25-29 August 2024
inter.noise
NANTES FRANCE

# Acoustic aspects in the construction and upgrading of military firing ranges - Part 2


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**ABSTRACT**

*Military firing ranges are indispensable facilities to train armed forces in handling and use of small arms. In the past, such ranges were outdoor installations. Due to noise problems around some of these shooting ranges they will be replaced more and more by indoor shooting facilities, which increases the noise impact on the personnel. First, the design of shooting ranges must consider the internal and external firing safety. However, acoustics comes next. There are two different but equally important objectives. The facilities should be built in such a way that (1) the noise impact on the hearing of personnel and (2) the noise impact on the neighbourhood is as low as possible. The design of shooting ranges should already take these aspects into account during the planning phase. This article focusses on the topic of acoustic safety (1) and is divided into two parts.*
*Part II: The second part of the article describes the practical application of the new directive, with its acoustic material and measurement requirements, based on a recent competitive dialog in which various companies were offered the opportunity to develop acoustic wall and ceiling systems for indoor shooting ranges as part of a so-called competitive dialog.*



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## 1. INTRODUCTION

Firing ranges (site firing ranges, indoor firing ranges) are an indispensable part of the training facilities where armed forces are trained in the handling and use of small arms and prepared for operations. When constructing or adapting these facilities to new training and exercise scenarios, meeting military requirements is naturally the first priority. The design is then carried out with regard to internal and external firing safety. The facility must take structural measures to ensure that firing on the ranges is safe for personnel and that there is no danger to the neighborhood. According to the procedure *Acoustic Safety* [1], acoustics now also play an increasingly important role with two different but equally important objectives.

This article deals with the planning of interior wall and ceiling system of an indoor shooting range. The focus is on the development of surface claddings in cooperation with industrial partners as part of a competitive dialog process. These wall and ceiling structures are optimized in such a way that the additional hearing load in the room during shooting is as low as possible. The assessment of the auditory load and the surface coverings is carried out on the basis of the *Acoustic Safety* procedure, which was described in detail within the first part of this article.

## 2. SPECIFICATIONS AND BOUNDARY PARAMETERS

Shooting ranges with a higher degree of protection and in particular indoor shooting ranges cause significantly more acoustic reflections than open ranges and therefore have a higher hearing load. The extent to which these additional reflections must be reduced by technical measures on walls and ceilings depends on the planned utilization of a facility. *Acoustic Safety* maps this correlation using the quality number $Q_S$. This relates the permissible number of shots in an indoor shooting range to an open range. The background to this is that the safe number of shots for a specific combination of weapon, ammunition and hearing protection is only known for open facilities without additional reflections.

The operator of a range therefore specifies the planned capacity utilization, which results in the quality number $Q_S$ to be achieved at as many positions in the room as possible.

In addition to the hearing exposure of the personnel in an indoor firing range, other important aspects such as shooting safety and fire protection must be taken into account, which can make appropriate compromises necessary.

In the competitive dialogue presented here, a quality number $Q_S$ of 50 % was set in order to meet the intended utilization of the planned facility. To achieve this value, the wall and ceiling systems must fulfill certain acoustic reflection classes (RK) in accordance with the requirements of *Acoustic Safety*. The reflection classes are determined in advance with the help of computer simulations. The geometry of the shooting room, which is determined by the planned training and exercise scenarios, plays an important role here. The specially developed web application *Chaser* therefore uses three-dimensional CAD models of the shooting range in order to properly assess the sound propagation. The location-dependent quality factor is thus optimized by varying the reflection classes of wall and ceiling systems.

### 2.1. Shooting Room Model

The model of the specified shooting range used is shown in Figure 1. The length is 66,5 m with a constant width of 16 m. A height of 3,80 m is estimated for the ceiling. In general, all small components such as doors or lamps, as well as mobile superstructures, are neglected and only larger, solid building enclosure parts are taken into account.

