200kW HIGH FREQUENCY PRESS FOR DIELECTRIC HEATING

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ABSTRACT

Upon introduction, the wood industry was hesitant to utilize high frequency heating methods. However, today`s modern timber industry could not function without high power, high frequency presses. Reason being the operational reliability, increased production speed, increased efficiency, and uniform quality of the final product.

With practical examples, it will be shown which steps are important in the design, modelling, and operation of such dielectric heating devices.

INTRODUCTION

The following is an example of utilizing dielectric heating to glue timber components together. This process is commonly used to create products such as LVL (laminated veneer lumber) and PSL (parallel strand lumber). Here, wood pieces are arranged in parallel and then bonded. This creates one large continuous wood plank that has physical properties far different from normal wood.

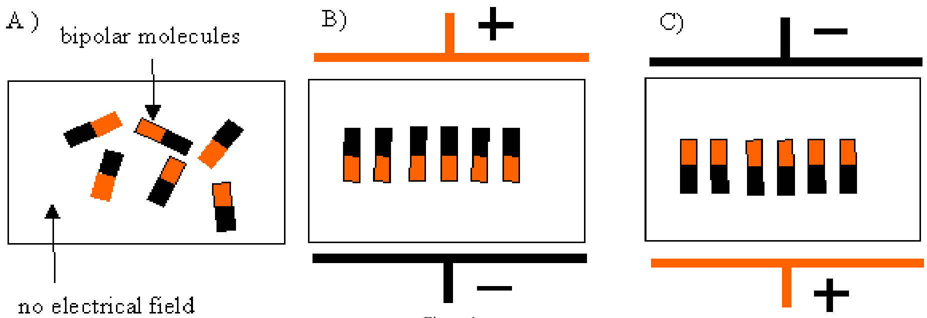


Figure 1

During this process both the wood and the glue are exposed to a high frequency electric field [fig. 1]. Figure 1A shows normal molecular configuration within the dielectric (e.g., wood or glue). Upon exposure to the electric field, the molecules within the dielectric organize themselves as seen in fig. 1B. When the polarity of the field is reversed, the molecules rotate by 180° [fig. 1C]. The number of molecules that are aligned is proportional to the electric field strength. With high frequency, the molecules move quickly back and forth between polarities creating friction within the dielectric, causing it to warm.

The simplified relationship between consumed high-frequency power (corresponding to thermal energy generated in the heated material) and voltage in the given volume is:

Equation 1

$$P = k \times U^2 \times f \times \varepsilon \times tan\delta$$

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

Because there are just a few 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.

Equation 2

$$E = (\text{ Voltage across electrodes / Distance between electrodes })(\ V / cm\ )$$

E = electric field strength

The molecules reverse their position several million times per second. The bonding juncture is heated with higher intensity than the surrounding wood because it represents considerably higher dielectric losses. Wood is a very heterogeneous material and its electrical properties depend on many different factors. Some being: grain direction, temperature, humidity, and the applied frequency. 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. The relative permittivity (ε_r) and dielectric losses ($tan\delta$) for different materials can be seen in Table 1.

Table 1

Material	ε_r	**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

It may generally be assumed that the dielectric constant, epsilon (ε), will increase slightly at a constant frequency and an increasing degree of humidity. However, the loss factor, tangent delta ($tan\ \delta$), will remain approximately proportional to water content [fig. 2].

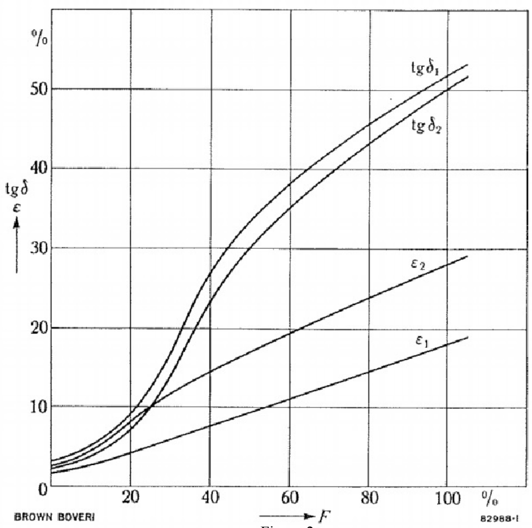


Figure 2

An advantage of utilizing this high frequency process is in the fact that the bonding agents feature loss factors of up to 40 times higher than wood. The bonding junction may thus be specifically targeted and heated. This resulting in greatly reduced energy loss. Bonding times of several hours (e.g., cold bonding) may therefore be reduced to several minutes. This phenomenon is also called "selective heating" and is the most prominent advantage of the dielectric heating method.

