Timber grading machine using multivariate parameters based on ultrasonic and density measurement

Sandoz Jean-Luc, Benoit Yann
CBT SA, Rue des Jordils 40, 1025, Saint Sulpice, Switzerland

Keywords: grading, machine, non-destructive evaluation, wood

ABSTRACT

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 ρ of wood.
The visual inspection being unable to give an accurate grading regarding these new norms, non-destructive technologies are developed to answer to these fundamental concerns.
This paper relates a new 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 calibration process for French species under the CTBA's supervision for a reliable European Grading Assessment.

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 has been developed – Sylvatest Duo – using not only the ultrasonic measurements, but also the acoustic phenomenon to increase the evaluated results reliability [3].
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, next year, in 2007, the timber industry will be asked to assume the traceability for each structural element, including the resistance class defined in the norms.
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.

Characteristics	Symbol	Strength classes								
		C 14	C 16	C 18	C 22	C 24	C 27	C 30	C 35	C 40
Bending [N/mm^2]	$f_{m,k}$	14	16	18	22	24	27	30	35	40
Tension ∥ [N/mm^2]	$f_{t,0,k}$	8	10	11	13	14	16	18	21	24
Tension ⊥ [N/mm^2]	$f_{t,90,k}$	0,3	0,3	0,3	0,3	0,4	0,4	0,4	0,4	0,4
Compression ∥ [N/mm^2]	$f_{c,0,k}$	16	17	18	20	21	22	23	25	26
Compression ⊥ [N/mm^2]	$f_{c,90,k}$	4,3	4,6	4,8	5,1	5,3	5,6	5,7	6,0	6,3
Shear [N/mm^2]	$f_{v,k}$	1,7	1,8	2,0	2,4	2,5	2,8	3,0	3,3	3,8
Elasticity modulus [kN/mm^2]										
– parallel average	$E_{0,mean}$	7	8	9	10	11	12	12	13	14
– parallel $f_{5\%}$	$E_{0,0.5}$	4,7	5,4	6,0	6,7	7,4	8,0	8,0	8,7	9,4
– perpendicular average	$E_{90,mean}$	0,23	0,27	0,30	0,33	0,37	0,40	0,40	0,43	0,47
Shear modulus average [kN/mm^2]	G_{mean}	0,44	0,50	0,56	0,63	0,69	0,75	0,75	0,81	0,88
Density minima [kg/m^3]	ρ_k	290	310	320	340	350	370	380	400	420
Density average [kg/m^3]	ρ_{mean}	350	370	380	410	420	450	460	480	500

THE NDE 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.

The Acousto-Ultrasonic phenomenon

The ultrasonic measurement

From 1985, the ultrasonic method for the measurement of the mechanical performances of timber – the modulus of elasticity: $MoE_{\|}$ and the bending resistance: σ_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):

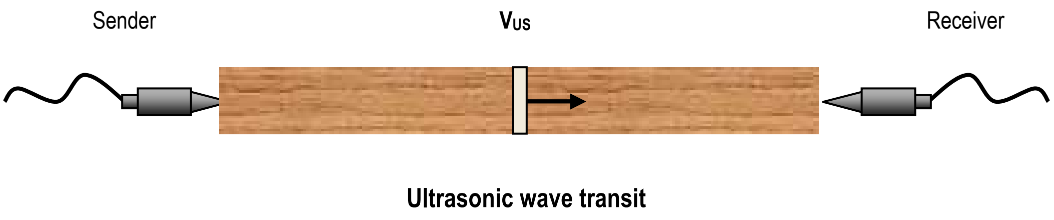

Figure 1: Longitudinal ultrasonic measurement in a wood piece.

$$V_L = \sqrt{\frac{C_{LL}}{\rho}} = \sqrt{\frac{MoE_{//}}{\rho.1.82}} \qquad [1]$$

For a species such as spruce, a calibrated model giving the $MoE_{\|}$ and the bending strength σ_b can be written as follow (equations 2 and 3):

$$MOE_{//} = \alpha_1 V_L + \beta_1 \qquad [2]$$

$$\sigma_b = \alpha_2 V_L + \beta_2 \qquad [3]$$

Where:

V_L: the waves' velocity in the longitudinal axis [m/s];
$MoE_{//}$: the modulus of elasticity parallel to the grain [N/mm^2];
ρ: the density of the material [kg/m^3];
σ_b: the bending modulus of rupture [N/mm^2];
α And β: calibration parameters.

