Development of acoustic device to measure the moisture content

The EMPIR initiative is co-funded by the European Union's Horizon 2020 research and innovation programme and the EMPIR Participating States

Michal Voldán, Czech Metrology Institute (CMI)

BIOFMET 2nd Stakeholders' Workshop

PTB Braunschweig 28 – 29 March 2023

Objectives

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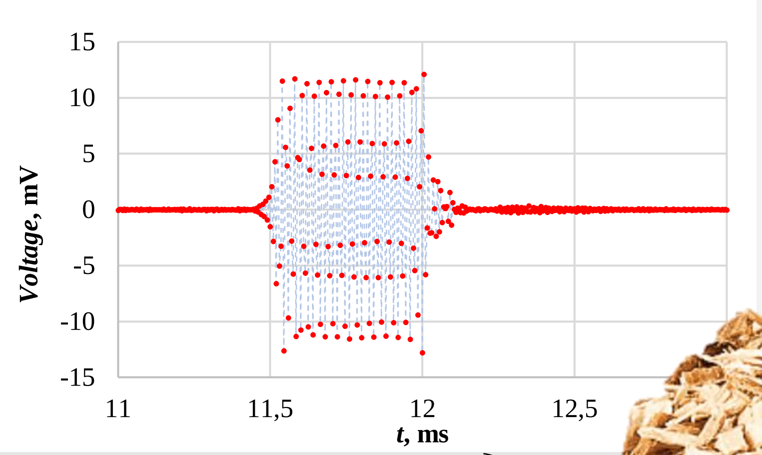
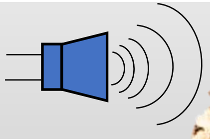
- *To measure moisture in wood chips and wood pellets by sound*

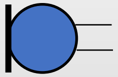


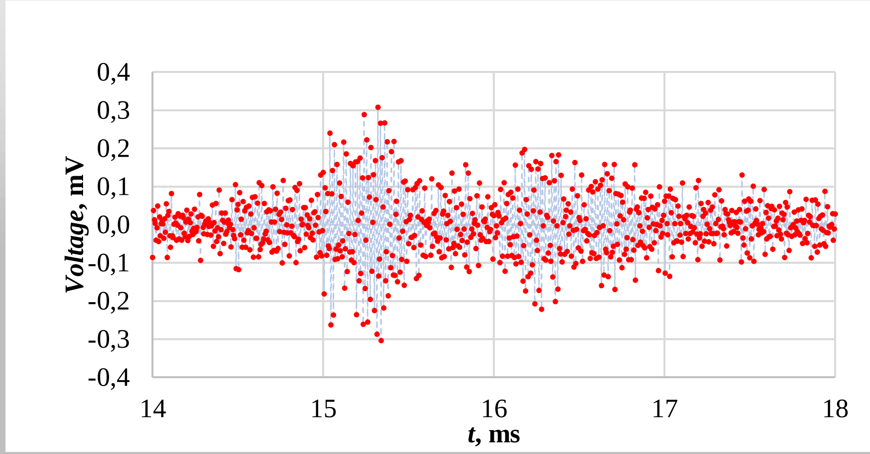


- *Changes in:*

  Δu .... speed of sound

  ΔP.... power





State of the art

Appl. Phys. A 90, 191–196 (2008)
DOI: 10.1007/s00339-007-4256-6
Applied Physics A
Materials Science & Processing

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Calibration of non-contact ultrasound as an online sensor for wood characterization: Effects of temperature, moisture, and scanning direction

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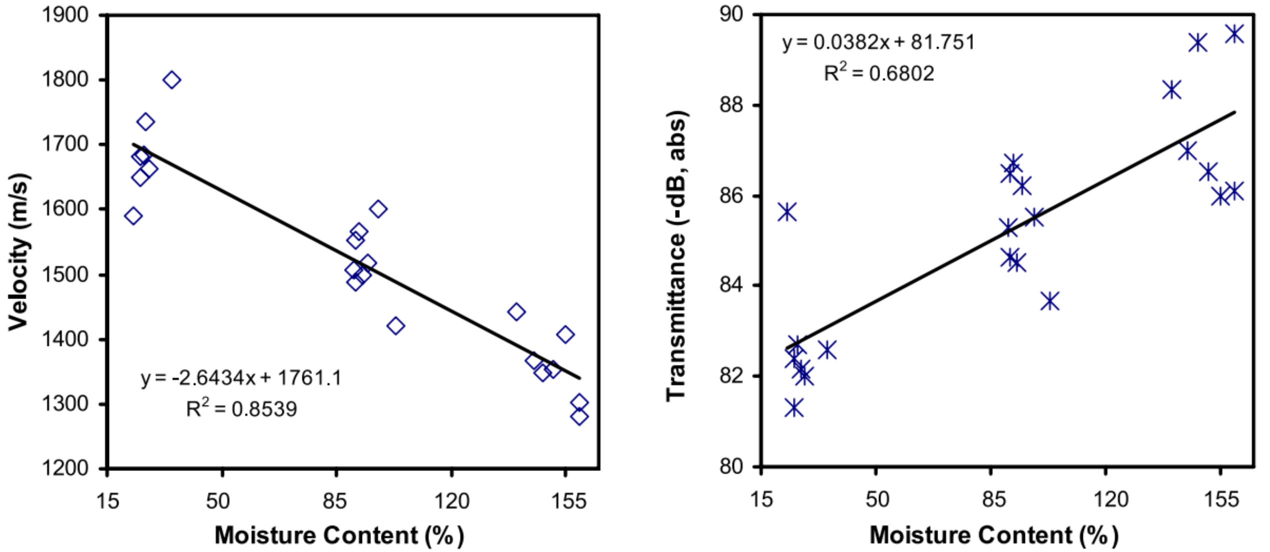
[2] Pennsylvania State University, Department of Entomology and School of Forest Resources, University Park, PA 16802, USA

- *Method inspired by several articles measuring moisture in wood by sound*

- *Ex.: high power transducers at 140 kHz measuring remotely moisture in solid red pine samples*


25x100-mm lumber 100x100-mm lumber

Δu, ΔP



- *Red pine samples*

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RELATIONSHIP BETWEEN SPEED OF SOUND AND MOISTURE CONTENT OF RED OAK AND HARD MAPLE DURING DRYING

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(Received April 1998)

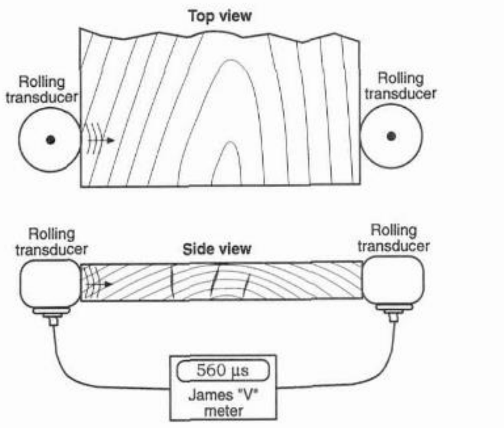

FIG. 2. Speed of sound transducer aligned for measurement across the width of a board.

Δu

- *oposite results of speed of sound dependence by contact method*

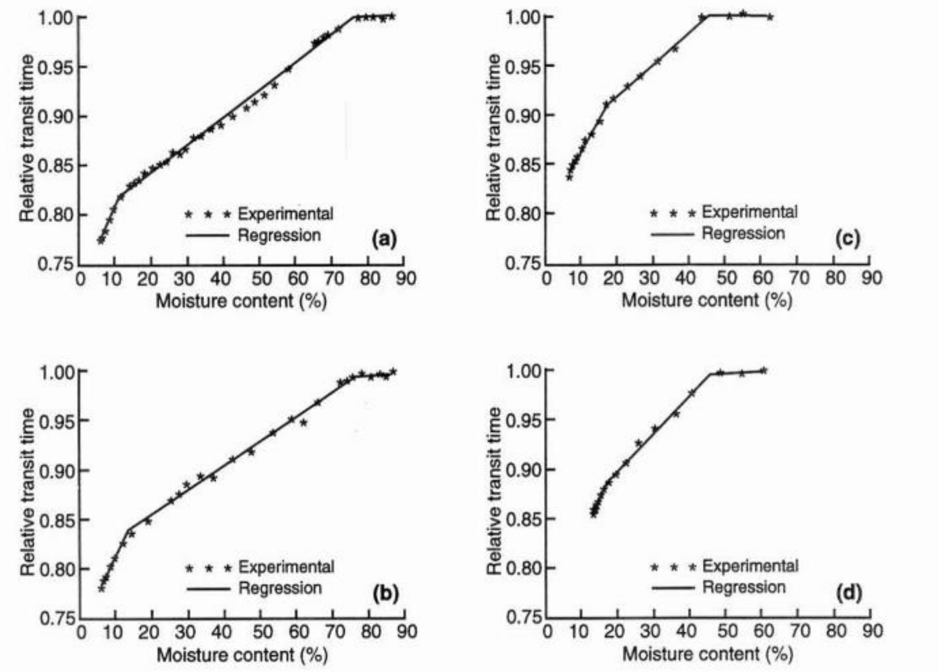

FIG. 5. Relationship between relative transit time and moisture content parallel to the grain for (a) red oak, Group 2; (b) red oak, Group 3; (c) hard maple (30% relative humidity), Group 4; and (d) hard maple (65% relative humidity),

- *Similar conclusions on red oak and hard maple*

State of the art

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Maderas. Ciencia y tecnología 17(2): 407 - 420, 2015
DOI:10.4067/S0718-221X2015005000038

INFLUENCE OF MOISTURE CONTENT ON THE WAVE VELOCITY TO ESTIMATE THE MECHANICAL PROPERTIES OF LARGE CROSS-SECTION PIECES FOR STRUCTURAL USE OF SCOTS PINE FROM SPAIN

M.J. Montero [1], J. de la Mata [1], M. Esteban [1,♠], E. Hermoso [2]

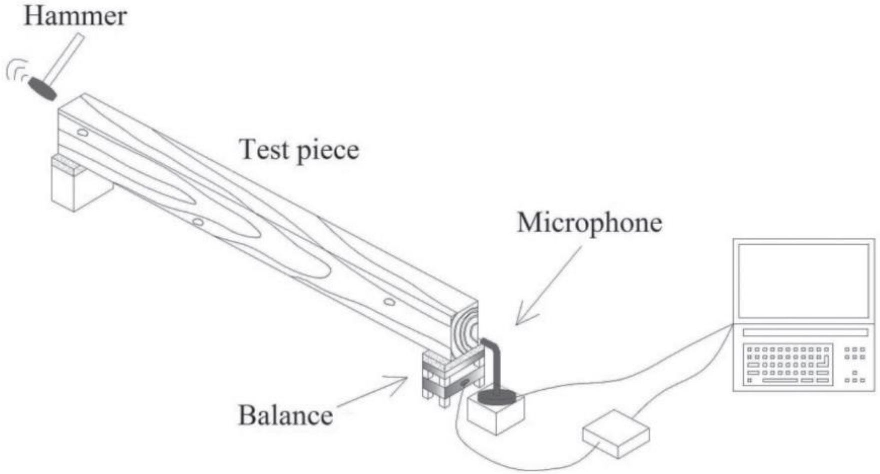

Figure 2. Test with Portable Lumber Grader equipment (de la Mata 2011).

