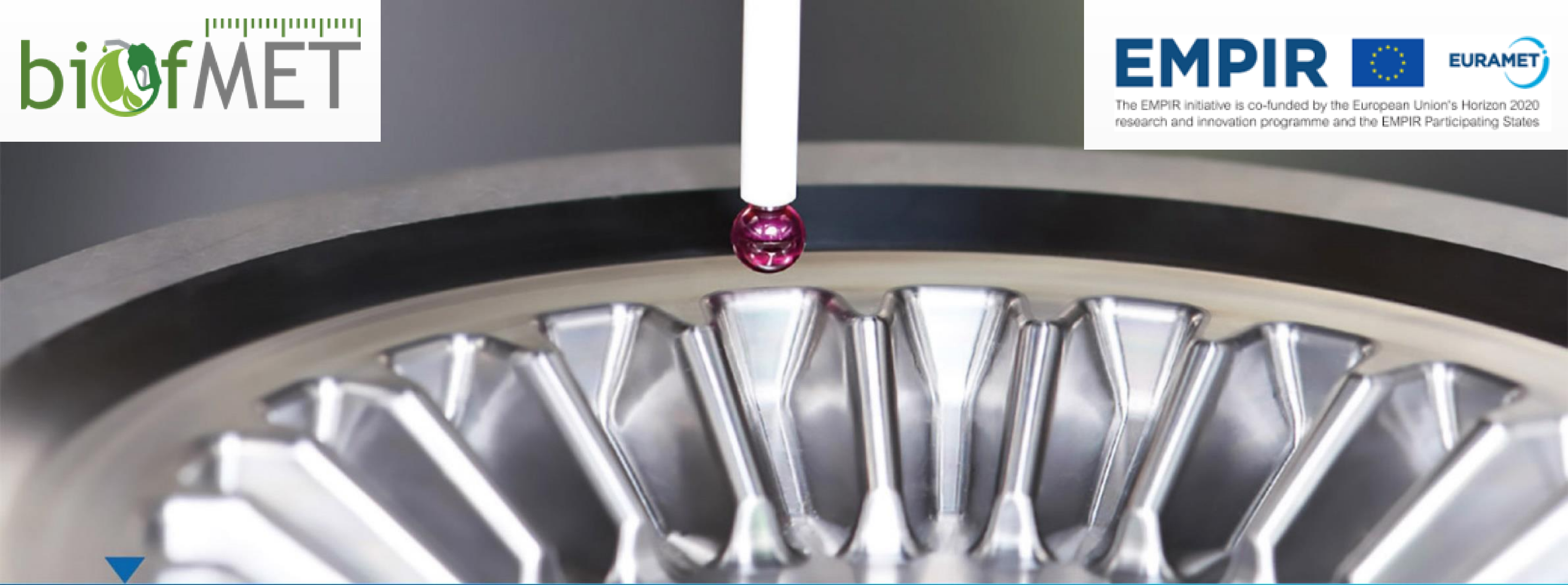


The EMPIR initiative is co-funded by the European Union's Horizon 2020 research and innovation programme and the EMPIR Participating States

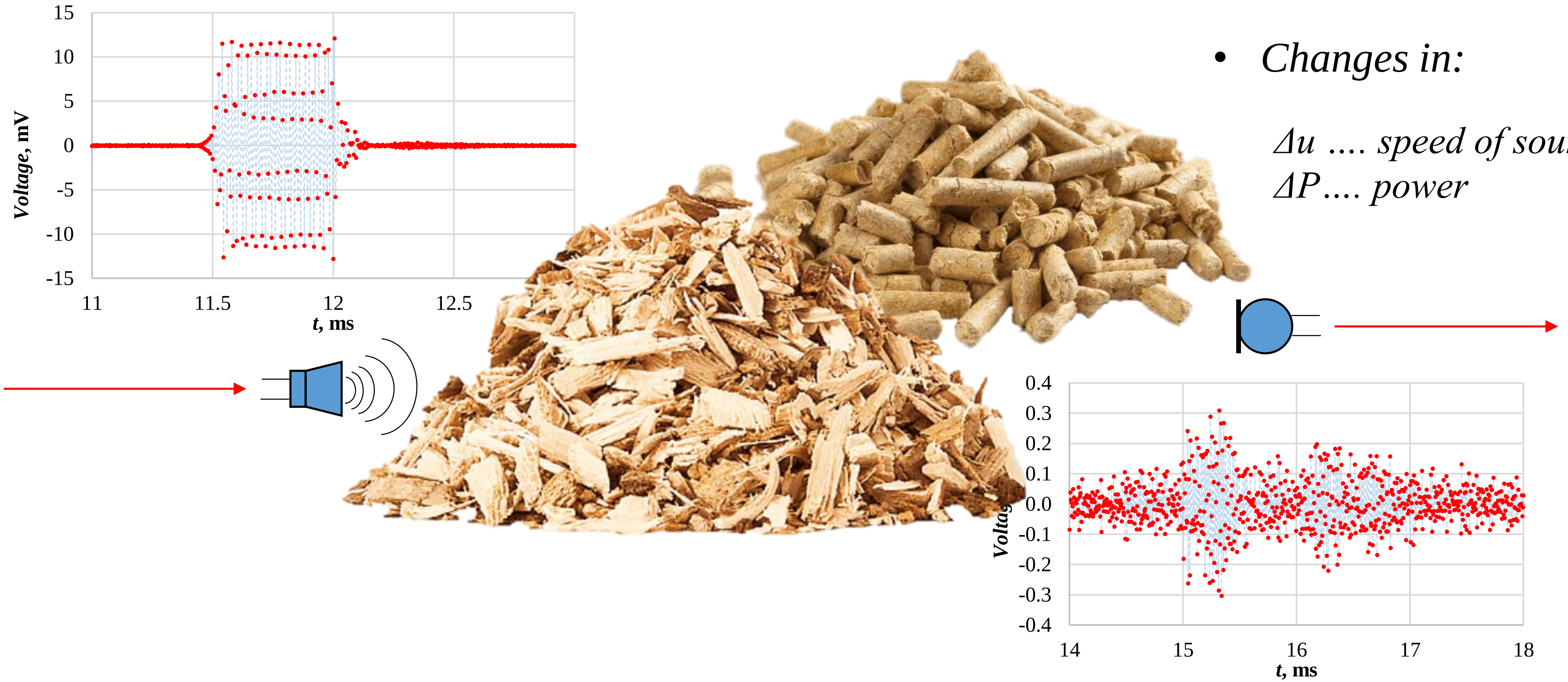
Development of acoustic hygrometer at CMI

June 2nd, 2022

Michal Voldán, mvoldan@cmi.cz

Objectives

- *To measure moisture in wood chips and wood pellets by sound with target uncertainty of 5 %*



- *Changes in:*

  Δu .... speed of sound
  ΔP.... power

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

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K. HOOVER[2]
J. JANOWIAK[2]
M. BHARDWAJ[2]

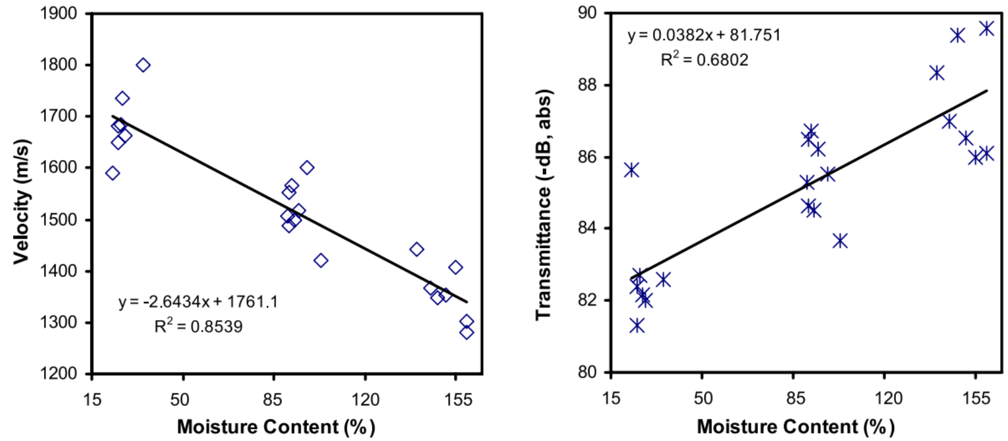
Calibration of non-contact ultrasound as an online sensor for wood characterization: Effects of temperature, moisture, and scanning direction

[1] Former applications/research engineer of The Ultran Group, Head, Division of Advanced Products Development and Research, State College, PA 16801, USA
[2] Pennsylvania State University, Department of Entomology and School of Forest Resources, University Park, PA 16802, USA

- *High power transducers at 140 kHz*

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)

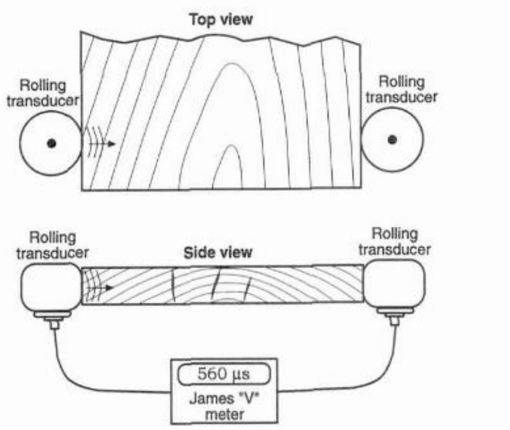

FIG. 2. Speed of sound transducer aligned for measurement across the width of a board.