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.
The new generation of device, Sylvatest Duo, deals with the analysis of the acousto ultrasonic response of the wood [3] (figure 2).

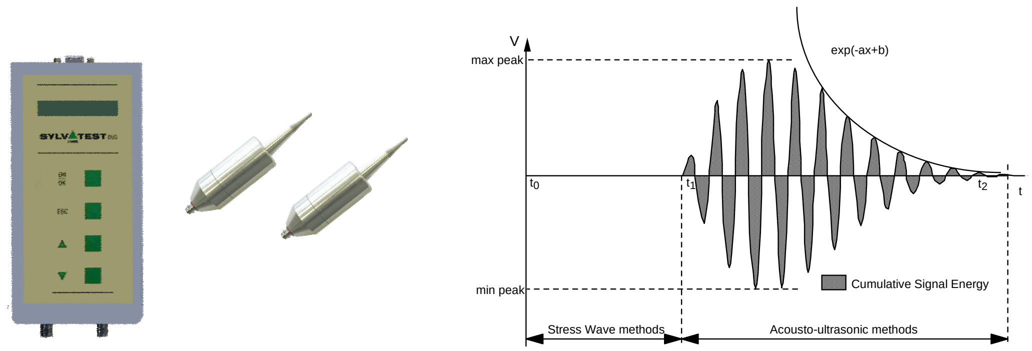

Figure 2: ***Sylvatest-Duo and its transducers (left) and analysis of the acousto-ultrasonic signal with the measurements of the speed and of the maximal peak of energy of the transmitted waves (right).***

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 ($MoE_{||}$), 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.

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.

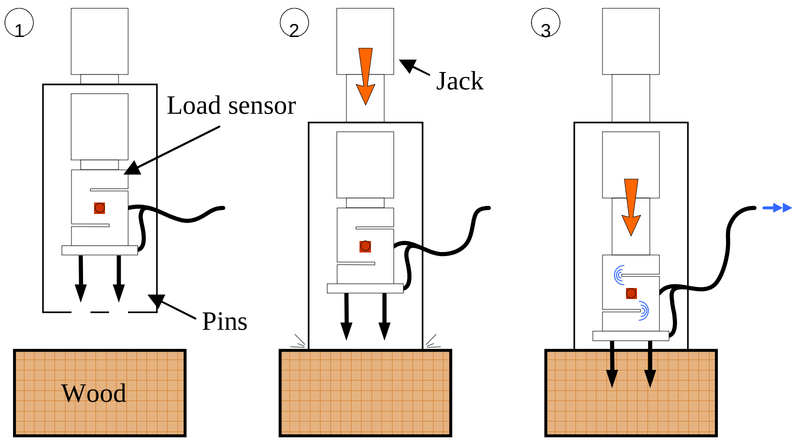

Figure 3:
Density measurement module. Two pins are screwed on a load sensor. The compression load is measured in order to evaluate the wood's density

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

$$\rho = \alpha C + \beta \qquad [4]$$

With:
ρ: The local wood density [kg/m^3]
C: The compression load measured when the pins penetrate the wood [V]
α and β: Calibration parameters

<u>The moisture content measurement</u>
Affecting the speed of the ultrasonic waves and the compression load value the wood moisture content must be measure
This parameter can be evaluated thanks to a common Gann as illustrated by the figure 4.