Δu

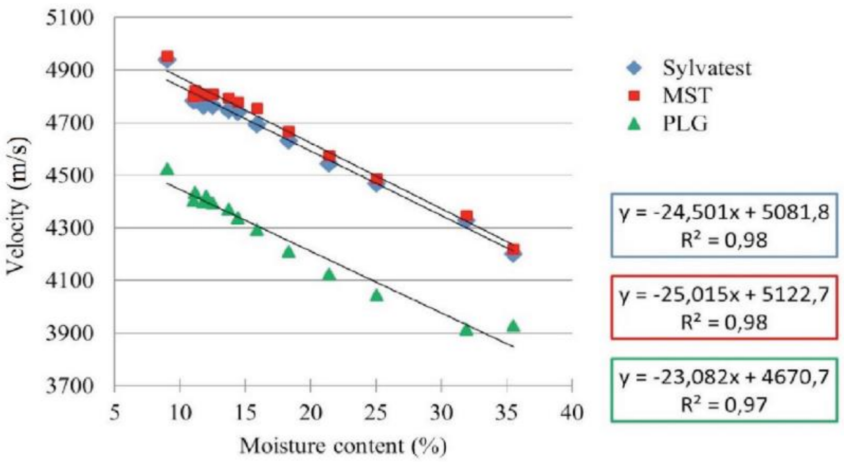

Figure 4. Linear relationship between the average values of propagation velocity and moisture content of the specimens for each set of equipment.

- *On Spanish Scots pine as well*

State of the art

Moisture Content Effect on Ultrasonic Velocity in *Goupia Glabra*

Fabiana Goia Rosa de Oliveira[a], Marcela Candian[b], Francieli F. Lucchette[b],*

*José Luis Salgon[b], Almir Sales[b]**

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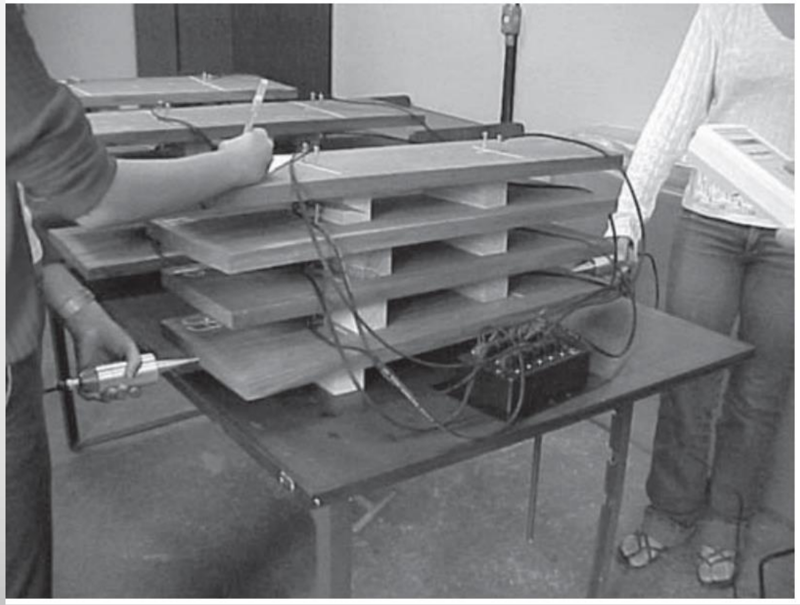
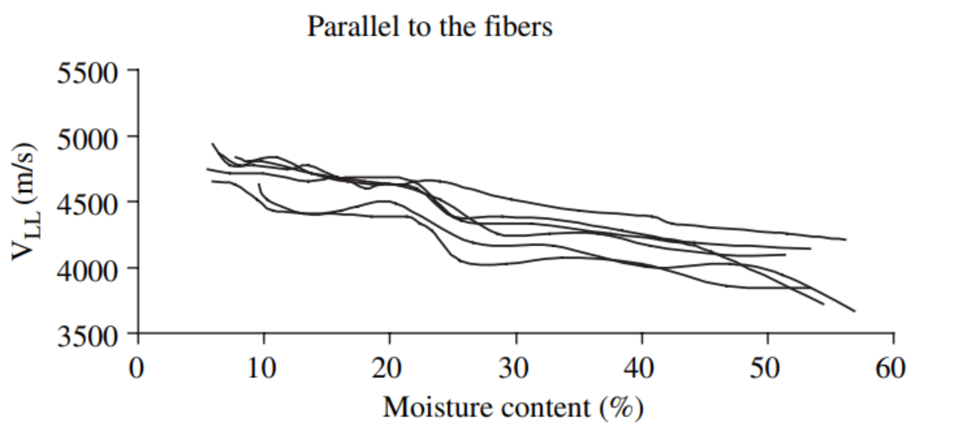
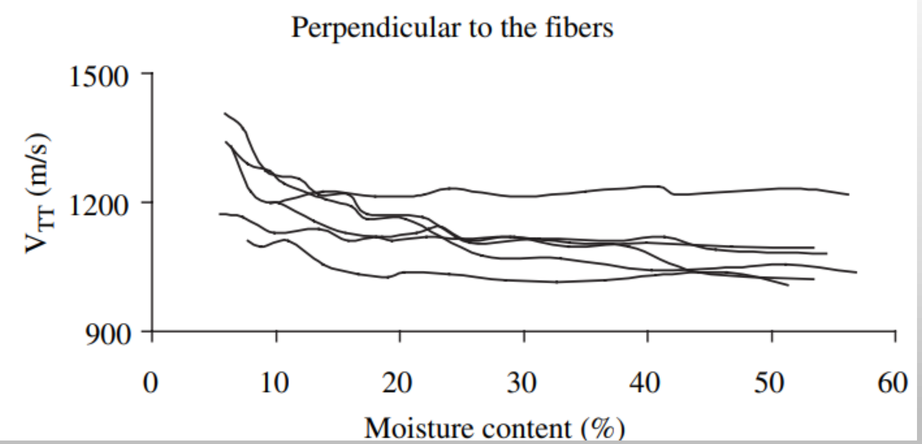
Received: June 10, 2003; Revised: January 10, 2005





Δu



- *Brazilian hardwood..*

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Building and Environment 40 (2005) 311–318
BUILDING AND ENVIRONMENT
www.elsevier.com/locate/buildenv

The effect of moisture content on sound absorption of expanded perlite plates

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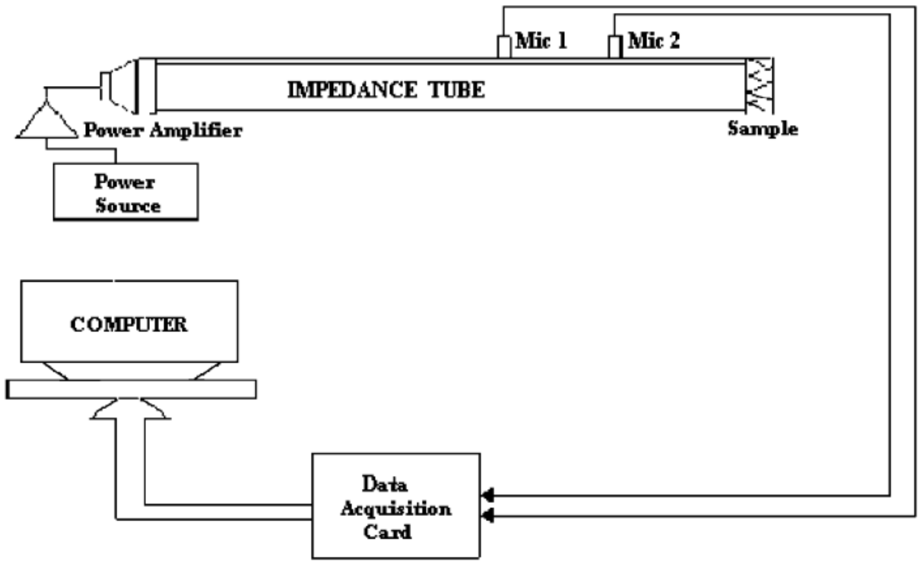


Fig. 3. System scheme of two-microphone impedance tube.