Δu

- *Red oak and hard maple*

- *Similar results on speed of sound*

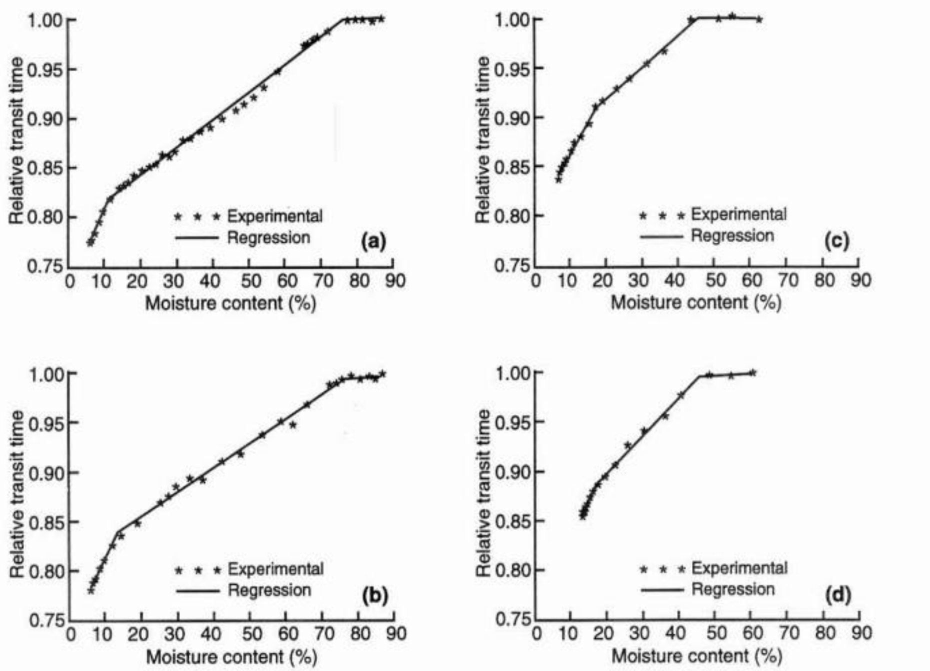

FIG. 5. Relationship between relative transit time and moisture content parallel to the grain for (a) red oak, Group 2; (b) red oak, Group 3; (c) hard maple (30% relative humidity), Group 4; and (d) hard maple (65% relative humidity),

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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]

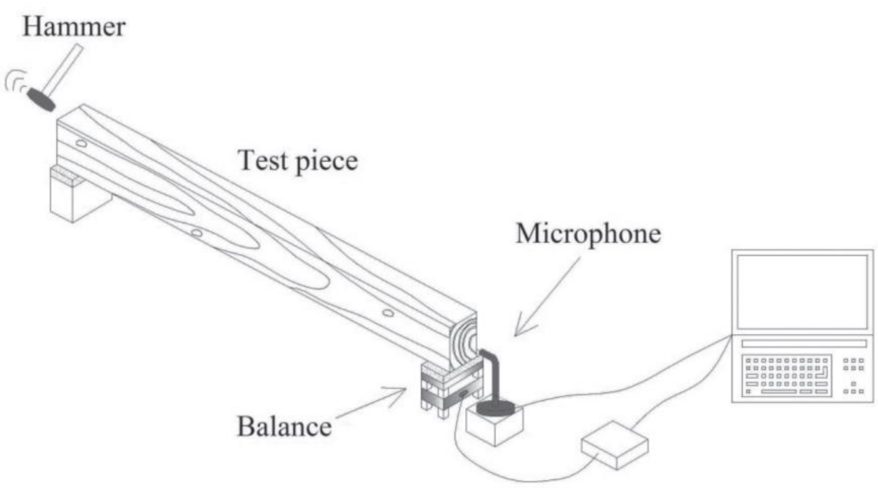

Figure 2. Test with Portable Lumber Grader equipment (de la Mata 2011).

Δu

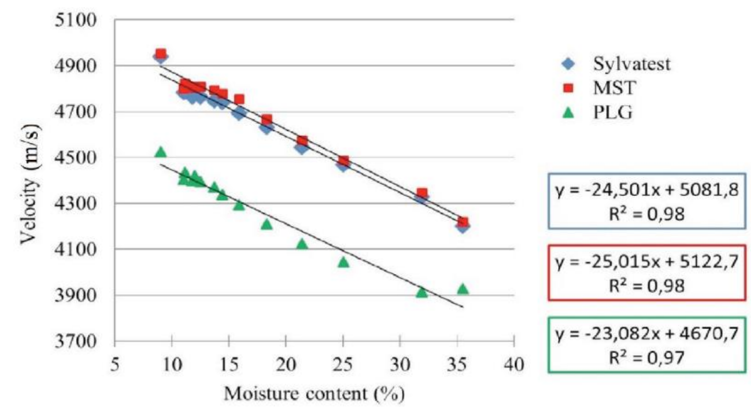

Figure 4. Linear relationship between the average values of propagation velocity and moisture content of the specimens for each set of equipment.

- *Spanish Scots pine*

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Moisture Content Effect on Ultrasonic Velocity in *Goupia Glabra*

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

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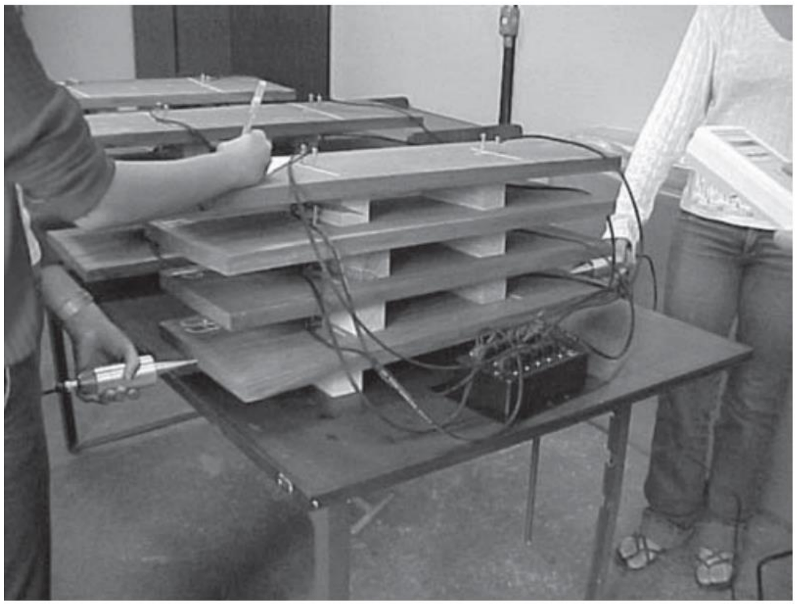
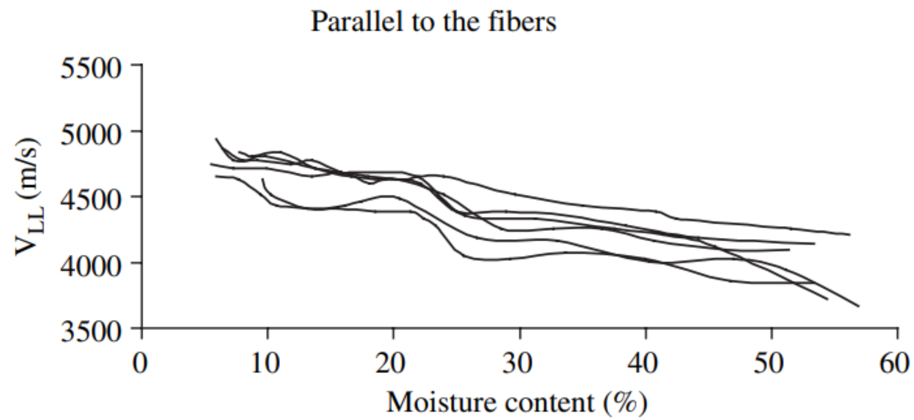
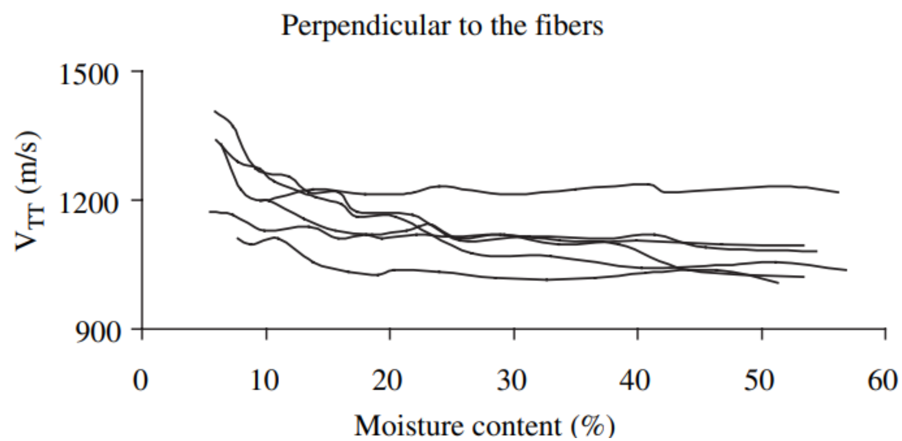
Received: June 10, 2003; Revised: January 10, 2005





Δu



- *Brazilian hardwood*

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Building and Environment 40 (2005) 311–318

