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Measurement of reverberation time with rotating microphone in test chamber and its problems

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When measurement of reverberation time is done in a test chamber to evaluate acoustical property of materials, spatial averaging of reverberation time should be done. Using microphone rotator is recognized as one of the tool to do spatial averaging. This study compared results between three methods of spatial averaging of reverberation times measured in small rectangular test chamber (3m x 4m x 5m). The first method is averaging reverberation time measured at 5 of fixed position used as standard positions for testing, the second is at 72 fixed positions on the circle of microphone rotator, and the third is with microphone rotator (64 s/rotation). The result of comparison between three methods revealed that reverberation time measured by rotating microphone has more scatter than those measured by other method and presented different reverberation time from others especially at lower frequency bands. Simulation of microphone rotation with the decay curves measured at 72 fixed positions suggests that spatial distribution of steady state sound pressure level, rotation speed of microphone, and reverberation time of test chamber are key factors of errors. As a conclusion, the strict guideline for measurement of reverberation time with microphone rotator should be presented to minimize errors.

1 Introduction

It is required to do spatial averaging when measuring reverberation time in test a chamber [1]. In general, spatial averaging is obtained by calculating mean value of reverberation time at several fixed receiving positions.

On the other hand, it is allowed in new ISO 3382-2 FDIS [2] to do spatial averaging of reverberation time with rotating microphone when it is measured by interrupted noise method for the "survey method." It suggests that using microphone rotator is recognized as one of the tool to do spatial averaging. Using moving microphone seems to save measurement time.

The intention of this study is to find possible error of measuring reverberation time with rotating microphone. This study compares results between three methods of spatial averaging of reverberation times measured in small rectangular test chamber. The first method is averaging reverberation time measured at 5 of fixed position used as standard positions for testing, the second is at 72 fixed positions on the circle of microphone rotator, and the third is with microphone rotator.

2 Measurement of reverberation time

2.1 Specification of the test chamber used for measurements

The dimension of test chamber is 4 m width, 5 m depth and 3 m height. The test chamber is served as measurement room for floor impact sound at Kobayasi Institute, Japan. The structure is solid reinforced concrete and surface is finished with polished concrete. Three different conditions were prepared for the measurement. The "Case 1" is a controlled condition with absorption treatments evenly distributed to room surfaces to control reverberation time within certain range. The "Case 2" is bare room without any absorption materials. The "Case 3" has same absorption materials as "Case 1" but all the materials were put only on the floor.

2.2 Measurement method

Figure 1 presents arrangement of two sound sources, five of fixed microphones and a microphone rotator. The microphone attached on microphone rotator moved on the circle which radius was 1.03 m. The circle was on the plane 19 degree inclined against the floor. Two of omni directional sound source were used as sound source. The first method is the standard method for this chamber with five fixed microphone. The second and third method is using microphone rotator.

