DOI: 10.61782/fa.2023.1236

NEW ANECHOIC CHAMBERS (50HZ AND 100HZ) AND OTHER VIBRATION-FREE FACILITIES FOR POLISH NATIONAL METROLOGICAL OFFICE (CENTRAL OFFICE OF MEASURES): DESIGN AND PRELIMINARY PERFORMANCE

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ABSTRACT

This paper discusses the design and realization of two anechoic chambers (50 Hz and 100 Hz), as well as multiple vibration-free structures for metrological measurements. These are located at the new GUM (Polish National Metrology Office) campus in Kielce, Poland. Several design aspects are addressed: the sound insulation design of the chambers' envelope, the design of the ventilation system, protection from vibrations possibly caused by several active quarries nearby, room acoustics, and structural details. Due to delays in the building process, only some preliminary measurements are described. Finally, the paper shows the importance of considering factors in the design process that could influence the future contractor's ability for easy access and maneuvering during the construction phase.

Keywords: *anechoic chambers, sound insulation, noise level, vibration design.*

1. INTRODUCTION

In 2018, the outcome of an architectural contest for a new 17,000 m^2 complex of the Polish National Metrological Office (GUM), inclusive of two anechoic chambers (50 Hz and 100 Hz) in Kielce, Poland, was declared. The victors were BDMA Architekci, a Warsaw-based architectural firm. The author was enlisted to aid the architects in acoustically designing the complex, including the two anechoic chambers and additional vibration-free facilities. As of May 2023, the complex is still under construction, with a postponed opening planned for December 2023. The initial building cost was estimated at 21.5 million Euros (net), with 5.2% assigned for the entire design (inclusive of acoustics). The building cost has since risen (due to COVID and a nearby war) to 40 million Euros. Approximately 50% of the original building cost was financed through EU funds. Below are the images of the complex exterior as per the competition design (Fig.1) and as it was in April 2023 (Fig.2).

Figure 1. GUM complex (competition phase)

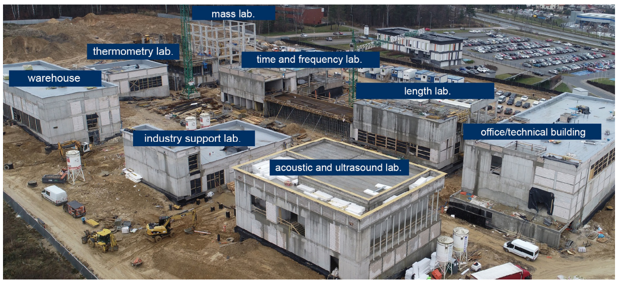

Figure 2. GUM complex (as of 04.2023); in foreground - acoustic lab with anechoic chambers

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As observed from the aforementioned figures, each laboratory type is situated in a separate building, thereby minimising noise and vibration transmission between labs.

2. ANECHOIC CHAMBERS

For the GUM project, the author designed two anechoic chambers: a large one with a 50 Hz cut-off frequency, measuring 10.7x11.7x11.2 m (1402 m^3), and a smaller one with a 100 Hz cut-off frequency, measuring 6.45x6.95x7.12 m (319 m^3). Polyether polyurethane grey foam wedges, 170 cm (50 Hz) and 86 cm (100 Hz) long, will be situated on all internal surfaces [1,2]. Other features include double sound-insulation entrance doors, silent lighting, and a steel cable floor with a catch-net below. The design of anechoic chambers presents several challenges in terms of architecture, structure and ventilation. From a purely acoustical perspective, the chambers envelope need to provide the highest possible airborne sound insulation. Impact sounds from adjacent corridors and offices should be minimized. Technical and ventilation plant rooms should be located as far away from the chambers as possible to prevent potential direct noise transmission and to allow sufficient space for extended ductwork, ensuring noise from ventilation units is attenuated. Air speed (within ducts and upon entering chambers) should be kept to a minimum to control self-noise. Structural vibrations from the surrounding buildings and other possible sources (like nearby quarries, future construction sites or renovation works) need to be minimized, enabling long-term measurements to proceed unattended. In the case of GUM and its anechoic chambers, the client specified two primary requirements. The first stipulated that the noise level inside the chambers should not exceed ISO 8253-2 [3], which may be approximated by the more familiar NR5 [4] curve (see Fig.3). The second requirement stipulated that vibrations in the chambers should be below the "Class V0" standard set by the client (see Table.1). Concerning vibrations, it's worth noting that due to funding limitations, no on-site vibration measurements were possible during the design phase. Hence, design decisions were primarily based on the author's experience and certain assumptions, rather than detailed FEM[1] analysis. This was particularly challenging as there is an active quarry (Trzuskawica) approximately 5km from the construction site, with two more slightly further away. Vibration measurements and FEM analysis were eventually conducted during the construction phase, affirming the design's adequacy. To meet both specified requirements (Fig.3 and Table.1), the acoustical design proposed construction of both chambers as a massive, reinforced concrete box-in-box structures. These chambers are supported on vibration isolation and separated from each other and all surrounding rooms (see Fig.4-7). HVAC units were moved to the basement of a nearby building (Industry Support Lab - see Fig.2) and connected to the Acoustic and Ultrasound Lab (see Fig.2) via an underground passage housing lengthy ducts and split silencers (see Fig.9).

