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LIGHTWEIGHT MACHINE ENCLOSURES FOR DYNAMIC AND EFFICIENT PRODUCTION PROCESSES

Usually machining centres for processing wood-based and composite materials have moving partial machine enclosures in the *X*-axis direction. Because the workpieces to be machined are often large (e.g. aircraft doors), these partial enclosures have prevailed on the market compared to voluminous complete enclosures. Owing to the general trend towards complete machining through process integration, an increasing number of additional units are integrated into machining centres in addition to the main spindle. This leads to an increase of the mass to be moved as well as a larger and thus heavier partial enclosure. This inevitable increase in mass leads to a deterioration of the dynamic properties of the machine. To counteract this increase in mass, the use of lightweight design materials for machine enclosures becomes in the focus of attention. The lightweight materials to be used must comply with the requirements of modern mechanical engineering and legislation: retention in the event of tool breakage, reduction in the noise exposure of the machine environment and cost-effective solutions compared to the materials used nowadays. The sheet steel used today as material for partial enclosures is therefore to be supplemented or replaced with suitable lightweight design materials. Different lightweight materials are qualified for suitability as machine enclosure. Apart from mass reduction, ecological as well as economic aspects of the used materials play an important role. For this purpose, the safety properties (impact resistance in case of tool breakage / collision) of these weight-reduced materials have to be determined. In addition, an improvement in the acoustic behaviour of the machine is achieved by the new lightweight materials since the machine enclosure shields the distinctive sound sources.

1. INTRODUCTION

Woodworking CNC machining centres often have machine enclosures that move in the *X*-axis direction as the machine moves. This partial enclosures are well-established on the market due to the often large plate-shaped workpieces to be machined (for example, particleboards in the furniture industry) compared to the otherwise very bulky full enclosures (Fig. 1). The partial enclosures are a cost-effective way to meet the required

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safety regulations, to dispense with a complex complete enclosure and to protect the operator from entering the danger area of the machine [1, 2]. In comparison to complete enclosures, partial enclosures have the advantage that they are better accessible in the case of manual workpiece changes. Partial enclosure are becoming increasingly larger because a growing number of ancillary components are added to the main spindle (e. g. drilling units with up to 28 tool stations, sawing units, narrow surface coating and postforming units) in machining centres. These auxiliary devices increase the accelerated mass of a machining centre. However, this mass increase leads to a deterioration in the dynamic properties of the machines.

To counteract this trend, the use of lightweight materials in partial enclosures reduces the increasing moving masses. In order to qualify these materials, tests of the retention capacity in accordance with the standard DIN EN 848-3 [2] (in the event of tool breakage / collision) were carried out. In addition, the legal limit for noise pollution at the workplace must be observed. From a daytime noise exposure level ($L_{EX,8h}$) of 80 dB(A) (lower triggering value) up, noise abatement measures, such as e. g. ear protection as personal protective devices, have to be provided; from $L_{EX,8h}$ = 85 dB(A) up, these must be implemented or worn. To reduce noise at the control panel of a machine, the materials of the machine enclosure wall, which shields the operator from the noise sources, play an important role [3]. However, in order to certify a machining centre according to the European Machinery Directive EG 42/2006, all of the above requirements must be fulfilled [4].

moving partial enclosure	**complete enclosure**
 SCM Group	 SCM Group
- higher moved masses -> deterioration of the dynamics + low costs + handling	- high costs + no additional moved masses, less energy consumption + lower noise immission + suction

Fig. 1. Different types of machine enclosures partial enclosure and complete enclosure

2. EXPERIMENTAL MEASUREMENTS

When selecting materials for partial enclosures of CNC-machining centres, it is most important to enclose the hazardous area. The partial enclosure must prevent any access to the hazardous area, the flying around of tool parts and any crushing or entanglement points between fixed and moving machine parts. When using lightweight materials to build walls for partial enclosure, it is necessary to analyse the retention capacity. These materials are specified and described in the standard DIN EN 848-3 with standard materials such as 2 mm steel sheet (at a minimum tensile strength of 350 N mm^{-2}), 5 mm polycarbonate and 3 mm aluminium (at a minimum tensile strength of 300 N mm^{-2}).

