Experimental Study of Air Leakages Using Three Different Ultrasonic Microphones

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Abstract. Compressed air serves as a valuable energy carrier, yet its production and preparation come with significant costs. During compression, a substantial amount of energy is dissipated as waste heat, while approximately 30 % is lost through leakage during distribution and utilization. Implementing a heat recovery system effectively addresses the waste heat issue, but identifying and quantifying leaks remains critical.

The primary obstacle lies in the fact that eliminating leaks necessitates reducing system pressure to zero, which is both expensive and feasible only if the benefits outweigh the costs. While ultrasonic microphones are commonly employed for leak detection, their reliability in quantifying leaks is compromised by indirect measurements and various factors affecting accuracy, such as noise, reflections, distance, and angle relative to the leak.

In this study, we utilize three distinct broadband microphones to assess leaks in standard geometries and compare their performance across different scenarios.

Keywords: Ultrasonic detection, Compressed air, air leakage quantification.

1 Introduction

Compressed air (CA) finds extensive application across various industries, accounting for 10 % of industrial energy consumption within the European Union [1]. According to the life cycle cost analyses (LCC) of compressors, energy expenses constitute approximately 78 % of the total cost, while initial investment and maintenance contribute to the remaining 22% [2].

In 2001, Peter et al. conducted a comprehensive study on the energy consumption of compressed air systems (CAS) in the European Union, highlighting significant potential for enhancing energy efficiency and economic savings, with leakage reduction being a key focus [3-8]. Meeting the EU's target of reducing energy consumption by 11.7 % by 2030, compared to the baseline of 2020, necessitates substantial improvements in CAS energy efficiency [9].

Ultrasonic detection, based on emissions, remains a prevalent technique for identifying air leaks. While some manufacturers offer devices capable of estimating leakage rates, these values are derived from indirect measurements. Variations in sound emissions due to factors such as distance and device positioning relative to the leak can impact the accuracy of these estimations.

In our research, we investigated the effectiveness of three distinct microphones for leak detection and conducted a comparative analysis of their performance.

2 Material and methods

We designed a test setup specifically for studying compressed air (CA) leaks. This enabled us to accurately measure a range of parameters, including temperature, pressure, flow rate, dew point, and ultrasonic emissions.

2.1 Experimental setup

Figure 1 depicts the layout of the test configuration. Situated on the ground floor is the compressor, accompanied by a weather station for monitoring ambient conditions. Directly at the compressor outlet, we measure discharge pressure and temperature. Compressed air undergoes humidity measurement via a sensor to ascertain the dew point. Utilizing a proportional valve, we can regulate pressure within the range of 1 to 11 bar$_a$, with valve opening controlled by current values ranging from 4 to 20 mA, managed by a fuzzy controller. The flow rate value can be modulated by both the set pressure and the geometry of the leak.

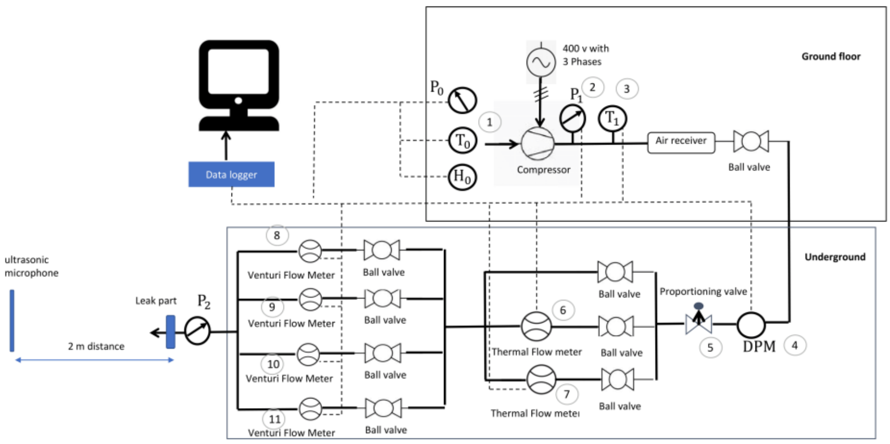

Fig. 1. Experimental setup

Information of flow meter devices is detailed in Table 1. Flow rates are assessed using four Venturi flow meters and two thermal flow meters. Thermal flow meters serve the purpose of acquiring a secondary measurement. Various nozzle sizes and thermal flow sizes are employed to encompass diverse flow ranges.

