

FAKOPP

Portable Lumber Grader

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1. Device

1.1. Components

- Weighing scale
- Scale display unit
- Tape measure
- Steel hammer (100 g)
- Battery and charger
- Microphone
- USB to serial converter cable
- Portable Lumber Grader Software

1.2. Minimum software requirements

- Operating system: Windows 7 SP1 (recommended: Windows 10 or newer)
- Processor: 1 GHz
- RAM: 512 MB
- Disk space: 300 MB
- 1 free USB port

2. Principles of measurement

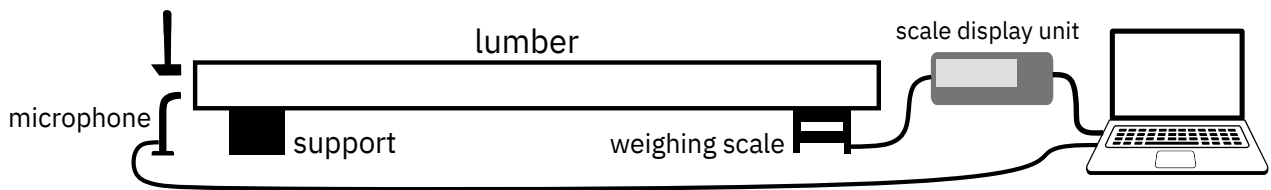
The portable Lumber Grader is designed to estimate strength classes of structural timber, as defined in the EN 338 standard (see Appendix 2: EN 338) The software handles two different species classes: deciduous and coniferous (including poplar). Grading is based on the modulus of elasticity (MoE) and the average specific gravity of the lumber.

3. Connection to computer

- Connect the microphone's cable to the microphone socket of the computer
- Connect the weighing scale to the scale display unit
- Connect the RS-232 cable from the scale display unit to the computer, using the USB-to-serial converter cable
- Place 4 fully charged AA batteries into the Rinstrum force meter Display Unit.

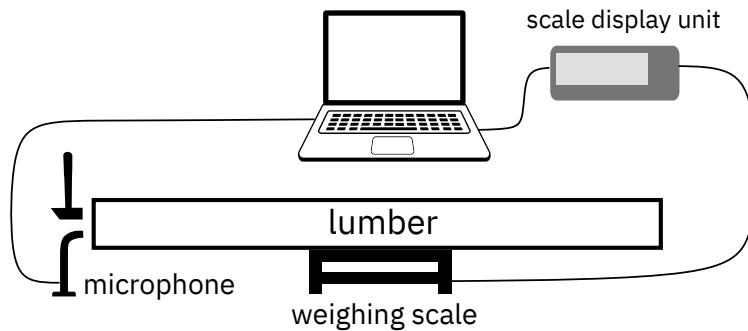
3.1. Half weight setup

Below you can see the setup for measuring half lumber load. Recommended for longer samples where length is larger than 2 meters.



3.2. Full weight setup

Below you can see the setup for measuring full lumber load. Recommended for shorter samples where length is below 2 meters.



3.3. Indicate the setup in the software

Select whether the weighing scale is at the center of the lumber (“*Measuring full weight*”), or at one of it’s ends (“*Measuring half weight*”).

- Measuring half weight
- Measuring full weight

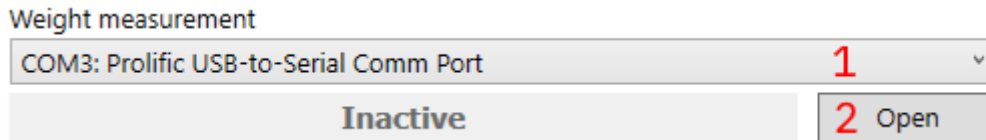
3.4. Selecting audio input device

Audio device

Headset Microphone (Plantronics Blackwire 3210 Series) ▼

- Connect the microphone cable to the PC
- The software selects the current default audio device of the computer automatically when the application starts.
- In case there are multiple audio input devices available, select the one that the microphone in use is connected to from the “*Audio device*” selector. (On some systems audio output is also available as a virtual microphone. Ignore items like “Stereo mixer”, “CD volume”, “Line volume”)

3.5. Selecting scale USB port

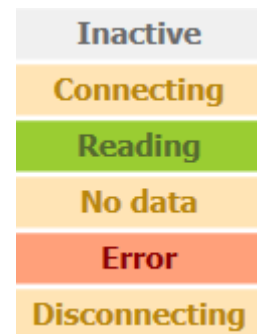


- Connect the USB-Serial cable to the PC
- Select the COM port of the scale from the “*Weight measurement*” selector (1) and click “*Open*” (2).

