ABSORPTION OF GILDING IN CONCERT HALLS

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ABSTRACT

A few renowned concert halls have walls, statues, and ceiling surfaces covered at least partially with gilding. Despite its appearance, such material is not actually gold. Instead, it is composition gold, which is a very thin leaf of copper-tin-zinc alloy, finished with shellac lacquering. In order to investigate the effect of treatments on room acoustics, we asked an artisan, a Master Gilder, to prepare gypsum cylinders that were pre-cut to diameter of 29 mm for impedance tube measurement. The top surfaces of these specimens were treated either with composition gold, real 24 carat gold leafs without shellac, or linseed oli paint. The absorption coefficients of all these cylinders were measured with an impedance tube. Each specimen was measured on both sides to provide a direct comparison between different surface treatments to untreated gypsum. This paper describes the measurement process, the practical issues encountered in fitting the specimens tightly for measuring, and finally the results of the measurements. The results show that the absorption coefficient of the composition gold is 0.02 over a wide frequency range, and it absorbs approximately 50% less sound energy than bare gypsum.

1. INTRODUCTION

Many old concert halls have statues, ornamentations and other decorative elements. In some halls those decorative elements are gilded, most probably for visual purposes. In particular, the Musikverein in Vienna is famous of its gilded decorations and caryatids (the female statues) and therefore the hall is often called as the Golden hall. The gilding in the Golden hall is not real gold leaf, the material used is called the ”composition gold”. It is a thin foil of metal leaf made out of a copper-tin-zinc alloy, that is installed on the decoration made out of plaster, wood or gypsum, and finally covered with shellac. The shellac guarantees that the metal keeps its yellow color as gasses cannot react with the metal. The caryatids are made out of zinc and they are also gilded with the composition gold finished with shellac.

In addition to its visual impression, thin metal leaf coverage finished with shellac is interesting from the acoustical point of view. Metal leaves and shellac occlude the pores in plaster, thus it could be assumed that this material absorbs hardly any sound at high frequencies. Therefore it is interesting to find out the absorption coefficient of the gildening.

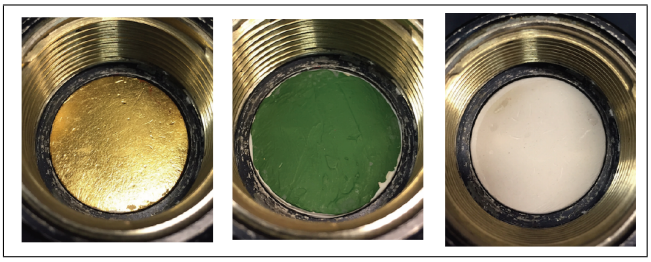

Figure 1. The investigated specimens in the impedance tube sample holder. From left to right: metal leaves with shellac, .i.e., composition gold; oil painted; bare gypsum.

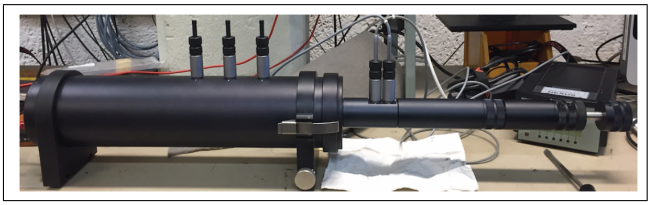

Figure 2. The B&K impedance tube 4206-T with the extension part for high frequency measurements (500 - 6400 Hz, tube diameter 29 mm).

Another motivation for the presented work is the high frequency noise from the ceiling that we heard during room acoustical measurements in the Golden hall in 2012 [1]. In the end of the sine sweeps, there were clearly audible noise-like effect that could be localized to the ceiling. Apart from Konzerthaus Berlin with similar gilded decoration in the ceiling and balcony fronts, we did not hear such noise-like tail in the end of a 5 s logarithmic sweeps. Both of these halls are known form the brilliant string sound, thus, could the secret lie in the acoustical effects of gilding?

2. PREPARING THE SPECIMENS

For the absorption coefficient measurements, the specimens of the materials that fit perfectly to the impedance tube are needed. The B&K impedance tube 4206-T has a tube diameter 29 mm for high frequency measurements. Thus, several mockup material samples were 3D printed to find out the exact size that would be tightly fitted into the tube. When the suitable mockup was found, it was given to the professional craftman (a Master Gilder), who made a mold for gypsum specimens with the 3D printed prototype. The final specimens were made with base gypsum

and water without any adhesives.

The Master Gilder made the 30 mm long gypsum specimens according to the mold and treated one of the tops for each specimen. The other top was left as bare gypsum so that it could be measured for the reference value. There were three different coatings on the tops:

- 24 karat leaf gold without shellac,
- composition gold with shellac,
- linseed oil paint.