Table 1. Measuring device

Position number	Device	Measuring Range	Measurement accuracy
6	VA520 ¼”	0 l_N/min – 105 lN/min	±1 % m.v. ±0.3 % e.v.
7	VA520 ½”	0 l_N/min – 1500 lN/min	±1 % m.v. ±0.3 % e.v.
8	VSM02 (Optiserve) 0.5 mm	0.1 l_N/min – 2.3 lN/min	± 1 m.v.
9	VSM02 (Optiserve) 1 mm	0.6 l_N/min – 10 lN/min	± 1 m.v.
10	VSM02 (Optiserve) 2.4 mm	2.5 l_N/min – 55 lN/min	± 1 m.v.
11	VSM02 (Optiserve) ½”	50 l_N/min – 1000 l_N/min	± 1 m.v.

Figure 2 illustrates the microphone setup for measurements. The microphones are positioned 2 meters away from the leaks. An automated measuring boom, adjustable to different angles, encompasses a semicircle around the leaks.

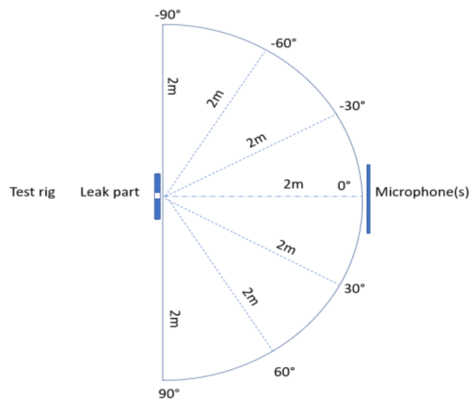

Fig. 2. Schematic of microphone(s) positions

Table 2 outlines the microphone equipment employed for sound emission measurements, comprising two individual microphone devices and one microphone array. All devices are capable of capturing ultrasonic frequencies ranging from 20 to 100 kHz. Given their physical specifications, these microphones can record sound pressures within the range of 30 to 120 dB.

Table 2. Specification of microphone devices

Device number	Microphone amount	Weight [g]	Sample rate [kHz]	Microphone technology	Sound pressure [dB]
1	72	1500	200	Digital Mems condenser	30 − 120
2	1	80	200	electret condenser	20 − 120
3	1	60	384	electret condenser	20 − 120

2.2 Manufacturing of idealized leaks

To create leakages with circular holes, we employ a stationary drill along with aluminum discs having a thickness of 0.5 mm. Reamers are utilized to maintain low manufacturing tolerances for the circular holes. Details of all circular holes utilized are provided in Table 3.

Table 3. List of manufactured leaks

Type	Amount	No.	Dimensions
Circular hole	3	D-005-01 D-005-02 D-005-03	0.5 mm
Circular hole	3	D-007-01 D-007-02 D-007-03	0.7 mm
Circular hole	3	D-010-04 D-010-05 D-010-06	1 mm

2.3 Test procedure

The test procedure is depicted in Figure 3. We oversee and document the entire measurement process through a custom LabView program. Data logging occurs every second. Once the pressure is configured, it typically takes around 2 minutes to achieve a stable flow rate. As the flow stabilizes, the boom position automatically adjusts and reaches its designated location. Angle positions are secured using a grid plate. Once the boom position stabilizes and the flow rate settles, the measurement commences.

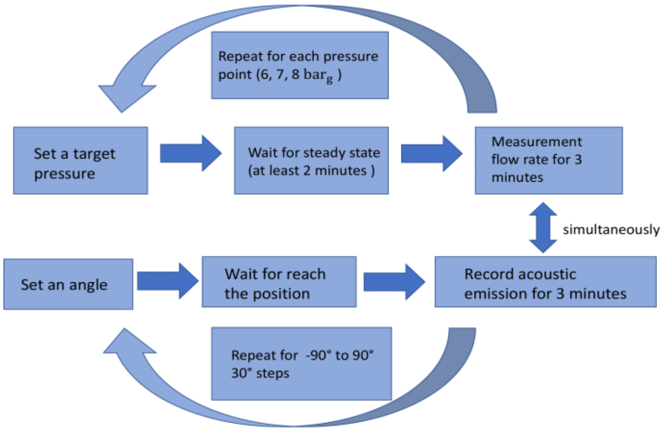

Fig. 3. Test procedure

3 Results

Table 4 displays the measured flow rates, with a maximum deviation of approximately 1 %. This indicates that the steady-state deviation following three runs is notably minimal.

