The primary measurement standard of ultrasonic power and radiation conductance at Inmetro

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Abstract. In this work, the results of the measurement of the radiation conductance performed in the ultrasonic power measurement system of the Laboratory of Ultrasound (Labus) of Inmetro are presented. According to IEC 61161:2013, the Labus / Inmetro measurement system is considered a "primary measurement setup" since it took part in the BIPM Key Comparison CCAUV.U-K3.1, achieving satisfactory results. The measurements were carried out based on the primary measurement procedure for the determination of the radiation conductance, and the new results were compared with those previously obtained on the occasion of Key Comparison.

1. Introduction
The standard IEC 61161:2013 [1] establishes methods to determine the ultrasonic power based on the measurement of the radiation force using a gravimetric balance. Moreover, according to the same standard, "a primary measurement setup" means a measurement setup that has taken part in an international key comparison or another international comparison, organized by the CIPM/BIPM [1]. The last key comparison of ultrasonic power was CCAUV.U-K3.1 [2]. Although the ultrasound power is the measurand of the key comparison, the CCAUV.U-K3.1 participants were asked to report the radiation conductance, which is independent of the applied voltage and is, therefore, a characteristic property of the transducer at a particular frequency. Hence, the goal of the key comparison CCAUV.U-K3.1 was to show the capabilities of the participating laboratories to determine the acoustic radiation conductance of an ultrasonic transducer by measuring the total time-averaged ultrasonic power emitted for an applied RMS voltage. The nominal frequency ranged from 2 MHz to 16 MHz and the nominal output power values varied between 10 mW and 15 W. The Laboratory of Ultrasound of Inmetro (Labus/Inmetro) took part in the key comparison CCAUV.U-K3.1. During the key comparison CCAUV.U-K3.1, beyond the key comparison standard transducer, Labus/Inmetro has also measured an own set of ultrasonic transducers to have reference measurement standards to perform periodic evaluation of the measurement system.
The present work presents the result of a new complete set of radiation conductance measurements, performed with the Labus/Inmetro standard transducers set, which were compared with the results that had previously been achieved at the time of the key comparison CCAUV.U-K3.1.

2. Material and Methods

The primary measurement standard at Labus/Inmetro is composed of a radiation force balance based on an absorber target, and it is composed of the following equipment and accessories: a tank containing distilled and deionized water; a calibrated analytical balance model CP224S (Sartorius, Germany); 5 degrees of freedom positioning system (Newport Corporation, USA) to align ultrasonic transducer; support in which the absorbing target is positioned; a dissolved oxygen meter model XL40 (Accumet Instruments, Singapore) for monitoring dissolved oxygen; a thermo-hygrometer model Hygropalm 3 (Rotronic, Switzerland) for monitoring the water temperature. The experimental setup is disclosed in Figure 1.

The set of reference measurement standard transducers is composed of six ultrasonic transducers (Panametrics, Olympus-NDT, USA), all of them with a nominal case diameter of 12.7 mm and the following central frequencies: 1 MHz (model A303S), 2.25 MHz (model V306), 5 MHz (model V309), 7.5 MHz (model A320S), 10 MHz (model V311), and 15 MHz (model A319S).

The ultrasonic output power (temporal average) \( P \) was measured (in watt) using the primary system radiation power measuring Labus/Inmetro with absorbing target, according to IEC 61161:2013 [1]. The transducers were excited with sine waves in a continuous mode, with voltages and frequencies described in Table 1. The input voltage \( V \) was measured at the end of the transducer cable with the oscilloscope (measured in RMS volts). Measurements were taken at three different distances between the absorber target and the face of the transducer, and for each of the three distances, \( \frac{1}{4} \) wavelength offset measurements were taken. The final ultrasonic power was determined as the extrapolated power value for the zero distance between the target and the face of the transducer. The whole procedure was repeated four times. The final result was determined from the mean values obtained in all replicates and expressed as the radiation conductance given by

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G = \frac{P}{V^2}.
\]  

In which \( G \) (mS) is the radiation conductance, \( P \) (mW) is the output power, and \( V \) (Vrms) is the input voltage.

