially hesitating introduction of high frequency heating methods in the wood industry, today's industry can not imagine the modern timber wood production and other applications without high power, high frequency presses. The reason for that are reliable operation of RF-generators and presses which are today to customer's disposal, increased speed production, accuracy of dosing and uniform quality of the final product. On practical examples, it will be shown, which steps are important in the design, modelling and operation of such dielectric heating devices.

INTRODUCTION

By using high frequency technology, for instance for bonding purposes, the wood or the carrier material and the bonding agent are exposed to a capacitive or dielectric heating process in an alternating high frequency electrical field [1].

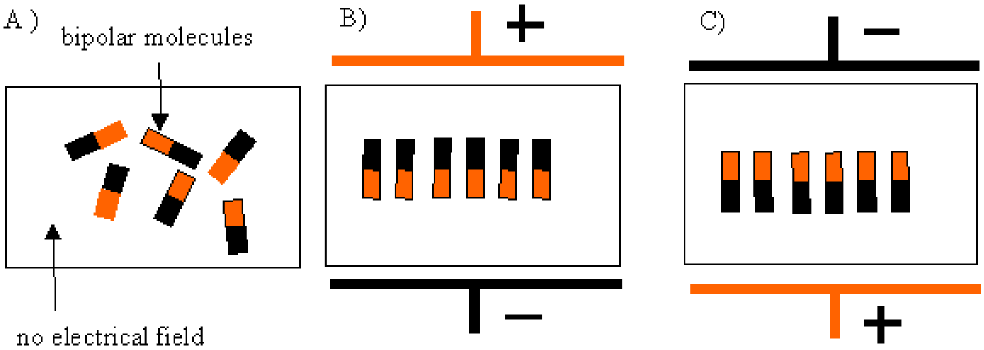

Figure 1.

Fig. 1A shows the disorientated bipolar molecules in dielectric material. If we put the material between electrodes under voltage, the molecules take the orientation as shown in Fig. 1B. When we change the polarity we get the molecule orientation as shown in Fig. 1C. With a stronger electrical field more and more dipoles will be oriented according to Fig. 1B/C. With an increase of the electrical field frequency, the dipoles are moving faster, thus increasing the friction. The simplified relationship between consumed high-frequency power (corresponding to thermal energy generated in the material) and voltage in the given volume is:

TELEPHONE: +41 56 426 80 81

FAX: +41 56 427 23 34

$$P = k * U^2 * f * \varepsilon * \tan\delta \qquad (1)$$

Where:
k = constant, f = frequency, ε = dielectric constant, U = high frequency voltage, $\tan\delta$ = loss factor

Because there are just a few free frequencies available for industrial applications (as specified by law), a change of heating power with change of working frequency is of theoretical interest only. The change of electrical field strength by a factor 2 will increase the thermal energy by a factor of 4.

$$E = \frac{\text{Voltage across the electrodes}}{\text{Distance between the electrodes}} \left[\frac{V}{cm}\right] \qquad (2)$$

Where:
E = electric field strength

The molecules change their direction and move several million times per second. The bonding juncture is heated up directly with higher intensity and faster than the surrounding wood when the high frequency alternating voltage is applied, because it represents considerably higher dielectric losses. Wood is a very heterogeneous material. The electrical properties do not only depend on its characteristics, but also on the grain direction, temperature, humidity, and on the frequency applied. With degrees of humidity as generally permitted for finished products of the wood industry (furniture, design elements), i.e. with a water content of about 8 - 12%, wood may still be regarded as a "dielectric". The formulas valid for high frequency heating of isolating material may thus also be applied for wood. In the following Table 1. the relative permittivity (ε_r) and dielectric losses ($\tan\delta$) for different materials are given.

Material	**Relative Permittivity**	**tan δ**
Vacuum	1	0
Air dry	1.006	> 0
Teflon	2	> 0.0001
PVC	3	0.016
Ceramic	10	0.0005 < …< 0.002
Water	80	1
Wood dry	4	0.05
Wood 60% water	20	0.4
Wood glue dry	3	0.02
wood glue wet	50	0.5

Table 1.