All surfaces are assigned reflection classes (RK) to assess quality numbers using the web application *Chaser*. By varying the reflection classes of wall and ceiling elements, the influence of the acoustic properties of the surface cladding on the hearing load becomes clear. During this process the reflection classes of the floor and the surfaces in the bullet trap chamber are kept

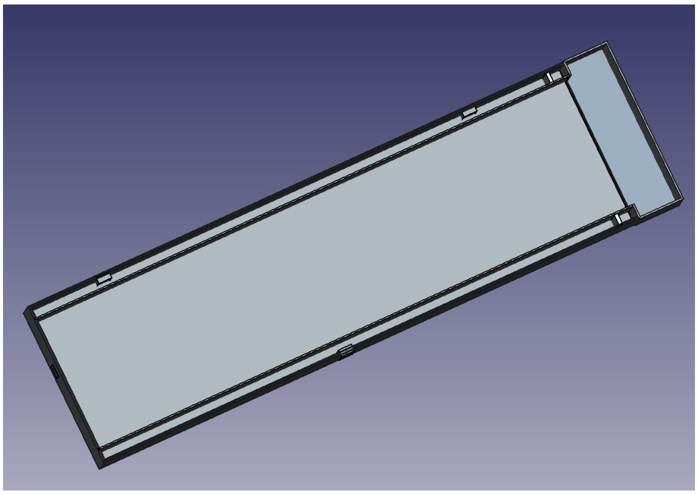


Figure 1: CAD model of the shooting room from a bird's eye view (the ceiling has been blanked out).

constant. Thus, the bullet trap chamber in the model is regarded as an empty room whose surfaces are sound-reflective and satisfy the reflection class RK0. A conservative estimate is also made for the floor and therefore RK0 is also applied to this area.

The rear wall, the side walls and the ceiling were each assigned the reflection classes RK2, RK6, RK10 and RK15 according to table 1.

Table 1: Combinations of reflection classes in the shooting range.

| **Index** | **Floor & Bullet Trap** | **Rear Wall, Side Walls & Ceiling** |
|---|---|---|
| 1 | RK0 | RK2 |
| 2 | RK0 | RK6 |
| 3 | RK0 | RK10 |
| 4 | RK0 | RK15 |

### 2.2. Free field reference

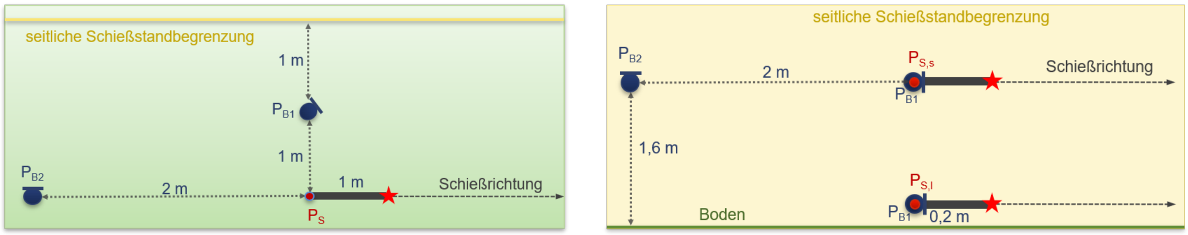
To determine the quality number, the hearing exposure of an open shooting range is used and compared with the hearing exposure in the shooting room. The floor space of a type A shooting range is selected as such a reference system. Therefore, the only relevant reflective surface is the gravel floor, for which the reflection class RK6 was determined by measurement.

### 2.3. Boundary Parameters of the Simulations

The following boundary values are assumed for the *Chaser* forecasts:

- the weapon class selected is the pistol class with standing firing position
- the source's sound pressure time curve is generated according to Friedlander [2]
- $P_{B,2}$ according to Figure 2 is used as the assessment point, which lies 3 m behind the muzzle's position. $P_{B,2}$ provides a more conservative estimate compared to $P_{B,1}$, since room reflections have a greater influence there

– an open area consisting only of the gravel floor with reflection class RK6 is used as a reference




(a) Top view (b) Side view

*(seitliche Schießstandbegrenzung = Lateral shooting range boundary; Schießrichtung = Firing direction; Boden = Floor)*

Figure 2: Assessment positions $P_{B,1}$ and $P_{B,2}$ [1].