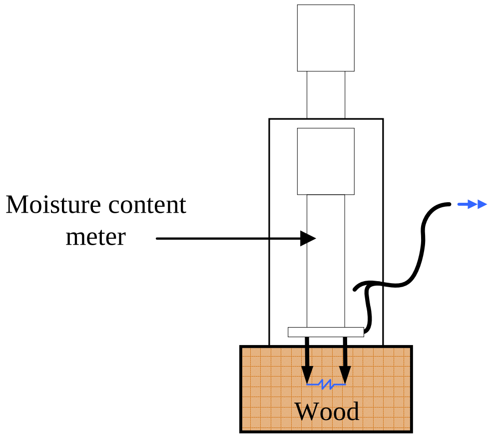

Figure 4: Moisture content measurement principle

THE INDUSTRIAL MACHINE: TRIOMATIC

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 side effect for the plank, two density measurements are realized: one is above the plank, and the second makes a measurement from under the plank, like a jaw (figure 6).

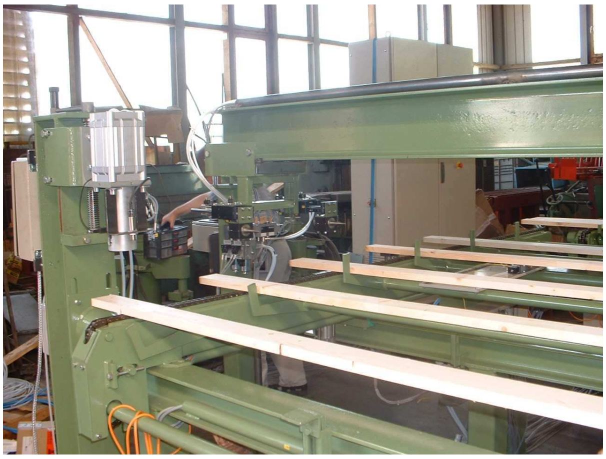

Figure 5: Ultrasonic module composed here by two pairs of transducers. Triomatic Ecolam, Belgium. More pairs could be added in order to increase the process if needed.

Figure 6: Density and moisture content measurement module. A jaw composed by two load sensors on which a pair of pins is screwed measures the wood local density from above and from under the plank. The moisture content is simultaneous measured once the pins are in the wood. Triomatic, Ecolam, Belgium.

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).

$$\rho_a = \alpha C_a + \beta \qquad \text{If } C_i > C_{max}, \text{ then } C_i = C_{knot} \quad \rho = \frac{\rho_a + \rho_u}{2} \qquad [5]$$
$$\rho_u = \alpha C_u + \beta$$

With:

ρ_a: Density measured from above the plank [kg/m^3]
ρ_u: Density measured from under the plank [kg/m^3]
ρ: 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_{max}: Maximal compression load considered [V]
C_{knot}: Compression load considered if knots are present [V]

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.

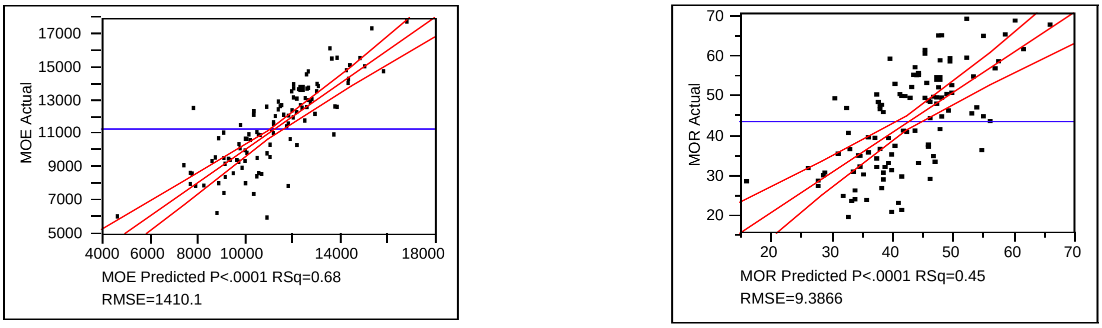

Figure 7: Results of the non-destructive measurements given by the Triomatic(X axis) machine versus the failure tests (Y axis) for Spruce from Russia and Finland MOE, left, MOR right. From Combigrade project 1