It may generally be assumed that the dielectric constant epsilon (ε) at a specific frequency will increase slightly with an increasing degree of humidity, while the loss factor tangent delta (tan δ) will remain approximately proportional to the content of water. Special advantage is taken from the fact, during bonding with high frequency, that bonding agents feature loss factors up to 40 times higher than wood. The bonding junction may thus be heated up with a minimum of energy. Bonding times of several hours (in case of cold bonding) may therefore be reduced to several minutes only. This phenomenon, much faster heating of the glue in the bonding junction, is also called "selective heating" and is most important advantage of dielectric heating method.

DESIGN, MODELING, OPERATION

Special frequency bands are assigned by law for the industrial application of high frequency in order to avoid functional disturbances (according to European Standard EN 55011): 13.56, 27.12, 40.68, 2450, 5800 and 24125 MHz, each with a small tolerance range. These frequencies are available for industrial, commercial and medical applications within Europe. The frequency of 13.56 MHz is most often used for the bonding of wood, because it heats up the wood thoroughly and provides an equal voltage distribution within the pressed goods. The high frequency stability is of paramount importance here. This stability may not be attained without special measures.

At all gluing processes the load of the generator changes, depending on wood humidity, glue consistence and the material quantity. It is impossible to keep the frequency constant, without the online regulation which is working all the time. Due to a special Plustherm method, we are able to keep the frequency constant (13.56MHz +/- 0.05%) independent from load changes. One special power regulating system keeps the power constant during the gluing cycle, all the time, independent if we look at the middle or at end of gluing process.

For practical industrial applications, a possible high HF power is required. For example: to glue the timber wood in the necessary quantities, generators from 100kW to 200kW output power are used. In this high power level, very careful design is required to assure the safe and long disturbance-free operation. For such a high power level, a long (typically 6.5m) and wide (up to 2m) press is needed. At such dimensions (lambda ¼ at 13.56MHz is 5.53m) the good voltage distribution along the press is very important [2].

a) b) c)

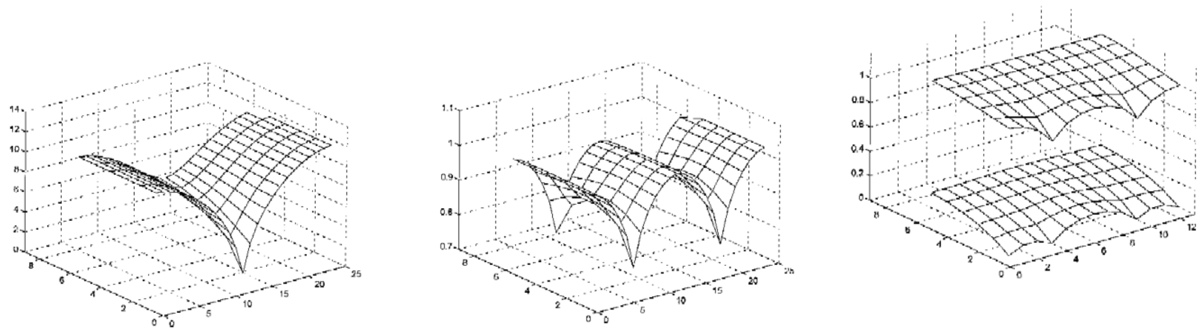

Figure 2. a) Bad load adjustment, b) average load adjustment, c) good load adjustment

In Figure 2. you can see the results of distribution optimization along the electrodes. This optimization is made with SPICE and MATHLAB. With special measures we can assure the uniform voltage distribution on the press electrodes up to 10m . The voltage distribution will be calculated three-dimensional, to assure optimal field distribution in the length and in the width. Additionally, one special finite element program is used to find the right solution in the critical zones of the press itself.

To achieve the optimal matching between the high frequency generator and the electrodes, the cold measurements with the network analyser for each wood dimension will be made

