Timber grading machine using ultrasonic and density measurements:
TRIOMATIC

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Summary

The latest European standards for timber grading (EN 338) include now up to ten resistance classes, based on the modulus of rupture MOR, the modulus of elasticity MOE and the density $\rho$ of wood.

This paper relates an industrial machine performing all these new characteristics – TRIOMATIC – based on the previous industrial equipment using ultrasonic – Sylvamatic – and on a new parameter: the density measurement.

If Sylvamatic succeeded in the first step of the Combigrade project managed by VTT – Finland, the upgraded version Triomatic has participated to the second phase of the project and has followed the settings calibration process for both Scandinavian and French species to get the official European Certification accordingly to the EN 14081.

The next step of calibration concerns the green beams thanks to the new moisture content meter developed by CBS-CBT.

1. Introduction

CBS-CBT Group [1] is specialized in timber engineering and non-destructive technology for wood quality assessment.

In 1985, the ultrasonic technology was transferred into a patented portative device, Sylvatest, thanks to a thesis work done at the Swiss Federal Institute of Technology, Lausanne [2].

In 1998, a newer portative version was developed – Sylvatest Duo – using not only the ultrasonic measurements, but also the acoustic phenomenon to increase the evaluated results reliability [3].

Today, in 2008, the very new version is launched: Sylvatest Trio, with the same technology as the previous version, but much faster for the measurements.

Concerning the industrial equipment, CBS-CBT was among the firsts to propose a reliable industrial technology with the Sylvamatic machine.

In parallel, the European standards EN338 [4] were developed until the proposal of new classes of resistance, and especially the recognition of high performance timber with the class C40 (table 1).

If the visual inspection can be used from the class C14 to C30 (assuming hazardous reliability), non-destructive technologies are now needed in order to answer to the new standards concerns.

Moreover, in August 2008, the timber industry will be asked to assume the traceability for each structural element, including the resistance class defined in the standards.
Industrial non-destructive grading is then a fundamental topic today in Europe. It is for this reason why VTT, in Finland, launched last year a comparison campaign between the different existing technologies [5].

If Sylvamatic has performed excellent results, a new machine has just been developed by CBS-CBT, adding the density measurement to the initial Sylvamatic parameters.

This paper relates the development and the European grading assessment process of this new industrial machine called TRIOMATIC.

### Table 1: Mechanical values for timber design, according to the European standards EN 388.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Symbol</th>
<th>C 14</th>
<th>C 16</th>
<th>C 18</th>
<th>C 22</th>
<th>C 24</th>
<th>C 27</th>
<th>C 30</th>
<th>C 35</th>
<th>C 40</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bending [N/mm²]</td>
<td>( f_{m,k} )</td>
<td>14</td>
<td>16</td>
<td>18</td>
<td>22</td>
<td>24</td>
<td>27</td>
<td>30</td>
<td>35</td>
<td>40</td>
</tr>
<tr>
<td>Tension ( \perp ) [N/mm²]</td>
<td>( f_{0,k} )</td>
<td>8</td>
<td>10</td>
<td>11</td>
<td>13</td>
<td>14</td>
<td>16</td>
<td>18</td>
<td>21</td>
<td>24</td>
</tr>
<tr>
<td>Tension ( \parallel ) [N/mm²]</td>
<td>( f_{90,k} )</td>
<td>0.3</td>
<td>0.3</td>
<td>0.3</td>
<td>0.3</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
</tr>
<tr>
<td>Compression [N/mm²]</td>
<td>( f_{c,k} )</td>
<td>16</td>
<td>17</td>
<td>18</td>
<td>20</td>
<td>21</td>
<td>22</td>
<td>23</td>
<td>25</td>
<td>26</td>
</tr>
<tr>
<td>Compression ( \perp ) [N/mm²]</td>
<td>( f_{c,90,k} )</td>
<td>4.3</td>
<td>4.6</td>
<td>4.8</td>
<td>5.1</td>
<td>5.3</td>
<td>5.6</td>
<td>5.7</td>
<td>6.0</td>
<td>6.3</td>
</tr>
<tr>
<td>Shear [N/mm²]</td>
<td>( f_{s,k} )</td>
<td>1.7</td>
<td>1.8</td>
<td>2.0</td>
<td>2.4</td>
<td>2.5</td>
<td>2.8</td>
<td>3.0</td>
<td>3.3</td>
<td>3.8</td>
</tr>
<tr>
<td>Elasticity modulus [kN/mm²]</td>
<td>( E_{0,\text{mean}} )</td>
<td>7</td>
<td>8</td>
<td>9</td>
<td>10</td>
<td>11</td>
<td>12</td>
<td>12</td>
<td>13</td>
<td>14</td>
</tr>
<tr>
<td>– parallel average</td>
<td>( E_{0,0.5} )</td>
<td>4.7</td>
<td>5.4</td>
<td>6.0</td>
<td>6.7</td>
<td>7.4</td>
<td>8.0</td>
<td>8.0</td>
<td>8.7</td>
<td>9.4</td>
</tr>
<tr>
<td>– parallel 5%</td>
<td>( E_{0,90,\text{mean}} )</td>
<td>0.23</td>
<td>0.27</td>
<td>0.30</td>
<td>0.33</td>
<td>0.37</td>
<td>0.40</td>
<td>0.40</td>
<td>0.43</td>
<td>0.47</td>
</tr>
<tr>
<td>Shear modulus average [kN/mm²]</td>
<td>( G_{\text{mean}} )</td>
<td>0.44</td>
<td>0.50</td>
<td>0.56</td>
<td>0.63</td>
<td>0.69</td>
<td>0.75</td>
<td>0.75</td>
<td>0.81</td>
<td>0.88</td>
</tr>
<tr>
<td>Density minima [kg/m³]</td>
<td>( \rho_k )</td>
<td>290</td>
<td>310</td>
<td>320</td>
<td>340</td>
<td>350</td>
<td>370</td>
<td>380</td>
<td>400</td>
<td>420</td>
</tr>
<tr>
<td>Density average [kg/m³]</td>
<td>( \rho_{\text{mean}} )</td>
<td>350</td>
<td>370</td>
<td>380</td>
<td>410</td>
<td>420</td>
<td>450</td>
<td>460</td>
<td>480</td>
<td>500</td>
</tr>
</tbody>
</table>