DESIGN, MODELING, and OPERATION

By law and in order to avoid functional disturbances, special frequency bands are assigned for the industrial application of high. Frequencies are as such: (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.

13.56 MHz is commonly used for the bonding of wood. This is because it heats the wood thoroughly and provides an equal distribution of voltage within the pressed goods. The high frequency stability is of paramount importance here, and may not be attained without special measures.

The load on the generator is never exactly the same. There are many inconsistent factors that attribute to this: e.g., wood humidity, glue consistence, and material quantity. With a varying load, it is impossible to keep the frequency constant without onboard regulation. However, due to a special method, we are able to keep the frequency at a constant 13.56MHz that varies by only +/- 0.05% independent from load changes. This special Plustherm regulating system keeps the power constant during the entire gluing cycle, start, middle, and end.

For practical industrial applications, high power is often required. In order to glue timber for a high output operation, generators ranging from 100-200kW are often used. In this high power level, very careful design is required to assure safe and highly reliable operation.

For such high power levels a large press is needed (typically 6.5m x 2m). At such dimensions ($\lambda/4$ at 13.56MHz is 5.53m) the good voltage distribution along the press is very important [fig. 3].

Figure 3

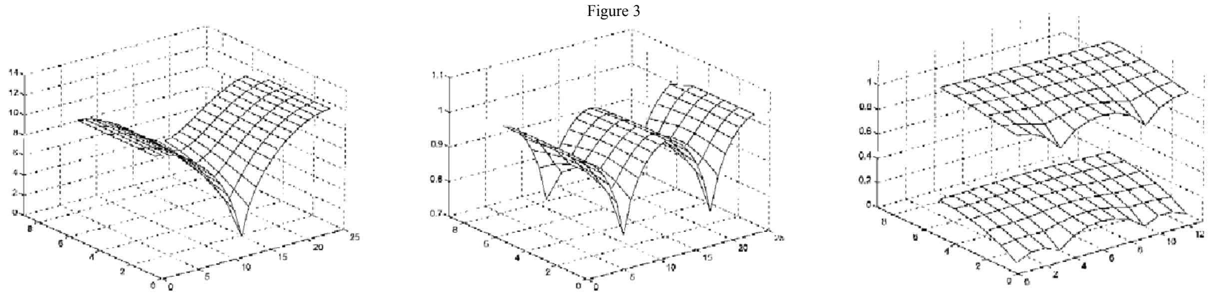


Fig. 3a: Bad load adjustment Fig. 3b: Average load adjustment Fig. 3c: Optimal load adjustment

In Figure 3 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-dimensionally to assure optimal field distribution. 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.

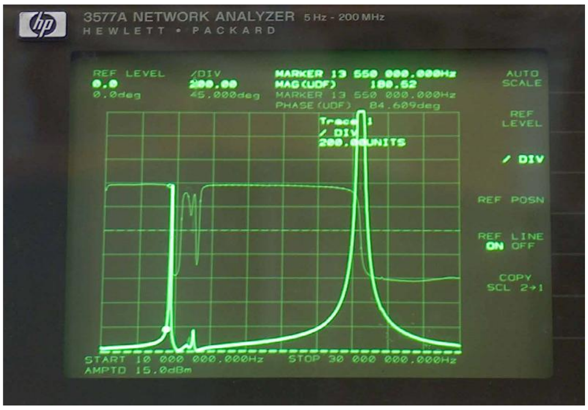


Figure 5: Impedance curves as seen with a network analyzer

Here is a typical impedance response as seen with a network analyzer [fig. 4] for between the frequencies of 10-30MHz. 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 the higher harmonics correspond to this frequency.