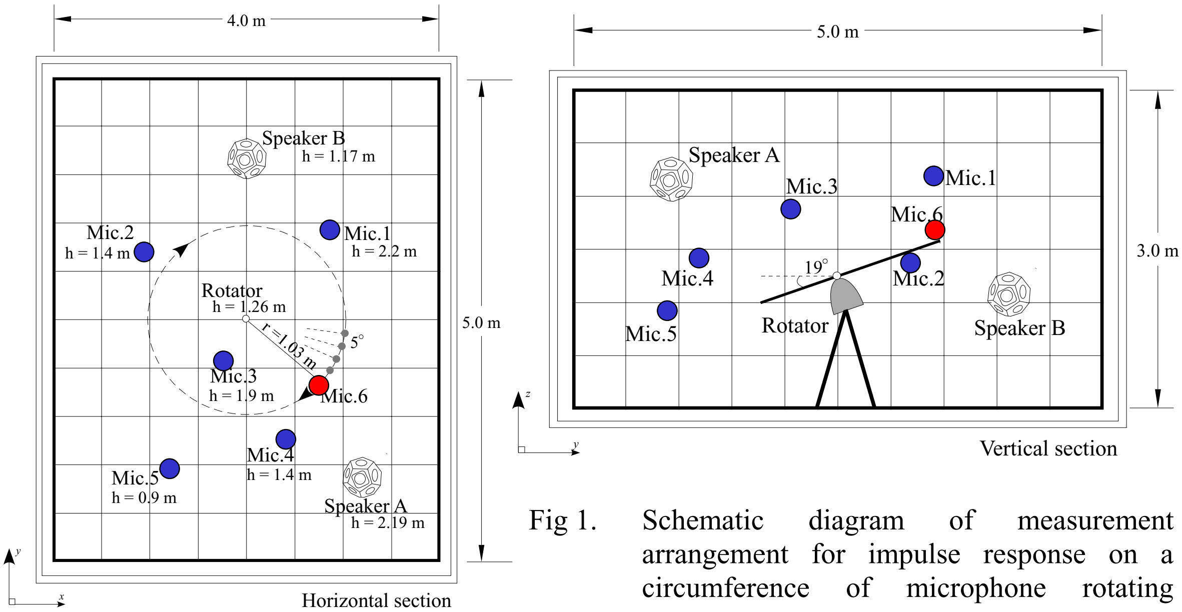

Fig 1. Schematic diagram of measurement arrangement for impulse response on a circumference of microphone rotating system.

The second is impulse response measurement [3] at 72 of fixed positions on the circle. The measurement signal was swept-sine (fs = 44.1 kHz) and its duration time was 12 s to cover 6 octave band from 125 Hz to 4 kHz without synchronized averaging. The third method is interrupted noise method with rotating microphone. The rotation speed was 64 s per rotation.

2.3 Simulation of interrupted noise method using impulse response

The simulated interrupted noise method was used to calculate reverberation time with measured impulse response. Eighteen of 1/3-octave band noises from 100 Hz to 5 kHz were convolved with impulse response. Each band noise had 10 s of duration time for Case 1 and Case 3 and 20 s for Case 2. Reverberation time was calculated from -5 dB to -25 dB from steady state sound pressure level (T20). Ten different pink noises were used to create 1/3 octave band noise and reverberation times were calculated as mean value of ten of reverberation time for each position.

2.4 Simulation of rotating microphone by fixed microphone measurement on the circle of rotation

First, decay curves were calculated from 72 of fixed microphone measurement on the circle of rotating microphone by simulated interrupted noise method. The steady state level is not set at 0 dB and comparable in each measuring positions. Time scale of each decay curves is started at the time when the sound source was stopped. This means that all of decay curves have same time scale started at same 0 s.

Second, decay curves were divided into pieces those duration times were a rotation cycle divided by 72.

Third were selecting a starting position and connecting the next segment of next position and continuing this step until decay curve reaches the level of -25 dB from steady state level of starting position.

The last step is calculating reverberation time with simulated decay curve obtained by this procedure.

3 Results of measurement and discussion

3.1 Comparing method of spatial averaging

Figure 2 presents frequency characteristics of reverberation time and its coefficient of variance measured in each case by three measuring methods. The first method used five fixed measuring positions. The second method used 72 fixed measuring positions on the circle of rotation. These two methods used the simulated interrupted noise method. Both methods were done at two source positions and with 20 results (10 noised for each band and 2 source positions) were averaged. The third method is actual interrupted noise method with rotating microphone. The rotating cycle (t) was t = 64 s/rotation. Starting positions of microphone rotation were located in 45degree interval. Eight measurements were made for two source positions.

Figure 2 suggests that there is little difference between measuring methods in Case 1 and Case 3 except low frequency bands from 100 Hz to 250 Hz, where coefficients of variance are twice as higher bands. The coefficient of variance for Case1 and that of Case 3 are quite similar. It is found that a result of rotating microphone method has wider variation and requires more number of measurements to decrease variance.

The room with Case 2 configuration has longer reverberation time than other cases. Coefficient of variance presents same tendency as other case except 100 Hz band. The mean reverberation time of 100 Hz band is quite longer and its scatter is significantly larger than other cases.

Figure 3 presents the difference of reverberation time between average of fixed 72 positions and result of rotating microphone measurement for Case 1 and Case 3. Because of low SN-ratio of measurement for 250 Hz and lower band, the difference is not consistent. Although longer reverberation time is found at higher bands from 250 Hz, the difference is around 0.02 s and it is less than S.D. of measurement result with 5 of fixed microphones. Thisresult suggests that using rotating microphone in rooms with shorter reverberation time has fewer problem than in rooms with longer reverberation time.