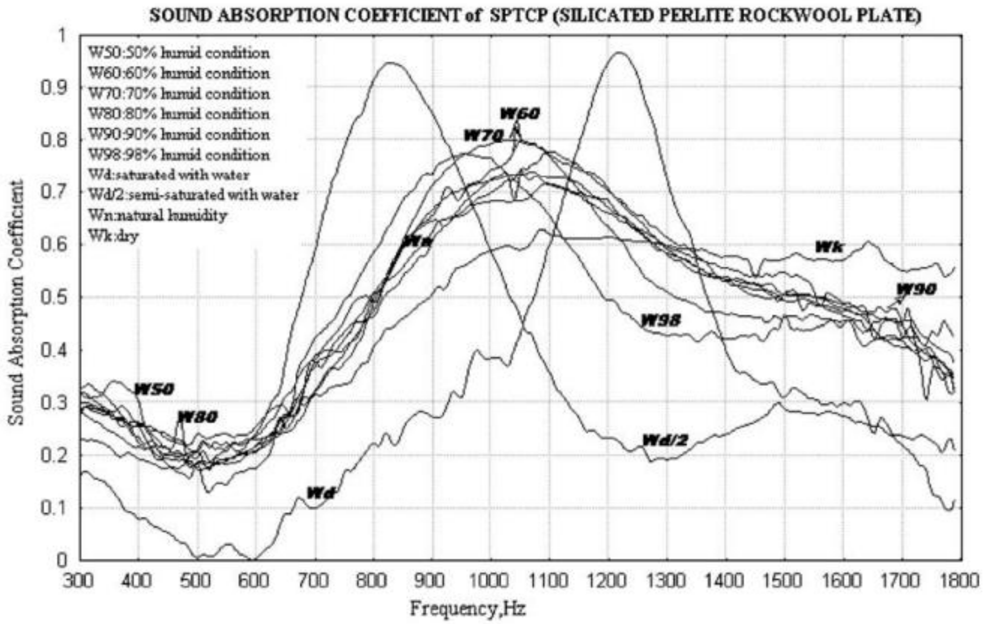
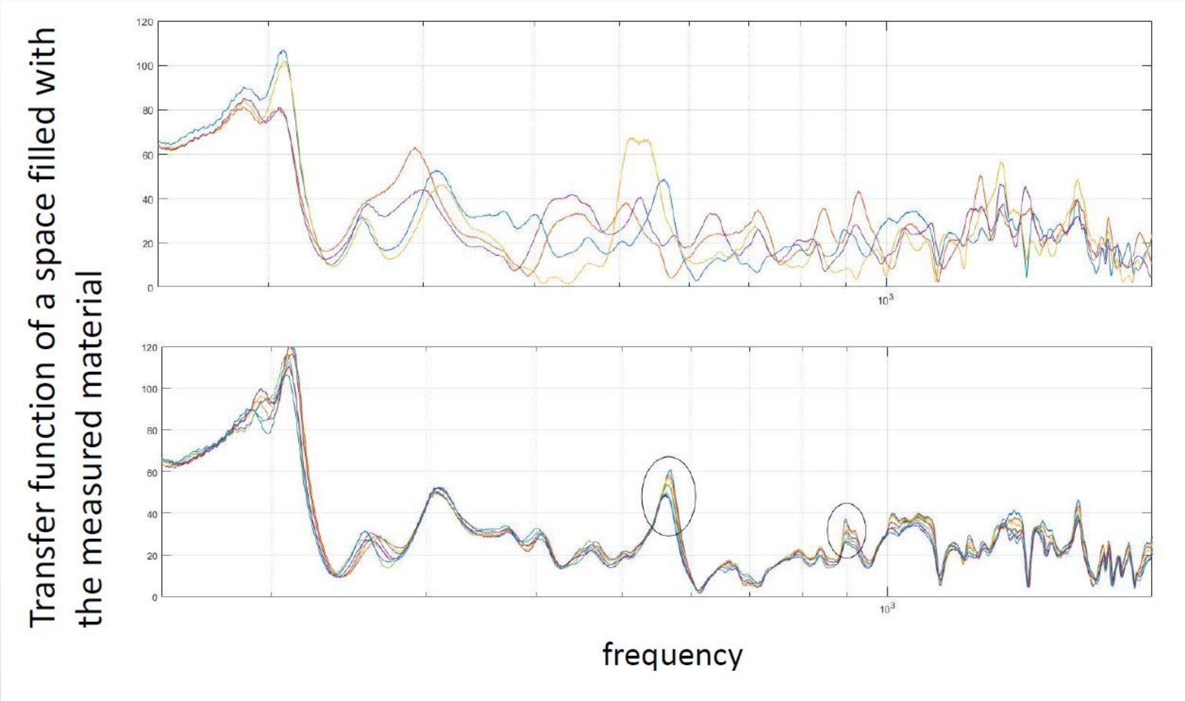


Fig. 8. Sound absorption coefficients of SPTCP (sodium silicate coated perlite–rock wool–cement plate).

ΔP

- ***Most promising method***
- *Moisture influence on attenuation*
- *Characteristics varying with f*

Experiments at CTU

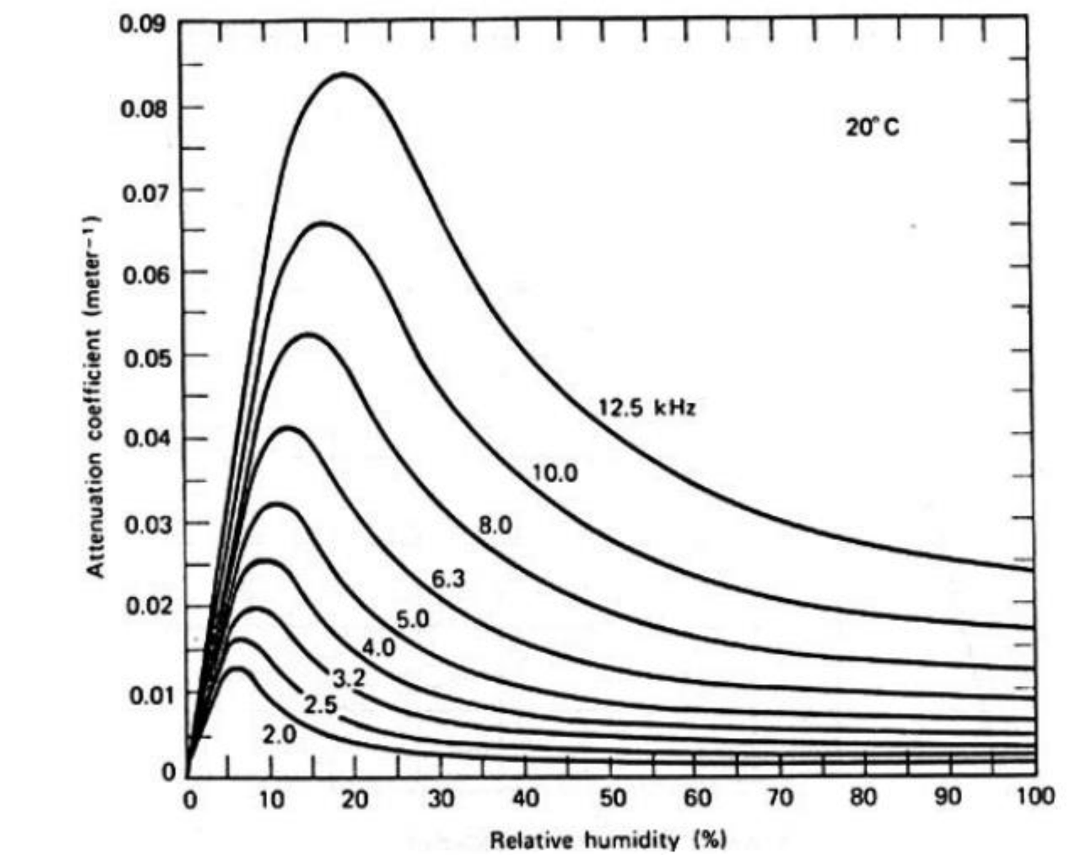


- *Similar experiment at CTU*

  ΔP at longitudinal resonances

Influence of temperature and humidity

- *Attenuation of sound depends in RH, changes with f and T*



ρ_d = 1.20479 kg/m^3 ,
ρ_v = 0.756182 kg/m^3

$$\frac{u_d}{u_v} = \sqrt{\frac{\gamma_d}{\gamma_v}\frac{\rho_v}{\rho_d}} \cong 0.813$$

$$u_{air} = \sqrt{\frac{\gamma RT}{M}} \cong 331.41 + 0.61 \cdot t$$

Longitudinal resonances in a cylinder

$$f_n = \frac{n \cdot (331.41 + 0.61 \cdot t)}{2 \cdot L}$$

Moisture and acoustic impedance

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For plane wave and perpendicular wave impact

$z_{\text{air}} = \rho_{\text{air}} u_{\text{air}}$

$z_{\text{solid}} = \rho_{\text{solid}} u_{\text{solid}}$

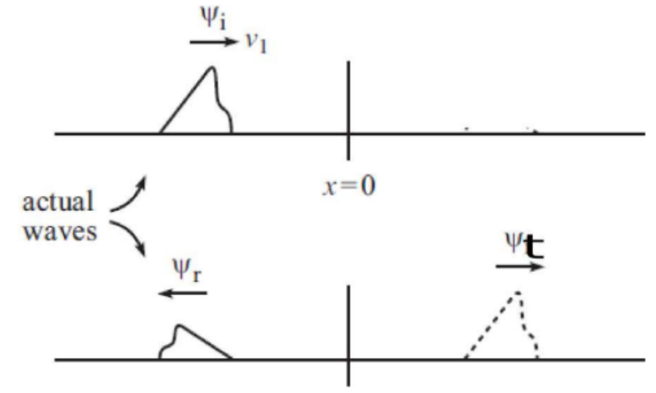

Figure 1. Incident, reflected and transmitted waves.

$$\psi_r = \frac{Z_1 - Z_2}{Z_1 + Z_2}\psi_i$$

$$\psi_t = \frac{2Z_1}{Z_1 + Z_2}\psi_i$$

- ***u*** *depends on moisture, humidity, temperature and frequency*
- *Another influences: angle of impact, pores, ..*

Acoustic Hygrometer

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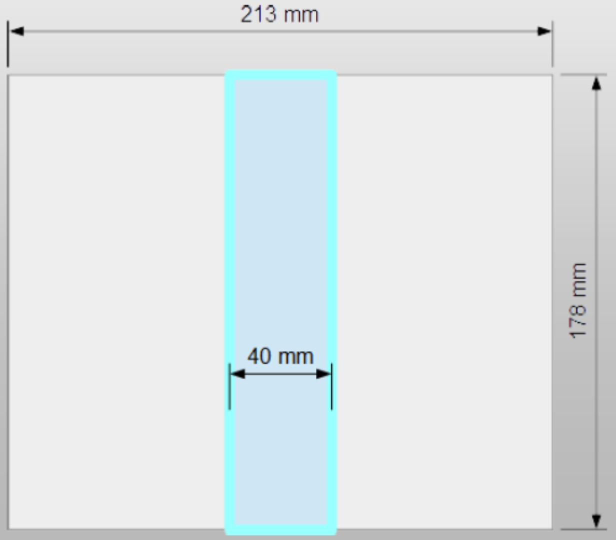
tion programme and the EMPIR Participating States

- *secondary method*
- *stainless steel container*
- *tight enclosure*
- *compact*