2.1. IMPACT TEST

The impact tests of safeguards were carried out with a test facility at the IfW (University of Stuttgart Institute of Machine Tools) (Fig. 2). The sample of the material to be tested with a dimension of 500 mm x 500 mm was fastened onto a suitable frame on top of the machine. The test projectile should hit the test specimen at an angle of 90° to the centre of the material sample or at the weakest point.

The guards must be able to withstand a 100 g test projectile with an impact velocity of v = 70 m/s ± 5% in accordance with DIN EN 848-3 [2]. The speed of the test projectile, which is equivalent to the impact speed, was determined by means of light barriers at the exit of the shot tube. The safeguards pass the test according to the standard if the test projectile is held back by the material sample (test object) and if the damage is only due to bulges/ bends/ deformations without crack or cracks visible only on one surface. The second permissible damage category is if a conditional cracking occurs which is only visible on the entrance side of the test projectile and no continuous crack (Fig. 2) [2].

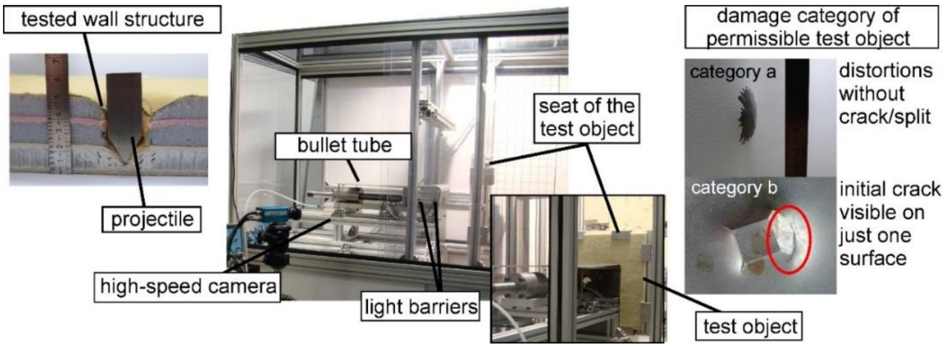

Fig. 2. Device for testing impact resistance

2.2. ACOUSTIC CHARACTERISTIC TEST

In addition to the criterion of the material's retention capacity, the acoustic properties (insulation, damping properties) lead to the selection of suitable materials for the wall of a machine enclosure. To assess the insulating capacity of machine enclosures, the sound power reduction ΔL_W is determined, which is achieved by install material samples into the test bench. Therefore, this is also called the insertion loss I_L. The insertion loss is the difference between the sound power level L_L radiated with and without enclosure of the sound source [5]:

$$I_L = L_{W0} - L_{WK} \tag{1}$$

Furthermore, the sound pressure level reduction D_p may indicate the difference in sound pressure levels achieved due to the enclosure at a particular place. Especially for partial enclosures, this value is appropriate to achieve the noise reduction in a specific place such as a workplace. With regard to the legal noise exposure level, the A-weighted sound pressure reduction D_{pA} and thus the effectiveness of the machine enclosure in terms of occupational safety can be determined at this place. This is a measure which is derived from the sound pressure reduction according to ISO 717-1 [6]. The sound pressure level reduction as well as the insertion loss are always measured and indicated in third-octave or octave bands [5], [7].

For this purpose, a test bench was developed at the IfW to investigate the suitability of the materials for the acoustic properties. The test bench was designed in the form of a machine enclosure. At present, woodworking CNC machining centres often have no machine enclosure on the top and at the back. This situation was taken into account in the implementation of the experimental set-up. As shown in Fig. 3, specimens measuring 500 mm × 500 mm can be placed in the experimental set-up. This encloses the sound source located at the centre of the experimental set-up. The sound source is a dodecahedron loudspeaker with a uniform sound output. Depending on the number of test specimens (closed sides in the test set-up), partial or complete enclosure was modelled. This model of a machine enclosure allows experiments with the same material samples as in the impact test, as mentioned before.