Table 4. Leakage rates of all runs plus mean leakage rate of different circular holes

Leak sizes [diameter]	System pressure [bar$_g$]	Leakage Rate [l_N/min]				
		Run 1	Run 2	Run 3	Mean	Max. Deviation [%]
1 mm	6	48.47	47.82	47.47	47.92	0.94
	7	55.52	54.93	54.6	55.02	0.76
	8	62.64	62.35	61.75	62.25	0.80
0.7 mm	6	25.62	25.60	25.44	25.55	0.44
	7	29.55	29.34	29.24	29.38	0.47
	8	33.48	33.37	33.02	33.29	0.81
0.5 mm	6	10.01	9.93	10.01	9.98	0.53
	7	11.71	11.46	11.58	11.58	1.06
	8	12.51	12.73	12.68	12.64	1.03

Figure 4 illustrates the diverse sound pressure measurements across angular ranges for different circular hole sizes at 6 bar_g. The sound pressure level (SPL) escalates corresponding to both hole size and flow rate. Microphones 1 and 2 exhibit heightened sensitivity across the angular range, whereas Microphone 3 appears to experience reduced sensitivity at higher flow rates across angles. Across all scenarios, the SPL is lowest at 0° and 90° to the leaks, while it peaks at 30° to the leaks.

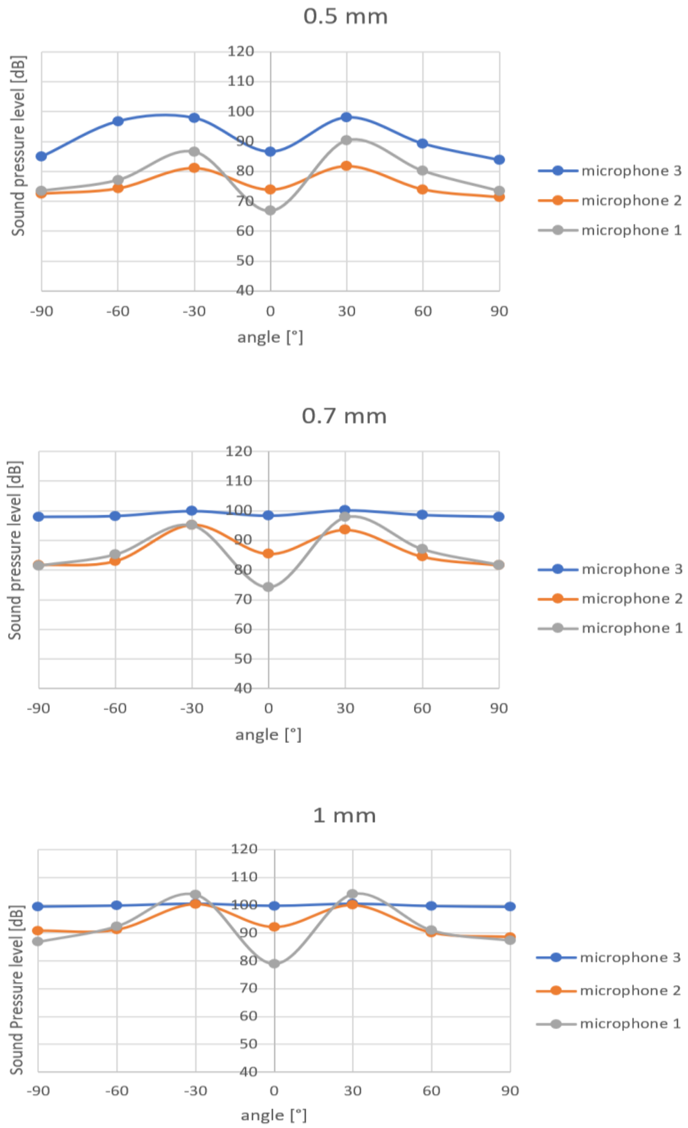

Fig. 4. Sound pressure level over angle range in different circular hole sizes

Figure 5 depicts the variation in Sound Pressure Level (SPL) with changes in pressure. Microphone 1 exhibits a higher SPL with larger hole sizes compared to the other microphones, while the lowest SPL observed at a 0.5 mm hole size. While SPL increases with rising pressure, the effect is notably less