Sampling chamber

- Volumes
  - Total ≈ 6,34 l
  - Inner cylinder ≈ 0,22 l



as for MW technique

Acoustic Hygrometer

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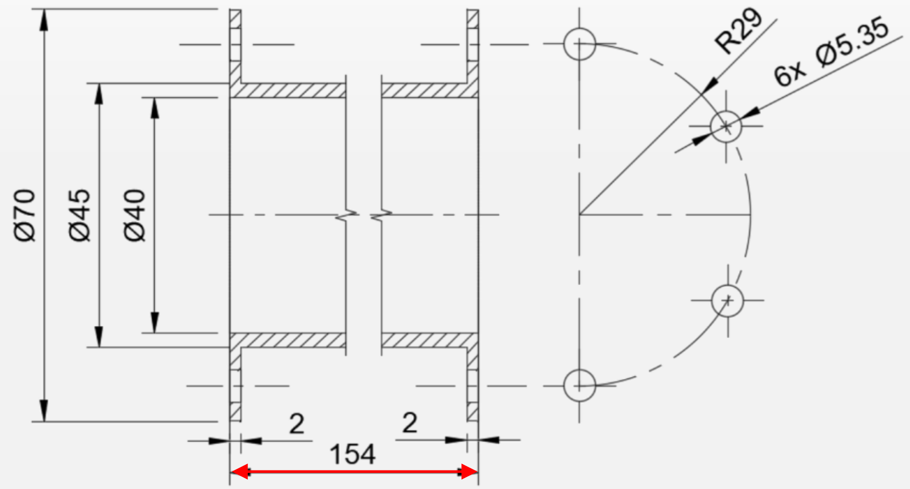


- *Axial resonance modes of higher magnitude than radial ones*

$$f_n = \frac{n \cdot u}{2 \cdot L}$$

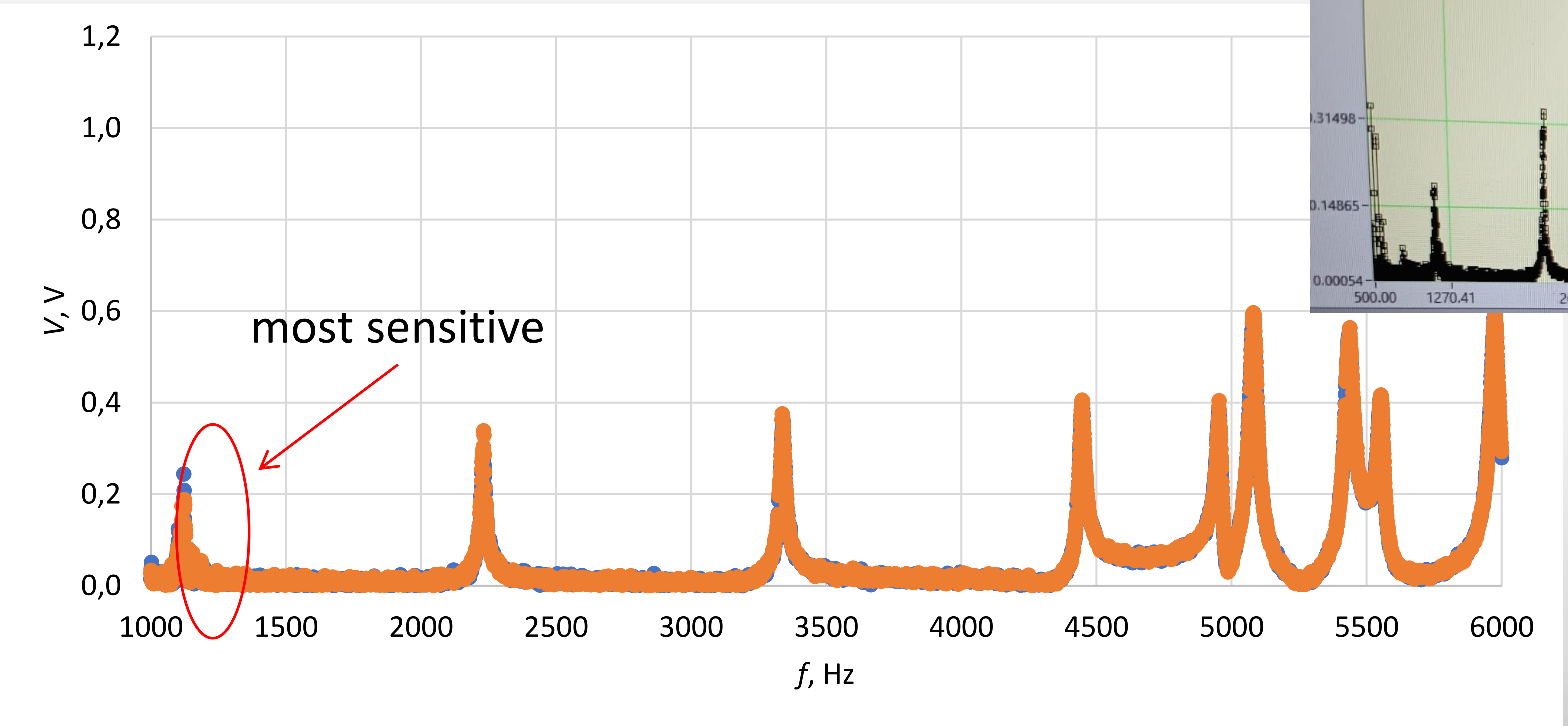
- *Expected* ***longitudinal*** *acoustic modes* ***of unloaded cavity*** *at 23 °C close to (1122, 2243, 3365, 4486, 5608) Hz*

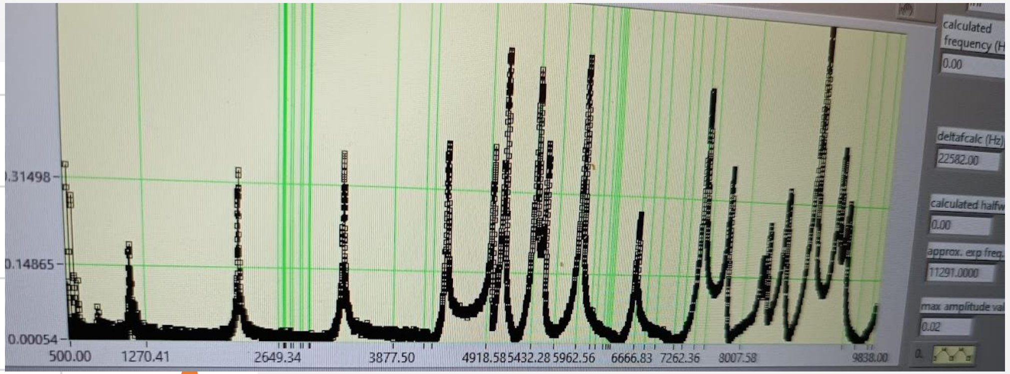
L is the inner length of the cavity and *n* = 1, 2, 3, …

$$u_{air} = \sqrt{\frac{\gamma RT}{M}} \cong 331.41 + 0.61 \cdot t \quad \longrightarrow \quad f_n = \frac{n \cdot (331.41 + 0.61 \cdot t)}{2 \cdot L}$$

Acoustic Hygrometer

- *Expected* ***longitudinal*** *acoustic modes* ***of unloaded cavity*** *at 23 °C close to (1122, 2243, 3365, 4486, 5608) Hz*





- *Measured* ***longitudinal*** *acoustic modes* ***of unloaded cavity*** *at 23 °C around (1122, 2233, 3337, 4447, -) Hz*

Measurement of reference wood chips from DTI

- *Traceable to LoD and evolved LoD method*

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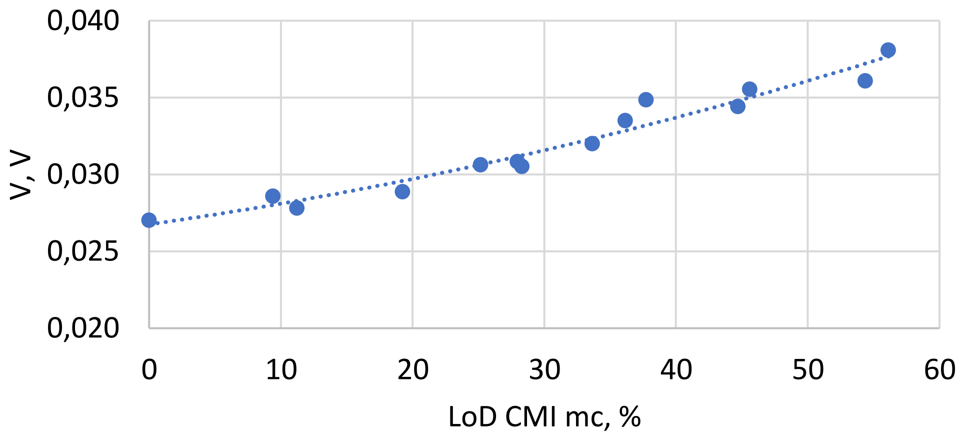