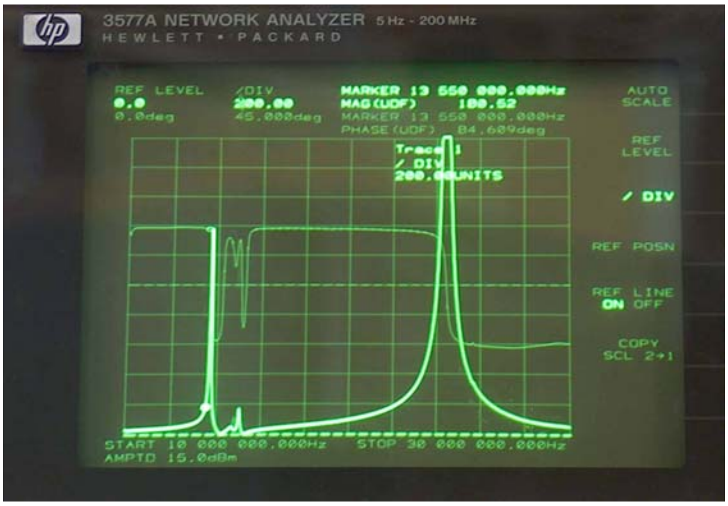

Figure 3. Cold measurements with the network analyser

Figure 3. shows the typical impedance response between 10 and 30 MHz. The first resonance is the impedance in the operating point at 13.56MHz, the second wide peak is parasitic resonance. It is important to avoid that higher harmonics correspond to this frequency.

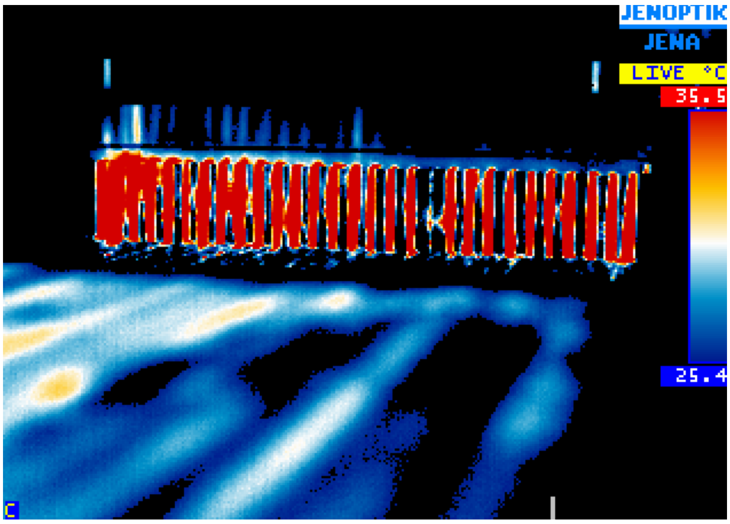

Figure 4. Picture taken with thermal infrared camera

Figure 4. shows the temperature distribution in the timber wood. On this picture we can clearly see the so called selective heating. Only the bonding junction is heated to high

temperature. The typical temperature in the joint is 80 °C , the wood between two joints will reach only 30-35°C. The heating time is for example for wood 80mm high, only 120 seconds.

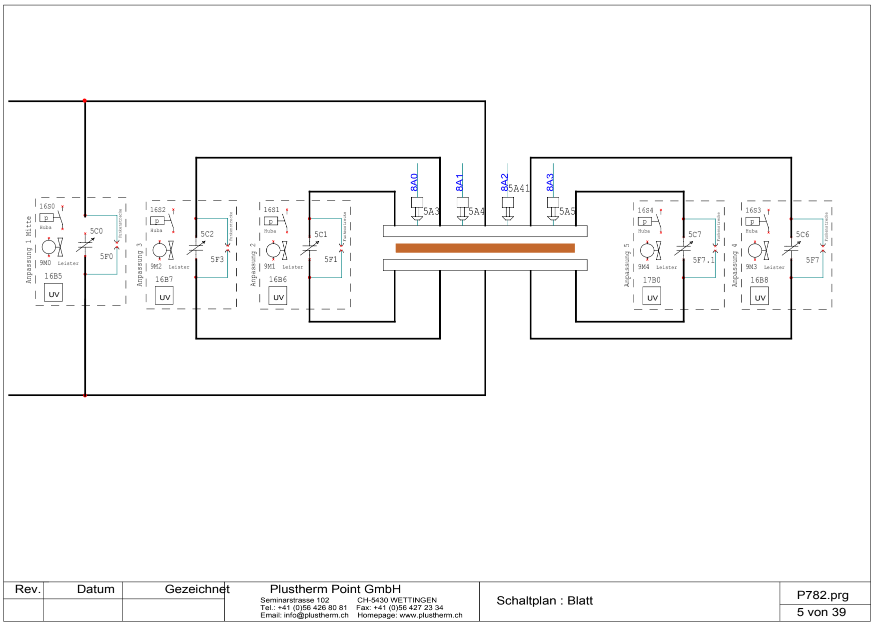

Figure 5. Electric diagram showing the press electrodes and matching components

Figure 5. shows all important components to achieve the good matching and optimal voltage distribution along the press [3]. This solution on the picture use variable vacuum capacitors for the matching. The same results can be also achieved with variable inductances and fix capacitors.

