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PARAMETERS MEASUREMENT OF TAPPING MACHINE AND ITS ACOUSTIC CHARACTERISTICS

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The tapping machine is a standard instrument to measure the impact sound insulation of building floors. Its parameters affect the sound insulation measurement result. A system including acoustic measurement devices and laser interferometer was developed to measure the parameters of tapping machines, such as impact interval, impact velocity, impact SPL on specific specimen. Three tapping machines from different manufactures were tested and it was found that only one was fulfilling the specification of the requirement in ISO standard. The impact SPL was direct measured to obtain its acoustic characteristics. The impact SPL in a one-third-octave band was recorded when the tapping machine struck a hard work-piece. The results showed that the SPL from 1 kHz to 5 kHz was higher than 100 Hz to 1 kHz. The SPL value in high frequency range related to the curvature of the hammer heads and it would be less when the heads had larger curvature. Test results also showed that the impact SPL from 100 Hz to 5 kHz in a semi-anechoic room was almost the same as the measurement in a normal test room. And the repeatability of impact SPL could be used to check the working condition of the tapping machines.

Keywords: Tapping machine, Impact velocity, Impact SPL

1. Introduction

Although the characteristics of tapping machine is some different with living sound [1], the tapping machine is still widely used as a standard impact sound source for the measurement of sound insulation of building floors. It has five hammers placed in a line. The impact sound is generated by the free fall of each hammer and the interaction between the hammers and the floor or other specimens within a specified time interval.

The requirements for tapping machines are specified in annexes of ISO 140-6 to 8 [2-4].They are hammer mass, impact interval, impact velocity, falling angle and etc. The momentum of each hammer which strikes the floor shall be that of an effective mass of 500 g which falls freely from a height of 40 mm within tolerance limits for the momentum of ±5 %. As friction of the hammer guidance has to be taken into account, it shall be ensured that not only the mass of the hammer and the falling height but also the velocity of the hammer at impact lie within a specific range. The accuracy of the parameters affect the evaluation of the sound insulation of building floors [3]. In this paper a preliminary system for parameters measurement of tapping machine was established at NIM to verify its qualification.

2. Test systems

It is easy to get the mass, diameter, distance and the fall height of the hammers. Here the test system focused on the measurement of the impact velocity and the time interval. The time interval also depends on the characteristics of the impact object. To simplify the measurement system, hard work-pieces with the dimensions of 800 mm(W)×400 mm(D)×20 mm (H) and 800 mm(W)×400 mm(D)×10 mm (H) made of stainless steel,were used instead of real floors made of concrete.

When the mass is known, the impact energy acting on the specimen depends on the velocity and the direction of the falling hammer. The sum of relative error from mass and impact velocity of the hammer is required to be less than 5%. Here a laser vibrator Polytec OFV552 was chosen to measure the impact velocity from a small hole in the specimen. The diagrammatic sketch was shown as Fig. 1. The cylindrical hammer and the hole are coaxial.

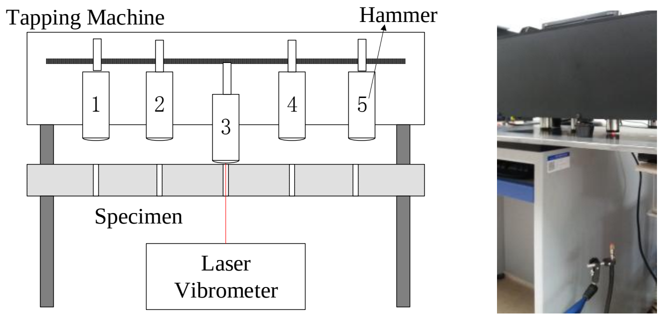


Figure 1: Diagrammatic sketch and picture of impact velocity measurement

Firstly adjust the supports of the tapping machine to remain fall height of the hammer at 40 mm. Secondly set the hammer at its lowest point and lie on the specimen. Then focus the laser on the surface centre of the hammer head through the hole in the specimen and turn on the machine. Finally the velocity signal of the falling hammer was captured by a digital telescope. If the reflective laser was not strong enough from the surface of the hammer head, a thin reflective film could stick on the surface.