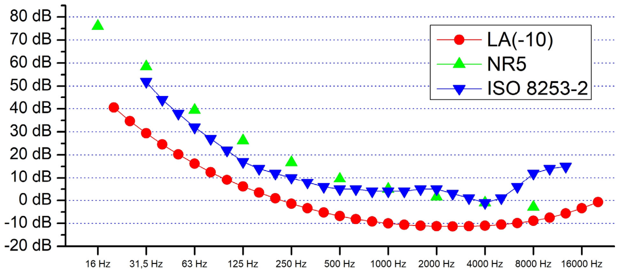

Figure 3. Requirements for background noise

Table 1. Client requirements for vibration isolation.

Class	requirement		
	frequency range [Hz]	**velocity [μm/s]**	**acceleration [mm/s²]**
V0	f > 1,0	v < 4	-
V1	f = [0,1~8,0]	v < 2	-
	f > 8,0	-	a < 0,1
V2	f = [0,1~5,0]	v < 1	-
	f > 5,0	-	a < 0,03

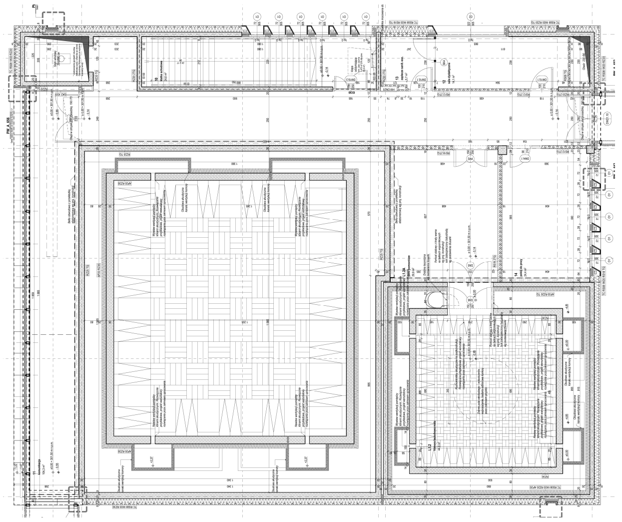

Figure 4. Anechoic chambers – plan (level +2)

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[1] FEM – Finite element method

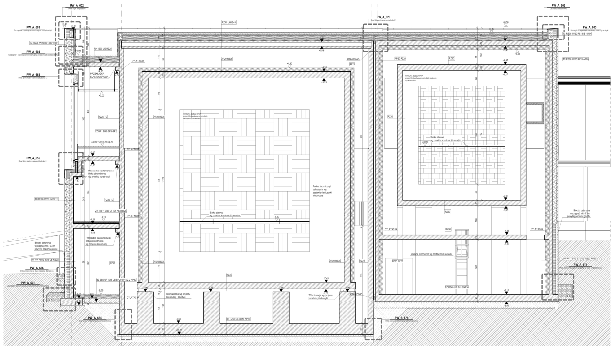


Figure 5. Anechoic chambers - section

Figure 6. Acoustic lab without a roof, with box-in-box structure around both anechoic chambers clearly visible