3.2 Change of reverberation time on the circle

Figure 4 presents changes of reverberation time for 125 Hz, 1 kHz and 4 kHz band on the circle measured by the fixed microphone method in the room with Case 2 configuration. Figure 4 also presents measured reverberation time with fixed microphones (M1 - M5). Figure 4 presents only the result with the sound source B ("Speaker B" on Figure 1).

It is found that many of results exceed the range of measured reverberation time by five microphones of fixed measurement at 250 Hz and 1 kHz bands. It is also found that changes are very steep. Although number of measurement points on the circle doesn't represent all through the room, it should be noted that number of measurement positions and selection of them and selection of measurement positions are critical.

3.3 Discussion on microphone rotation

The results of measurements present possible errors of microphone rotation but the results also suggests that errors seems not large except some cases in average. However, because of large variation of reverberation time, the reason of variation should be discussed.

There are two main reasons causing the variation of reverberation time when using rotating microphone. The first is changing the distance between sound source and

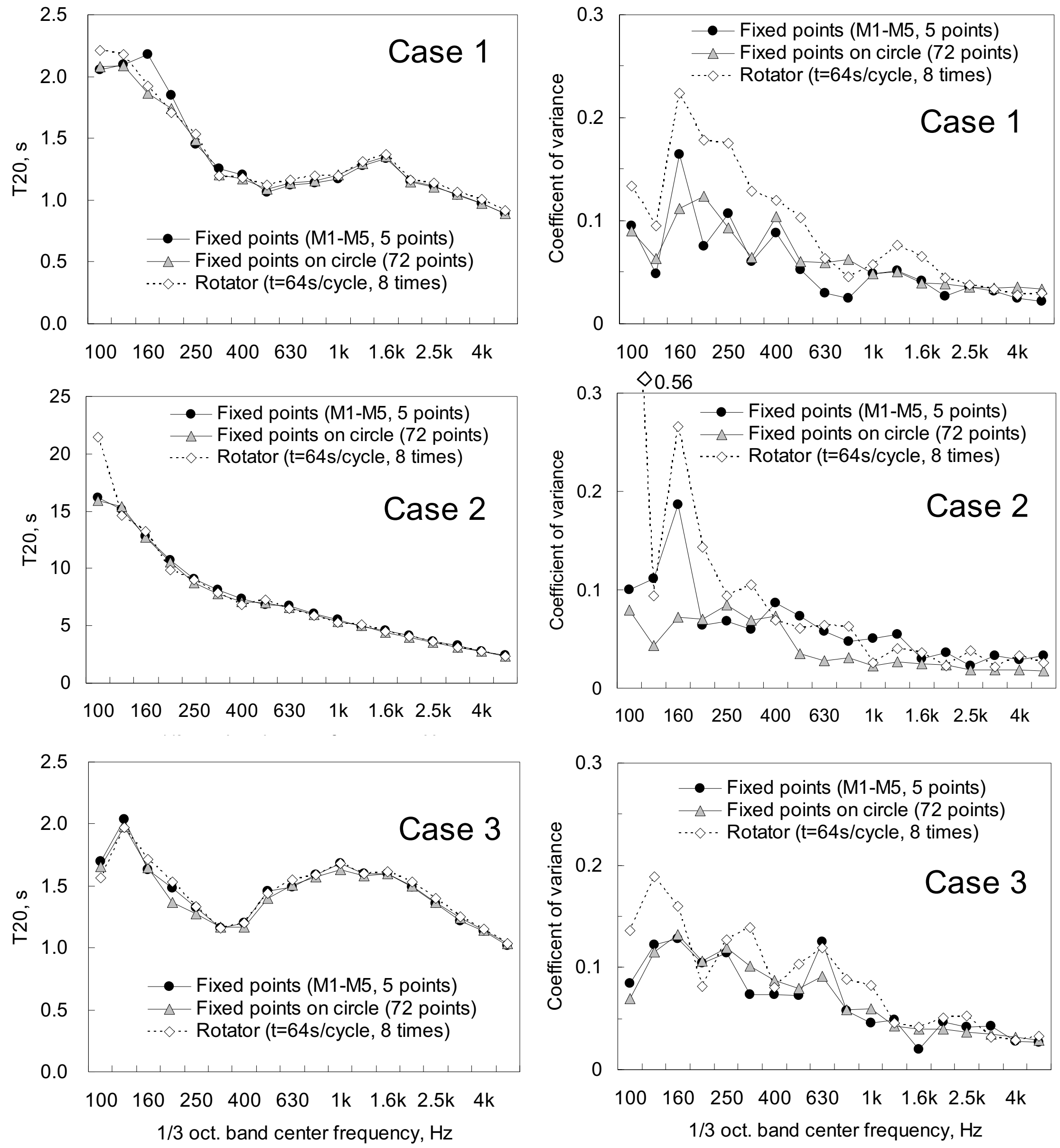