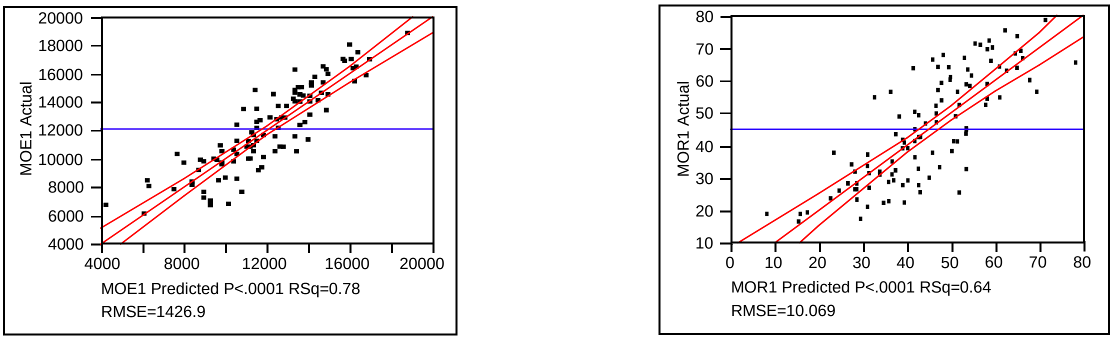

Figure 8: Results of the non-destructive measurements given by the Triomatic machine (X axis) versus the failure tests (Y axis) for Pine from Russia and Finland MOE, left, MOR right. From Combigrade project 1

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.

Spruce	**Value**	**r^2**
Triomatic	MOE	0.68
	MOR	0.45

Pine	**Value**	**r^2**
Triomatic	MOE	0.78
	MOR	0.64

CONCLUSION

Triomatic is a machine available on the timber strength grading market. Its good results and its 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 norms can be properly evaluated: MOE, MOR and density of each wooden beam.
By adding the density measurement to the ultrasonic value, the gain on the reliability is very interesting as illustrated by the table 3.

Table 3: Gain obtained by adding the density measurement (Triomatic) to the single ultrasonic value (Sylvamatic).

	Pine	
r^2	**MOE**	**MOR**
Sylvamatic	0.67	0.51
Triomatic	0.78	0.64
Gain	**16.4%**	**25.5%**

Triomatic is ready for the CE label which should appear from the next year in 2007 all over Europe.

A new calibrating project has been launched with the collaboration of the CTBA, France, in order to validate the machine for French species.
Samples of a same species are studied according to their growth location (region + altitude), the log's diameter, and the plank's position of the in the original log.
If Triomatic is fully automatic, a mobile semi-automatic version can also be proposed, especially for smaller timber companies.

REFERENCES

[1] Group CBS-CBT, www.cbs-cbt.com
[2] Sandoz, J.-L., 1990: "Grading and reliability of construction timber, validation of the ultrasound method", thesis n°851, EPFL, IBOIS, Lausanne, Switzerland
[3] Sandoz, J.-L.; Benoit, Y.; Demay, L., 2000: "Wood testing using acousto-ultrasonic", World Conference on Timber Engeneering, Whistler, Canada.
[4] European Standards for Timber Construction EN338. Mechanical properties for sawn wood used as a structural material
[5] Hanhijärvi, A.; Ranta-Maunus, A.; Turk, G., 2005:"Poteantial of strength grading of timber with combined measurement techniques", Report of the Combigrad project, phase 1.
[6] Sandoz, J.-L., 1989: "Grading of construction timber by ultrasound", Wood Science and Technology 23:95-108