BUILDING AND ENVIRONMENT

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

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Received 3 July 2002; received in revised form 12 July 2004; accepted 19 July 2004

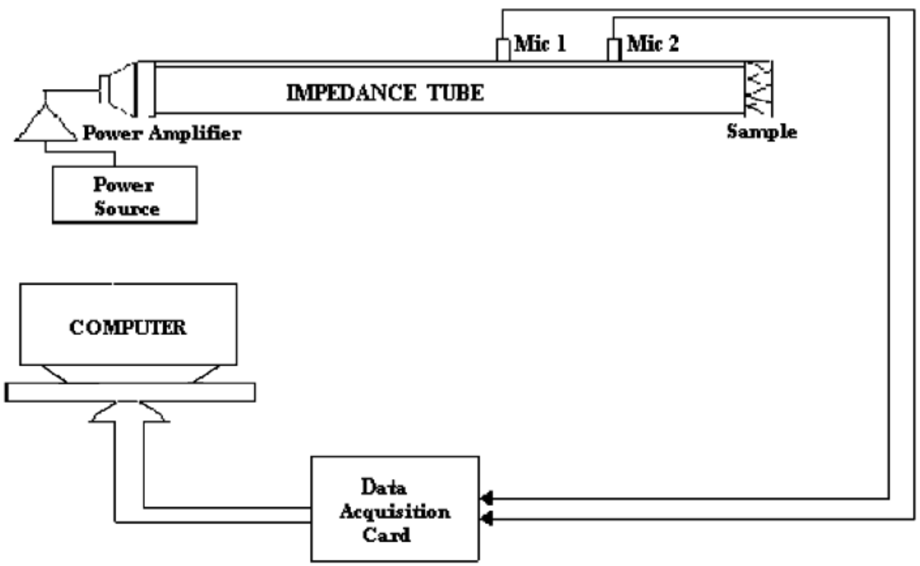


Fig. 3. System scheme of two-microphone impedance tube.

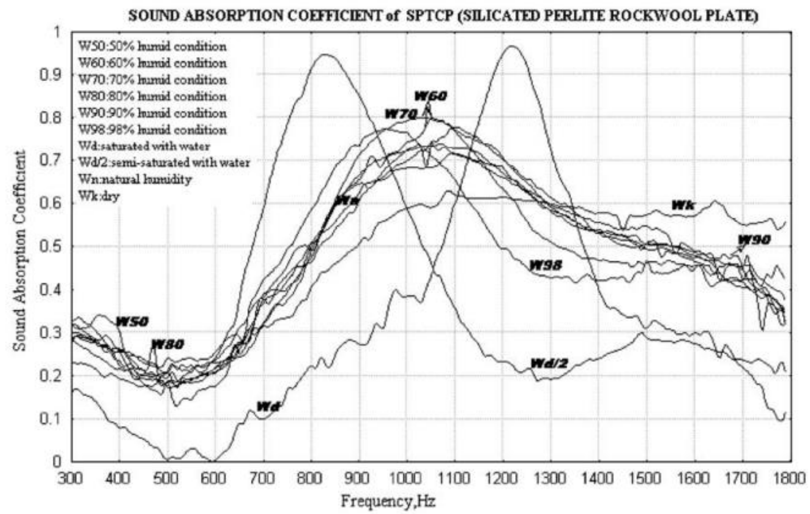
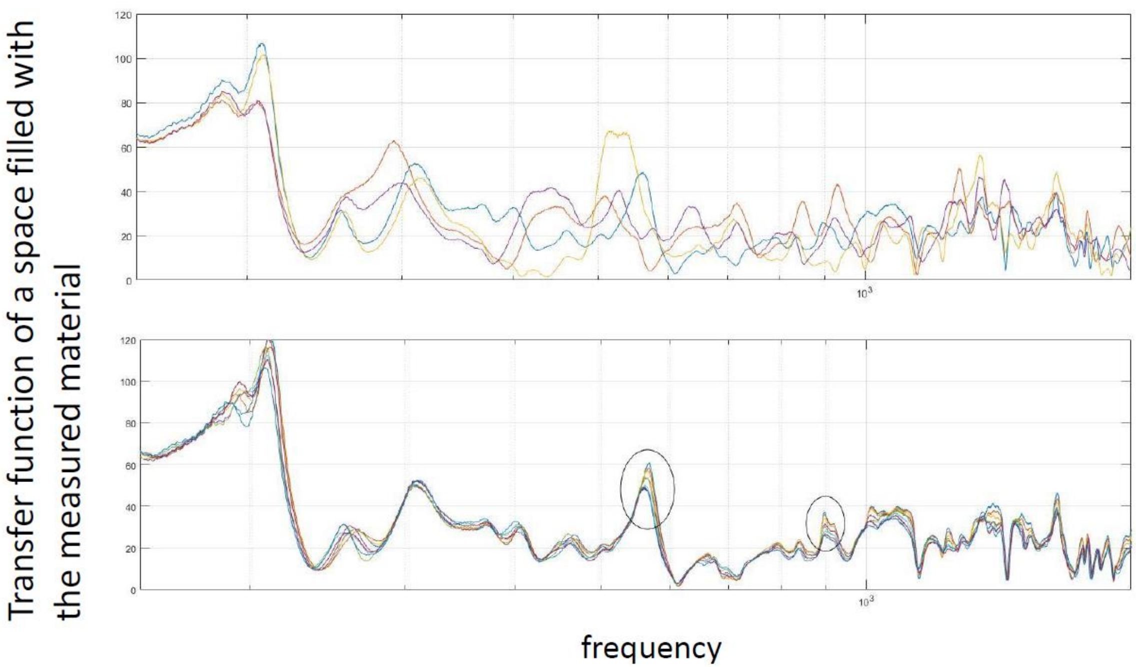


Fig. 8. Sound absorption coefficients of SPTCP (sodium silicate coated perlite–rock wool–cement plate).

ΔP

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

Experiments at CTU

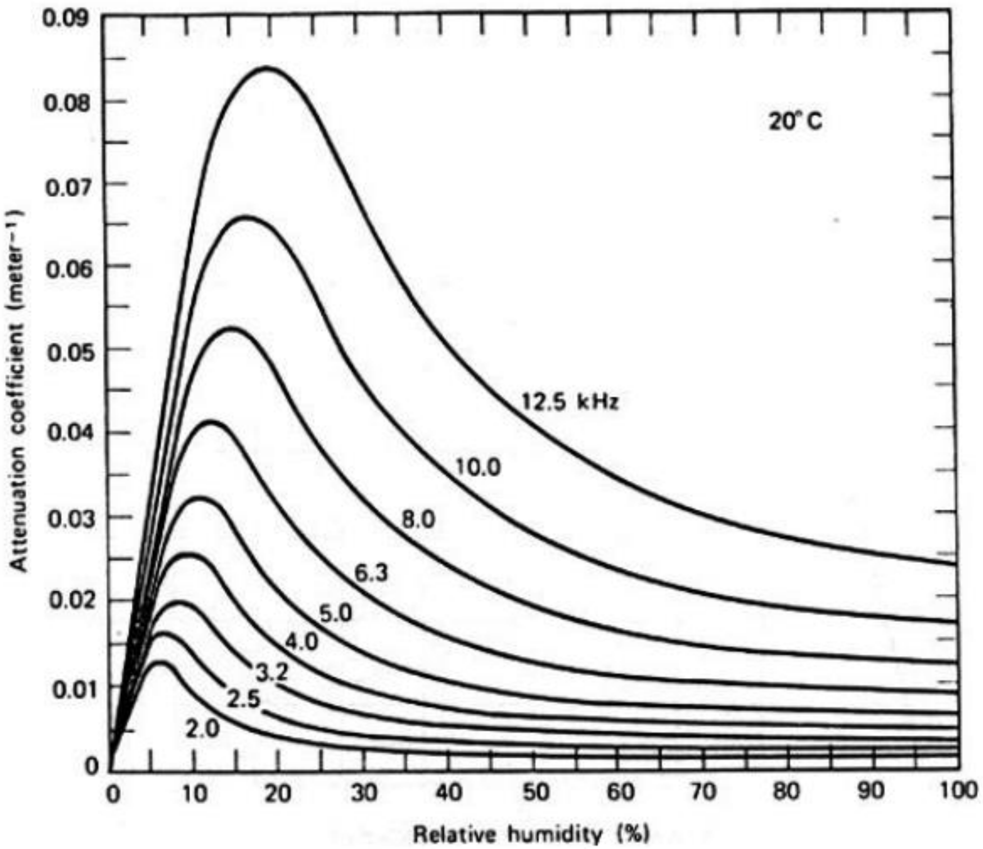


- *Similar experiment at CTU*

  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

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

Longitudinal resonances in a cylinder

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

Moisture and acoustic impedance

For plane wave and perpendicular wave impact

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

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

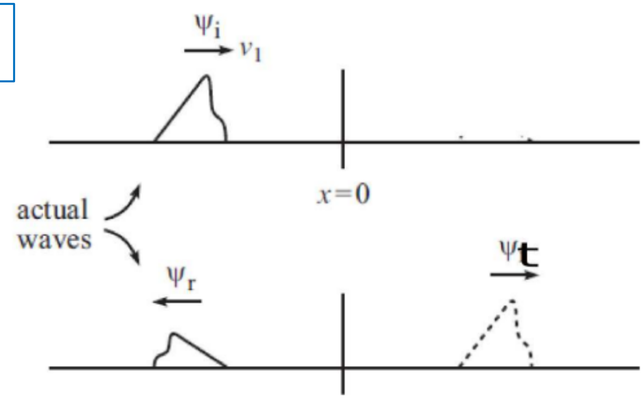


Figure 1. Incident, reflected and transmitted waves.