3.6. Connection state

Colored strips indicate the current state of the connection to the audio and scale devices:

- “*Inactive*” (gray): No connection found, press “*Open*”.
- “*Connecting*” (yellow): the PC tries to connect.
- “*Reading*” (green): the PC is receiving data.
- “*No data*” (yellow): there is no data flow through the connection. Verify that the correct device is selected and the device is turned on.
- “*Error*” (red): there was an issue with the connection. If the error state persists for more than 5 seconds then click “*Close*”, and once “*Inactive*” click “*Open*”.
- “*Disconnecting*” (yellow): the PC tries to disconnect.



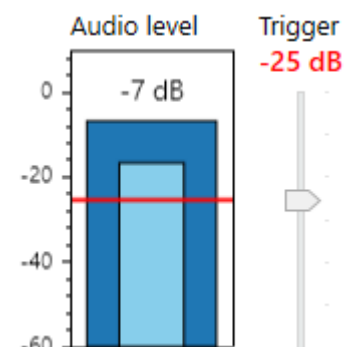
4. Setting up measurement in software

Before taking measurements, the following parameters should be entered: the audio “Trigger” level and whether the weighing scale measures full or half weight.

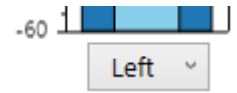
4.1. Audio and Trigger level

The software is constantly recording from the Microphone to detect hits from the hammer. To separate background noise from hits, the user must calibrate the software for the sound volume that hitting the lumber produces.

- The “*Audio level*” plot indicates the current volume recorded from the microphone. The light blue bar represents the current volume, and changes quickly. The dark blue bar indicates the maximum volume recently recorded, and changes more slowly. The black text above the dark blue bar shows the recent maximum volume in decibels.

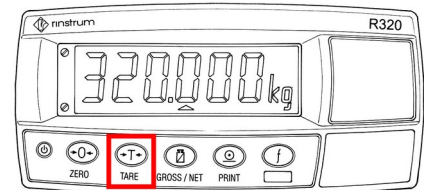


- The “*Trigger*” is the minimum level of volume that hammer hits produce. It is indicated by the red line in the “*Audio level*” plot, as well as the red text and slider position in the “*Trigger*” column.
- After hits the top of the dark blue bar should be above the trigger level, while without hits it should be consistently well below it.
- Most audio devices will provide “*Mono*” output, but in case stereo audio is recorded the audio channel to use needs to be selected (“*Left*” or “*Right*”).



4.2. Tare

Before taking measurements, use the Rinstrum display unit to tare (zero) the measurement when the scale is unloaded.



4.3. Settings window

Review the application settings, especially the “Auto-increment min. sample count” field on the “Misc.” tab. Using this field you indicate whether you want only a single measurement per lumber, or multiple. (For more details see: 8.3 Miscellaneous settings)

5. Measurement procedure

5.1. Lumber placement

Place the lumber in the position indicated in chapter 3.3 Indicate the setup in the software. When measuring full weight, ensure the scale is placed under the center of the lumber for precise measurements. When measuring half weight ensure that the end of the lumber is placed on the center of the scale.

5.2. Properties of the next lumber sample

Entering the parameters of the next lumber sample to be measured is critical for correct grading.

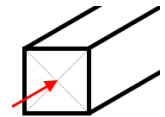
- “*Coniferous*”, “*Deciduous*”: Select the lumber type.
- “*Length [cm]*”, “*Width [cm]*”, “*Height [cm]*”: Enter the nominal dimensions of the lumber in centimeters. You may use the decimal point for precise entry.
- “*Current moisture content [%]*”: The moisture content of the lumber while grading
- “*Service moisture content [%]*”: The expected in-use moisture content

Next sample	
<input type="radio"/> Coniferous	<input checked="" type="radio"/> Deciduous
Length [cm]	80,2
Width [cm]	12,1
Height [cm]	10
Current moisture content [%]	18
Service moisture content [%]	12
CKDR	0
Sample identifier (#)	1 +
Auto-increment	<input checked="" type="checkbox"/>

