ACOUSTIC TREATMENT OF MACHINE WORKROOM FOR STAPLES PRODUCTION

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Abstract

A general reduction of noise in the machine workshop and a concurrent reduction of noise that is transmitted to the nearby residential buildings, may be accomplished. The first step is to conduct a noise survey of the machine workshop, in order to characterize the noise that the machinery operations emit. Once the survey data are analyzed and the noise are known, an architectural solution to the noise problem can be designed, which accounts for the unique character of the noise from this machinery. This may include the addition of noise absorption materials to the room, barriers, enclosures or walls. The approach taken will depend on the circumstances of each machine, and the overall manufacturing process.

Acoustical conditions in the small machine workroom for staples production presented in this paper were very unfavorable. There were 7 sources of noise that exceeded permitted levels. Measurement of the averaged equivalent noise levels yielded results in the interval from 90 to 99 dBA. The first stage of the noise reduction included acoustic treatment of machine workroom walls in order to reduce the reflected noise. In the second stage, noise dispersion from the source to the environment was prevented by setting up sound insulation of workroom walls. After the acoustic treatment works, average noise levels were reduced to 87 dBA in the machine workrooms.

Key words: *Noise reduction, Reverberation control, Sound insulation.*

1. Introduction

There are several noisy similar machines for staples production installed in workroom, which are the main source of noise in these premises. The noise is a problem not only for the workers who operate the machines as they are exposed to it, but also for other workers in the workroom and especially for nearby residential buildings. As a rule, the latter are not exposed to particular risks of hearing damage due to noise, but however, communication and concentration are seriously disturbed.

Workroom walls are rigid and the ceiling has mainly reflexive characteristics. This results in substantial reverberating field in the premises. Also, this resulted in interference between direct and bounced wave and high levels of noise in the premises, not only directly at the source of noise, but also at longer distances, practically all over the workroom.

2. Sound field of the machine workroom

2.1. The sources of noise

In the technological process of staples production 7 machines are installed in the machine workroom:

- Franc&Willy Lamert, type III 60-2D, 1 pcs.
- Prebena, tip 80-5D, 1 pcs.
- Schenker, tip KA-1B, 5 pcs.

The technological process of staples production is being carried out identically on all machines installed in the machine workroom.

2.2 The procedure for determination of the sound source power level

Parallelepiped surface areas have been selected for measurement and they entirely cover investigated sources of noise.

During the procedure of determination of sound source power level, the following measuring instruments were used:

- Dual Channel Real-time Frequency Analyzer, Brüel&Kjær, Type 2144;
- Sound Intensity Measurement Probe, Brüel&Kjær, Type 3519;
- Calibrator, Brüel&Kjær, Type 4230.

In tbe centers of defined segments of measurement surfaces, which entirely cover investigated source of noise, normal component of sound intensity was measured.

Based on obtained measurement results, the mean value of sound intensity can be defined as:

$$\overline{I_n} = \frac{1}{M}\sum_{k=1}^{M} I_{nk} \ , \qquad (1)$$

where M is the number of measuring segments.

Partial sound power of each segment can be calculated by using the equation:

$$P_i = I_{ni} S_i \qquad (2)$$

while overall level of sound power source of noise as:

$$\overline{L}_P = 10\log\sum_{i=1}^{N} P_i / P_0 \qquad (3)$$

where S_i is the surface of i measuring segment.

2.3 Results of the determination of sound source power level

Table 1 Sound power of noise source

Machine	frequency [Hz]							A
	125	250	500	1000	2000	4000	8000	
Prebena / $\overline{L}_P$[dB]	82.8	86.7	86.9	87.0	83.4	79.9	70.2	90.8
Lamert / $\overline{L}_P$[dB]	78.5	88.4	87.1	89.7	89.2	83.9	78.7	94.4
Schenker / $\overline{L}_P$[dB]	75.4	75.6	82.7	84.9	85.3	79.8	73.5	90.0

Comparative review of the frequency distribution of sound power level in investigated machines is given in Fig 1.