Figure 5-6 show the temperature distribution in the timber planks. On these pictures we can clearly see the selective heating, where only the bonding junction is heated to high temperature. The typical temperature joint is 80°C whereas the wood between will reach only 30-35°C. Estimated heating time for 80mm high wood slats is only 120 seconds.

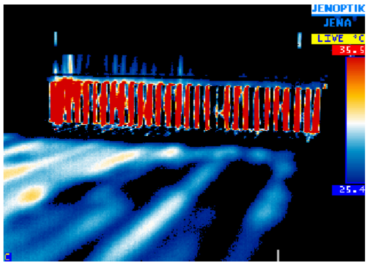


Figure 4: Photo of the heating process taken with a thermal camera. The red is the bonding material between the wood slats.

You can see all the important components to achieve good matching and optimal voltage distribution along the press [fig. 7]. This solution utilizes variable vacuum capacitors for the matching. The same results can also be achieved with variable inductances and fix capacitors.

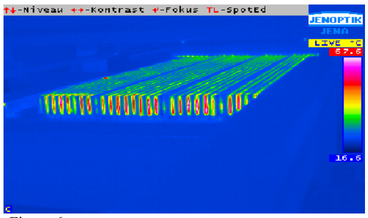


Figure 6

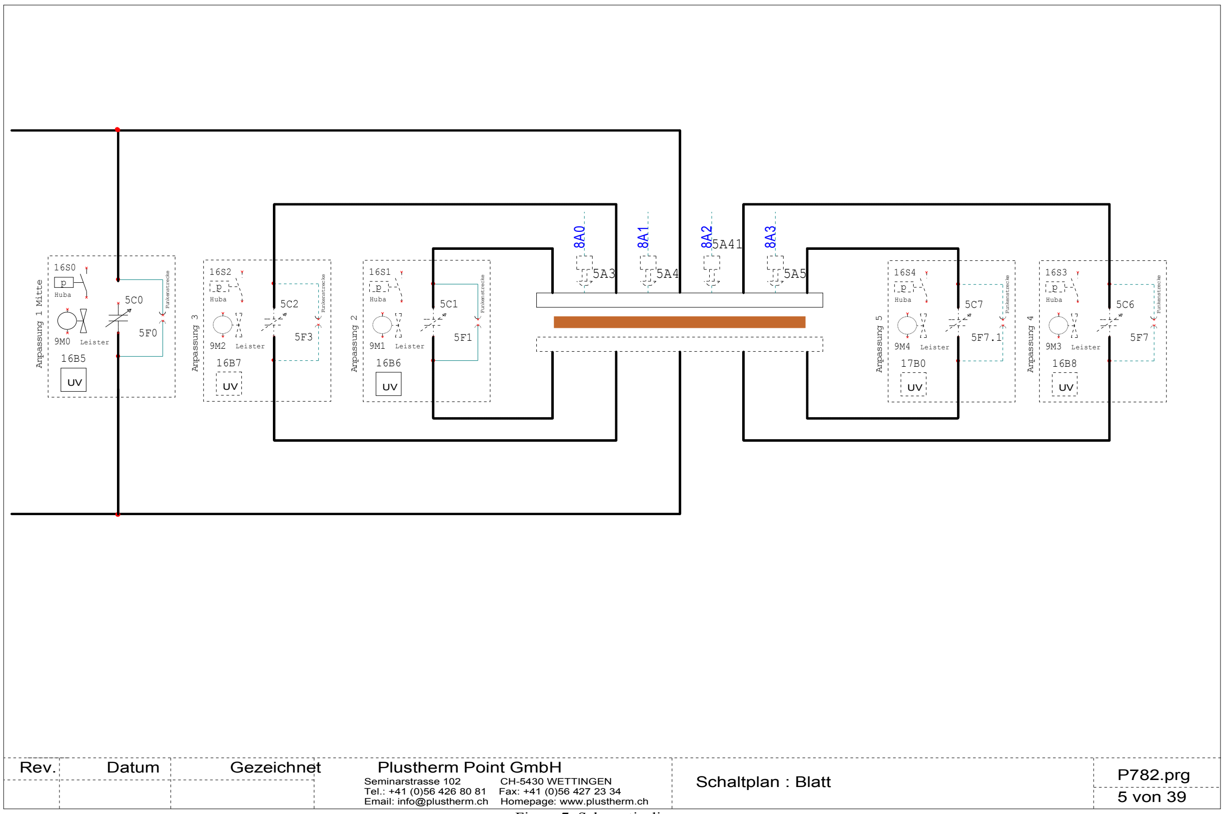


Figure 7: Schematic diagram

The resonator in Figure 8 is water cooled to ensure long and 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 9 shows the complete 200kW high frequency press with the cooling unit, high frequency generator, all necessary matching units and the press itself.

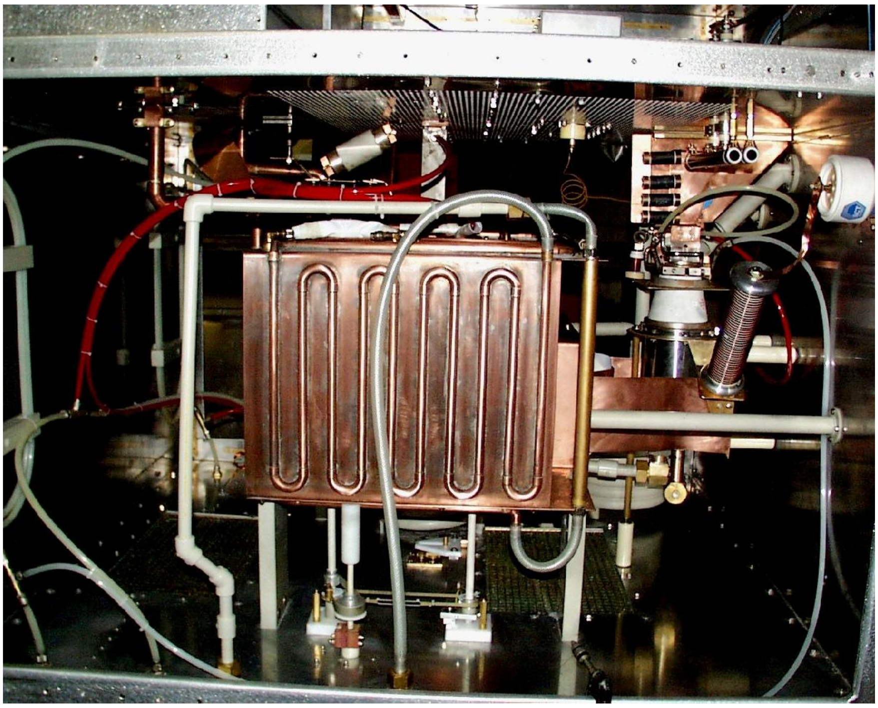
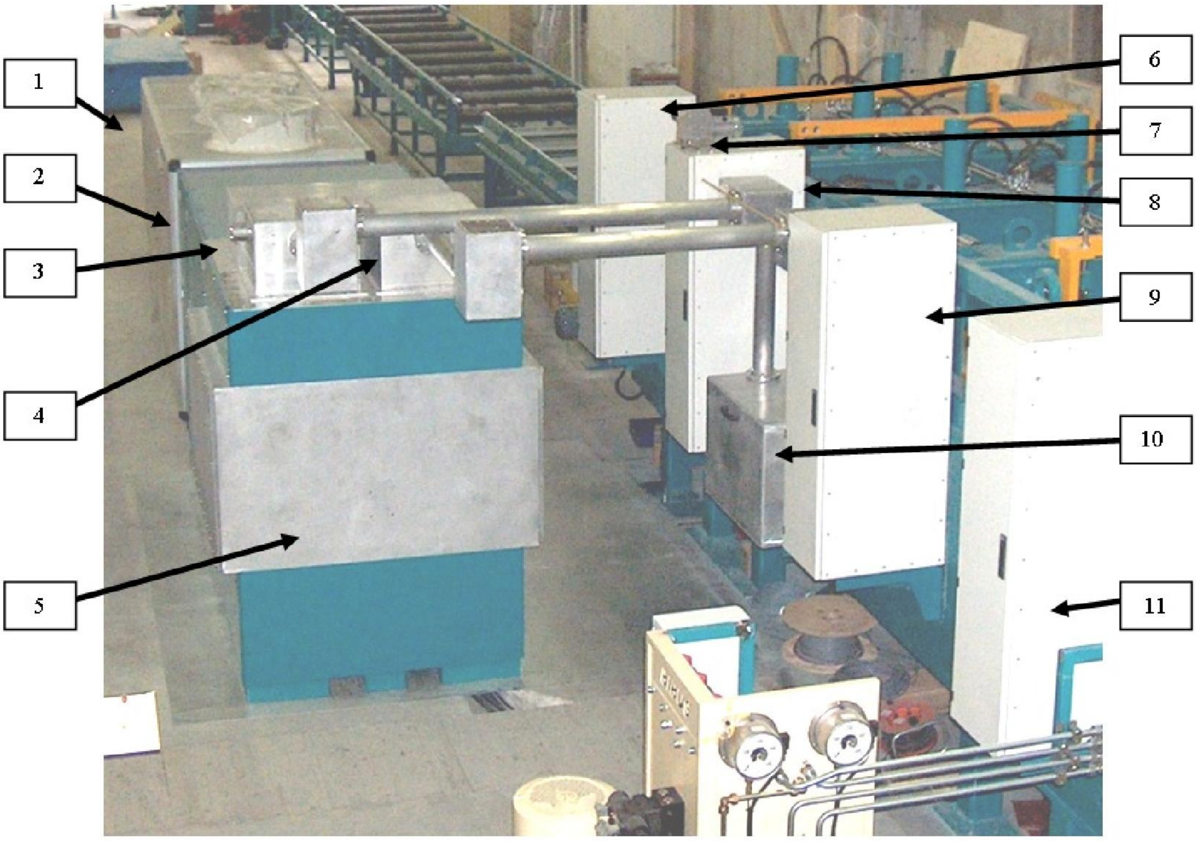