The first material, pure 24 karat gold leaf, was studied for curiosity to see how much it differs from the composition gold. The linseed oil paint is also interesting, as in the ceiling of the Golden hall, there are quite large paintings. The Master Gilder believed that the linseed oil paint is the closest equivalent for the paint used about 100 years ago in the paintings. Figure 1 shows the composition gold, oil paint and bare gypsum specimens installed in the impedance tube.

3. MEASUREMENT PROCEDURE

The absorption coefficient measurements were performed with a B&K impedance tube 4206-T, shown in Fig. 2. The responses were measured with two-microphone method using a logarithmic sweep. With the transfer function technique according to the ISO standard [2], the absorption coefficient of the measured material can be determined.

3.1 Calibration

The calibration of the measurement equipment is done to remove the unidealities of the transducers and to correct the possible mismatch between the measurement microphones. Based on our experience, the calibration is not crucial when highly absorptive materials are measured. However, in this case the materials were highly reflective, thus the calibration measurements had to be done with great care.

The ISO 10534-2:1998 standard proposes three different approaches to compute the calibration factor. The first one is said to be the normal method, the second one is recommended when there are some noise in the input and the third one when there are noise in both in the input and in the output. Here, all three of them were implemented and tested. The most smooth results were obtained with the second calibration method.

3.2 Tight fitting of the specimens

Highly reflective materials are difficult to measure with the impedance tube. The specimens have to be exactly the right size to fit in perfectly to the impedance tube, as the tiny leakage of the sound would easily influence the results. To fit the specimens very thighly, we used the thread seal tape around the gymsum body to prevent any leakeage. The thread seal tape is a polytetrafluoroethylene (PTFE) film tape commonly used in plumbing for sealing pipe threads. This tape was found to be good and after many attempts we managed to get reliable and reproducible results.

4. RESULTS

Each specimen was measured on both ways, as the other top had the treatment and the other was bare gypsum. This was thought to give us results where we can compare the treatment to bare gypsum. For each material there were two specimens, which were measured twice by removing the specimen from the tube in between the measurements.

The first result is the absorption coefficient of the composition gold, i.e., metal leaf with shellac. Figure 3 shows that the average absorption coefficient on wide band between 500 and 4000 Hz is 0.02. The highest theoretical frequency that can be measured with the used impedance tube is 6.4 kHz, but there seems to be some systematic bias above 4 kHz. Therefore, we believe that the results are reliable up to 4 kHz. The absorption coefficient of bare gympsum for these specimens were between 0.03 and 0.04, which is in line with the values presented in the other measurements [3, 4].

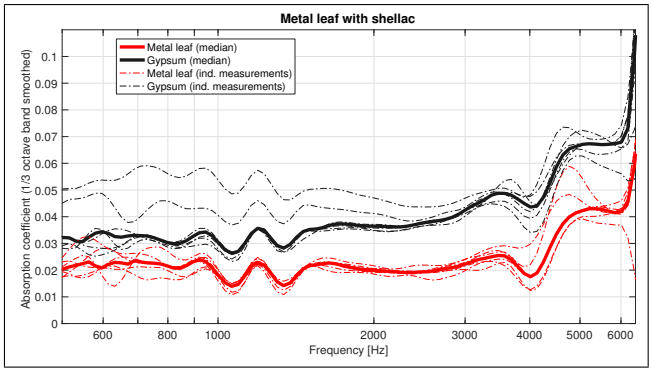

Figure 3. The measurement results with specimens covered with composition gold, i.e., metal leaf with shellac.

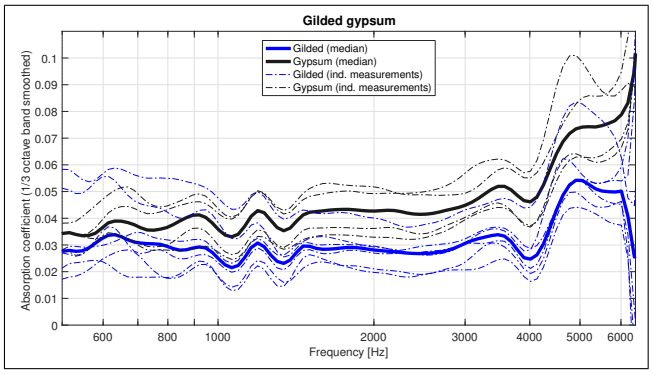

Figure 4. The measurement results with specimens covered with 24 karat gold leaves.

For curiosity, it is interesting to see the absorption coefficient of real 24 karat gold leaf. Figure 4 shows the results and it can be seen that the absorption coeffiencient is around 0.03. However, the bare gypsum values are a bit higher than seen in Fig. 3, thus no real difference in ab-

sorption between composition gold and real gold cannot be found with these measurements.

The linseed oil paint seems to absorb a bit more sound than the composition gold, see Fig. 5. Based on these measurements the oil painted specimens had absorption coefficient of 0.04 between 1 and 3 kHz.