- “CKDR” (Concentrated Knot Diameter Ratio): A correction factor for the amount of knots in the sample. Setting CKDR to zero turns off CKDR correction.
- *The knot diameter is a distance between the two tangential lines parallel to arises (longitudinal direction) of a lumber surface in which the knot exists. If a knot diameter is not less than 2.5 times as much as its smallest diameter, it shall be considered to have one half of its actual measured diameter. The knot diameter ratio (KDR) is a percentage of the diameter of a knot to the width of a lumber surface in which it exists. The concentrated KDR (CKDR) is the sum of KDR concerning the knots existing in any 15 cm length of a piece of the lumber. The highest - considering 4 faces - CKDR represents the piece of lumber. The CKDR value is between 0 and 1.*
- “Sample identifier (#)”: The sample identifier is an integer number (starting with 1) that uniquely identifies a lumber sample within the current project file. It is displayed in the “#” column of the measurements table. It may be entered manually, or increased by 1 using the “+” button. It is especially useful when storing multiple measurements of each lumber sample, as it indicates which measurement belongs to which sample.
- “Auto-increment”: Indicates whether the “Sample identifier (#)” is automatically incremented after a successful grading. See also: 8.3 Miscellaneous settings.

5.3. Hammer usage

- *Power*: Grading is not sensitive to the power of hammer hits except for outliers: a weak hit produces a smaller signal and may fail to trigger. A powerful hit may move the lumber or damage the microphone.
- *Direction*: The software measures longitudinal vibration therefore the direction of hits must be parallel to the long axis of the lumber.
- *Technique*: There is no special technique to hits. Do not touch the lumber. Let the hammer bounce back. Refrain from doing weaker “test” hits.
- *Hammer weight*: The weight of the hammer is important: usually lighter is better, but larger lumber requires the use of heavier hammers. Roughly 0.1 – 3 % of the lumber weight is appropriate.
- *Which Lumber end*: Either end of the lumber is acceptable. Take special care not to damage the microphone.

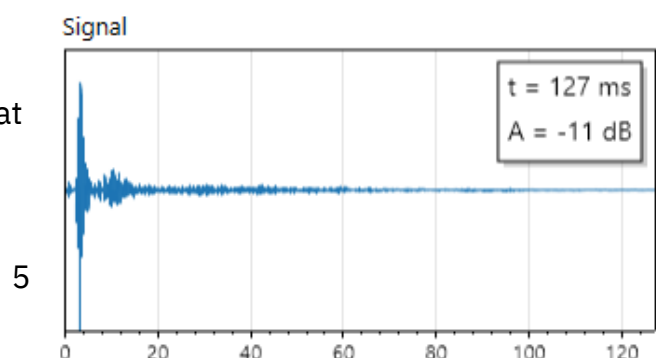


6. Measurement result

The software window is immediately updated once a hit is detected.

6.1. Signal plot

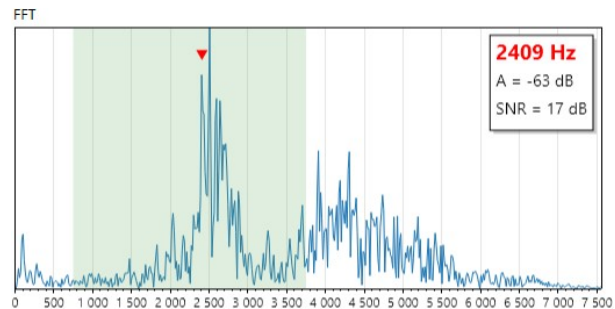
- Displays the audio waveform that triggered the measurement



- X axis: time in milliseconds
- “t”: the total duration of the audio sample that was analyzed
- “A”: the absolute maximum amplitude (Y value) in the waveform, in decibels

6.2. Frequency (FFT) plot

- Displays the frequencies present within the audio sample analyzed
- X axis: frequency in Hertz
- Green background: the frequency interval within which the longitudinal frequency is searched for
- Red triangle and text: the longitudinal frequency detected, in Hertz. Note that the peak detected may not be the largest peak when “*Secondary peak detection*” is enabled (see: 8.1 Audio settings).
- “A”: The maximum amplitude (Y value) detected, in decibels
- “SNR”: The signal-to-noise ratio within the audio sample analyzed, in decibels. A larger value indicates a clearer signal. See also: 8.2 Grading settings.