The hearing impairment risks required to calculate the quality number are determined using the AHAAH model [3]. The following boundary values apply for free-field simulations as well as for indoor simulations:

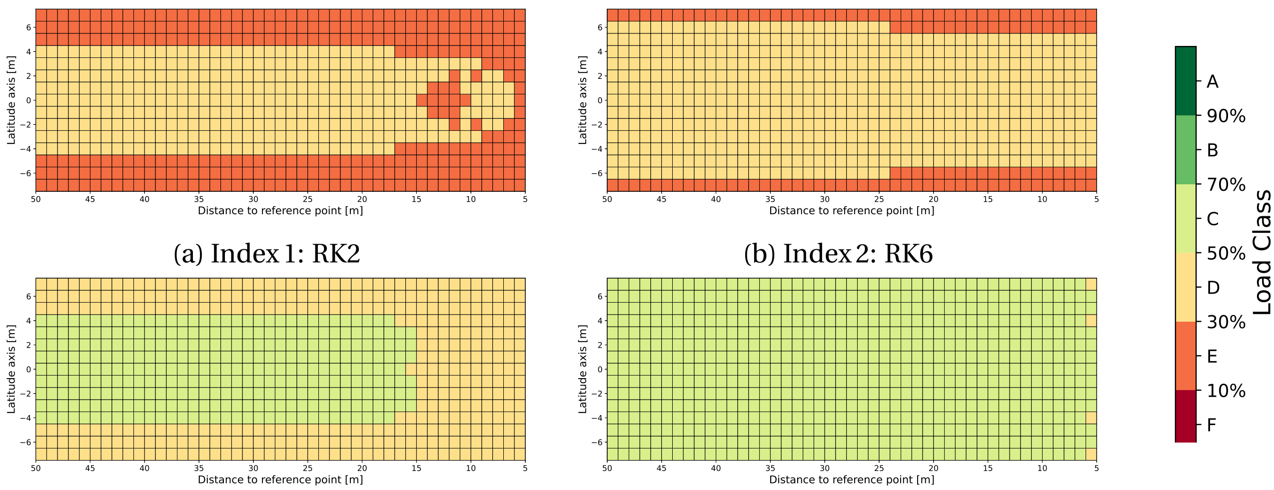
- unwarned
- no hearing protection
- frontal sound incidence

## 3. DETERMINATION OF REQUIREMENTS

With the previously presented boundary parameters, the next step is to determine the location-dependent quality number in the room firing system depending on the surface cladding.

### 3.1. Personnel Load Maps

The personnel load maps of the shooting room variants of Table 1 are shown in Figure 3 for the point $P_{B,2}$ which lies 3 m behind the muzzle. These maps show that at least systems that fulfill RK10 must be installed on the walls and ceiling in order to achieve load class C in the center of the room. This would allow 50 % of the shots of the reference system.




(a) Index 1: RK2 (b) Index 2: RK6

(c) Index 3: RK10 (d) Index 4: RK15

Figure 3: Personal load maps of representative surface cladding variations.

Only when a surface system of RK15 is used, a load class C can be achieved in large areas of the facility. This means that reflection class RK10 is the minimum requirement for the surface system.

### 3.2. Available Products

Existing surface cladding systems were reviewed as a solution that could fulfill the requirement of RK10 or higher. The search was made difficult by the fact that the classic sound absorption coefficient is not a suitable evaluation parameter for shooting noise. As the distance between the source and receiver is only a few meters when shooting, the sound incidence angle of the first surface reflections, which are decisive for the additional hearing impairment, is mostly approximately 80° to 90°. The angle-dependent reflection behavior must therefore be taken into account when determining the reflection behavior. According to DIN EN 1793-5 [4], the angle dependency of the reflection coefficient is taken into account, which is why measurements according to this standard are used as a meaningful evaluation parameter. However, this data is not available as standard for products, so it must first be collected.

In Figure 4, the reflection coefficients of three products are shown whose sound absorption coefficient $\alpha_W$ is between 0.7 and 0.95. In these systems, the 18 mm to 40 mm thick cover layers (expanded glass granulate panel, glass wool panels and wood wool panel) are each on top of approximately 50 mm mineral wool.