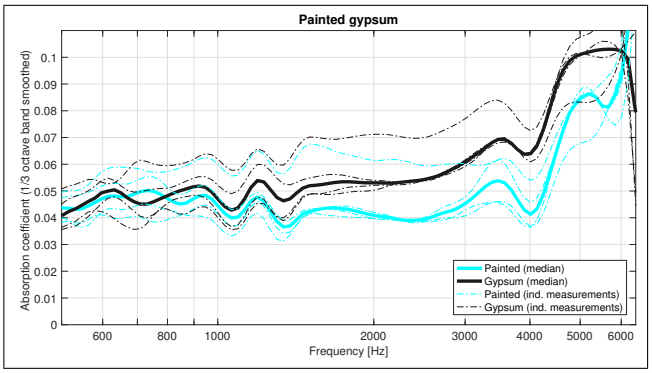

Figure 5. The measurement results with specimens painted with linseed oil paint.

Finally, all the results are compared in Fig. 6. There we can see that median curves of bare gypsum and oil painted specimens overlap almost the entire frequency range. In contrast, the absorption of composition gold is about half of the bare gypsum. In practice this means that in a concert hall the surface area of decorative elements could be twice as large as than untreated gypsum. We assume that the same conclusion could be made it the underlying material is plaster or lime on solid backing.

5. DISCUSSION

Visual analysis of a wide-angle photograph from the Musiverein's rear balcony to the hall suggests that the gilded areas over a typical cross-section of the hall can be up to 40% of the overall surface area. This result was obtained by processing the high-resolution image in the CIELAB color space and isolating the areas having a shade matching the color information of distinct gilded surfaces. With a high proportion of gilding, even a small change in absorption can have substantial acoustical effects.

When carefully analysing the recorded sweeps from our measurements both in the Musikverein and Konzerthaus, we found out that the heard high frequency noise in the end of the measurement sweep was in frequencies between 1 and 4 kHz. Both halls are relatively narrow rectangular halls with side balconies and high ceiling. Such a shape render the lateral early reflections before the first ceiling reflection, suggested to be beneficial for dynamic responsiveness [5–7]. Therefore, the most convincing explanation why this noisy sound from sweep was audible is that the reverberation time at those frequencies is so long that the decay is still audible in the end of the applied logarithmic 5 s long sweep. Moreover, the high frequency noise was located to the ceiling, thus, it is clear that the late reverberation develops in the upper part of the room volume and comes down relatively late. For such late mid and high

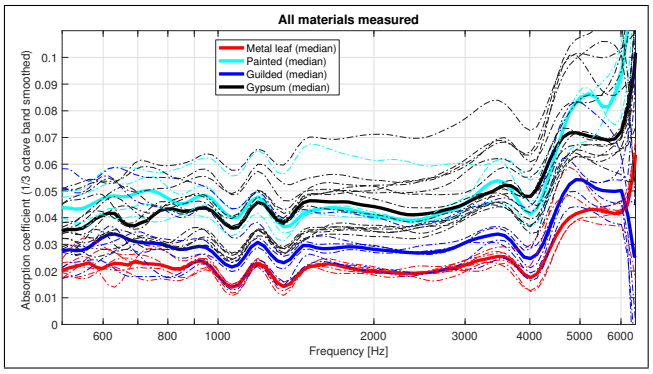

Figure 6. All measured materials in one figure.

frequency reverberation, the surface materials need to be as reflective as possible to minimize high frequency absorption and in this sense the guilding might be beneficial, being very reflective over a broad frequency range.

For the curiosity it should be mentioned here that in the Golden hall the ceiling construction is indeed very interesting. The original ceiling was burned in 1911 and the reconstruction, made also from wood, has extra material to prevent fires [8]. Clements wrote in her great article [8] as follows:

> *The ceiling itself is an unusual construction – the gilded decoration is applied to plaster over a system of wooden beams and panels that are suspended on rods from the roof trusses. Above this wooden construction is a layer of white, dusty sand about 75 mm thick and on top of this are flat terracotta bricks approx. 25 mm thick. The whole system is designed so that the ceiling load does not bear directly on the side walls but is carried to the walls via the roof beams.*

This description indicates that sand and bricks on top of lowered ceiling increase the mass of the construction significantly. Therefore, the ceiling is not leaking low frequencies from the hall. Moreover, the gilding is applied on plaster, which is equivalent to base gypsum used in this study. It could be concluded that the ceiling construction is very reasonable from the acoustics point of view, as the mass keeps the low frequencies inside the hall and the surface treatment minimizes the high frequency absorption for late reverberation, which often is lowpassed due to air and material absorption.

6. CONCLUSIONS

This paper presents measurement results of the gypsum specimens that were covered with composition gold or oil painting, which are sometimes used as decoration in the old concert halls. The measurement results indicate that bare gypsum itself has very low absorption coefficient, but when it is covered with composition gold with shellac lackequering the absorption coefficient was even smaller, being 0.02 between 500 and 4000 Hz. Such very low absorption

coefficient in ceiling and other surfaces was speculated to be beneficial from room acoustic in narrow and high halls where there are lot of space in the upper volume of the hall.

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