Fig. 2 Frequency characteristics of reverberation time and its coefficient of variance of each case. Each case shows results measured at fixed 5 points, fixed 72 points on circle and continuous averaged with microphone rotator.

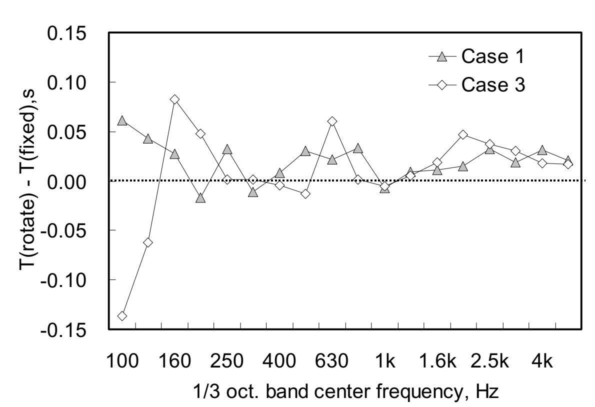

Fig. 3 The differences of reverberation time of each band between with rotating microphone and at fixed points on the circle of Case 1 and Case 3.

receiving positions. This will change time scale of decay curve. The second reason is distribution of steady state sound pressure level. It varies with positions and affected by room mode especially for lower frequency range. These factors might modify a decay curve measured by rotating microphone even if sound field is well diffused and same decay rate is expected to be found at every position.

Figure 5 presents changes of reverberation time and steady state sound pressure level at 100 Hz band as a function of degree of rotation in each case. Both changes are positively correlated for Case 1 and Case 2 but negatively correlated for Case 3. The difference between Case 1 and Case 3 is location of sound absorption materials. Because all of sound absorption was put on the floor for

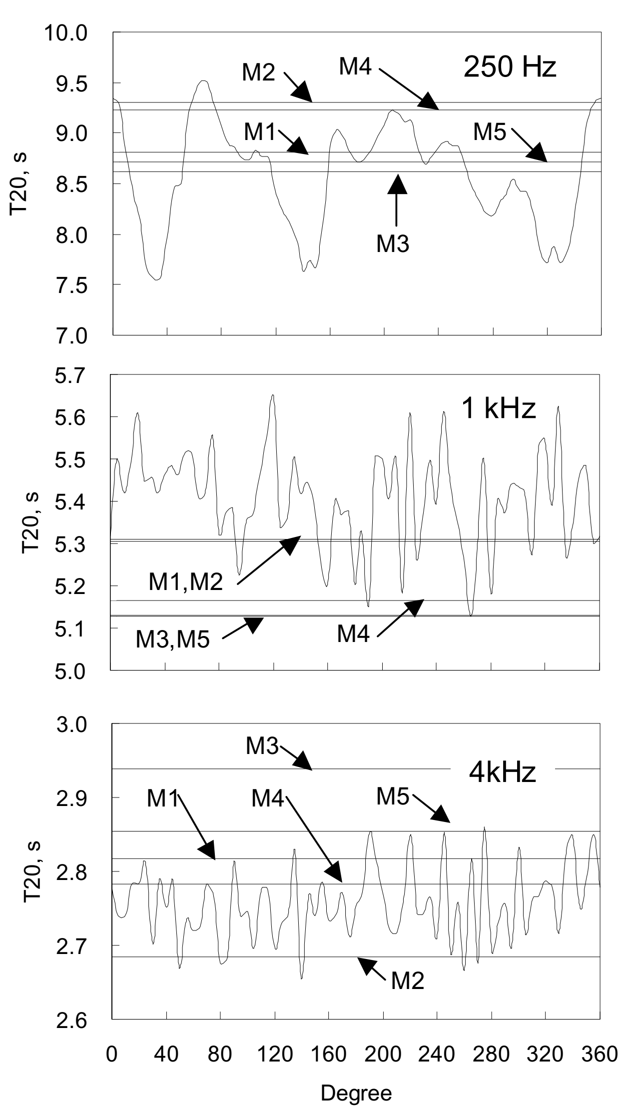

Fig. 4 Reverberation time of 250 Hz, 1 kHz and 4 kHz band measured at fixed 72 points on circle. Those measured at 5 fixed individual points are also presented.