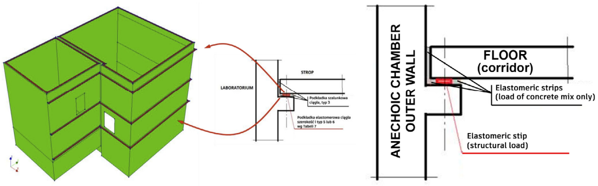
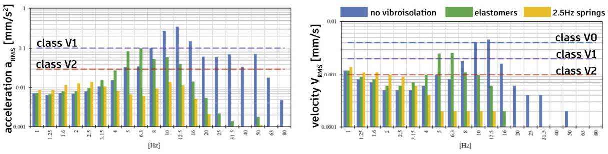
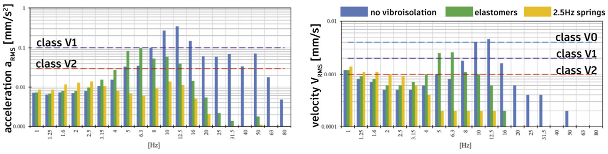


Figure 7. Anechoic chambers FEM model with scheme of elastic support of surrounding corridors on outer walls of box-in-box structure (prepared by Cracow Technical University).

During the construction phase, vibration acceleration was measured both on the ground and the foundation plate, generated by various sources (quarry explosions, heavy equipment movement, trucks, etc.). Based on these measurements, an FEM simulation was performed by Cracow University, predicting velocity and acceleration for different types of vibro-isolation (no isolation/elastomeric isolation/springs with f_0=2.5 Hz), and compared with requirements from Table.1. These predictions are shown in Fig.8 for both small (100 Hz) and large (50 Hz) chambers. The small 100 Hz chamber was designed with support from 100 mm thick elastomer pads (with f_0~5 Hz), what was confirmed as sufficient to achieve class V0. The large (50 Hz) chamber was designed on ~2.5 Hz steel springs with elastomeric pads, but with the option to improve vibro-isolation by using air-springs with active damping. As seen in Fig.8, the use of more traditional steel springs already met the stricter class V2, so there was no need for expensive air-springs. These measurements will need confirmation after the installation of steel springs (likely summer 2023).



Small chamber (100Hz) – requirement class V0



Large chamber (50Hz) - requirement class V0

Figure 8. FEM predictions (performed by Cracow Technical University) of acceleration and velocity levels in both anechoic chambers in "Z" direction compared to vibration classes from Table 1.

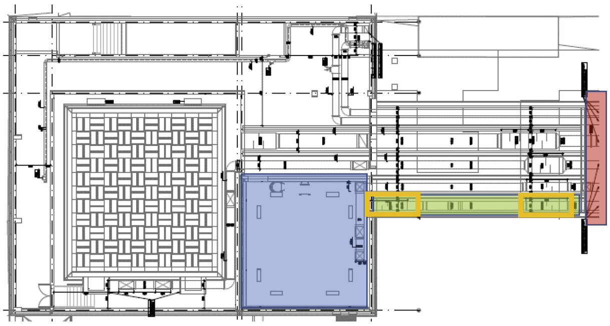


Figure 9. Mineral wool duct 7 m long and two 3 m long split silencers – measured damping in Table 2.

Table 2. Comparison of measured and calculated attenuation values for 13 m long duct (as per Fig.9)

	Attenuation [dB]							
Hz	**63**	**125**	**250**	**500**	**1k**	**2k**	**4k**	**8k**
measurement	30	73	91	91	95	95	58	52
calculation [5]	23	64	126	139	135	110	93	88

Concept of ventilation assumes that fresh air will be pushed into chambers via continuous ducts with silencers and small expansion chambers just before entering the anechoic chamber. Used air from the chambers will be taken from void between both box-in-box structures, to minimize possible dust entering both chambers. Additional ducts, silencers and expansion chambers are located on extract side of both chambers.