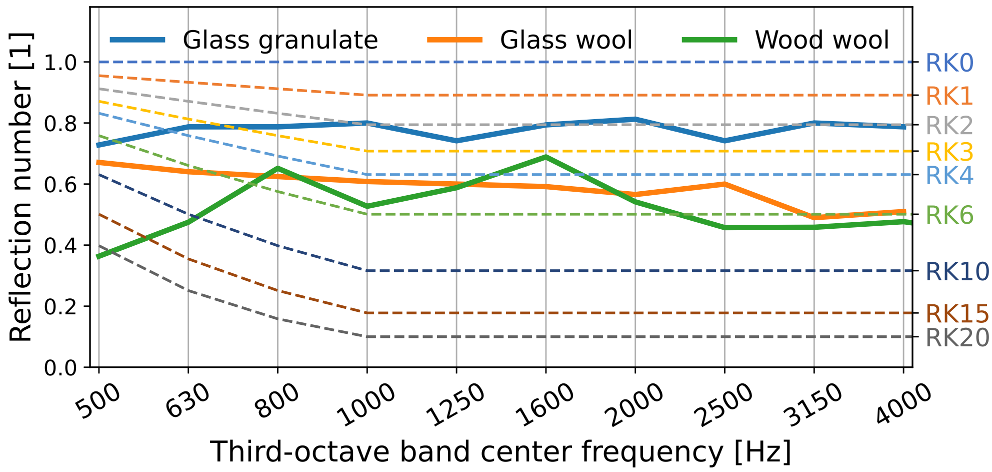



Figure 4: Third-octave band-dependent reflection coefficients of the systems with the cover layers: Expanded glass granulate board, glass wool panels and wood wool.

The classification of these systems into reflection classes shows that the expanded glass granulate panel system is assigned RK1, the glass wool panel system RK4 and the wood wool panel system RK3. According to Figure 3, in the best case 30 % and in the worst case no more than 10 % of the shots of an open type A shooting range would be permissible with these systems. Therefore, no product was found that meets the requirements of the interior fittings.

## 4. PRODUCT DEVELOPMENT WITHIN A COMPETITIVE DIALOG

In order to find a suitable product for the surface cladding of the ceilings and walls, a competitive dialog was initiated. In this procedure, the client and the applicant jointly search for solutions on the basis of which the applicant can then submit a bid. First, some of the requirements for the systems are listed and then the individual stages of the procedure are outlined.

**Most important Requirements for Surface Systems**

- maximum installation depth of 1 m
- self-supporting (no attachment to walls)

- impact-resistant top coats
- flame retardant or non-combustible materials
- acoustic reflection class RK10 or better
- shooting safety (there must be no rebounds)
- thermal resistance of $R \leq 2{,}5\,\mathrm{m^2K/W}$ so that no critical dew point shift occurs on external walls

**Stage 1 - Preselection**

Out of nine applicants, five were selected on the basis of entrepreneurial parameters such as company size, experience with shooting ranges or field of activity.

**Stage 2 - Material Samples**

As part of the second stage of the competitive dialog for the development of acoustic wall and ceiling cladding for indoor shooting ranges, preliminary acoustic tests were carried out. These were used to estimate the reflection properties of individual samples for the special case of shooting noise. A measurement system based on near-field holography was used as an alternative measurement method to DIN EN 1793-5[4][1]. The measuring probe specially developed for this application is a further iteration of a measuring array [5] used to date and also enables acoustic field separation and the associated determination of a complex reflection factor.

The choice of the alternative measurement method results primarily from the relatively small test sample size. Samples with a size of approximately $1\,\mathrm{m}^2$ are sufficient to generate meaningful results for the relevant frequency range. For measurements according to DIN EN 1793-5[4] - despite permissible simplifications - test samples with the dimensions 2,4 m × 3,6 m would be necessary. This would mean significantly higher material and measurement costs, which would not be cost-effective for this early development or product discovery phase.

This allowed the reflection coefficients for vertical sound incidence of up to five systems or materials to be determined for each of the five participants. The materials tested were various panels made of mineral wool, glass wool, wood wool, melamine resin foam and PET acoustic fleece. Combinations of the individual materials were also measured.