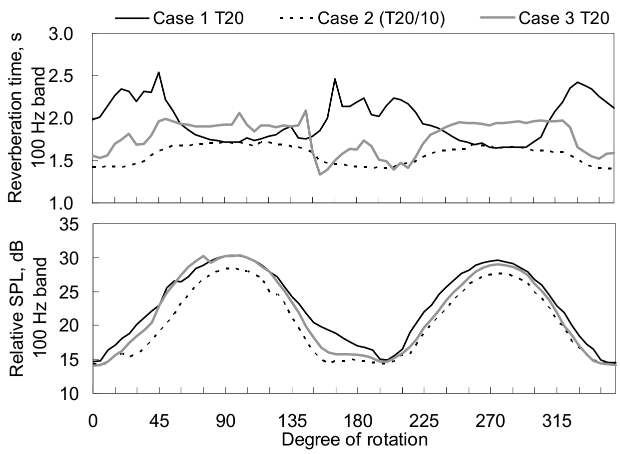

Fig. 5 Variation of reverberation time and steady state sound pressure level of each case measured at fixed 72 points on circle.

Case 3, sound distribution pattern is mainly generated by walls and distribution of sound absorption materials varies reverberation time.

The range of variation of reverberation time is 15 dB and it will be happened within 90 degree of rotation in this case. If the rotation speed is faster than changes of steady state sound pressure level, decay could not be observed.

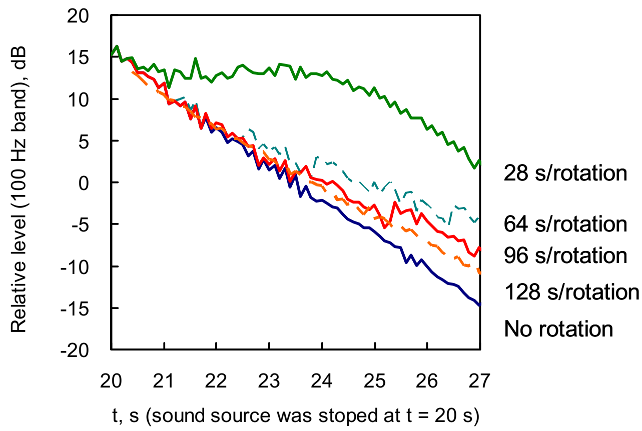

Fig.6 Decay curves obtained by simulation of microphone rotation started at the same position with 4 rotation speed under condition with increasing of steady state SPL. Fixed microphone case also presented.

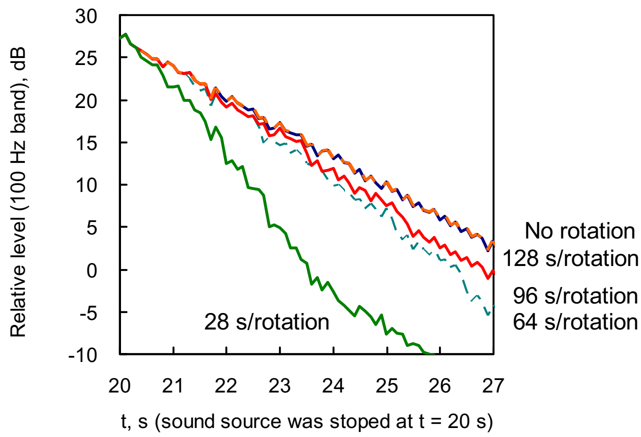

Fig.7 Decay curves obtained by simulation of microphone rotation started at the same position with 4 rotation speed under condition with decreasing of steady state SPL. Fixed microphone case also presented.