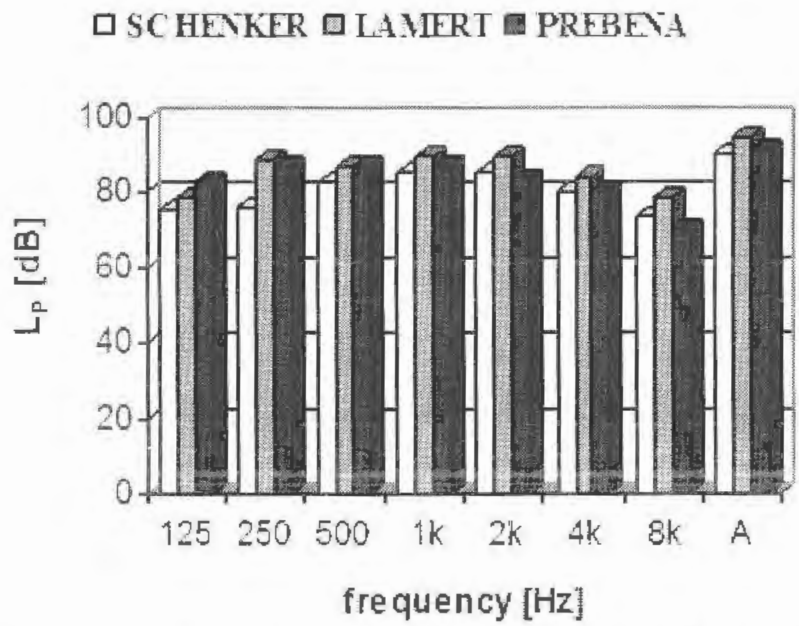


Fig. 1 Frequency distribution of sound power level of machines

2.4 Calculation of sound field in acoustically untreated machine workroom

In all simulations of the sound field, the layout of machines shown in Fig. 2 was used. The coordinates of the acoustic centers of machines in relation to the chosen coordinate system are displayed in the same figure.

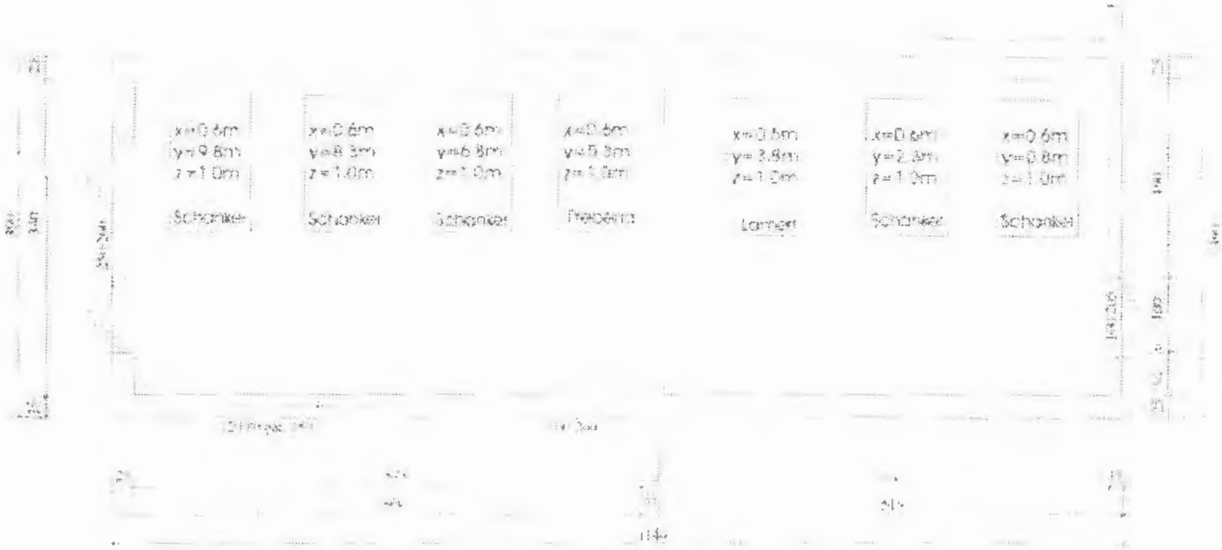


Fig. 2 Machine layout in machine workroom

In order to assess possibilities to reduce noise level in the machine workroom, a simulation of the sound field was carried out based on the assumption that the walls of the workroom absorb sound maximally. In this case, the sound field in the machine workroom can be characterized as a free sound field, which is only a consequence of noise sources influence. The influence of sound reflection is minimized.

The spatial distribution of noise levels within the dimensions of machine workroom is shown in the Figures 3 and 4.

Octave spectrum of the average noise level within the dimensions of machine workroom is shown in Fig. 5.