Several of these products achieved the required reflection class RK10 and some even almost achieved RK15. The problem with these acoustically permissible systems was that the top layers were not robust enough to be used in shooting ranges. This gave rise to the task for the companies of finding a combination between a hard and robust top layer and the acoustic requirements.

Six weeks later, all companies had the opportunity to have their revised systems measured again. This revealed that PET acoustic panels were the most promising materials for the top layer. On the other hand, solid arguments for and against taking individual companies to the next stage of the competitive dialog were presented.

**Stage 3 - Prototypes**

In this third and final stage, the two remaining companies were asked to build a prototype measuring 3,6 m × 2,4 m. These constructions fulfilled the requirement for a standardized measurement based on DIN EN 1793-5 [4]. In addition, they were measured with the measuring probe using the near-field holography method. The build-up depths of the individual prototypes were from 170 mm to 250 mm, whereby the individual material layers were a maximum of 60 mm thick. The approximately 1000 mm × 500 mm large top layer panels, the multi-layer systems, were clamped with approximately 30 mm wide hat profiles. Such a hat profile is shown in Figure 6.

### Stage 3 - Measurement Round One

In the first round of measurements, only one of five measured prototypes met the requirements of the competitive dialog. As an example, the third-octave band-dependent reflection coefficients of such a system are shown in Figure 5. The curve of the relevant measurement method based on DIN EN 1793-5 shows that the reference value of the 3,15 kHz third octave band is exceeded. The prototype therefore does not meet the required reflection class RK10. The other test samples also showed a significant increase in the 3,15 kHz third octave band, which - with the exception of one system - always led to the guideline values of RK10 being exceeded.

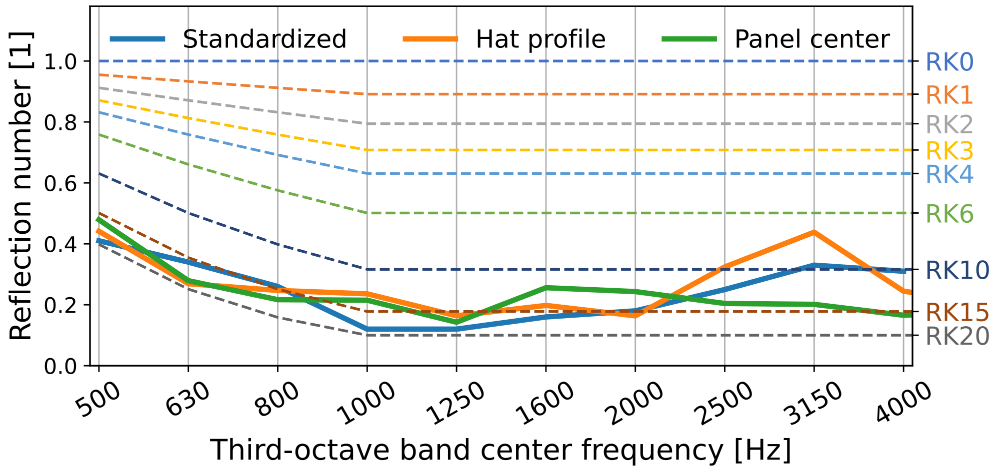



Figure 5: Third-octave band-dependent reflection coefficients of a prototype according to DIN EN 1793-5 and by means of near-field holography in the center of the plate and above the cap profile.

With the standardized measuring method, nine measuring points over the area of approximately 0,64 $m^2$, which means that the construction can be measured over a large area. With the measuring probe, however, individual areas of the test structures could be examined more closely. For example, measurements were taken in the middle of the panel and above a hat profile. The reflection coefficients of these two measurements up to the 2 kHz third octave band are largely consistent with each other and with the standardized measurement. From 2,5 kHz to 4 kHz, however, there is a significant difference between the two measurement points. The reflection coefficient above the cap profile is about twice as high as above the area in the middle of the plate.

The most likely cause of this phenomenon is the hat profiles that were used for all test samples. This assumption is supported by the fact that the profile width of 30 mm corresponds to approximately 1/4 of the wavelength of the critical frequency band.