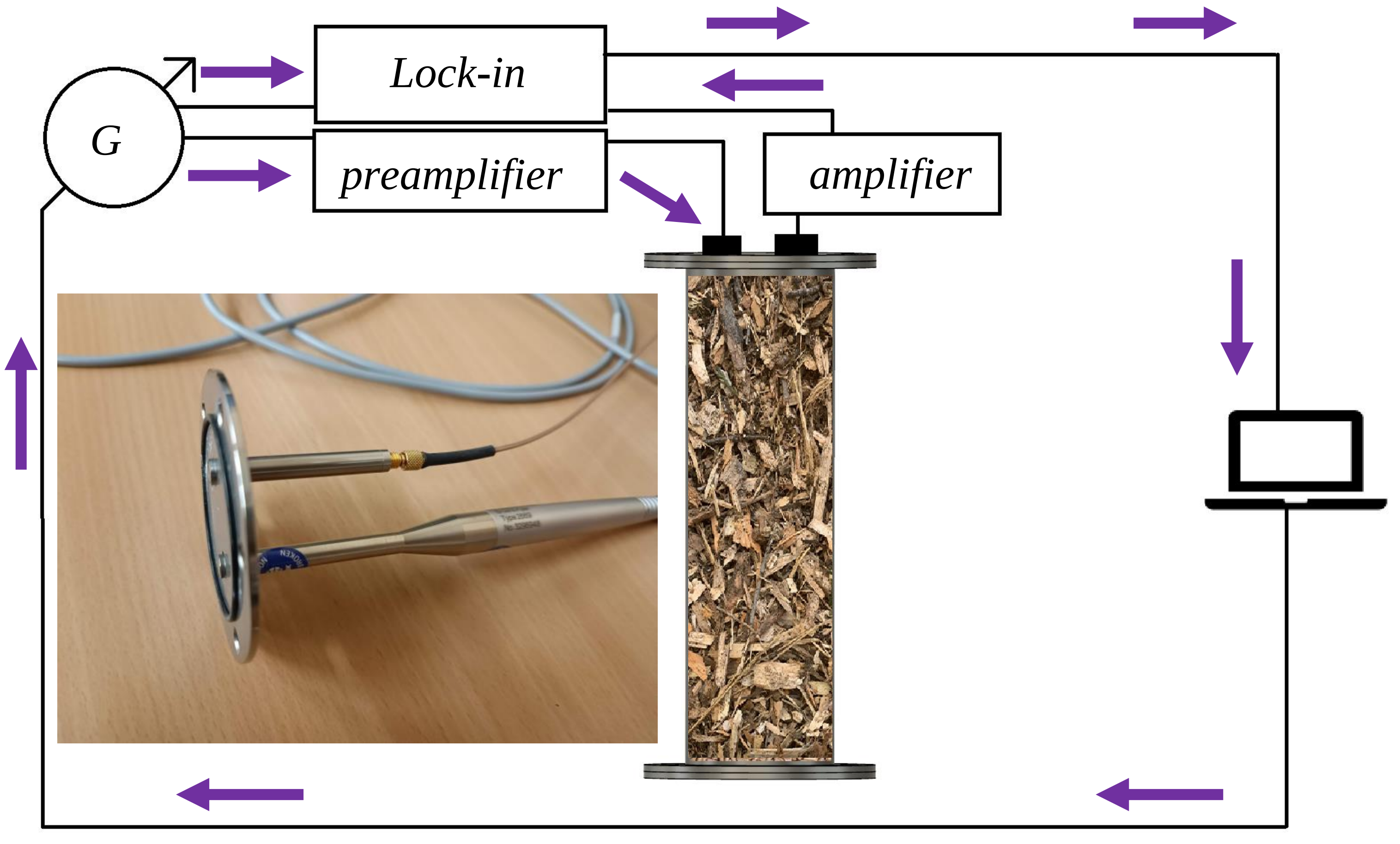

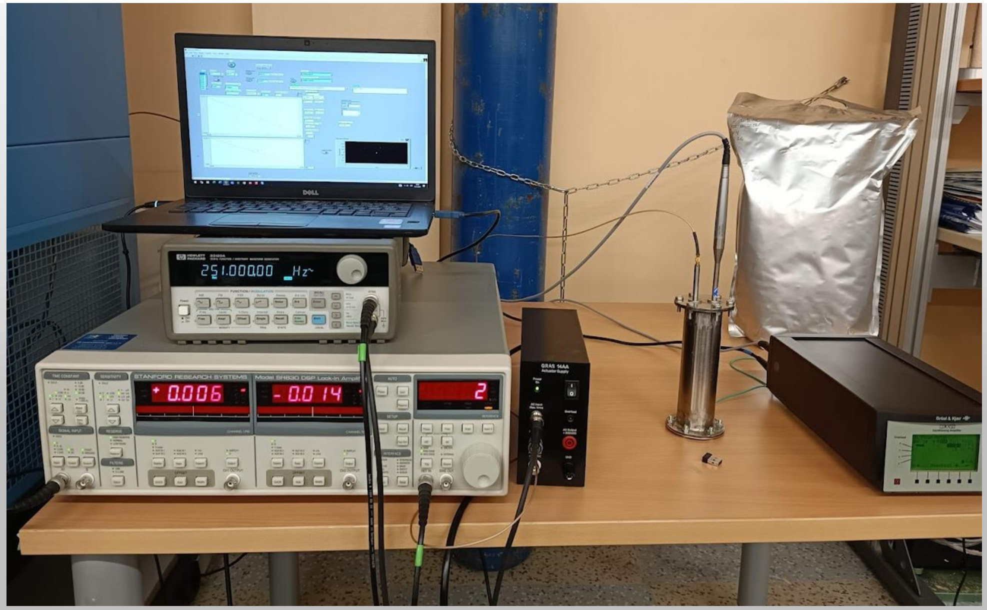

Portable system for common measurements

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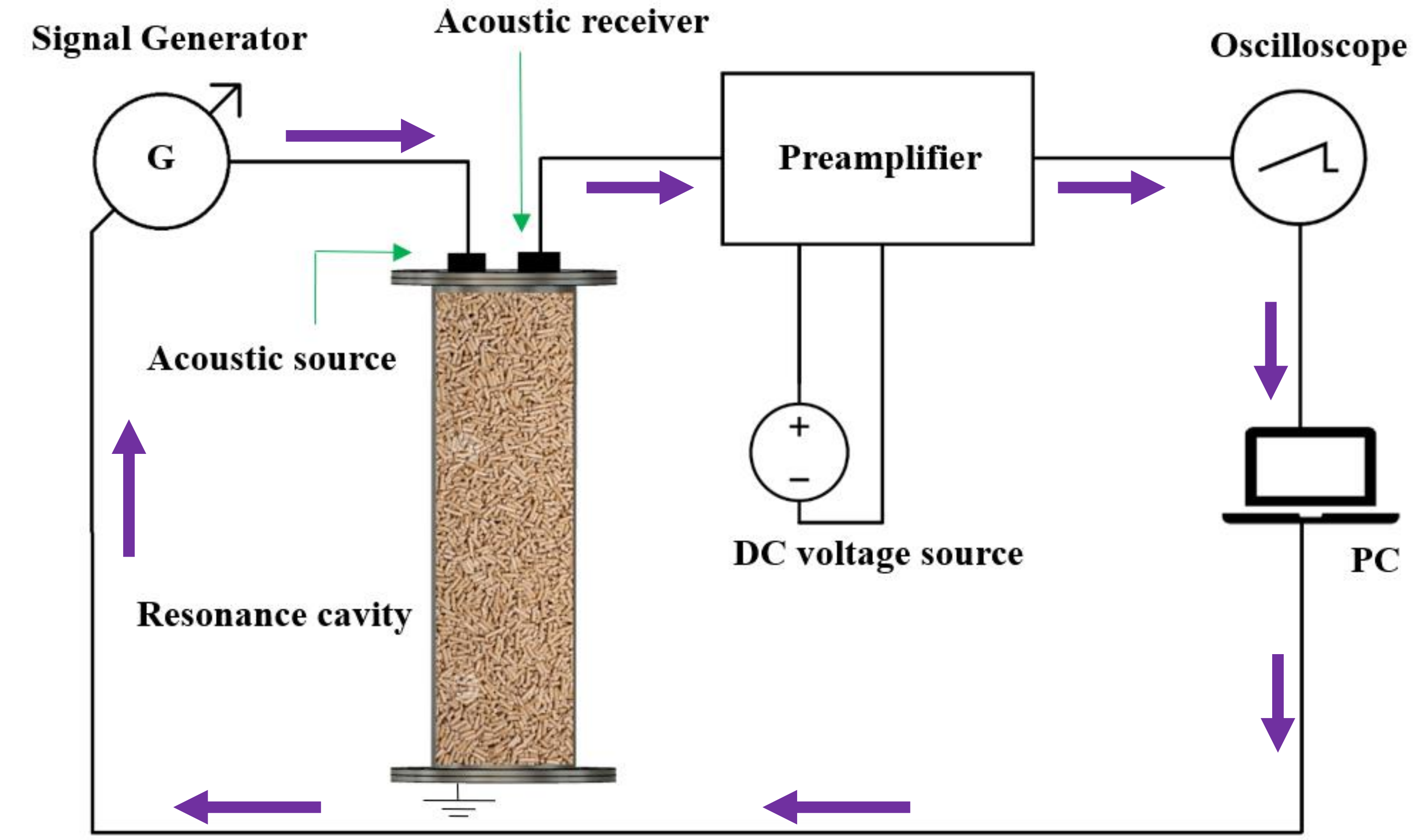

Calibration at CMI by LoD method

Woodchips:

- produced by *AGRO CS a. s.* company
- originally purposed as a drainage layer for raised flowerbeds
- **made of natural, chemically untreated coniferous wood** (of unspecified type)
- only mechanically "chipped" into small pieces
- Their coarse structure with sufficient non-capillary pores ensures increased permeability to air and water

Wood pellets:

- (of unspecified wood type) produced by *Dřevovýroba HEPA, s.r.o* company
- According to the producer, **purely natural pellets**
- compressed under a pressure of 1220 $kg \cdot m^3$, and thus are produced completely without adhesives and chemicals

Both materials are commonly available at local DIY shops and are distributed in closed plastic bags.