Figure 8: A look inside a 200kW 13.56 MHz resonator

Figure 9: DGX200



1) Cooling unit
2) High voltage unit
3) Filter box
4) Feeder lines
5) Resonator
6) Matching unit #1
7) Matching unit #2
8) Matching unit drive motor
9) Matching unit #3
10) Central matching unit
11) Matching unit #4

Figure 10: Two heating units working simultaneously. Courtesy of Mayr-Melnhof Systemholz Gaishorn GmbH

In a particularly unique system [fig. 10], two heaters are working simultaneously to create large plywood boards (16.5x3m). This process only takes a few minutes and the product can be processed immediately.

Dielectric heating has very many applications, some of which are listed below along with their advantages.

Material	Application	Advantages
Wood	Drying	3 times shorter process time as with hot air. No overheating (the heating energy is negligible without water).
	Gluing	20-100 times shorter processing time. Selective heating. No overheating.
	Restoration	Elimination of parasites. Non-toxic.
Food	Defrosting	Shorter processing time (factor of 50). Reduced possibility of contamination with packed food.
	Baking and post-baking	Shorter processing time. Separate control of surface and core heating rates.
	Pasteurization	Shorter process time with pre-packaged food.
Other	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	Non-toxic.
	Paper	No overheating.
	Book	No overheating.
	Tobacco	No overheating.
	Paint	Short processing time. No overheating.

CONCLUSION

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

- **Increased production speed**: 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 an electronic regulator, independent of any power fluctuations or varying material characteristics. The heat may be regulated within predefined limits.
- **Uniform quality**: This dielectric method results in a localization of the heat. Exact dosing, high processing speed, and the lack of deformation will result. The products will be more consistent and of superior quality.

To achieve these goals, it is necessary that these devices are designed and built with utmost diligence. All possible issues such as: frequency stability, uniform voltage distribution along the press, continuous matching during heating process (due to changes in loss factor and dielectric constant), stable power regulation, good isolation, and high voltage control measures must be taken in account.

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