An experimental setup was designed to validate this assumption. For this purpose, two 1000 mm × 500 mm × 100 mm melamine resin foam panels were placed on a solid, reverberant surface. A hat profile was placed between the long edges of these two panels, which was filled with a PET fleece strip according to Figure 6. Then the third-band-dependent reflection coefficients were determined at the height of the hat profile using the measuring probe. In the next step, the PET fleece strip was removed from the cap profile without changing anything else in the measurement setup. A new near-field holography measurement with the measuring probe was used to determine the reflection coefficients of the setup with an empty cap profile. In Figure 7, the reflection coefficients of the systems with empty and filled hat profiles are compared. This shows that the hat profile does not influence the reflection coefficients below a frequency of

Figure 6: Hat profile with PET fleece strips.

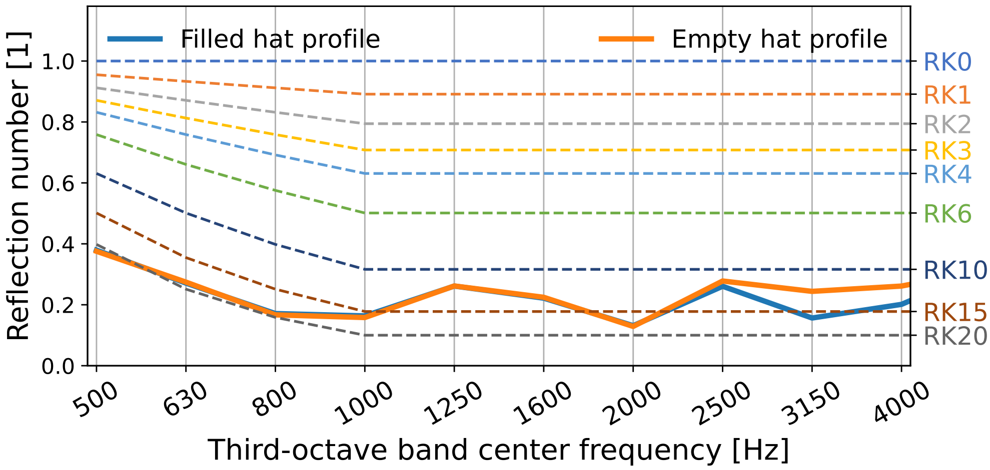



Figure 7: Reflection coefficients of the empty and filled with melamine resin foam hat profile determined by means of near-field holography.

2,5 Hz. Above this frequency, it is clearly recognizable that the reflection coefficients increase significantly due to the hat profile.

### Stage 3 - Measurement Round Two

This information, together with the recommendation to fill the hat profiles with acoustically effective materials, was passed on to the two companies. The manufacturers therefore revised their test samples and new standardized acceptance measurements were carried out in accordance with DIN EN 1793-5. The results of these measurements are shown in Figure 8, again as an example for a test sample. By filling in the hat profiles, the high-frequency reflection coefficients of the test sample could be significantly reduced. As a result, this, as well as the other four test setups, fulfills the requirements of reflection class RK10 with a sufficient buffer. From an acoustic point of view, product development is therefore complete.