6.3. Results box

- “*Density*”: the estimated lumber density
- “*Dynamic MoE*”: the dynamic modulus of elasticity estimated (the MoE based on the longitudinal velocity measurement)
- “*Static MoE*”: the estimated static modulus of elasticity (MoE under static load)
- “*Velocity*”: the estimated velocity of the sound wave within the lumber

Results	
Density [kg/m ³]	1030,5
Dynamic MoE [GPa]	30,8383
Static MoE [GPa]	27,1162
Velocity [m/s]	5470

6.4. Strength class box

The large box below the “*Next sample*” and “*Results*” boxes displays the estimated strength class of the lumber if it could be graded, or the cause of the out-of-grade measurement.

- A gray background indicates that the measurement could be graded.
- A red background indicates that the strength class could not be determined. In this case the box contains an error message detailing the cause. If there is no error message, than either one of the devices is not connected, or one of the “*Next sample*” fields is empty or out-of-range.

D70

Can not be graded
 Static MoE below lower limit: 6,89 GPa < 9,5 GPa

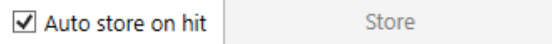
6.5. Measurements storage & table

☰	Delete last	Delete selected	Delete out-of-grade rows	<input type="checkbox"/> Auto store on hit	Store							
#	L [cm]	W [cm]	H [cm]	Current MC [%]	Service MC [%]	CKDR	Mass [kg]	Freq [Hz]	Density [kg/m ³]	Velocity [m/s]	Static MoE [GPa]	Class
2	80,2	12,1	10	18	12	0	10	2975	1030	4772	18,0704	D60

Measurements may be automatically or individually stored into the current project file. The currently stored measurements are displayed at the bottom of the “Record” tab, or on the “Data” tab, with the latest measurement located at the top of the table.

6.5.1. Storing new measurements

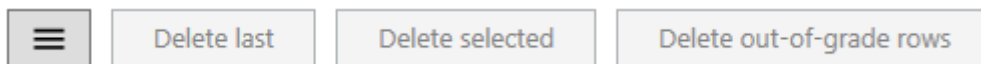
Measurements may be added to the currently open project either manually or automatically. Keep in mind that the project file must be saved using the *File* → *Save* or *Save As* menu commands (or when being notified about unsaved changes) to preserve measurements for later perusal.



- “*Store*”: this button is used to store the latest measurement, which is shown in the software. Note that if you do not click “*Store*” and instead make another measurement, then the button will only store the latest measurement and the one before is lost. You may use this button to only store the measurements you want to. (The button is disabled when there is no measurement to be stored, after the latest measurement was stored, or if “*Auto store on hit*” is enabled.)
- “*Auto store on hit*”: immediately stores the next measurement after the “*Trigger*” is detected. The “*Sample identifier (#)*” may also be automatically increased as specified in the settings window (see: 8.3 Miscellaneous settings).

6.5.2. Deleting & exporting measurements

The content of the table may be edited using the buttons above it:



- “☰”: Allows exporting the content of the table into an Excel (.XLSX) file.
- “*Delete last*”: deletes that latest (i.e. top) measurement from the table
- “*Delete selected*”: deletes the selected row from the table
- “*Delete out-of-grade rows*”: deletes all rows from the table containing out-of-grade measurements (red backgrounds).

Static MoE [GPa]	Class
29,562	Out-of-grade

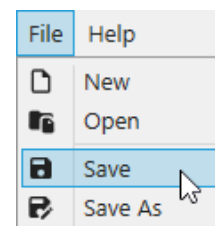
6.5.3. Measurements table

The table contains the following columns:

- **#:** the “*Sample identifier*” of the lumber
- **Timestamp:** the time the measurement was taken. Only visible on the “*Data*” tab and in exported Excel files.
- **L, W, H [cm]:** the length, width and height of the lumber, in centimeters
- **Current MC [%]:** the moisture content of the lumber while grading
- **Service MC [%]:** the moisture content of the lumber while in use
- **CKDR:** the “*Concentrated Knot Diameter Ratio*”
- **Mass [kg]:** the mass measured at the time the “*Trigger*” was detected
- **Freq [Hz]:** the longitudinal frequency detected, in Hertz
- **Density [kg/m³]:** the estimated density of the lumber in kilograms per cubic meters
- **Velocity [m/s]:** the estimated velocity of the sound wave within the lumber, in meters per second
- **Static MoE [GPa]:** the estimated static modulus of elasticity of the lumber, in gigapascals
- **Class:** the estimated strength class

7. Finishing the measurement

- Save the project: *File* → *Save*
- Turn off the Scale display unit to preserve battery life



8. Settings window

The settings window can be opened using the “*Settings*” menu command in the “*File*” menu.