Traceability – reference dry samples

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- *Loss-on-Dry method*

- *Drying < 24 h @ 105(±2) °C*

$$MC(\%) = \frac{m_{initial} - m_{dried}}{m_{dried}} \cdot 100$$

- *Traceable to SI unit **kg** through calibrated balance*

According to ISO 18134-3:2015

Traceability – moistening the samples

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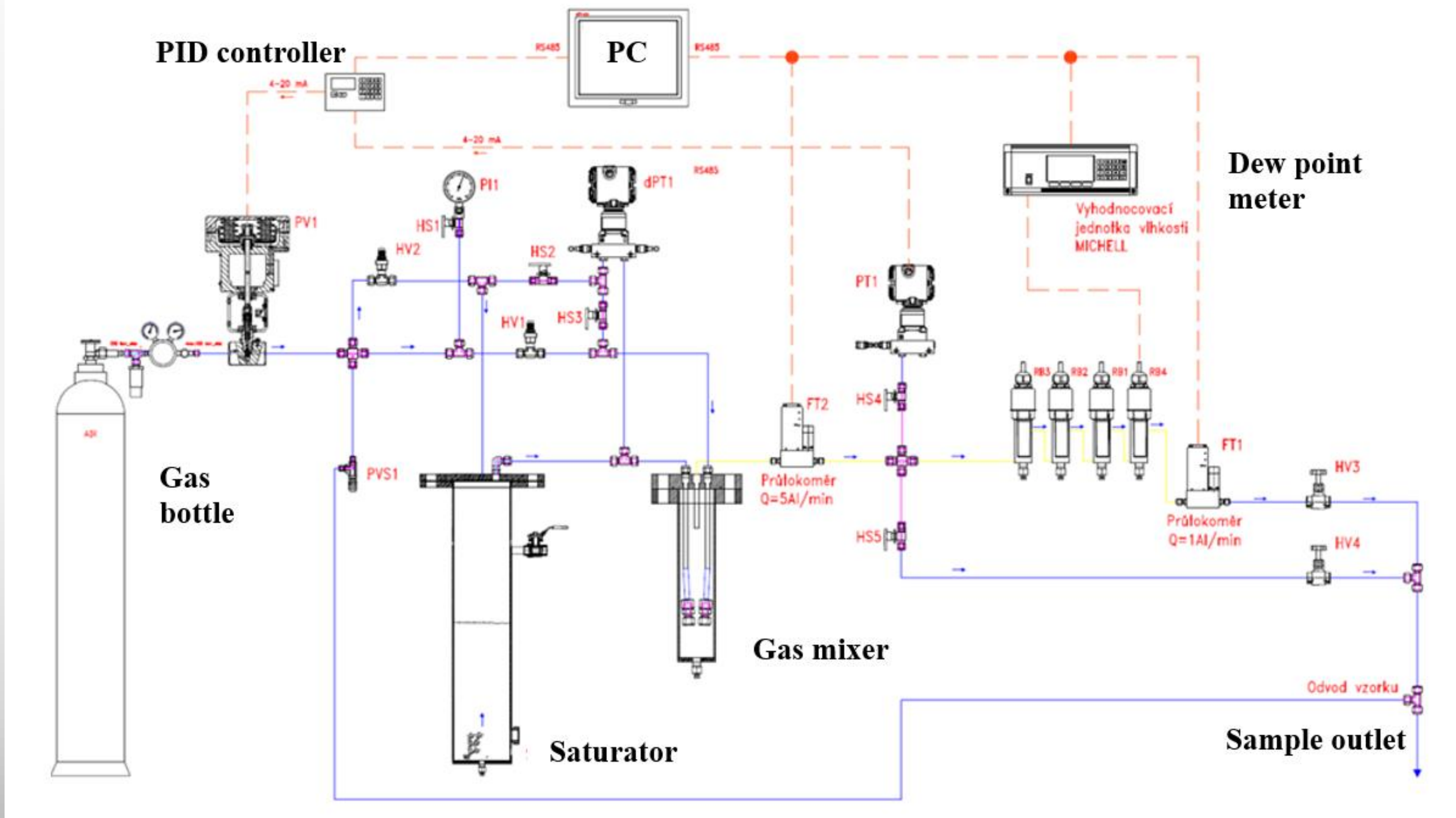

Figure 2: Principal scheme of humidity generator

Traceability – moistening the samples

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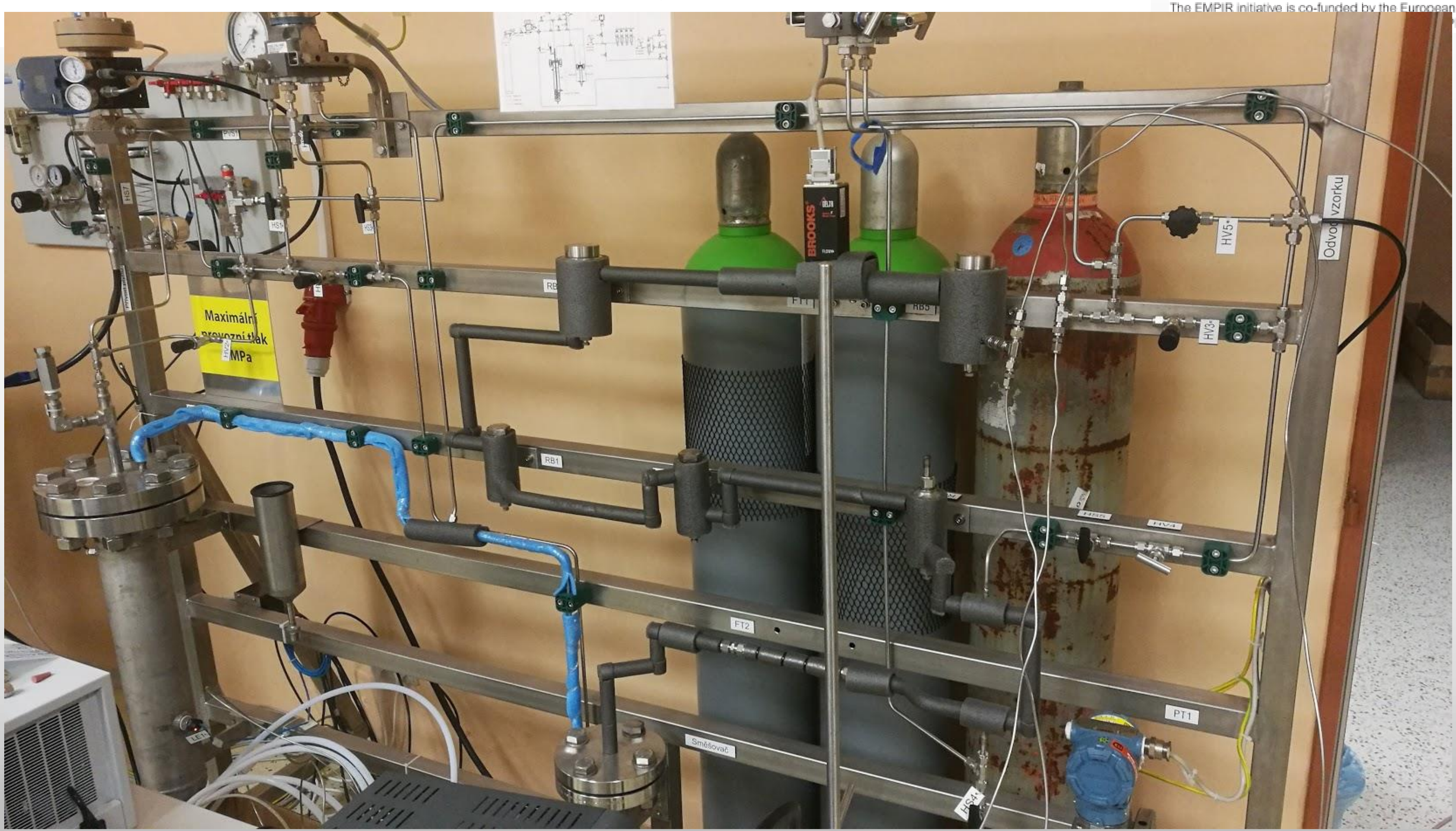

Samples directly inside the container

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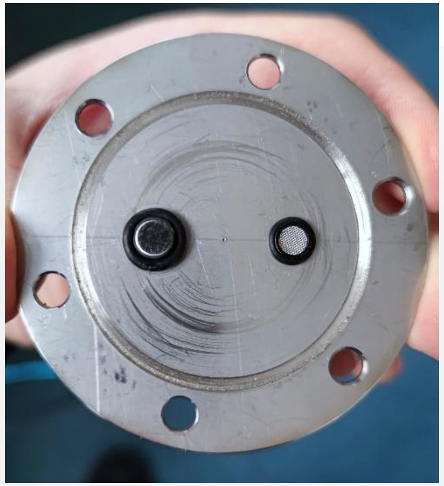

- *Shaking when filling*

Portable version

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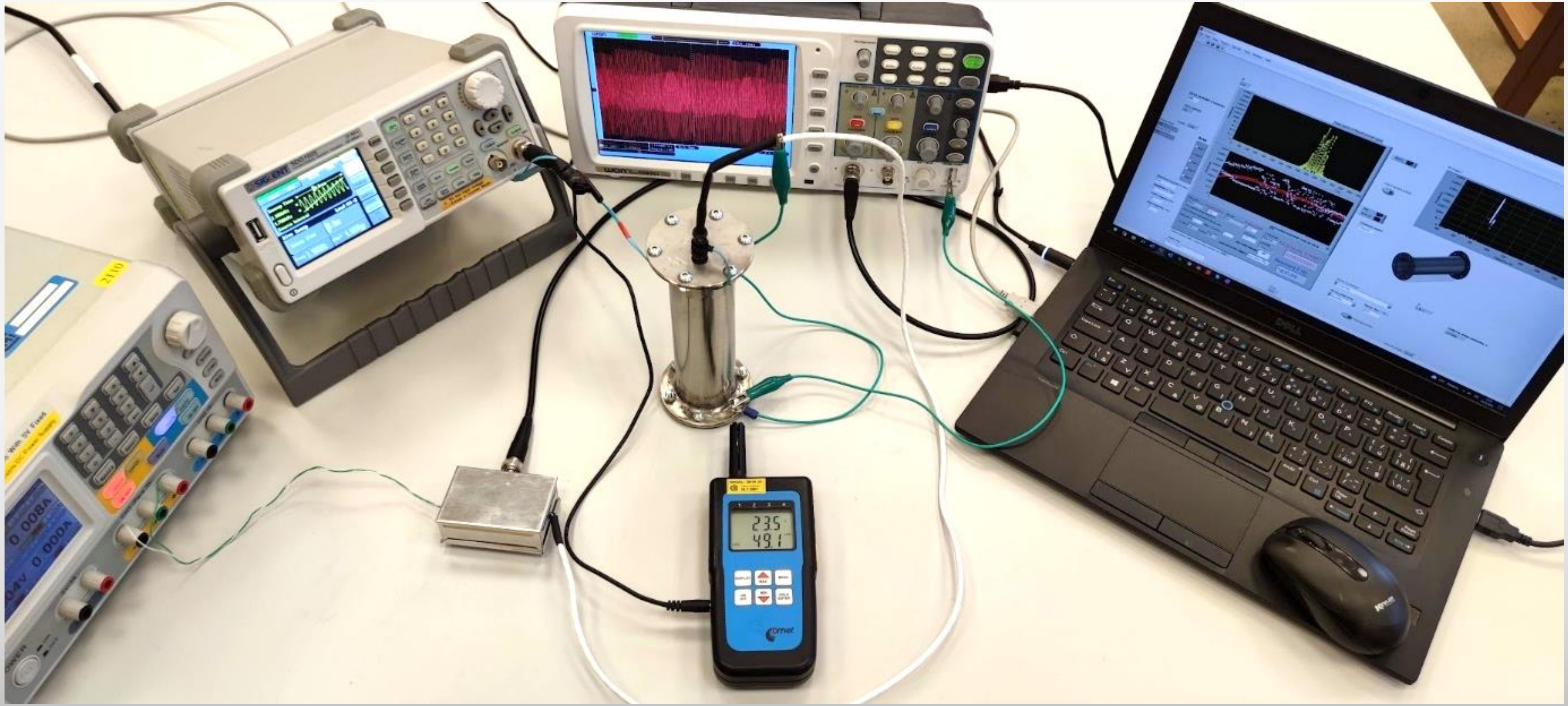