The measurements were carried out according to the enveloping surface method according to DIN EN ISO 3744 [8]. The test environment was a semi open room where only the floor surface was sound-reflecting. Otherwise, there were no other reflective planes or objects that may interfere with reflectance measurements in the test environment. In the method using an enveloping measurement surface, the microphones were arranged in a square envelope around the reference cuboid. The reference box enclosed the entire sound source. The test bench itself did not belong to the sound source and the reference.

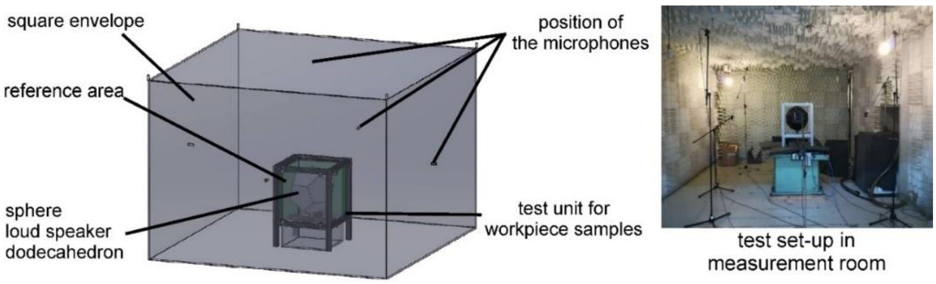

Fig. 3. Test bench and test environment for measurements using the enveloping surface method

3. RESULTS AND PROPERTIES OF THE MATERIALS

Three materials with different characteristic properties were examined here by way of example. The 5 mm thick polycarbonate material (P1) sample is the standardized material used for inspection windows in the work area in industry. Material P2 has a sound-absorbing liner in the wall structure carried by a backing layer, which is used as machine enclosure. Sound-absorbing material, integrated in the wall of the machine enclosure, reduces the reflection of the sound waves back into the working space and thus this intermediate layer contributes to the reduction of the sound levels. An aluminium sandwich panel (P3) acts here as a sonically hard comparison element. Sonically hard means that the test specimens have a high acoustic impedance and the incident sound energy is not attenuated by the specimens but reflects only.

The example materials passed the impact test, so further investigations were made into the acoustic properties of the materials.

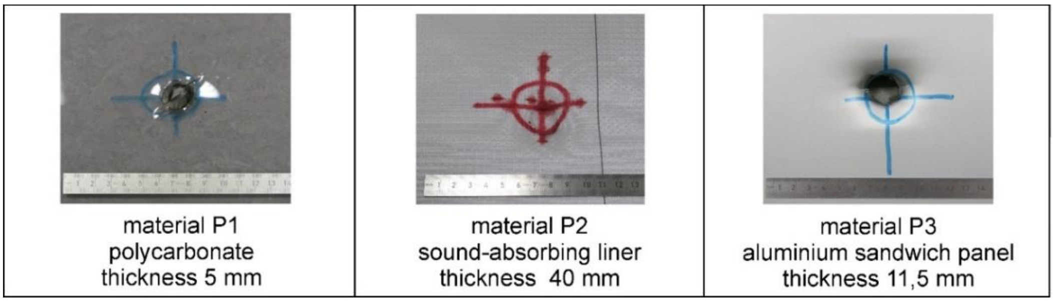

Fig. 4. Results of the impact test

Figure 5 shows the test results with five workpiece samples inserted at the test bench which was open on the top. The workpiece sample P2 with a sound-absorbing intermediate layer in the wall has a maximum insertion loss ratio of $I_L = 19.28$ dB under these experimental conditions. These values were achieved at a frequency of 12,500 Hz as well as at 630 Hz. Regarding the workpiece samples, the peak values are also at these frequencies, i.e. 13.70 dB for P3 and 12.9 dB for P1. The A-weighted insertion loss ratios reach values of $I_L = 5.80$ dB(A) at P1, $I_L = 9.50$ dB(A) at P2 and $I_L = 6.3$ dB(A) at P3. A reduction in sound pressure by 6 dB corresponds to a halving of the sound emission by the machine tool.