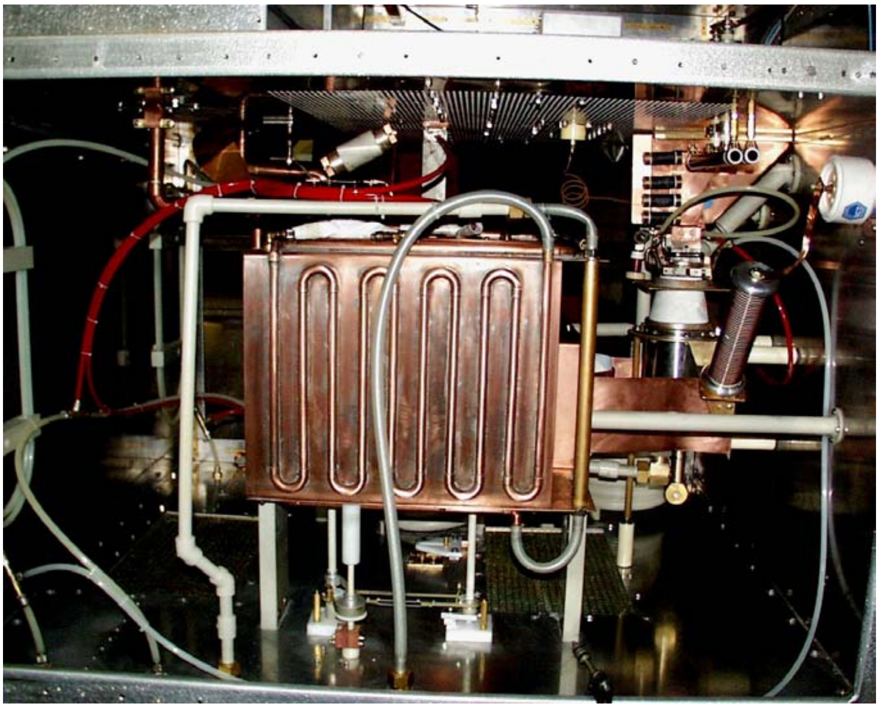

Figure 6. Look inside the 200kW 13.56 MHz Resonator

The resonator in the Figure is water cooled, to assure a long reliable operation. Inside the copper resonator are water cooled vacuum capacitors. The electronic tube is also water cooled and can make up to 280kW peak power.