- *One button measurement*
- *Portable measurement system*
- *No qualified person needed for measurement*

Stabilisation time necessary < 30 min

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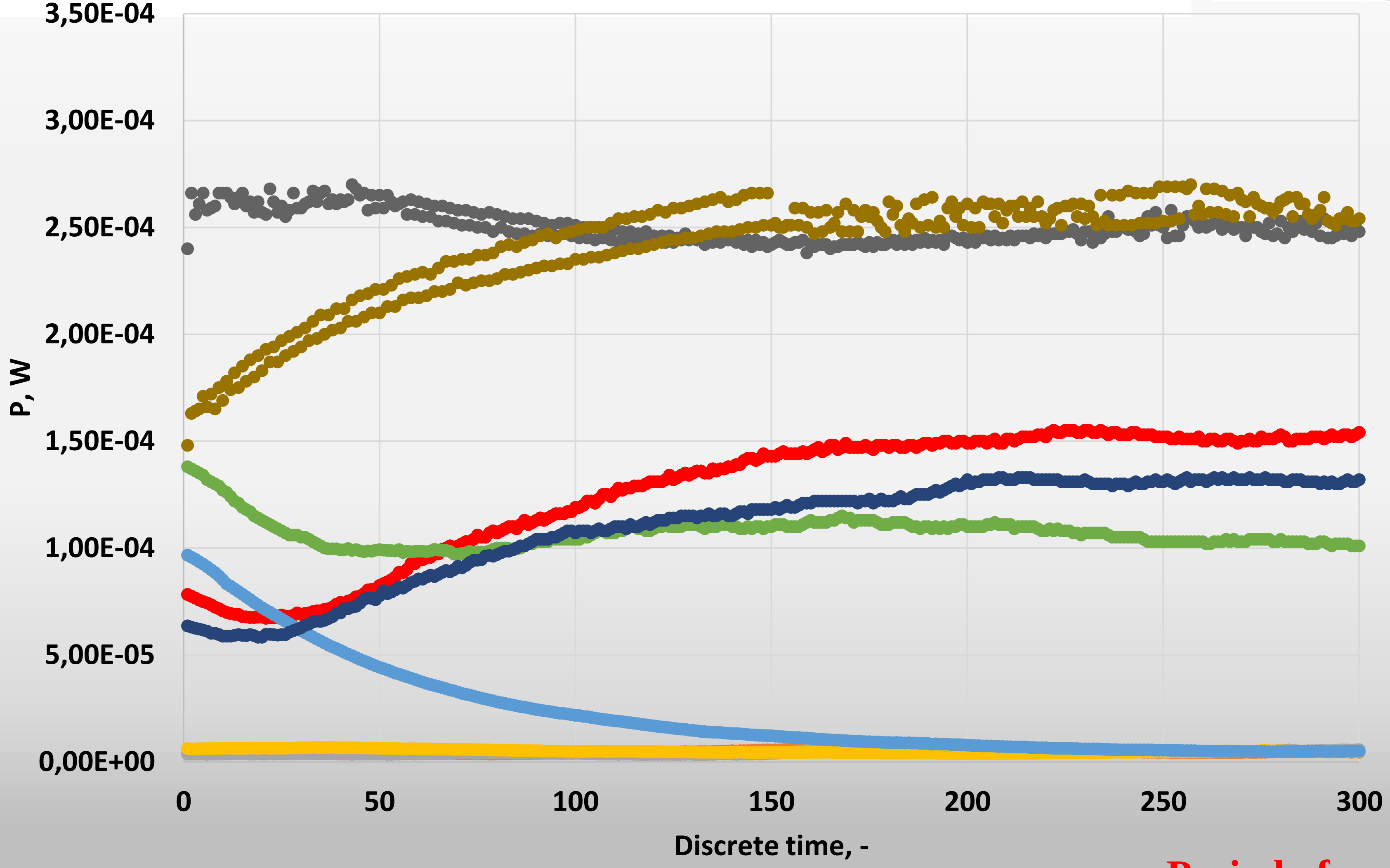

- Period of reading ~ 6 s

Stabilisation time necessary < 30 min

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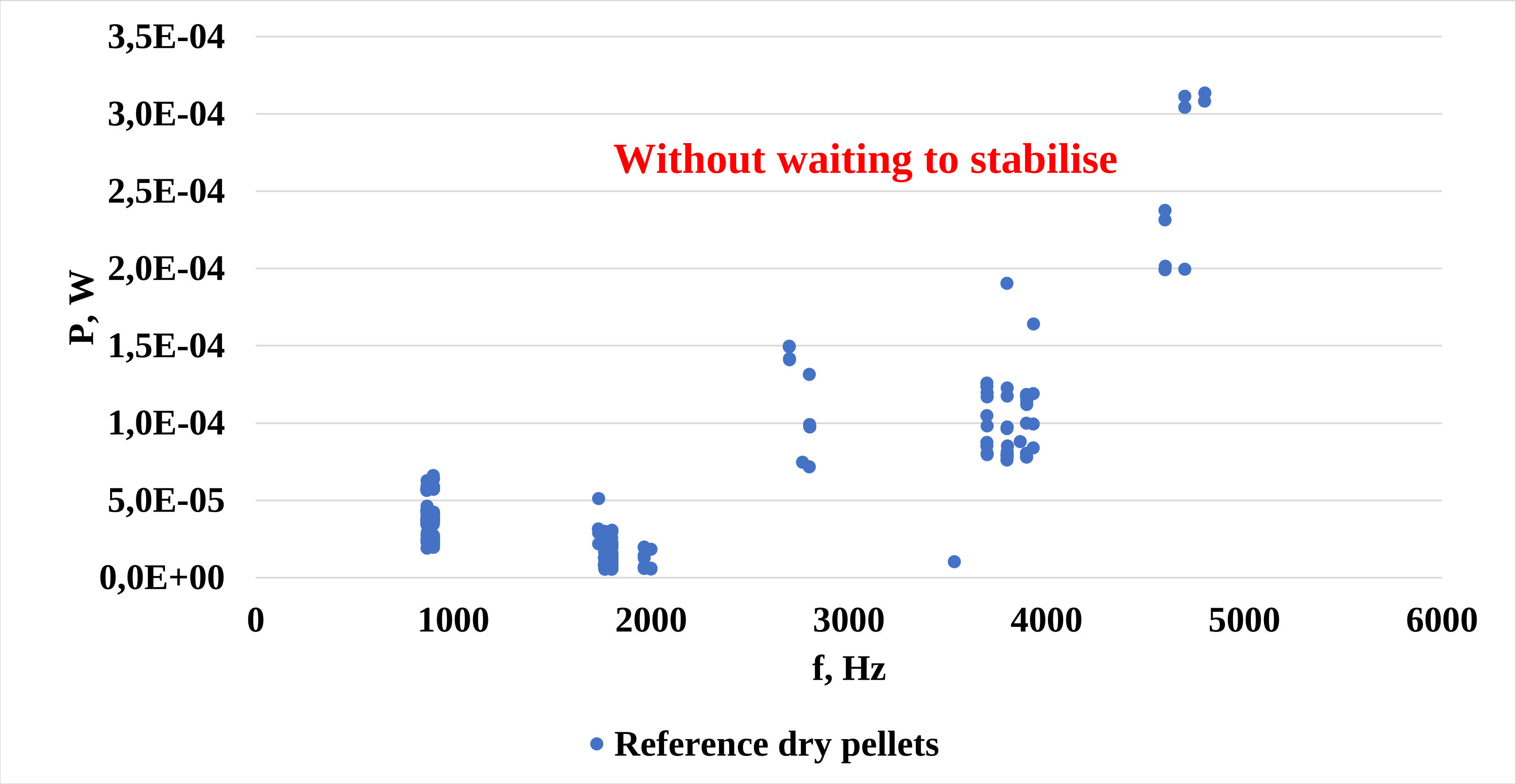

- *F shift due to T, gas composition, thermal expansion, p*

Measurement results

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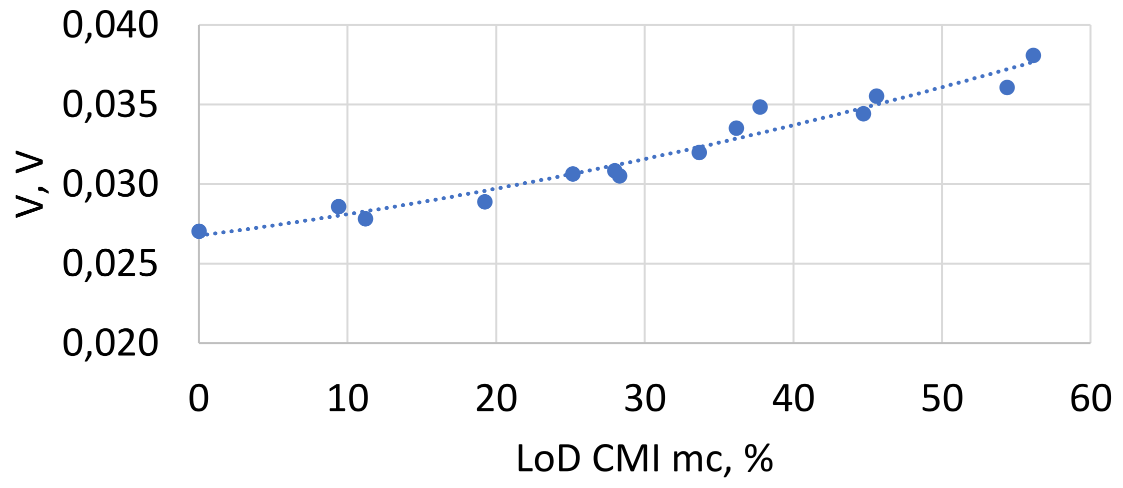