To measure the time interval of the impact, a sound analyzer with the function of recorder was used. A microphone was arranged in the distance at 1 m from the tapping machine, with the sound axis perpendicular to the line made of the five hammers and pointed to the middle hammer. As shown in Fig. 2, when the hammer strikes on the specimen, the impact sound is generated. The mean time between impacts and the time between successive impacts, which shall be (100 ±5)ms and (100 ±20)ms respectively, could be obtained from the recorded acoustic signals. The difference of the distance from each hammer to microphone could be neglected when determining the time interval.

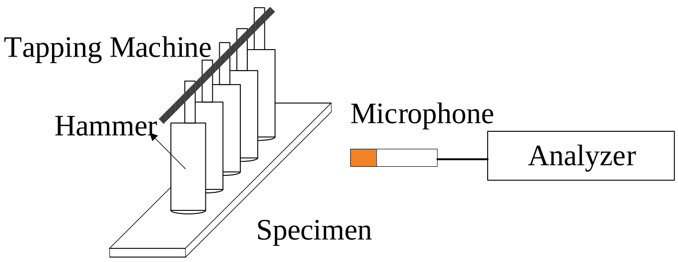


Figure 2: Sketch of time interval and impact SPL measurement

The repeatability of the impact sound could also show some characteristics of its working conditions and stability. The impact sound pressure level on the test specimen is defined as Eq. (1),

$$L = 10\lg \frac{\frac{1}{T_{\mathrm{m}}}\int_0^{T_m} p^2(t)dt}{p_0^2} \tag{1}$$

Where L is the average sound pressure level, T_{m} is the measurement time, $p_{(\mathrm{t})}$ is the sound pressure level at the measurement point and p_0 is the reference sound pressure, 20 μPa.

During the measurement, the specimen was fixed on a vibration isolative table. And the mass of table is much larger than the specimen to avoid resonant vibration induced by the impact from the hammers. The specimens with the thickness of 10mm and 20mm are used to carry out the test to verify whether the thinner one is enough for the impact SPL measurement. And the test was carried out in both the semi-anechoic room and the common room without acoustic treatment.

3. Results and discussion

Three tapping machines from different manufactures (B&K, BSWA, AWA) were tested. The test machines were marked as tapping machine A, B and C, which are not corresponding to the manufactures order.

3.1 Impact velocity

The mass of the hammers in the three tapping machines are all limited to 500g±6 g, so the impact velocity is required as 886 mm/s±33 mm/s. Here 886 mm/s is the ideal falling velocity from 40 mm height. The typical signal captured from the telescope was shown in Fig. 3. The peak of the pulse represented the maximum falling velocity, viz. impact velocity. The velocity could obtain from the voltage waveform and the velocity sensitivity of the laser vibrometer, as Eq. (2) showed,

$$v_{impact} = \frac{u_{\max}}{s_{laser}} \tag{2}$$

Where v_{impact} is the impact velocity of hammer, $u_{\max}$ is the maximum voltage value from the laser vibrometer and s_{laser} is the velocity sensitivity of the vibrometer. In Fig.3 the sensitivity is 100 mm/s/V. The uncertainty was evaluated around 6 mm/s (k=2). Uncertainty evaluation is not the main focus of this paper and the evaluation process is omitted here.

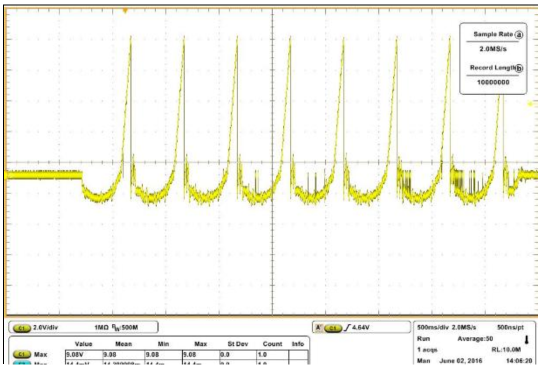


Figure 3: Typical waveform from laser vibrometer

The impact velocity of each hammer in the three tapping machines were listed in Table 1. It was obvious that only tapping machine B meted the requirements of the impact velocity limit. The impact velocity of hammers in both A and B was less than lower limit due to the friction of the hammer guidance.

Table 1: The impact velocity of each hammer (mm/s)

Hammer No.	1	2	3	4	5
Tapping machine A	796	810	786	812	792
Tapping machine B	896	898	872	884	886
Tapping machine C	810	812	816	818	806

3.2 Impact time interval

Impact time interval includes the mean time between impacts and the time between successive impacts, and the time between impact and lift of the hammer. The tapping machine and measurement microphone were arranged as Fig.2, then the sound analyser could capture the impact sound and record it, as shown in Fig. 4. According to the peak of each impact sound, the impact time interval could be obtained, as shown in Table 2. Both the mean time and the time between successive impacts are in accordance with requirements.