8.1. Audio settings

- “*Hit detection pause*”: After each Trigger detected the microphone stops recording for a very short while. This allows the sound of the hit to dissipate (avoiding multiple Triggers for the same hit).
- “*Secondary peak detection*”: The detection of secondary peaks is an optional feature useful when the frequency plot (see: 6.2 Frequency (FFT) plot) shows two peaks close to each other. When “*OFF*”, the largest (maximum) peak is selected from the frequency search range (green background). The second highest peak is selected instead when “*ON*” (and a second peak exists).

- *“Sensitivity”*: The minimum magnitude of the secondary peak, defined as a percentage of the current primary (maximum) peak. A larger value indicates that the secondary peak should be closer in magnitude (Y axis) to the primary peak.
- *“Frequency range”*: The secondary peak is only searched for in the close neighborhood of the primary peak, directly to the left from it (the secondary peak is expected to have a smaller frequency). The exact range of frequencies checked is defined as a percentage of the total frequencies shown in the plot (the X axis).

8.2. Grading settings

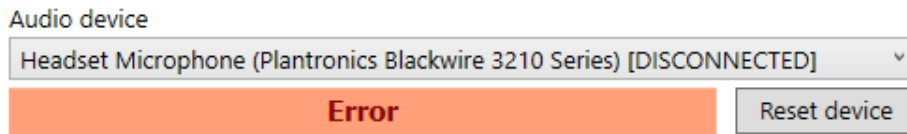
- The *“Upper limit”* fields help determine when the static MoE or density values of the current measurement can not be graded. The minimum of the valid range for each of the two is defined by the EN 338 standard (see: Appendix 2: EN 338) however the maximum is not. We introduce these maximum values to indicate when static MoE or density is obviously erroneous (this may happen when small numbers are entered as the sample dimensions).
- *“Minimum signal-to-noise ratio (SNR)”*: Environmental noise can affect the grading algorithm negatively. This value is a minimum for the ratio of the magnitude of the peak detected, and the average magnitude of the frequency search range (green background), defined in decibels. The measurement is considered unusable when the noise is too high (SNR is less than this number). The SNR for the latest measurement is indicated on the frequency plot (see: 6.2 Frequency (FFT) plot).

8.3. Miscellaneous settings

- *“Auto-increment min. sample count”*: this number determines when to automatically increment the *“Sample identifier (#)”*. It has no effect when *“Auto-increment”* is unchecked (see: 5.2 Properties of the next lumber sample).
 - When set to 1: The sample identifier is increased after each gradable measurement.
 - When greater than 1: The sample identifier is increased only after this many gradable measurements are available for the current sample identifier. Out-of-grade measurements (red background) are ignored. In this case there is also a short sound effect played when the sample identifier is increased, so that the user knows when enough gradable measurements were taken without having to look at the screen.
- *“Open autosave directory”*: Copies of recently open projects are preserved in this location temporarily. In case of data loss (due to power or storage failure) you may be able to find a copy of the project based on when it was last open.