pronounced than that of hole size. This trend is consistent across different flow rates. Thus, there is a direct correlation between flow rate and SPL, while pressure playing a significant role in most datasets.

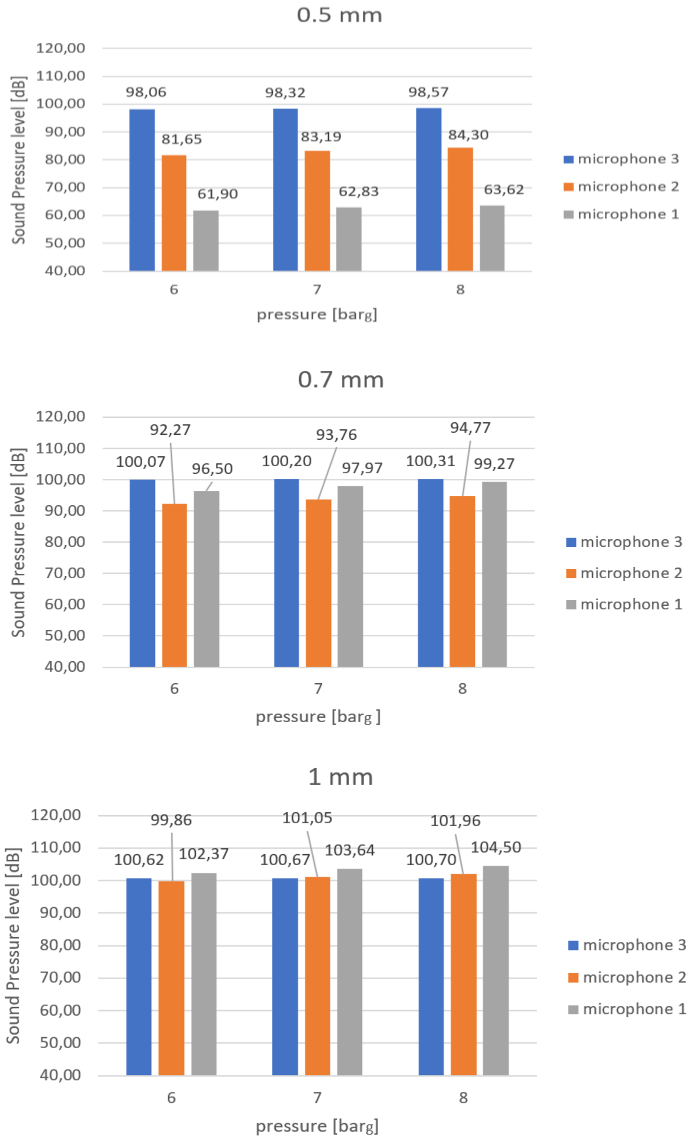

Fig. 5. Sound pressure level over pressure changes

4 Discussion and Conclusions

This study highlights the challenges associated with estimating flow rates based on ultrasonic emissions, particularly given the significant variations among available microphone options. When measuring angles, two microphones exhibited a 20 dB change in value from 0° to 30° to the leak, whereas another showed only a 5 dB change. Similarly, for flow rate changes from 10 to 40 l_N/min, one microphone displayed values ranging from 60 to 100 dB, whereas others showed smaller differences of 20 and 2 dB. higher sensitivity to flow rate changes allows a better estimation of the flow rate. However, increased sensitivity to angular positions relative to leaks poses challenges, leading to varying sound pressure levels for the same flow rate.

This study underscores substantial research opportunities for enhancing quantification applications, both in terms of hardware and software development. As highlighted earlier, attempting to eliminate leaks without accurate flow rate knowledge carries increased risk due to associated costs.

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