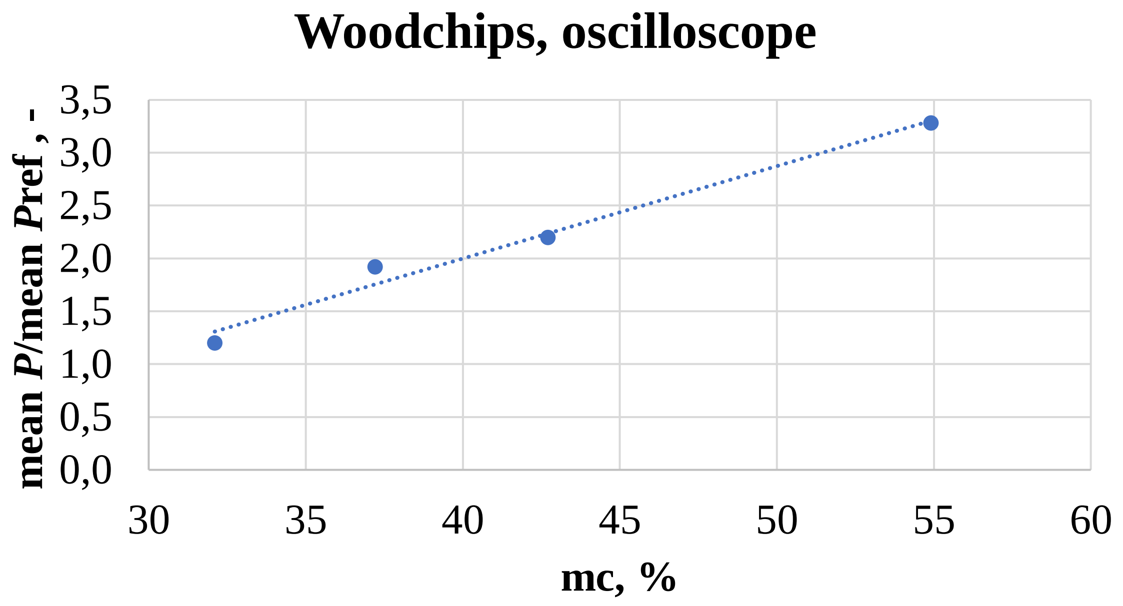

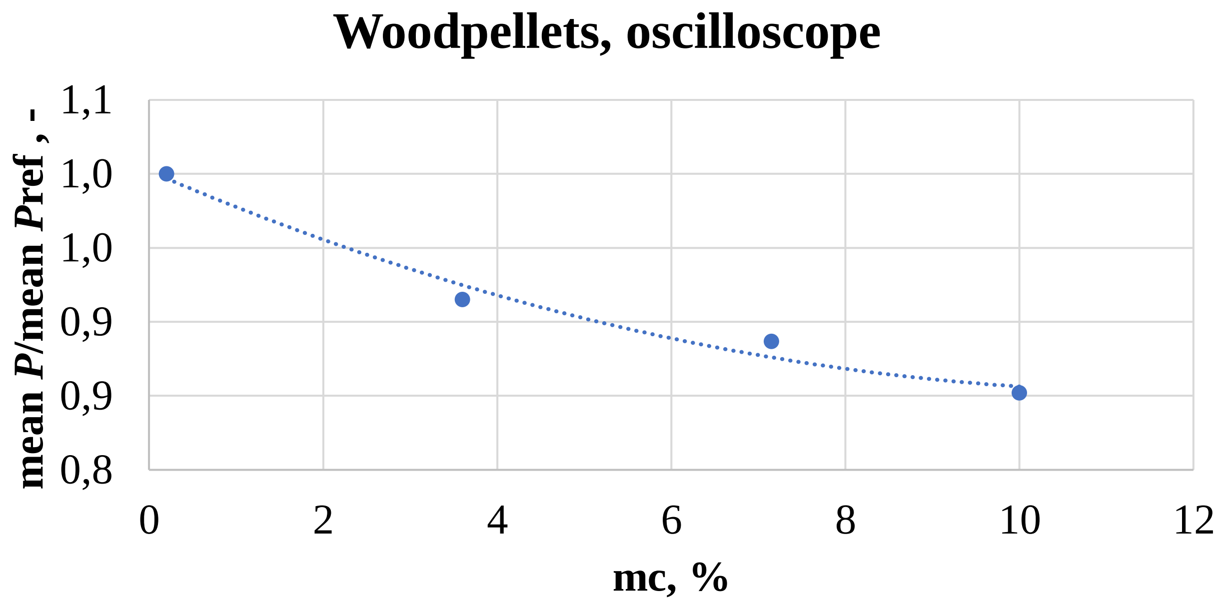

Interlaboratory comparison

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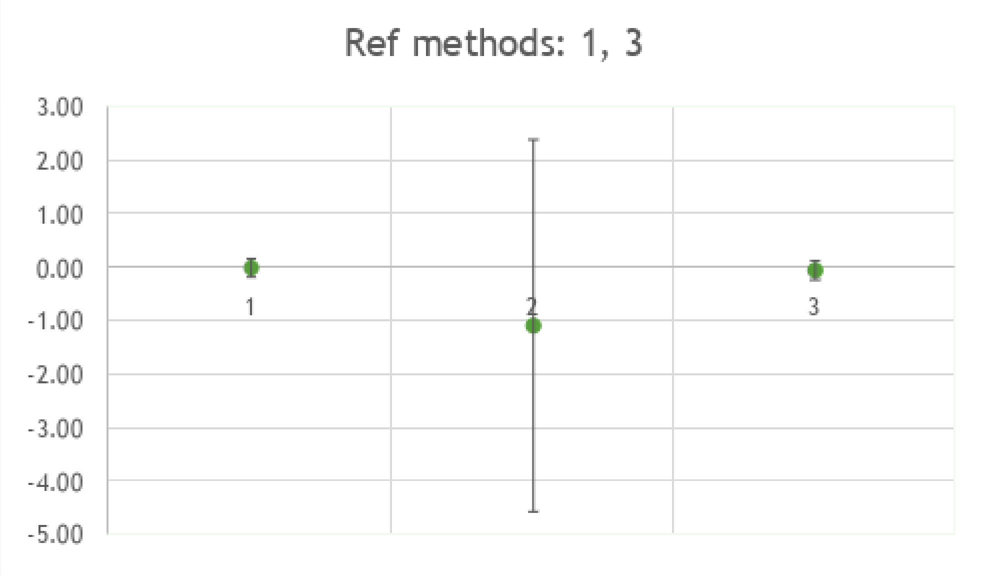

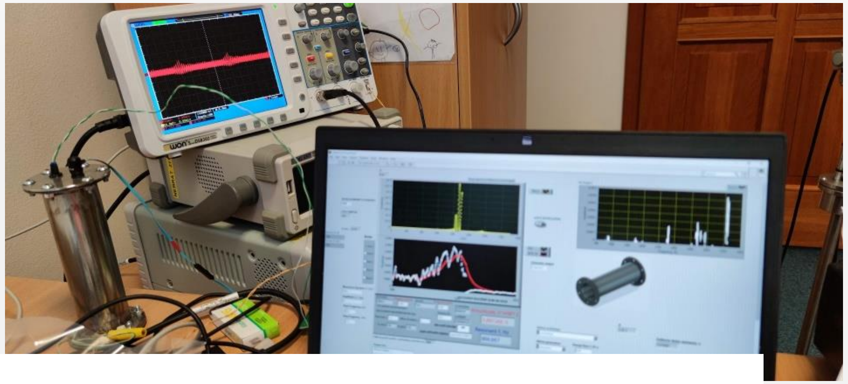

19ENG09 BIOFMET

biofMET EURAMET

INTERLABORATORY COMPARISON OF MOISTURE MEASUREMENTS WITH BIOMASS RELEVANT SAMPLES

COMPARISON PROTOCOL
Version v0.1 (draft)

Background

In accordance with the project protocol of the 19ENG09 BIOFMET project, the relevant partners of the JRP-Consortium will arrange an interlaboratory comparison of moisture measurements with biomass relevant samples (T1.4) in 2022. It was agreed in the meeting (online) of DTI, CMI and CETIAT 3/4 2021 that wood pellets are used as the samples in the first round of this comparison, because they have been found relatively stable and homogeneous. DTI, CETIAT and CMI will take part in the comparison.

Conclusion

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Secondary method

- *One button measurement*
- *Article will be sent for Review in April*

Future work:

- *Characterisation in climate chamber at various temperatures (+ machine learning?) and pressures*

-> change in construction based on characterisation results

PORTABLE MOISTURE MEASUREMENT BY ACOUSTIC MANNER USING STAINLESS STEEL CYLINDRICAL RESONATOR

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[b] *Department of Radio Engineering, Faculty of Electrical Engineering, Czech Technical University, Technická 2, 166 27 Praha 6, Czech Republic*

Abstract This article describes the experimental device for the determination of water content in wooden pellets and woodchips by measuring the power loss at several acoustic resonance modes. The apparatus was developed in the framework of Project 19ENG09 BIOFMET, funded by the EURAMET.

Several longitudinal acoustic resonance modes are excited in the cylindrical waveguide. Such a sound field arises as a result of sweeping the frequency of the waveform generator that includes eigenfrequencies of the resonance cylinder. The power at each longitudinal mode is then derived from the data record of the response from the microphone.

The metrological traceability was performed by the loss on dry method supported by calibrated balance. Woodchips and wood pellets were used as moisture transfer standards, covering together calibration points of 32.1 %, 37.2 %, 42.7 %, 54.9 % at wood chips, 3.6 %, 7.15 %, 10 % for wood pellets and reference dry samples of 0 % for both types.

The stainless-steel cavity served as a container for measured samples. The ratio of power measured by an acoustic receiver at specific sample moisture to power measured at reference dry sample, at various resonance frequencies is dependent on the content of moisture in a sample. Construction, the principle of operation and uncertainty estimation are also discussed in this paper.

Keywords: Biofmet, Moisture, Water content, Acoustic cylindrical resonances, Woodchips, Wood pellets.

1. Introduction

One of the most important properties of solid biofuels is moisture. As mentioned, e.g., by [1] and [2], it affects its dimensional stability, biodegradability and many other chemical and physical attributes. According to [2], the moisture dependency of these properties has consequences on many areas of industry.

SI traceable absolute methods of measurement such as The loss-on-drying (LOD) (see [3], [4] and [5]) and the Karl Fischer method (see [6]) take always not negligible time to obtain results and require specific environmental conditions and specialized equipment. On the other hand, conventional indirect ("inferential") measurement methods are usually faster, but need traceability to primary methods, and can be sensitive to the surrounding environment, type of substances and ranges of measurement (as mentioned in [7], [8] and [9]).

Thank you for your attention!

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