2. The non-destructive technology

The non-destructive technology used by the Triomatic is based on the following parameters:
- Acousto-Ultrasonic phenomenon
- Local density measurement
- Moisture content measurement

This paragraph describes the measurements of these different parameters.

### 2.1 The Acousto-Ultrasonic technology

#### 2.1.1 The ultrasonic measurement

From 1985, the ultrasonic method for the measurement of the mechanical performances of timber – the modulus of elasticity: MoEₐ and the bending resistance: \( \sigma_b \) – has been validated for the wood as a structural material [6].

At the end of the 80’s, a technology transfer has been realised with the Sylvatest device [6] through the results of a thesis work [2]. This device was based on the measurement of the speed of propagation of a low frequency wave transmitted in the longitudinal axis of the wood (figure 1) as shown on the equation (1):

\[
V_{us} = \frac{\text{Ultrasonic wave transit}}{\text{Distance between sender and receiver}}
\]

**Fig 1: Longitudinal ultrasonic measurement in a wood piece.**
\[ V_L = \sqrt{\frac{C_{LL}}{\rho}} = \sqrt{\frac{\text{MoE}_\parallel}{\rho \cdot 1.82}} \]  

(1)

For a species such as spruce, a calibrated model giving the MoE and the bending strength \( \sigma_b \) can be written as follow (equations 2 and 3):

\[
\text{MOE}_\parallel = \alpha_1 V_L + \beta_1
\]  

(2)

\[
\sigma_b = \alpha_2 V_L + \beta_2
\]  

(3)

Where:

- \( V_L \): the waves’ velocity in the longitudinal axis [m/s];
- \( \text{MoE}_\parallel \): the modulus of elasticity parallel to the grain [N/mm\(^2\)];
- \( \rho \): the density of the material [kg/m\(^3\)];
- \( \sigma_b \): the bending modulus of rupture [N/mm\(^2\)];
- \( \alpha \) and \( \beta \): calibration parameters.

On the basis of these models obtained by ultrasonic measurements, Switzerland could have validated the 0 class (\( \text{MoE}_\parallel = 14000 \text{ N/mm}^2 \) and \( \sigma_b = 17 \text{ N/mm}^2 \)), and then the 0* class (\( \text{MoE}_\parallel = 15000 \text{ N/mm}^2 \) and \( \sigma_b = 20 \text{ N/mm}^2 \)), 10 years before the arrival of the Swisscodes based on the European grading of the EN 388 standards (table 1).

2.1.2 The acousto-ultrasonic measurement

In 1998, IBOIS, the laboratory for timber construction of the Swiss Federal Institute of Technology in Lausanne, has developed and improved the ultrasonic technology for wood by adding the measurement of the acoustic damping of the ultrasonic wave in the wood [3] (figure 2).

![Fig 2: Sylvatest-Duo and its transducers (left) and analysis of the acousto-ultrasonic signal with the measurements of the speed and of the maximal peak of energy of the transmitted waves (right).](image)

The system always measures the speed of the transmitted low frequency wave (22 kHz), and measures too the maximal peak of energy of these waves thanks to the equipment presented by the figure 2.

The speed of propagation is still correlated to the modulus of elasticity (\( \text{MoE}_0 \)), but the energy is correlated to the local singularities (knots, grain direction, degradation area…).