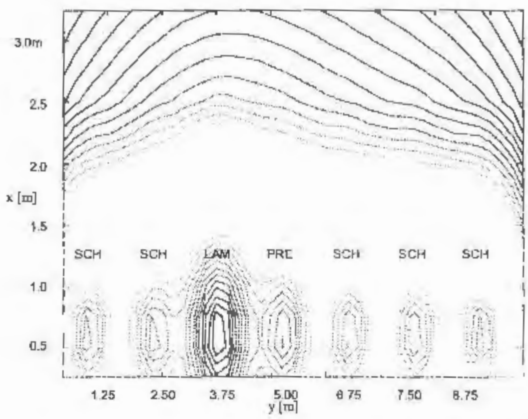


Fig. 3 Iso-lines of equal noise level at z=1.5 m

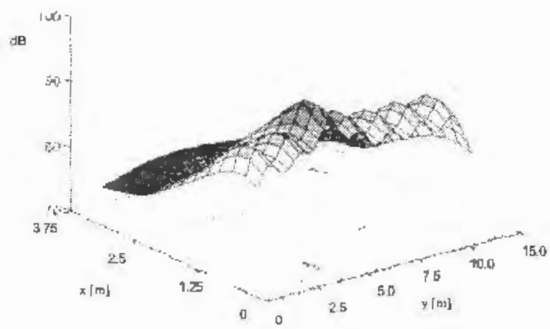


Fig. 4 3-D presentation of spatial distribution of noise levels at z=1.5 m

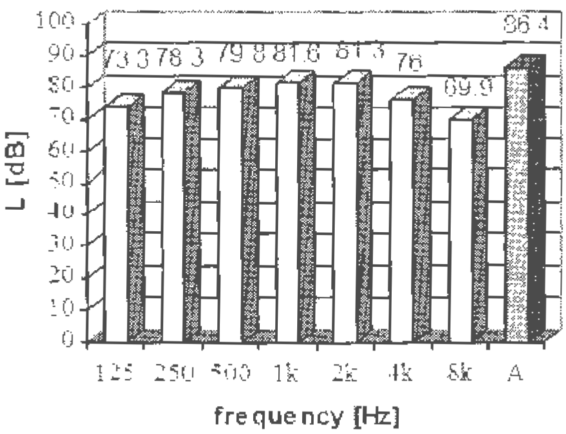


Fig. 5 Octave spectrum of the average noise level in the machine workroom at z = 1.5m

The sound field simulation was performed in the machine workroom with no acoustical treatment. The spatial distribution of noise levels within the dimensions of machine workroom is shown in Figure 6. Octave spectrum of the average noise level within the dimensions of machine workroom is shown in Fig. 7.

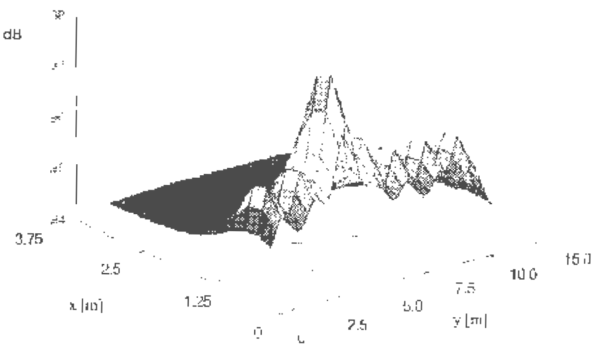


Fig. 6 3-D presentation of spatial distribution of noise levels at z=1.5m

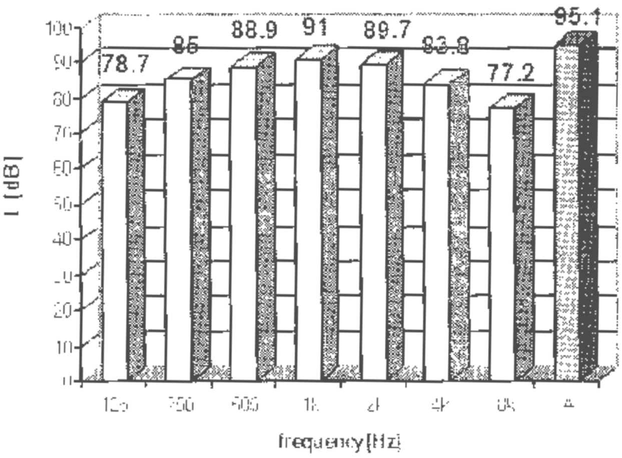


Fig. 7 Octave spectrum of the average noise level in the machine workroom at z=1.5m

3. Estimation of reverberation time and its impact on noise

The acoustic qualities of the room are described by sound-absorbing coefficient or reverberation time. The longer the reverberation time, the worse the absorption in the room and consequently more noise and speech which can not be understood. Reverberation time is defined as the amount of time it takes the sound pressure to drop by 60 dB after the end of the sound signal. In practice it is defined by 20 dB (T_{20}) and 30 dB drops (T_{30}), which are extrapolated to the value of 60 dB drop.