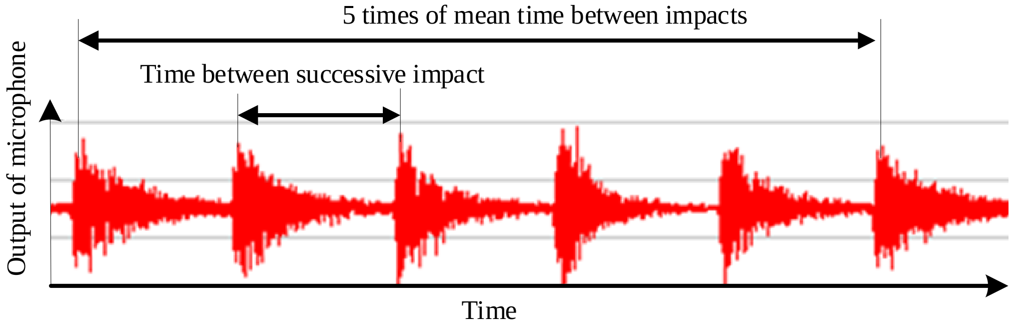


Figure 4: Sketch map of impact time interval measurement

Table 2 Measurement result of impact time interval (ms)

Hammer No.	1-2	2-3	3-4	4-5	5-1	Average
A	96.5	96.6	96.4	96.2	96.4	96.4
B	99.7	99.6	99.6	99.8	99.6	99.7
C	97.6	97.5	97.1	97.0	97.6	97.2

The time between impact and lift of the hammer depends on the stiffness of the specimen. The time would be shorter with hard specimen and be longer with soft specimen. For the specimen made of stainless steel, the time is far less than 10ms.It could be measured according to the switching characteristic of the strike.

3.3 Impact SPL on specimen

When the tapping machine worked continuously, stable impact sound was generated by the five hammers acting on the specimen. The typical frequency spectrum of the impact sound was shown in Fig.5. In the one-third-octave band from 100 Hz to 5 kHz， the SPL in 1 kHz to 5 kHz was always higher than 100 Hz to 5 kHz. It meant that there was more high frequency acoustic energy in the impact sound. Here the average time T_m in Eq. (1) was set as 5 s.

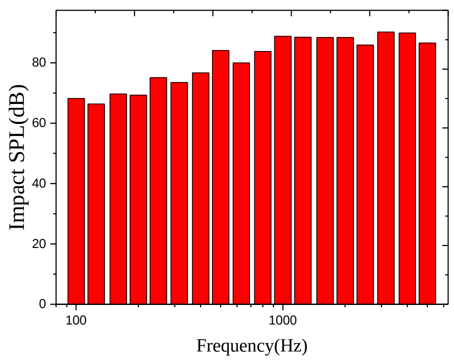
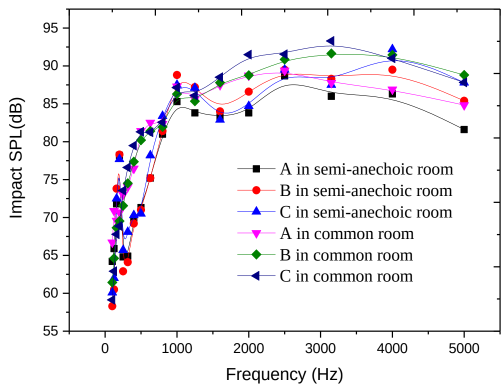


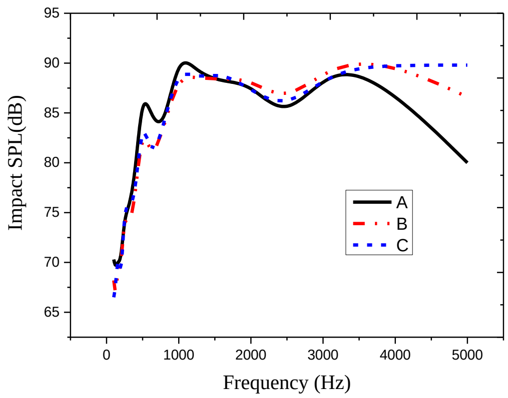
Figure 5: Typical impact sound in one-third-octave band