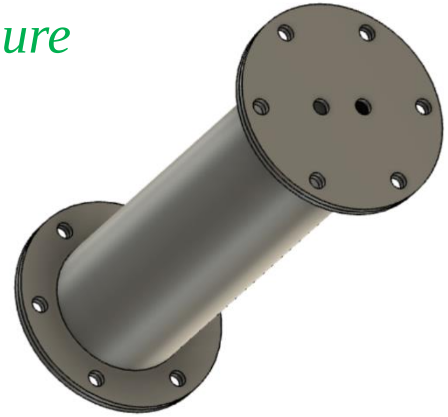
$$\boxed{\psi_r = \frac{Z_1 - Z_2}{Z_1 + Z_2}\psi_i}$$

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

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

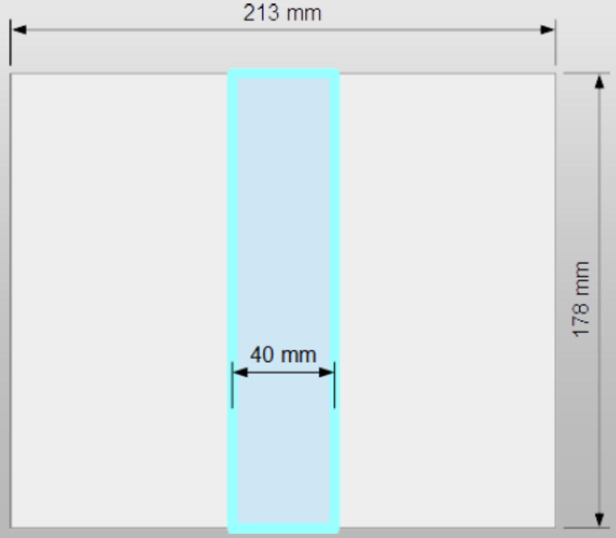
Acoustic Hygrometer

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



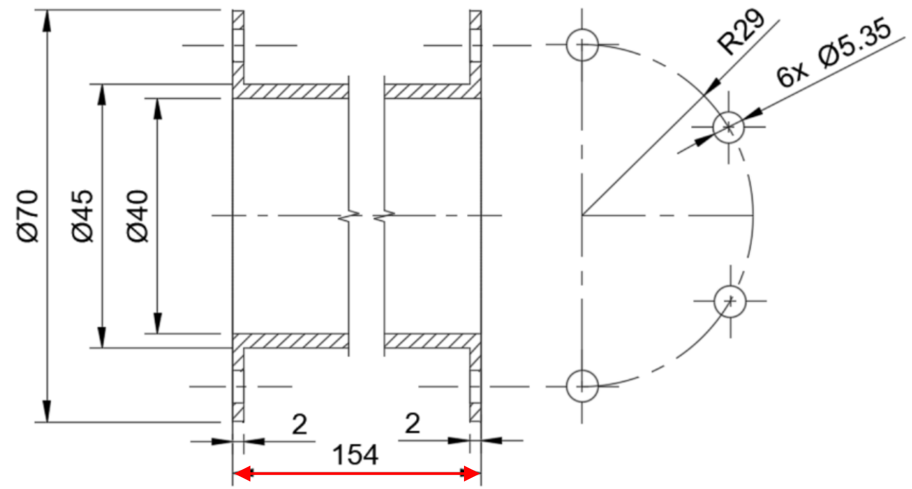
Sampling chamber

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



as for MW technique

Acoustic Hygrometer



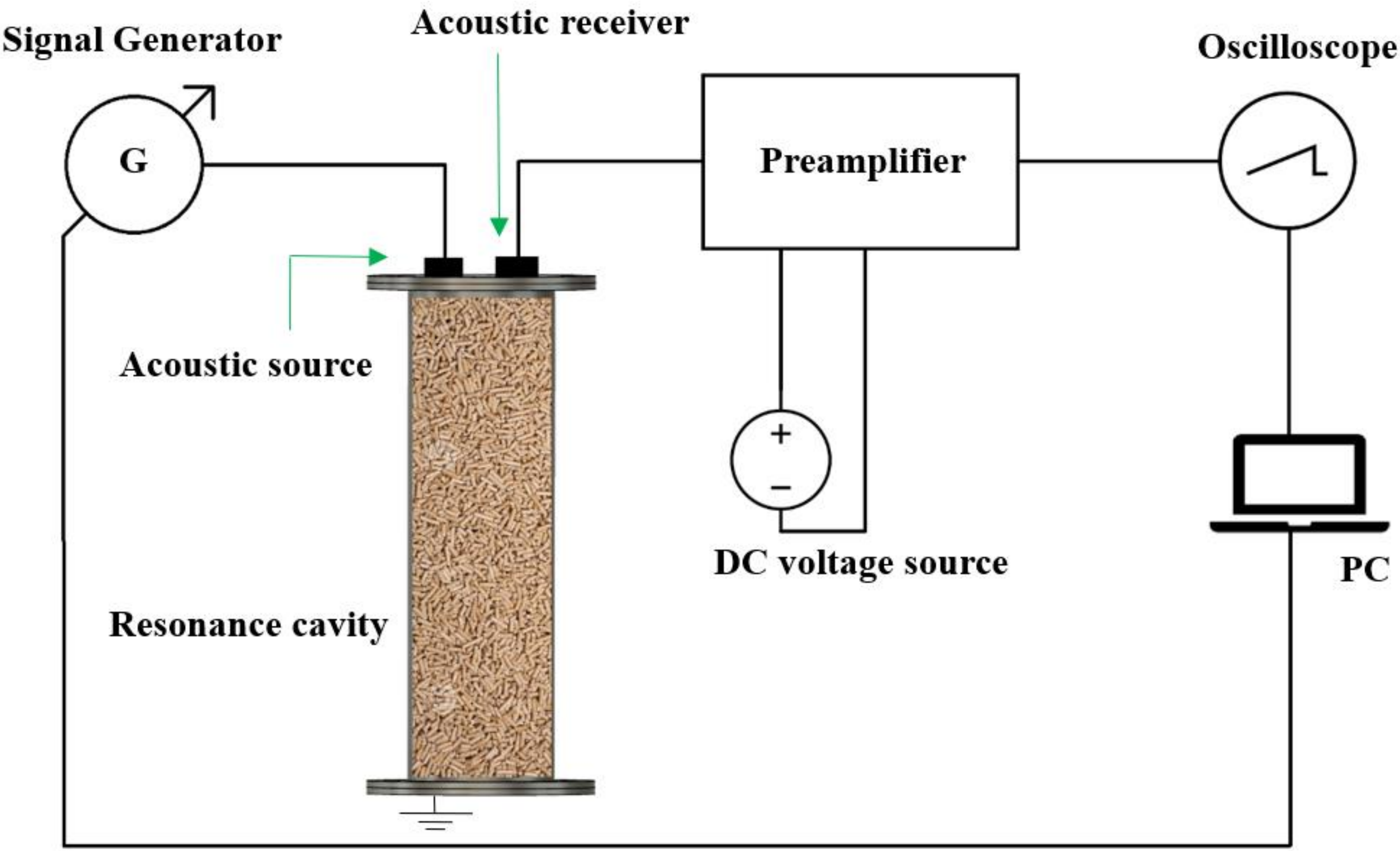
$$f_n = \frac{n \cdot u}{2 \cdot L}$$

- *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, …