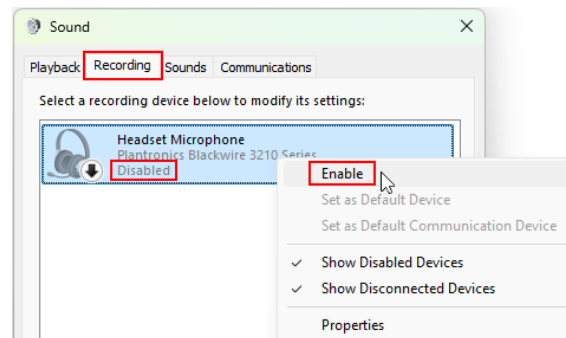
9. Troubleshooting

9.1. Audio device issues

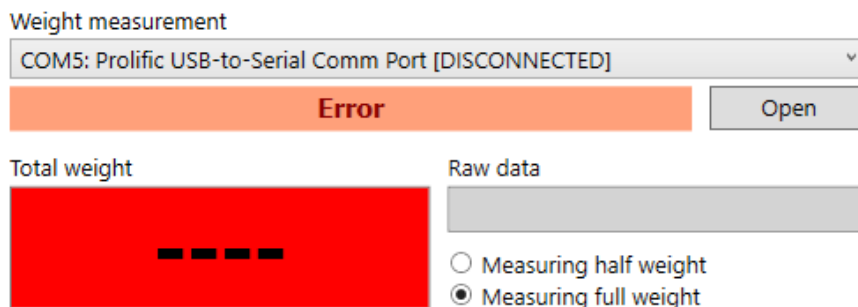


When there is an issue with the microphone you should see the red “Error” indicator, and you may also see the “[DISCONNECTED]” suffix in the audio device selector.

- Ensure that the microphone is well connected to the computer
- Ensure that the microphone is not disabled in Windows (see: *Settings / System / Sound / Advanced / More sound settings / Recording*)
- Click “Reset device”
- Ensure that the correct audio device is selected



9.2. Weighing scale issues



Multiple issues could occur with the scale:

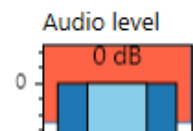
- The “[DISCONNECTED]” suffix appears in the device selector when the cable was unplugged. Ensure that the cable fully plugged into the computer. You may also try to use another socket if the issue persists.
- The “Connecting” and “Disconnecting” yellow status messages may appear for a long amount of time (up to a couple minutes in extreme cases). This issue should resolve itself automatically. You may also try restarting the application and/or the computer.
- The red “Error” status message may appear either because the device is “[DISCONNECTED]” (see above), or due to another communication issue. If the suffix is *not* visible, try to clicking the “Close” button, and once that finishes the “Open” button.

- The yellow “No data” status message indicates that no data is received from the device. First ensure that the correct COM port is selected (you may need to click the “Close” button to do so). You should also ensure that the display unit is turned on and has a fully charged battery.
- The “Total weight” box may display a red background and “- - -”. This indicates that no data is received from the device. Usually you also see the “No data” yellow status message (see above), however this may also be caused by data corruption. The latter may be caused by low battery voltage and bad cable connections (check that cables between the scale, display unit and computer are well connected). It may also be caused by damage to one of the cables. If none of the steps above resolve the issue, try replacing the USB-serial cable or contact support.

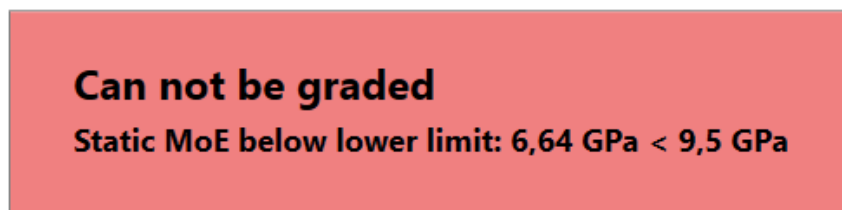
9.3. Trigger level issues

A correctly configured trigger level detects all hits, but only the hits.

- When random noise is detected as hits, the trigger level is too low and picks up noise. Observe the level of the dark blue bar when noise occurs and ensure the trigger level (red line) is above it.
- When hits are missed, the trigger level is too high and should be lowered. Observe the level of the dark blue bar when hits occur and ensure the trigger level (red line) is below it. This can also be caused when the microphone is too far away from the end of the lumber (the distance should be around 5 centimeters between the microphone head and the end of the lumber).
- A red background at the top of the audio level indicator signals that the audio volume is too high. As this may distort the signal, move the microphone slightly away from the lumber (a distance of around 5 centimeters is recommended).



9.4. Grading errors



The large grading result box may indicate multiple issues:

- “Static MoE below lower limit” or “Density below lower limit”: The measured static MoE or density was too low. The lower limit is determined by the EN 338 standard (see the left-most values in the coniferous or deciduous tables in Appendix 2: EN 338) Ensure that the dimensions are correct and that the measured weight is correct (check whether full/half weight measurement is selected in the software). Repeat the hit on the lumber, making sure to hit the center and not the edges.