In fact, the energy damping of the waves is directly dependant of local singularities. The maximal value of the peak of energy represents thus a measurement of the acoustic response of the wood which translates faithfully the damping function.

This new generation of device, able to measure and manage the two acousto-ultrasonic variables, allows working in the wood natural axis: the longitudinal, radial and the transversal ones.
2.2 The density measurement

In order to estimate the wood’s density, an extra measurement module can be installed. This module is based on the local density measurement composed by two pins screwed on a load sensor.

A jack pushes the system into the wood and the compression load is measured as described by the figure 3.

![Density measurement module](image)

**Fig 3: Density measurement module. Two pins are screwed on a load sensor. The compression load is measured in order to evaluate the wood’s density**

The compression load measured when the pins penetrate the material is correlated to the wood local density as illustrated by the equation 4.

\[ \rho = \alpha C + \beta \]

With:
- \( \rho \): The local wood density [kg/m\(^3\)]
- C: The compression load measured when the pins penetrate the wood [V]
- \( \alpha \) and \( \beta \): Calibration parameters

2.2 The moisture content measurement

Affecting the ultrasonic waves speed and the compression load used for the density evaluation, the wood moisture content must be measured.

This parameter can be evaluated thanks to a resistive moisture meter content as illustrated by the figure 4.

![Moisture content measurement](image)

**Figure 4: Moisture content measurement principle.**
3. The industrial machine: Triomatic

3.1 Presentation

Triomatic is the non-destructive machine using the parameters described in the previous chapter:
- Acousto-ultrasonic measurement
- Local density measurement
- Moisture content measurement

In order to increase the process, several pairs of transducers are possible (figure 5). Moreover, the density measurement and the moisture content measurement can be done within the same module.

To avoid the plank side effect, two density measurements are performed: one is above the plank, and the second one is from under the plank, like a jaw (figure 6).

Concerning the knots, a maximal value of compression load is considered. If this maximal value is reached or overtaken, the parameter “knot” is taken into account. Then, a special algorithm manages the density measurement, comparing the both measurements (from above and from under the plank) plus the consideration of the eventual knots (equation 5).
\[
\begin{align*}
\rho_a &= \alpha C_a + \beta \\
\rho_u &= \alpha C_u + \beta \\
\text{If } C_i > C_{\text{max}}, \text{ then } C_i &= C_{\text{knot}} \rho = \frac{\rho_a + \rho_u}{2} \quad (5)
\end{align*}
\]

With:
- \(\rho_a\): Density measured from above the plank [kg/m\(^3\)]
- \(\rho_u\): Density measured from under the plank [kg/m\(^3\)]
- \(\rho\): Evaluated local wood density [kg/m\(^3\)]
- \(C_a\): Compression load measured from above the plank [V]
- \(C_u\): Compression load measured from under the plank [V]
- \(C_{\text{max}}\): Maximal compression load considered [V]
- \(C_{\text{knot}}\): Compression load considered if knots are present [V]

### 3.2 Calibration

Some results of the first step of the Combigrade project can be presented. The results of the second step should be published during autumn 2006.

The first step of the Finnish project was involving 100 planks of Spruce and 100 planks of Pine both from Finland and Russia.

The presented results consider the correlations between the failure tests giving the modulus of elasticity MOE and the modulus of rupture MOR versus the Triomatic evaluation taking into account the speed of ultrasound, the density of the planks and the wood moisture content.

Figure 7 presents the results for Spruce and figure 8 for Pine.

Table 2 summaries the results about the reliability of the non-destructive evaluation.

[Graph images are not transcribed, but should be referenced for full context.]
Fig 8: Results of the non-destructive measurements given by the Triomatic machine (X axis) versus the failure tests (Y axis) for Pine from Russia and Finland MOE, left, MOR right. From the Combigrade project, part 1. 100 planks, 46mm x 146mm.

Table 2: Coefficient of determination $r^2$ results of the non-destructive evaluation operated by Triomatic versus the failure tests done on 100 planks of Spruce and 100 planks of Pine, both from Russia and Finland.

4. Conclusion

Triomatic has now obtained the European Certification according to the EN14081 for both French and Scandinavian species. Its good results and its attractive cost are very interesting factors for sawmills and gluelam factories.

Based on the measurements of ultrasonics, density and moisture content, all the characteristics expected by the standards can be properly evaluated: MOE, MOR and density of each wooden beam.

Triomatic is ready for the CE marking which should appear from August the 1st, 2008, in all over Europe.

If Triomatic is fully automatic, a mobile semi-automatic version can also be proposed, especially for smaller timber companies.

The new version of Triomatic is much faster thanks to the latest Sylvatest Trio equipment (figure 9).

The next developments for this technology concern both green beams and logs grading which give excellent hopes after the preliminary studies led on a large scale in France [7].
5. References

[4] European Standards for Timber Construction EN338. Mechanical properties for sawn wood used as a structural material