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

Acoustic Hygrometer



Calibration series

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

- *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 – moist samples

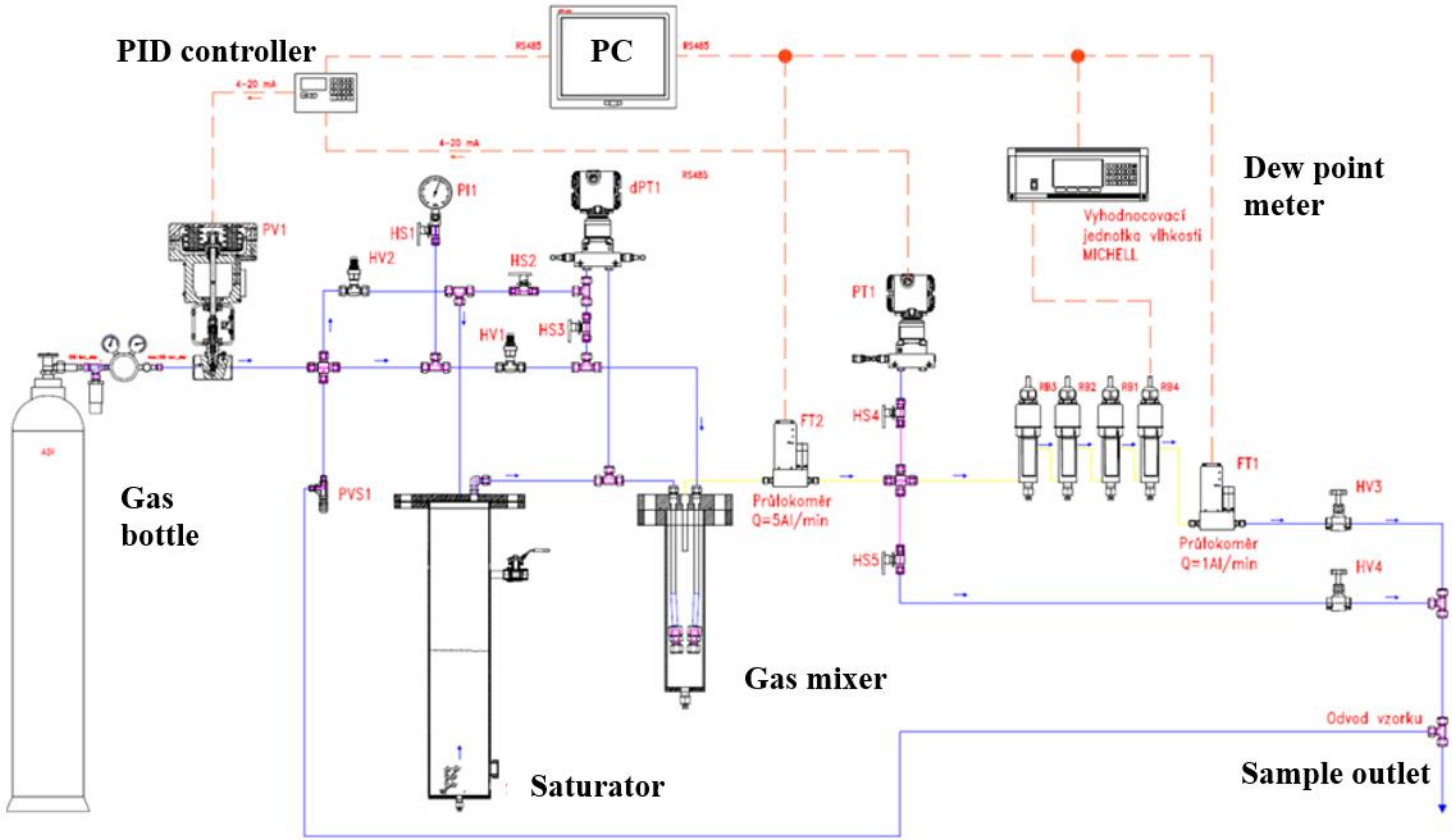
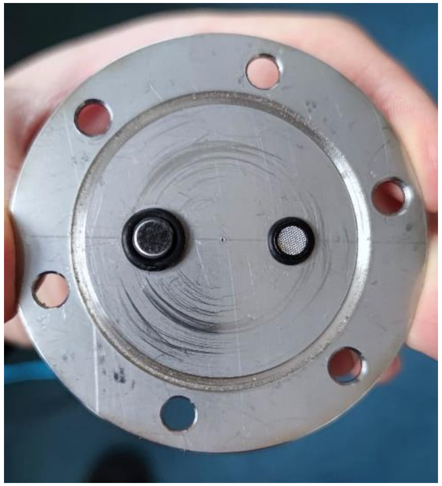


Figure 2: Principal scheme of humidity generator

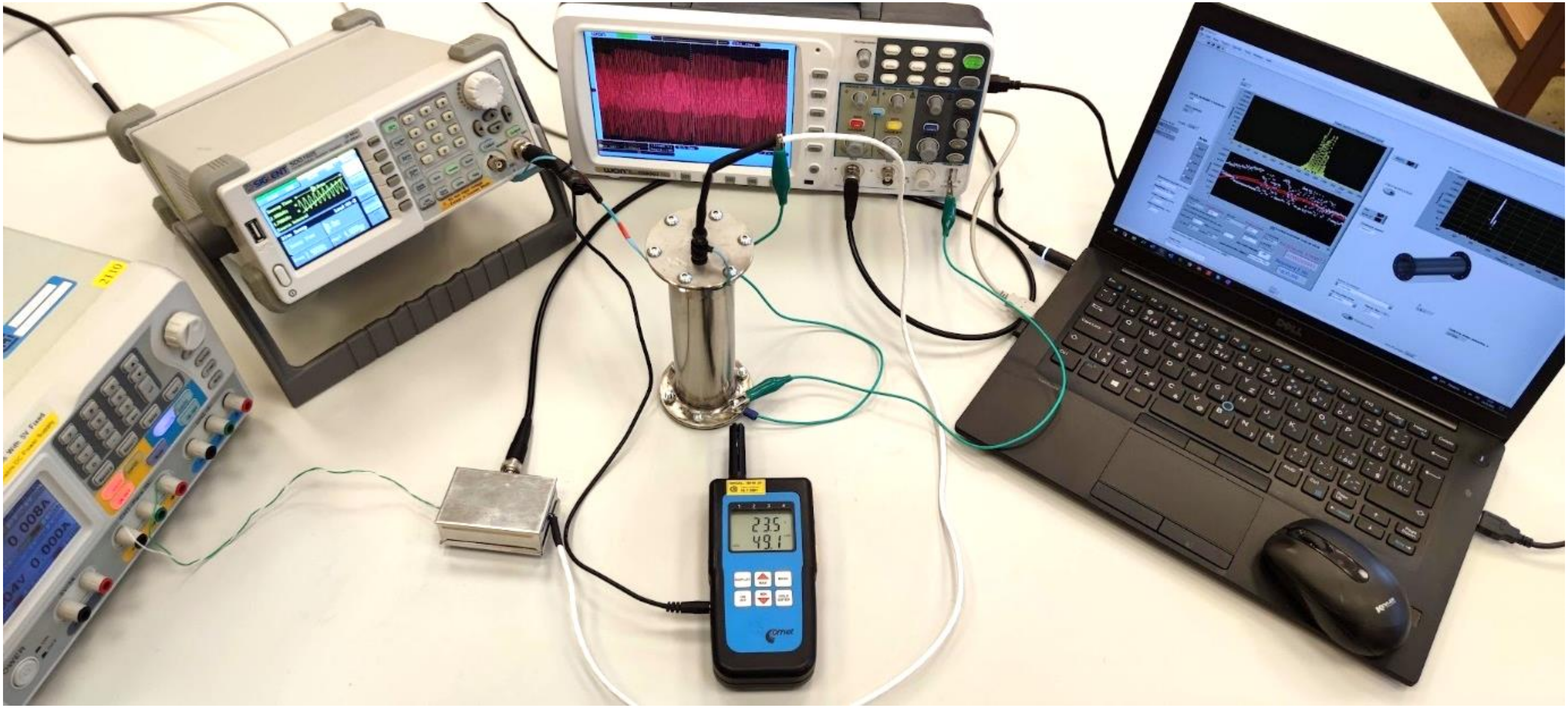
Traceability – moist samples

Samples directly inside the container



Shaking when filling

A 2.2.6 version 2

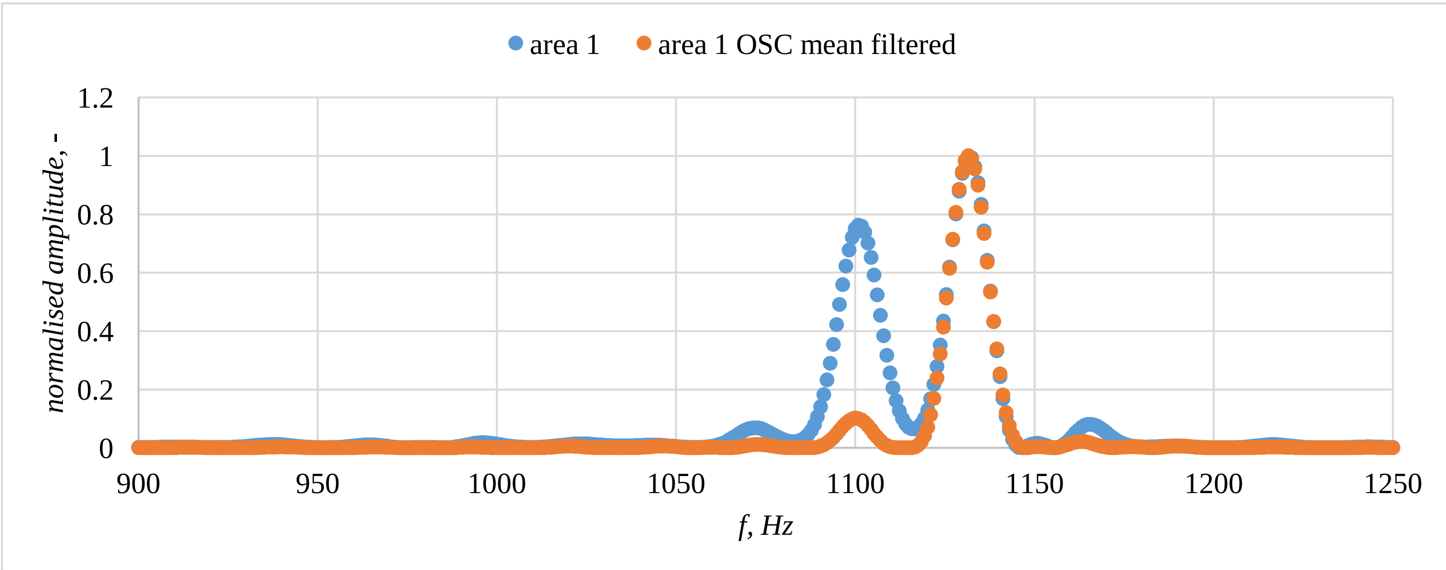


- *One button measurement*
- *Portable measurement system*
- *No qualified person needed for measurement*