There are negative values of the insertion loss in the frequency range of up to 500 Hz. These can be explained by various effects that occur inter alia when half the wavelength of the considered sound waves lies in the range of the enclosure dimensions. The formation of standing waves in the test rig leads to a greater excitation of the test specimens, causing them to emit more sound value. In addition, the excitation in the range of the natural frequencies of the specimens contributes to a higher sound radiation of the specimens. Because one side is open in the test bench, maxima occur in the low-frequency ranges due to the reflections. In the field of mechanical engineering, this is not considered to be critical, and psychoacoustics are not acoustically annoying.

Experiments on the test rig constructed for this purpose revealed two key factors influencing the insulating effect of the enclosure: the influence of the open areas in the enclosure and the lining with absorption material.

$$\theta = \frac{A_0}{A_{ges}} \tag{2}$$

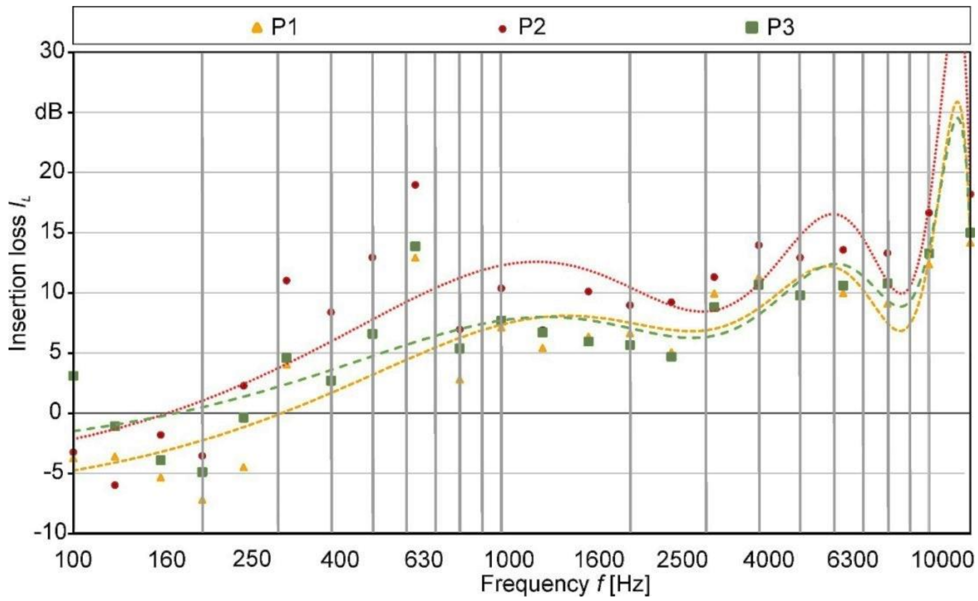

Fig. 5. Insertion insulation measure I_L over the frequency f for each test bench equipped with five test specimens

The opening ratio θ represents the proportion of the open area on the machine enclosure A_0 to the entire inner surface of the enclosure. According to Schirmer [5], it can be seen in Fig. 6 that the maximum achievable insertion loss at an opening ratio of 10 % is only reduced by 10 dB, compared to 30 dB at an opening ratio of 0.1%, which corresponds to a full enclosure. To model a CNC machining centre that is open on the top and towards the rear wall, four specimens were used in the test set-up. In this experimental set-up, the opening ratio of the enclosure is $\theta \approx 33\%$, and thus according to Schirmer [5] a maximum achievable insertion loss I_L of about 5-6 dB can be expected [5].