- “*Static MoE above upper limit*” or “*Density above upper limit*”: the issue is usually resolved similarly to the “lower limit” errors above. If you are measuring lumber with unusual properties (e.g. extreme density), you may manually increase the upper limits (see 8.2 Grading settings)
- “High background noise”: Ensure that the microphone is well connected to the computer and is placed reasonably close to the lumber (around 5 centimeters). You may also wish to ensure that the environment has no other sources of noise and that the microphone is undamaged. Decreasing the minimum signal-to-noise ratio may also resolve such issues, however please be aware that this may negatively affect the accuracy of grading (see 8.2 Grading settings). The signal-to-noise ratio at the time of the hit is displayed on the Frequency (FFT) plot.
- An empty red grading box indicates that grading can not be completed. Check that there are no issues indicated with the microphone and weighing scale, and that the lumber parameters are valid numbers (invalid user input is marked by red borders).

9.5. File errors

Damaged or lost project files may be recoverable if they were recently opened using the “*Open autosave directory*” button of the *Settings* window (see: 8.3 Miscellaneous settings)

10. Appendix 1: Mathematical model

The software models lumber using the following formula:

$$\rho = \frac{m}{(L \cdot W \cdot H)}$$

where:

ρ : density in $\frac{kg}{m^3}$	m : mass in [kg]	
L : length in [m]	W : width in [m]	H : height in [m]

10.1. Velocity

Velocity is derived from the longitudinal frequency of the lumber (estimated from the peak detected in the measurement).

$$v = 2 \cdot L \cdot f$$

where:

v : velocity in $\frac{m}{s}$	L : length in [m]	f : frequency in [Hz]
--------------------------------------	--------------------------	------------------------------

10.2. Dynamic MoE

$$MoE_d = \rho \cdot v^2 \cdot \left(1 - \frac{u}{50}\right)$$

where:

MoE_d : moisture corrected dynamic modulus of elasticity, in [Pa]	
ρ : density in $\frac{kg}{m^3}$	v : velocity in $\frac{m}{s}$
u : moisture difference in [%]: service moisture [%] - current moisture [%]	

10.3. Static MoE

The estimation for the Static MoE comes from the PhD work of Ferenc Sismándy-Kiss: *Relationship Between the Strength and Physical Properties of Sawn Timber* (2012)

$$MoE_{s,GPa} = 0.819 \cdot MoE_{d,GPa} + 1.158 - (1.981 \cdot CKDR)$$

where:

- $MoE_{s,GPa}$: static modulus of elasticity, in [GPa]
- $MoE_{d,GPa}$: dynamic modulus of elasticity, in [GPa] ($MoE_{d,GPa} = \frac{MoE_d}{10^9}$)
- **CKDR**: Concentrated Knot Diameter Ratio (dimensionless quantity)

11. Appendix 2: EN 338

Strength classes for softwood (coniferous species):

	C14	C16	C18	C20	C22	C24	C27	C30	C35	C40	C45	C50
MoE [GPa]	7	8	9	9.5	10	11	11.5	12	13	14	15	16
ρ [kg/m ³]	290	310	320	330	340	350	360	380	390	400	410	430

Strength classes for hardwoods (deciduous species):

	D18	D24	D27	D30	D35	D40	D45	D50	D55	D60	D65	D70	D75	D80
MoE [GPa]	9.5	10	10.5	11	12	13	13.5	14	15.5	17	18.5	20	22	24
ρ [kg/m ³]	475	485	510	530	540	550	580	620	660	700	750	800	850	900

The numbers shown are the minimum values for each strength class. If static MoE and density indicate different strength classes, then the smaller class is chosen.

12. Appendix 3: Technical data

Weighing scale

- Dimensions: 250 x 75 x 90 mm
- Max capacity: 500 kg
- Resolution: 10 g
- Output: RS232 signal
- Power supply: 12 V adapter or 4 AA size batteries

Microphone

- Type: unidirectional
- Sensitivity: -56 dB (0 dB = 1 V/mbar at 1000 Hz)

- Frequency range: 100 - 15000 Hz
- Operational temperature: 5 - 40 °C

Hammer

- Weight: 0.1 – 3% of lumber weight

Limitations

- The actual lumber dimensions need to be within $\pm 2\%$ of the nominal dimensions entered.
- The lumber length must be within the range of: 0.5m ... 10m