So far we only managed to measure damping of one 13m long HVAC duct between plant room and entrance to void between outer and inner box of 50 Hz anechoic chamber (Fig.9, Table 2). As can be seen from Table 2, measured values in high frequencies (4-8kHz) are lower than calculated using ASHRAE [5, as described in chapter 49] using attenuation data supplied by manufacturers. Also, both measured and calculated low-frequency attenuation (at 63Hz) were rather low compared to other frequency bands, so one additional dedicated low-frequency split silencer will be added to improve attenuation at low frequency. Additionally, to improve high-frequency attenuation (at 4-8kHz) that additional silencer will have staggered vertical splitters (compared to already installed silencers), so there is not direct line-of-sight through the silencers along duct lenght, as it was observed during measurements.

One point to note is, during ducts installation prep, it became clear that the 100 cm we planned between the outer and inner box-in-box (reduced further by 100 mm of sound-absorbing material) might be acoustically ideal, but it's 20-30 cm too narrow for people to work efficiently from a ladder while fixing HVAC ducts!

3. VIBRATION-FREE STRUCTURES FOR METROLOGICAL MEASUREMENTS

Additionally to anechoic chambers, GUM campus have multiple other highly specialized laboratories. Fig.10 shows cross section through typical clean room. Thirteen vibration-free floating foundations, each weighting 60-120 tons, aimed to fulfil most requirements of either V1 or V2 class (see Table 1) were designed in the campus.

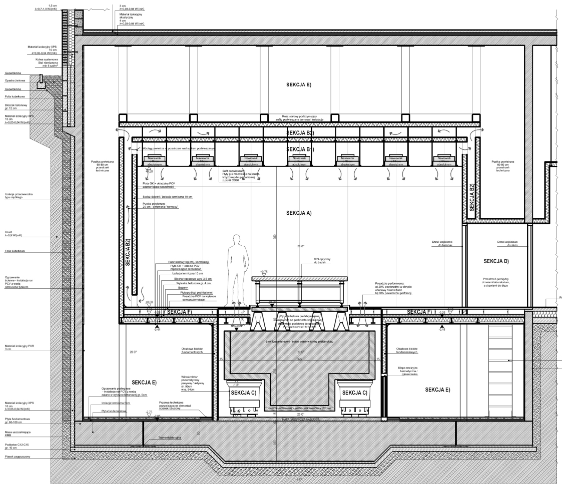


Figure 10. Typical vibration-free (class V2) clean room, with active air-springs and floating foundation.

Figure 11. Author (for scale) next to 60tons floating foundation blocks, supported temporarily on 100mm thick elastomeric pads.

Figure 12. Installation of f_0~2,3 Hz steel springs with elastomeric pads under 50Hz anechoic chamber (June 2023).

For this construction phase, all floating foundations are temporarily supported on 100 mm-thick elastomeric pads (f_0~5 Hz) to save costs. However, the design is aimed at using either active air springs (f_0~1 Hz) or the same steel springs as those under the 50 Hz anechoic chamber (f_0~2.5 Hz). FEM simulations, similar to those described above for both chambers, were conducted for all floating foundations. Results were similar. Elastomeric pads always enable fulfilment of class V0 and almost class

V1/V2, except at the resonance frequency (expected due to vibration amplification at resonance).

Even without active mode, using either air springs or steel springs enables V1 and V2 class fulfilment. Measurements to date confirm FEM simulation results with elastomeric pads, as testing steel springs or air springs on-site was not yet possible. The decision regarding the spring system to be installed under floating foundations is still under discussion within Client organization.

4. SUMMARY

It's an exciting, complex project. Construction delay aside, we're keenly awaiting the chance to perform sound level and insulation measurements in the completed chambers. We hope to do so before September, to report in Turin.

5. ACKNOWLEDGMENTS

Author wishes to express sincere gratitude to A.Szelag, B.Ziarko and K.Dusza for performing duct attenuation measurements, and to Annabud, the general contractor of GUM campus for granting us access to the building site.

6. REFERENCES

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[2] ISO 26101:2017 "*Acoustics — Test methods for the qualification of free-field environments*", ISO

[3] ISO 8253-2:2009 "*Acoustics - Audiometric test methods - Part 2: Sound field audiometry with pure-tone and narrow-band test signals*"

[4] ISO Recommendation R1996, 1st edition, May 1971

[5] ASHRAE, *Handbook – HVAC Applications.* 2019