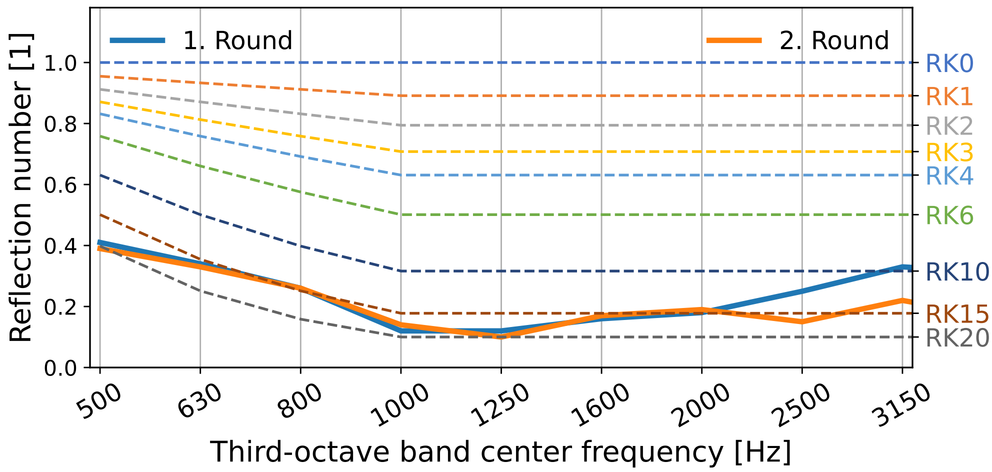
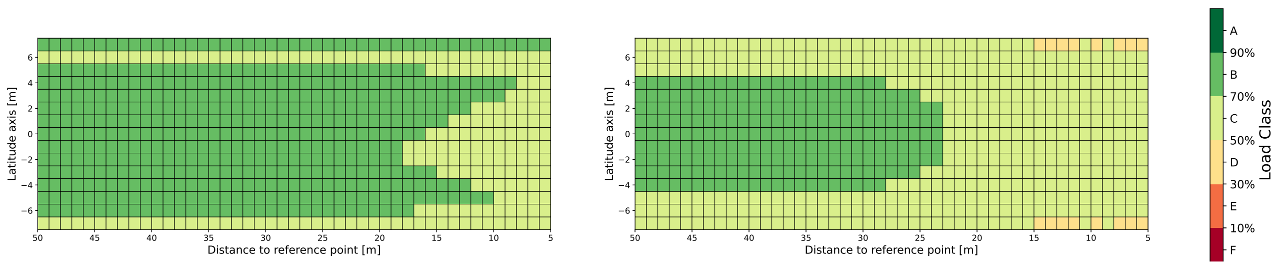



Figure 8: Reflectance values of a prototype with empty (1. Round) and filled (2. Round) cap profiles determined using a standardized measurement method.

## 5. PRODUCT EVALUATION

Finally, personnel load maps with third-band-dependent reflection coefficients of the developed surface coverings are calculated again, which are shown in Figure 9.




(a) $P_{B,1}$ (b) $P_{B,2}$

Figure 9: Personnel load maps with the final third-octave-dependent reflection coefficients of the prototype according to Figure 8 for both observation points.

The final personnel load maps show that for the observation point $P_{B,2}$ in the middle of the room 70 % and otherwise 50 % of the shots of the reference system are permissible. This means that the desired target from Figure 3d is even exceeded with the real RK10 system. The reason for this lies in the combination of the 315 Hz weapon center frequency of the pistol class and the frequency interval relevant for shooting noise of 1 kHz to 4 kHz. As a result, the frequency range at 1 kHz is particularly critical, as the source signal still has relatively high energy here and the sensitive range of the AHAAH model begins. In Figure 8, the frequency-dependent reflection loss of 1 kHz to 1,25 kHz of approximately 20 dB is significantly better than the RK15. This also explains the higher quality numbers.

## 6. CONCLUSIONS AND OUTLOOK

Almost all aspects of the *Acoustic Safety* procedure were dealt with using the example of the competitive dialog. In addition to the appropriate metrological determination of reflection properties for shooting noise, simulations for determining quality numbers and the associated personnel load maps were discussed. The relationship between the surface cladding and the permissible number of shots and the associated optimization options were also considered. A metrological validation of the personnel load maps by measuring shooting noise could not yet be carried out in this project, as the facilities are still under construction.

Wall and ceiling claddings of reflection class RK20 or higher provide only slightly higher quality figures compared to surfaces of RK15. In addition, significant improvements in reflection coefficients can probably only be achieved by changing the surface geometry and increasing the depth of the structure. The floor and bullet trap are the biggest levers for further minimizing hearing exposure in indoor shooting ranges. These surfaces have not yet been acoustically optimized and are therefore acoustically hard. Small improvements here can lead to significantly higher quality numbers.

## 7. ACKNOWLEDGEMENTS

The work on the *Acoustic Safety* is supported by IUD I 5 of the German Ministry of Defense.

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