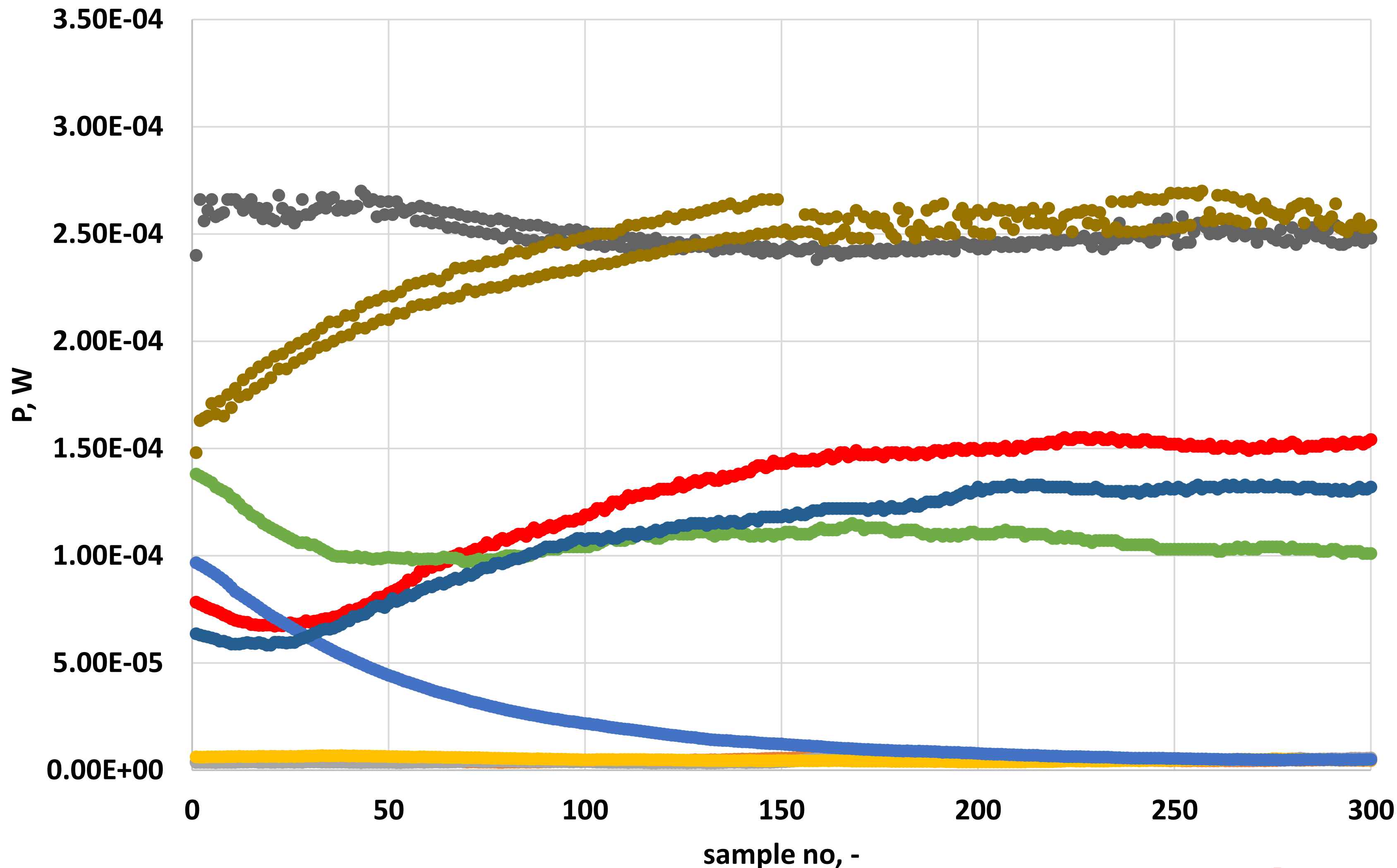
Frequency ranges

	Excitation signal		Bandpass filter	
Area no.	**f_{min}, kHz**	**f_{max}, kHz**	**f_{min}, kHz**	**f_{max}, kHz**
1	**0.8**	**1.2**	**0.5**	**1.5**
2	**1.7**	**2.1**	**1.5**	**2.3**
3	**2.6**	**3.0**	**2.4**	**3.2**
4	**3.6**	**4.0**	**3.4**	**4.2**
5	**4.5**	**4.9**	**4.3**	**5.1**