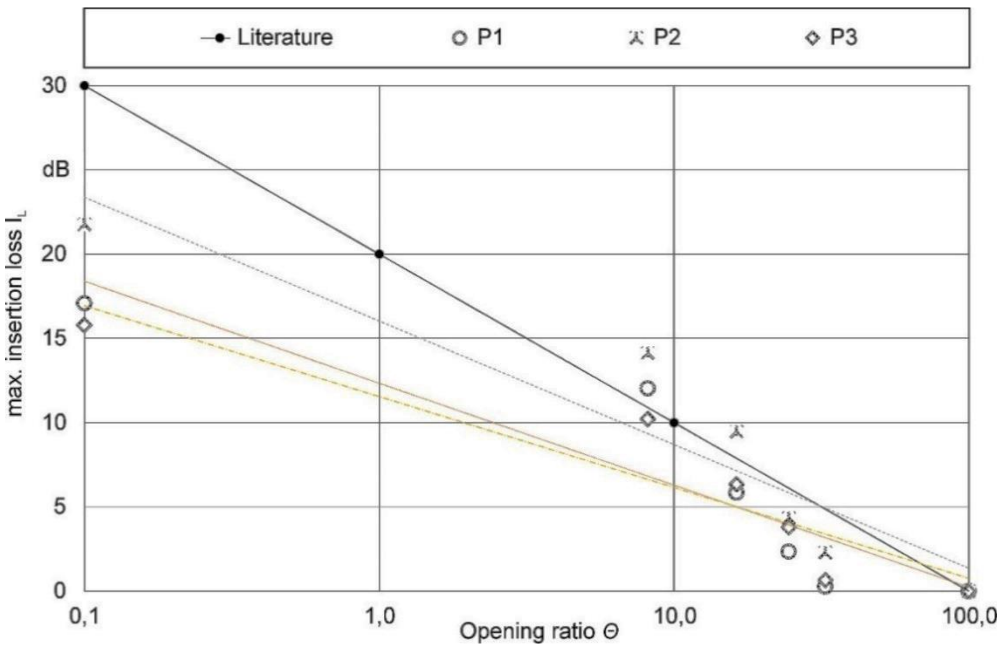

Fig. 6. Maximum achievable insertion loss depending on the opening ratio of a soundproof enclosure [5]

In the experimental set-up with the examined materials, the insertion loss ratio was $I_L = 0.26$ dB with P1, $I_L = 2.30$ dB for P2 with a sound-absorbing intermediate layer and $I_L = 0.65$ dB for the reverberant aluminium sample P3. The ideal values are not achieved with a material of great sound absorption as mentioned by Schirmer. It can be seen that there is an improvement in insertion loss if a further opening is closed by inserting a fifth workpiece sample. This improvement can be seen in all three material samples. The achieved values range between $I_L = 5.84$ dB – 9.46 dB and half the sound emission. The plotted values correspond to the sound absorption levels of the tested materials.

Sound-absorbing materials in a structure for machine enclosures make sense if the opening ratios of the machine enclosure remain constant. Due to the process integration in the machine, e.g. workpiece feeders, connections for the operating media, connections for the suction, etc., numerous openings in the enclosure are necessary. Yet, all unnecessary openings in the enclosure should be closed. At present, the CNC machining centres on the market are open on the top and towards the rear cabin. Only by closing unnecessary openings of the machine enclosure and using sound-absorbing material in the wall structure of the machine enclosure, it is possible to create an economically sensible noise protection for machining centres.

4. SUMMARY AND FUTURE RESEARCH

As the trend in machining is towards larger workpieces, the use of partially enclosed machines offers an economical alternative to a fully enclosed machining centre. Due to the increasing number of partially enclosed machines, the use of lightweight design materials as an alternative to steel sheet enclosures becomes more and more interesting. Lightweight wall designs have to fulfil even more properties, such as the retention capacity of fragments and a high noise emission. To determine the retention capacity, the impact test is used. Regarding noise emission, the insulation and damping properties are decisive. Since today the partially enclosed CNC machining centres are often designed without guards at the top and the back, there are large openings in the machine enclosures, which have a negative effect on the noise emissions of the machines. For examining the materials for machine enclosures, a test bench was developed modelling the machines with their openings. In this way, the configuration (partial or complete enclosure) and the material can be changed with little effort. It is possible to examine materials of various wall structures in machine enclosures for their soundproofing as a passive noise reduction measure on a machine enclosure without building a machine enclosure around a machine.

Three exemplary materials with different sound absorption levels (soundproof, sound-absorbing intermediate layer) were investigated.

The results showed that reducing the opening ratio in machine enclosures has a high potential for decreasing the noise emission of a machine. For CNC machining centres, this would mean to close the openings at the top and the back. For additional improvements, sound-absorbing materials can be integrated as intermediate layers in the wall structure of the machine enclosure. This reduces the noise levels for the operator at the control panel. Other materials will be tested for the use as safeguards. This qualification of materials, including the examination of further requirements for safeguards will be carried out and summarized in a guideline.

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