In determining the uncertainty, the dispersion of the results is considered as a function of the repeatability, instruments, and standards used. Details about uncertainty calculation can be found elsewhere [2]. The comparison between the results was carried out by using the normalized error [3].
3. Results
The radiation conductance values measured during the key comparison CCAUV.U-K3.1 (calibration certificate Dimci 2532/2014) and in 2019 (calibration certificate Dimci 0659/2019) are presented in table 1, with their respective expanded uncertainties and normalized error from the comparison of values of radiation conductance.

Figure 1. (a) Labus ultrasonic power measurement system. (b) Detail of the transducer positioned in the system and the absorber target.
Table 1. Radiation conductance values were measured in December 2014 and April 2019, with their respective expanded uncertainties, as well as the normalized error value (EN).

| Serial number | Frequency [MHz] | DEC/2014 | | APR/2019 | | EN |
|---------------|----------------|---------|------|---------|------|------|
|               |                | Vin [V] | P [mW] | G [mS] | U [mS] | Vin [V] | P [mW] | G [mS] | U [mS] |
| 851953        | 1              | 3.57    | 9.27  | 0.727  | 0.046  | 3.50    | 8.99  | 0.733  | 0.083  | 0.06 |
|               |                | 11.38   | 99.82 | 0.771  | 0.016  | 11.04   | 93.82 | 0.770  | 0.030  | 0.01 |
|               |                | 35.90   | 1006.00 | 0.781  | 0.0058 | 25.65   | 514.70 | 0.782  | 0.027  | 0.06 |
| 536444        | 2              | 4.40    | 10.99 | 0.568  | 0.058  | 4.29    | 10.84 | 0.588  | 0.057  | 0.24 |
|               |                | 13.69   | 110.30 | 0.589  | 0.024  | 13.23   | 105.20 | 0.601  | 0.021  | 0.39 |
|               |                | 39.20   | 994.35 | 0.647  | 0.086  | 25.46   | 400.30 | 0.617  | 0.027  | 0.33 |
| 884394        | 5              | 1.27    | 8.86  | 5.47   | 0.30   | 1.26    | 8.61  | 5.46   | 0.61   | 0.02 |
|               |                | 4.25    | 99.60 | 5.51   | 0.16   | 4.19    | 96.06 | 5.47   | 0.20   | 0.17 |
|               |                | 9.23    | 464.50 | 5.452  | 0.088  | 9.20    | 462.30 | 5.46   | 0.15   | 0.07 |
| 535099        | 7              | 2.36    | 9.90  | 1.77   | 0.20   | 2.24    | 8.66  | 1.72   | 0.22   | 0.17 |
|               |                | 7.37    | 97.48 | 1.794  | 0.056  | 7.31    | 96.51 | 1.808  | 0.054  | 0.18 |
| 857470        | 10             | 1.61    | 10.45 | 4.05   | 0.54   | 1.50    | 8.25  | 3.69   | 0.46   | 0.52 |
|               |                | 4.88    | 91.73 | 3.86   | 0.19   | 4.64    | 81.15 | 3.76   | 0.23   | 0.32 |
| 540390        | 15             | 7.64    | 107.25 | **1.84** | 0.11  | 7.48    | 67.80 | **1.21** | 0.43   | **5.05** |

4. Conclusion

Based on the normalized error values, one can conclude that the power measurement system in Labus/Inmetro continues to provide results statistically comparable to those obtained when the system was implemented at the time of participation in CCAUV key comparison. The dissonant result is that obtained with the 15 MHz-transducer, which showed a significant reduction of its radiation conductance value. Further tests have shown that 15 MHz-transducer has lost sensitivity, and it is not a reliable standard transducer.

References

[1] IEC 61161:2013 – “Ultrasonics - Power measurement - Radiation force balances and performance requirements”. IEC – The International Electrotechnical Commission.

[2] J Haller, C Koch, R P B Costa-Felix, P K Dubey, G Durando, Y T Kim, and M Yoshioka. Final report on key comparison CCAUV.U-K3.1. Metrologia 53(1A):09002; January 2016 (https://doi.org/10.1088/0026-1394/53/1A/09002)

[3] ISO/IEC 17043:2010 Conformity assessment – General requirements for proficiency testing. ISO/CASCO Committee on conformity assessment 2010.