- *5 f ranges*
- *Measuring P at resonance f*

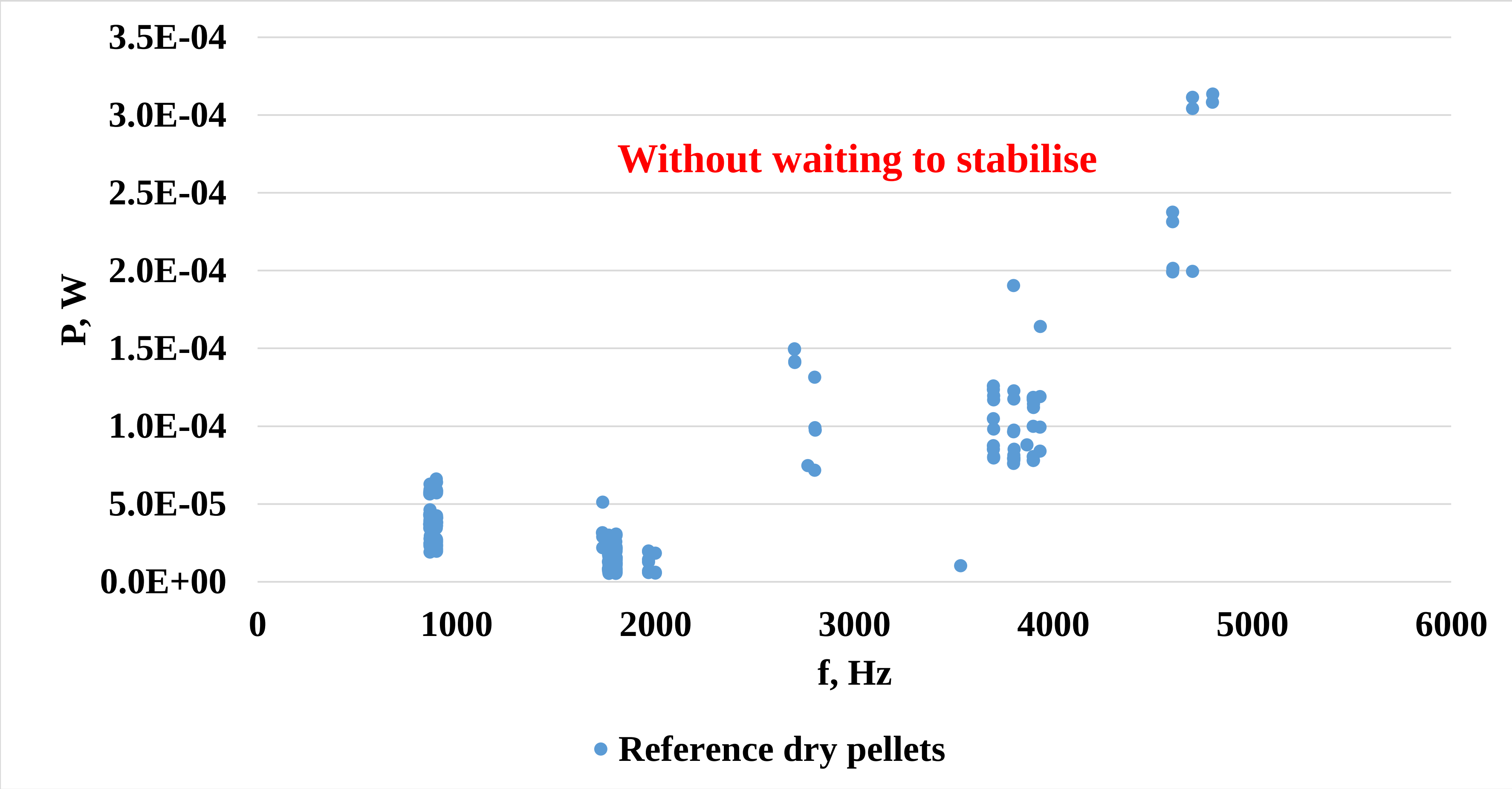


Stabilisation time necessary < 30 min



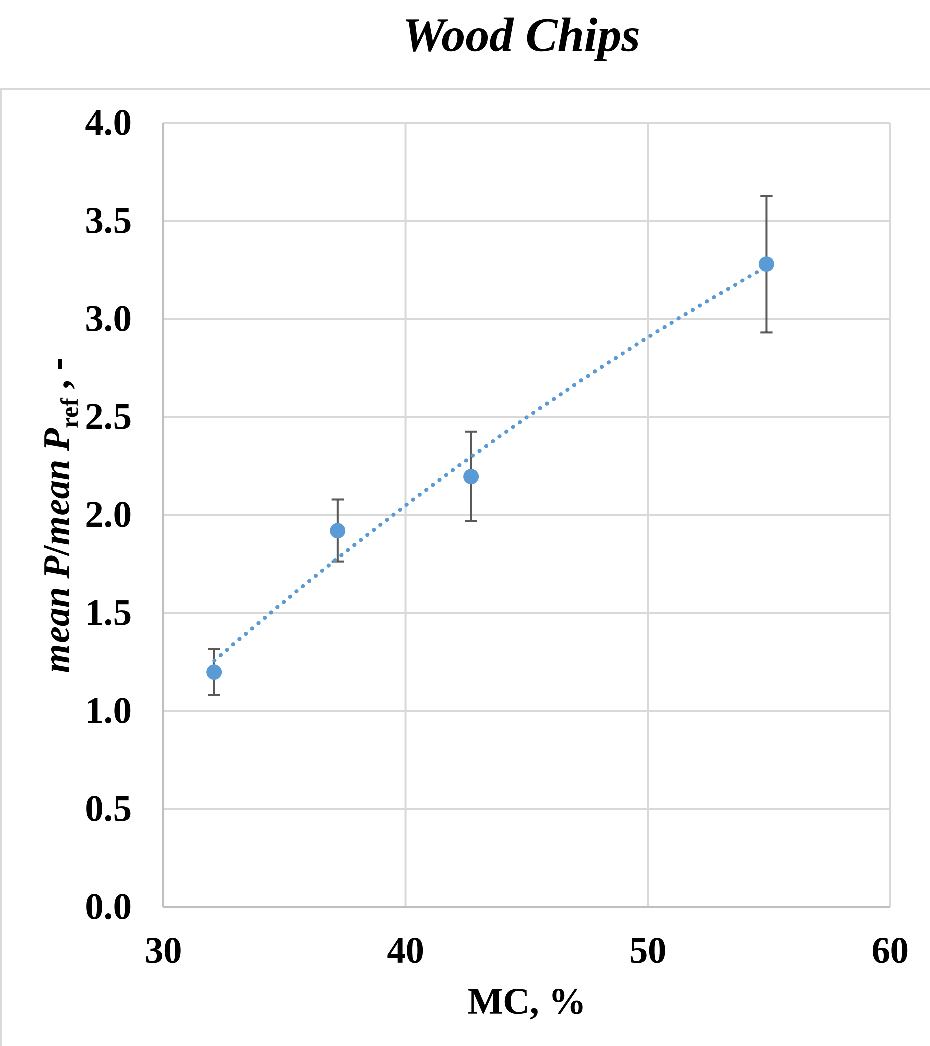
1 sample ~ 6 s

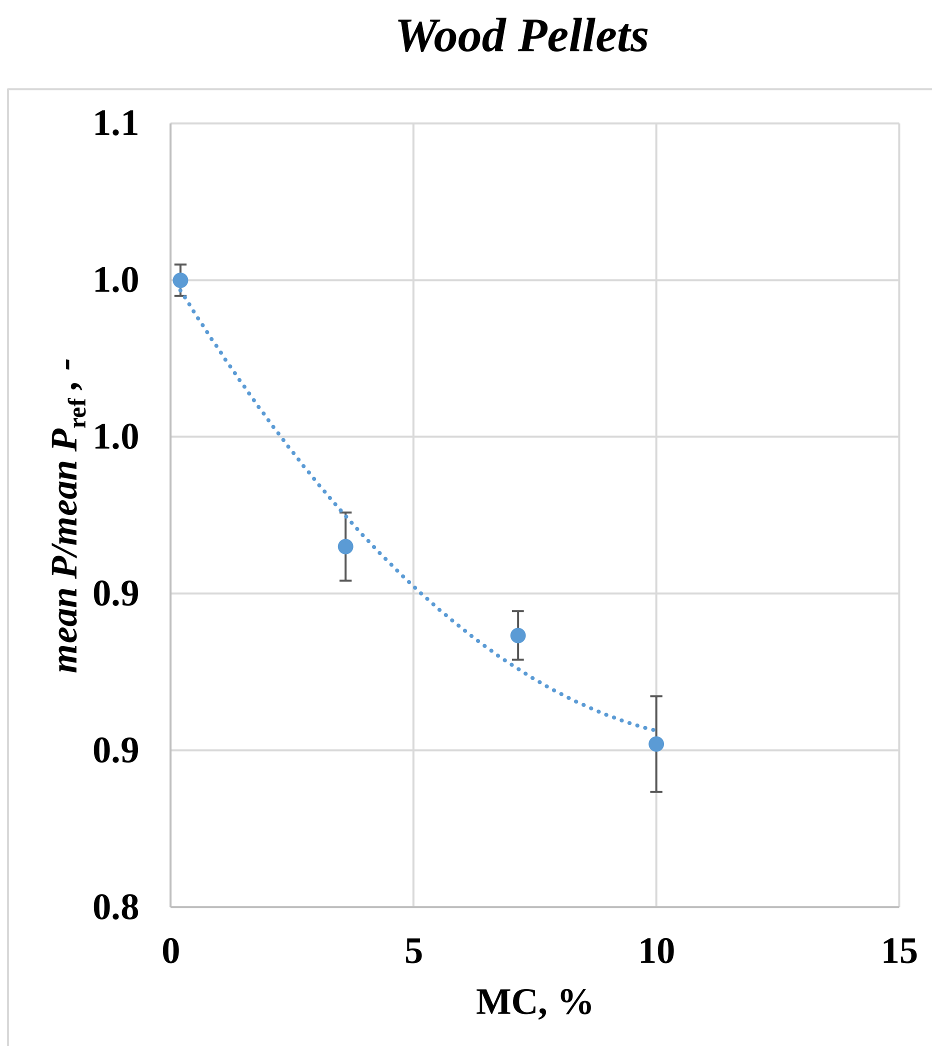
Stabilisation time necessary < 30 min



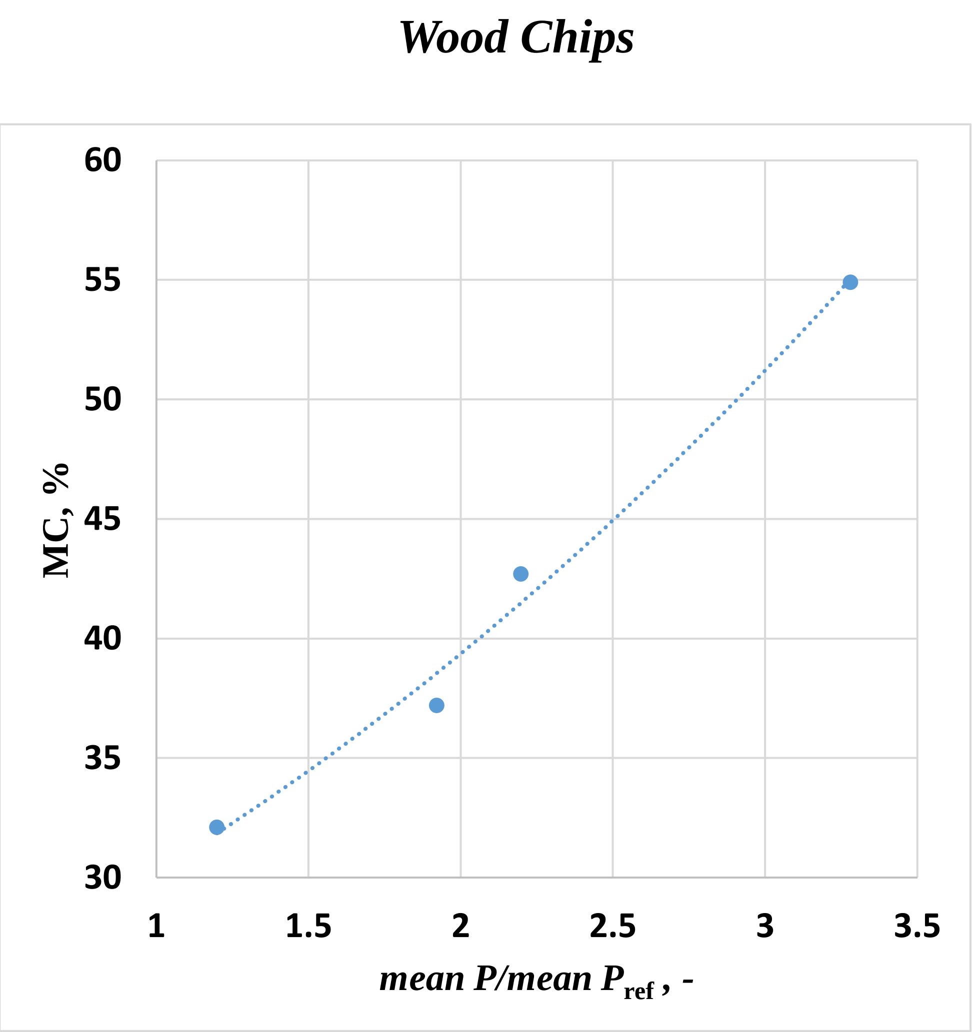
- *F shift due to T, gas composition, thermal expansion, p*