The impact SPL of Tapping machine A, B and C acting on the specimen made of stainless steel was illustrated in Fig. 6(a). The impact SPL of the three tapping machines presented similar distribution in spectrum both in semi-anechoic room and common room without acoustic treatment. The only difference in experiments was that the stainless steel plate was fixed on an anti-vibration stable made of steel in common room while in semi-anechoic room it was placed on a table made of fireproof board, lighter than steel. Because of the stiffness difference of the whole objects which the hammer impacted on, the test impact SPL in common room is a little higher above 1 kHz. When the specimen was changed to 10 mm thickness, the curve and the value remains also the same with 20 mm thickness, as shown in Fig.6 (b). Here it can say that for impact SPL measurement, the steel plate with the dimensions of 800 mm(W)×400 mm(D)×10 mm (H) is heavy enough. Figure 6(c) showed that when the table made of fireproof board was used instead of the steel plates, the impact SPL got smaller and smaller as frequency increased from 1 kHz.

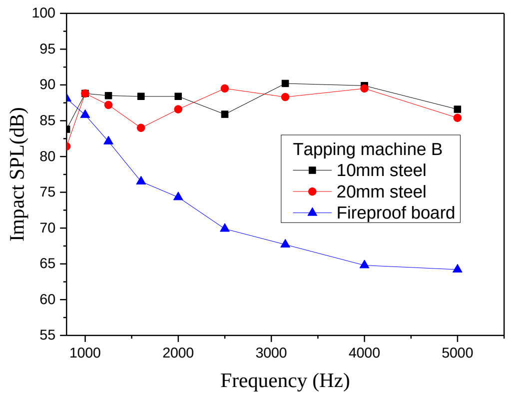
In Fig. 6(a) and (b), the impact SPL on the specimen from tapping machine A at the frequency above 3.15 kHz was always smaller than B and C. The difference of the impact SPL at 5 kHz could lead to 10 dB, which is much larger than the relative difference of the product of the hammer mass and the impact velocity showed in Table 1. While in some low frequency bands, the impact SPL from A is higher than B and C. What led to the difference? The reason was revealed by the measurements of the curvature of hammer heads. In Tapping machine A, the radius of the curvature was around 100 mm and it was around 460 mm and 500 mm for B and C respectively. With smaller curvature, the hammer heads got flatter and the impact SPL in high frequency became lower, while at some low frequency bands, it was higher.



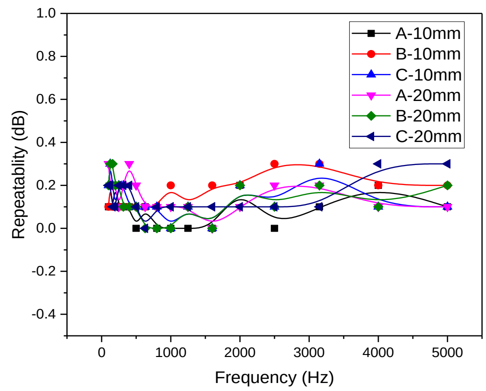
(a) Specimen with 20 mm thickness



(b) With 10 mm thickness in semi-anechoic room



(c) Comparison with steel and fireproof board



(d) Repeatability

Figure 6: Impact SPL on the specimens

The repeatability of the impact SPL on the specimen would also include the working conditions and the stability of the tapping machine. As Fig. 6(d) showed, the standard deviation of six measurements of the impact SPL at any frequency for each tapping machine was less than 0.4dB. The smaller the value was, the operation of the tapping machine more stable.

4. Conclusions

The parameters of the tapping machine are important for the impact sound generation and the sound insulation measurement of building floors. The developed system based on the laser vibrometer could be used to measure the impact velocity and the results showed that a considerable part of tapping machines didn't meet the requirements of the impact velocity due to the friction of the hammer guidance.

The impact SPL on the steel specimen showed that, for qualified tapping machine, the SPL in one-third-octave band in 1 kHz to 5 kHz was always higher than below 1 kHz. It also indicated that there was almost the same for the impact SPL measurement in the semi-anechoic room and common room without acoustic treatment. The spectrum distribution of the SPL could help to identify some defects of the tapping machines such as curvature of hammer heads out of limits. And the repeatability of the impact SPL could also indicate the working conditions and the stability of the tapping machine.

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