3.4 The effect of rotating speed on reverberation time

As previous section presents, shape of decay curve may be changed by rotating speed of a microphone. Figure 6 and Figure 7 presents decay curves measured with different rotation speeds. Figure 6 is observed when microphone rotate from the position with lower steady state sound pressure level to the position with higher level. Figure 7 is observed opposite case of Figure 6. When

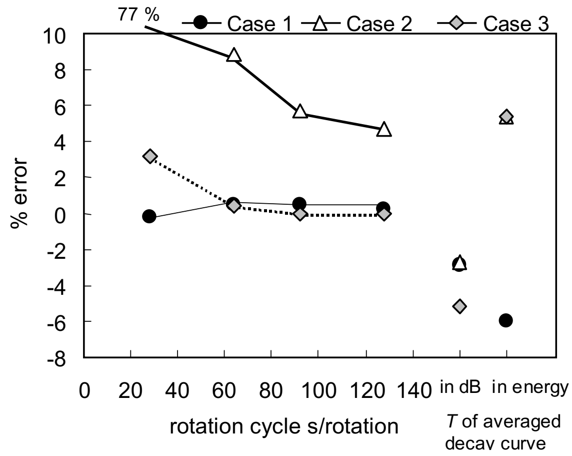

Fig. 8 Percent error of reverberation time observed in microphone rotation and decay averaging from average of 72 fixed point measurement.

rotating speed is quite high, it is possible to move the measuring position where the sound pressure level is higher than previous position. The case with the rotation speed of 28 s/rotation presents this phenomenon. Opposite phenomenon, which accelerate decrease of sound pressure level, is found in Figure 7. If enough number of reverberation time were measured with a rotating microphone, the mean reverberation time will be the same as the mean of results with fixed microphones.

Figure 8 presents percent error of reverberation time measured by microphone rotation method as a function of rotation speed from average of 72 results by fixed microphone method. Figure 8 also presents the error of reverberation time obtained from averaged decay curves. Decay curve averaging are done in dB scale and in liner scale.

The effect of rotating speed on reverberation time found in Case 2, which has longer reverberation time. It is necessary to use slower speed to minimize the error when a reverberation time of a room is long. More than error of 5 % is found only Case 3 with fastest rotation speed and Case 1 has less error than other conditions.

When averaging decay curve in dB scale, mean reverberation time is a couple of percent longer than mean value of 72 fixed positions except Case 1. The reverberation time of Case 1 by averaged decay curve in dB is shorter than 6 % than mean value of 72 fixed positions. In theory, if large number of rotations was made and starting points were evenly distributed on the circle, averaged decay curve would be same as the averaged decay curve of many of fixed positions. Because steady state sound pressure level has large variation, the beginning of and the end of averaged decay is smeared and reverberation time from it will be different from mean reverberation time of many of fixed positions. Errors are also found in reverberation times obtained by energy averaged decay curve.

Reverberation time is the decay rate of decreasing energy density in room. If a measured room is a complete diffused field without any room mode, a unique decay curve would be measured and reverberation time in a room also unique. In this case, there is no reason to do spatial averaging of reverberation time. However, even in test chamber, it is difficult to find ideal diffused field and this is the reason why spatial averaging is required. There is no doubt that mean reverberation time obtained from quite large number measurements at fixed positions is representative value of a room because source of reverberation time is physically clear and solid. It is also clear that averaging reverberation time is only averaging decay rate of decided period (e.g. -5 dB to -20 dB from steady state sound pressure level). If the microphone is moving around, it is not clear the steady state sound pressure level for the measured decay curve and calculation range of reverberation time. The error resulted by microphone rotation depends on rotating speed, distribution of sound pressure level and reverberation time. The range of conditions, where rotating microphone method is applicable, should be defined if this method will be used as standardized method.

4 Conclusions

This study founds possible error mechanism of measurement of reverberation time with rotating microphone. Errors are depending on rotating speed, distribution of sound pressure level and reverberation time. This study also presents that reverberation times at lower frequency bands have more error than those of higher frequency range because of room mode. It should be defined possible range of condition for reverberation time measurement with rotating microphone if this method is used as standardized method.

This study uses the mean reverberation time measured at 72 fixed positions as a reference value. However, there is no evidence that the "reference" value represents the measured room. The reference value will be confirmed in future by measuring reverberation time at as many positions as possible [4].

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