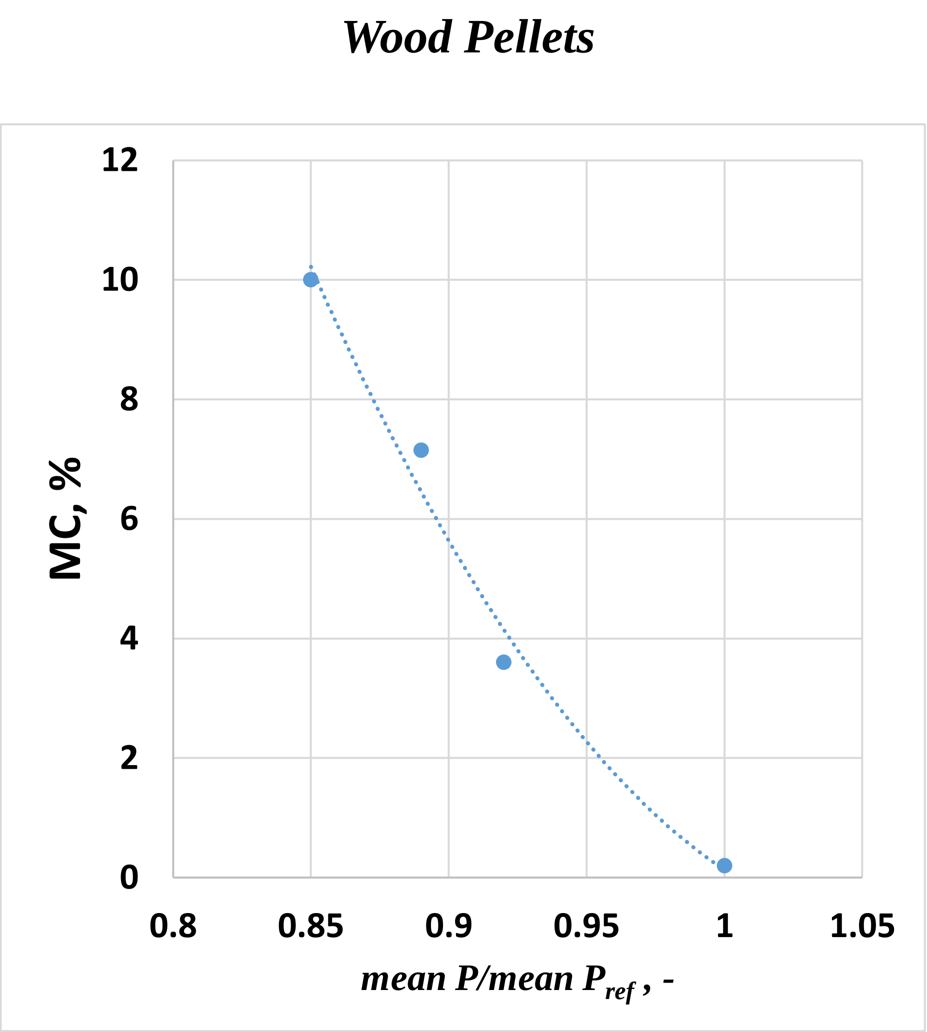
Results of Calibration, with σ



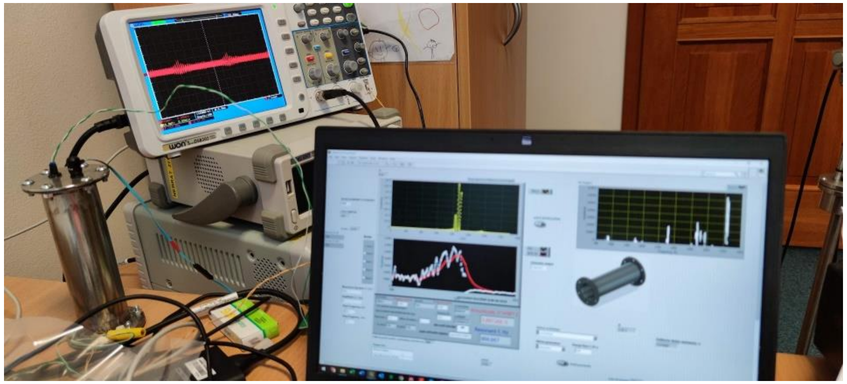


Inversed (transfer Function)





Interlaboratory comparison



19ENG09 BIOFMET

INTERLABORATORY COMPARISON OF MOISTURE MEASUREMENTS WITH BIOMASS RELEVANT SAMPLES

COMPARISON PROTOCOL
Version v0.1 (draft)

Background

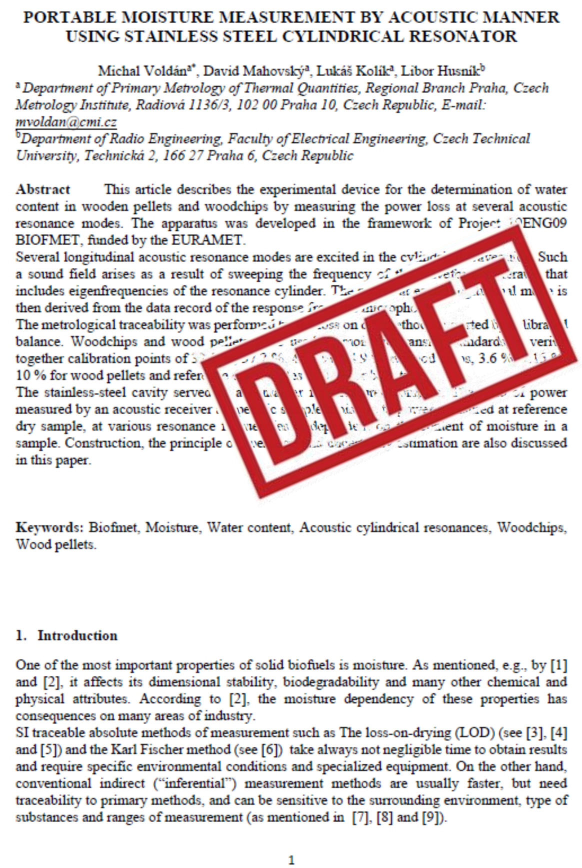
In accordance with the project protocol of the 19ENG09 BIOFMET project, the relevant partners of the JRP-Consortium will arrange an interlaboratory comparison of moisture measurements with biomass relevant samples (T1.4) in 2022. It was agreed in the meeting (online) of DTI, CMI and CETIAT 3/4 2021 that 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

- *Secondary method*
- *Measurement for interlaboratory comparison finished*
- *Draft of uncertainty budget*

- *One button measurement*
- *Article in development*

- *Future plans:*
- *Detailed recalibration at climate chamber at various temperatures (+ machine learning?)*
- *Employ device with thermometer*
- *Pressure dependence*
- *Testing in industry*



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*

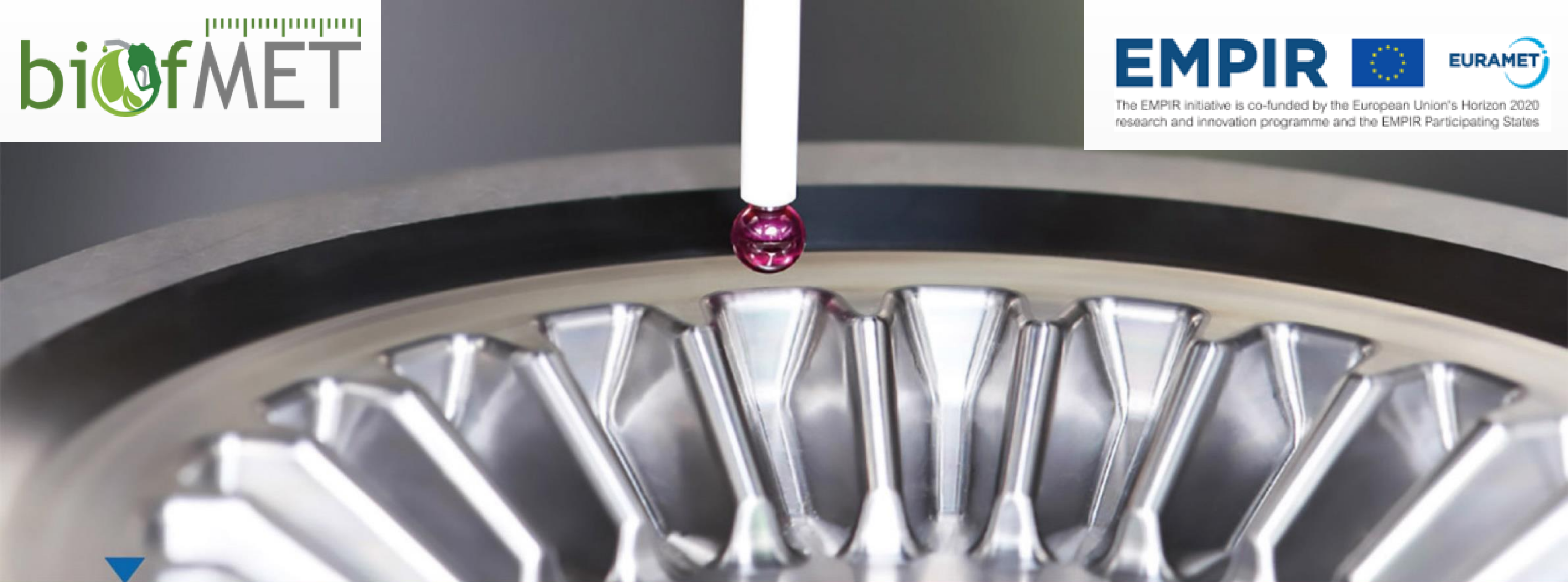
Abstract This article describes the experimental device for the determination of water content in wooden pellets and woodchips by measuring the power loss at several acoustic resonance modes. The apparatus was developed in the framework of Project [illegible]ENG09 BIOFMET, funded by the EURAMET.
Several longitudinal acoustic resonance modes are excited in the [illegible] Such a sound field arises as a result of sweeping the frequency [illegible] that includes eigenfrequencies of the resonance cylinder. [illegible] is then derived from the data record of the response [illegible]
The metrological traceability was performed [illegible] balance. Woodchips and wood pellets [illegible] together calibration points of [illegible] 3.6 % [illegible] 10 % for wood pellets and refer[illegible]
The stainless-steel cavity served [illegible] power measured by an acoustic receiver [illegible] at reference dry sample, at various resonance [illegible] of moisture in a sample. Construction, the principle o[illegible] 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]).

1



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

Thank you for your attention

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June 2nd, 2022

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