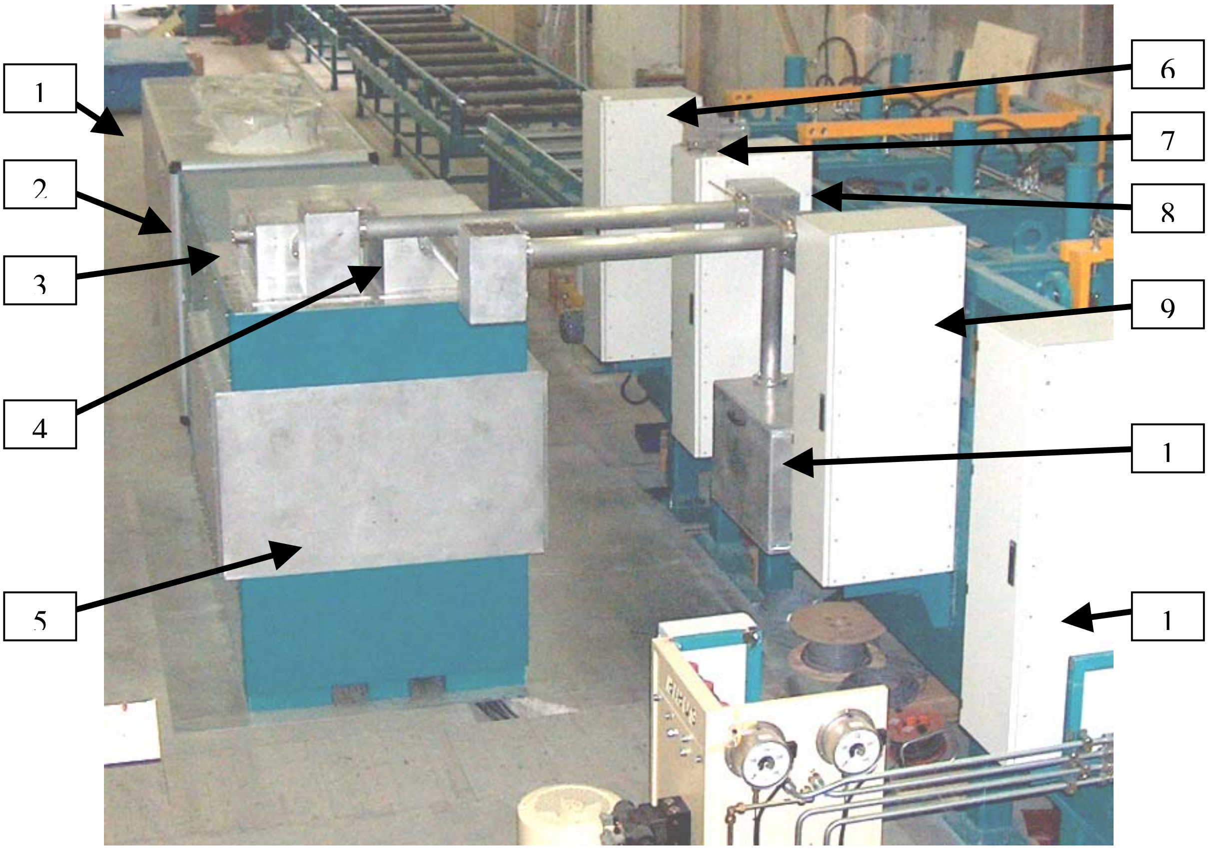

Figure 7.

Index:

1. Cooling unit
2. High DC-voltage part of DGX200
3. Filter box
4. Feeder-lines
5. Resonator DGX200
6. Matching box No.1
7. Matching box No.2
8. Drive-motor for matching boxes No. 1-4
9. Matching box No.3
10. Middle matching box
11. Matching box No.4

Figure 7. shows the complete 200kW high frequency press with the cooling unit, high frequency generator, all necessary matching units and the press itself.

On the end we have to mention also another heating application with dielectric heating. In the Table 2 is the brief summary:

Wood

	Advantages
Drying	3 times shorter process time as with hot air. No overheating (the heating energy is negligible when water is out)
Gluing	100 to 20 times shorter process time, no overheating. Selective heating
Restoration	Elimination of parasites without chemicals. No toxic process

Food

	Advantages
Defrosting	Shorter process time (factor of 50). Lower bacterial contamination possible with packed food
Baking and post-baking	Shorter process time. Separate control of surface and core heating rates
Pasteurization	Shorter process time possible with already packed food

Various

	Advantages
Textile dryers	Moisture removal in roving and bale with no overheating
Glass fiber drying	Moisture removal in roving and bale with no overheating
Elimination of parasites in corn	No toxic process
Paper drying	No overheating
Book drying	No overheating
Tobacco drying	No overheating
Paint drying	Short process time, no overheating

Table 2.

CONCLUSION

The most important advantages of high frequency dielectric heating can be summarized as following:

- Increased speed of production: The heat is not supplied from the outside, but is generated in the adhesive junction or in the wood without any heat conduction loss.
- Accuracy of dosing: The heat supplied may be controlled by means of microprocessors, independent of any fluctuations of the power supply or varying material characteristics. The heat may be regulated within predefined limits.
- Uniform quality: Due to the fact that the high frequency heat results in a local limitation of the heat, exact dosing, high processing speed and the lack of deformation will result, so that the products will be well-balanced and of superior quality.

To achieve these goals, a very careful design of such high frequency devices is necessary. All aspects of possible problems as frequency stability, uniform voltage distribution along the press, continuous matching during heating process because of changes in loss factor and dielectric constant, stable power regulation, good isolation and control over the high voltages must be taken in account.

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