Increased absorption coefficient in the production hall would result in shorter reverberation time and thus lower general level of noise. Decrease of the noise level ΔL depends on the change in reverberation time and it is expressed with the following equation

$$\Delta L = 10\log\frac{A_2}{A_1} = 10\log\frac{T_1}{T_2}, \tag{4}$$

where A_1 is the equivalent absorption surface of the hall prior to rehabilitation, and A_2 after the rehabilitation. Similarly, T_1 stands for the original reverberation time and T_2 for reverberation time when absorption has been added. It can be seen from the equation that the general level of noise in production hall may be decreased by 3 dB, if reverberation time is halved, while four times shorter reverberation time would mean also four times lower noise energy, or the level of noise would fall by 6 dBA, and ten-time decrease by 10 dB.

In practice decrease by 10 dB is the upper limit which may be achieved by such measures. In our case good reduction of the general level of noise in the hall can be expected. This is due to emphasized ground plan dimensions of the space, which are by several times longer than the height of the hall, and to a certain extent this space behaves like a two-dimensional space. Only the cutting department is not characterized by that. In such spaces it is sensible to focus on the highest possible absorption of the ceiling, and also floor, if possible, however, it is hardly feasible on the floor. This reduction could result in acceptable levels of noise and communication would be substantial easier.

Further decrease of the general level of noise may be achieved by interventions on the sources of noise themselves (sound insulated enclosures) and by enclosing the machines (insulation-absorption screens for machines) in their direct vicinity. Successful decrease of the noise level with new sound-absorbing materials mainly depends on the distance from the source(s) of noise, the existing absorption and size and shape of the space. In such space sound consists of two components: direct and indirect. Indirect is the consequence of reverberations in the space. In the vicinity of a noisy source direct component is prevailing, and its level falls more rapidly according to the distance. At longer distances noise is reduced mainly because of absorption. In order to assess the success of noise reduction by mounting sound-absorbing materials, distances at which the reverberation noise component starts to prevail have to be defined. Sound power L_W of individual sources of noise is constant; however, the emission level of their sound pressure L_p changes with distance. The following equation describes their relationship in a given space with average room constant R at the distance of r

$$L_p = L_W - 10\log\left(\frac{Q}{4\pi r^2} + \frac{4}{R}\right), \tag{5}$$

where Q is direction factor. In our case it is approximated by value 2, because machines are on the floor, that is above horizontal, reverberating surface and mostly they are at a sufficient distance from walls. The first part in brackets on the right of the equation represents the contribution of direct sound field from the source, and the second is the impact of reverberation. Absorption starts becoming efficient when the second part becomes bigger than the first, that is

$$\frac{4}{R} > \frac{Q}{4\pi r^2}, \tag{6}$$

$$\text{or:} \quad r > \sqrt{\frac{QR}{16\pi}}. \tag{7}$$

Room constant is connected with absorption through the following equation

$$R = \frac{S \cdot \alpha}{1-\alpha} = \frac{A}{1-\alpha}, \tag{8}$$

where A is the equivalent absorption surface. Therefore increased absorption has no effect on locations, close to the sources of noise, while it is efficient at longer distances. For well done absorption with the average sound-absorbing coefficient from 0.8 to 0.9 these are for examples distances, exceeding $0.5\sqrt{A}$. In general, in the rehabilitation with sound-absorbing materials a minimum value of the new room constant $R_{2\,\min}$ has to be ensured, in accordance with the following equation:

$$R_{2\min} > R_1 \cdot 10^{0.1 \cdot \Delta L}, \tag{9}$$

where ΔL is the required reduction of the noise level due to the increase of the room constant from the original value R_1.

In this regard the critical distance of r_c from the source of noise is important, from where the required reduction of noise by ΔL is achieved when the room constant is increased from value R_1 to R_2:

$$r_c > \sqrt{\frac{R_2\, Q\, R_1 \left(10^{0.1 \cdot \Delta L} - 1\right)}{16\pi \left(R_2 - R_1 \cdot 10^{0.1 \cdot \Delta L}\right)}}. \tag{10}$$

For spaces where one ground floor dimension is substantially longer that the height, reverberations from fitted walls has a minor effect, while the indirect component is mainly the consequence of reverberations between the floor and the ceiling.

Therefore, in such spaces it is reasonable to install absorption along the ceiling so that its average sound-absorbing coefficient exceeds the value of 0.9. In this case successful reduction does not depend only on the distance from the source, but also on the height of the ceiling. Better reduction is provided by a low ceiling than by a high one. There are no universal recipes for the distribution of sound absorbers, however, in general higher concentration is recommended above or in the vicinity of presses and other major sources of noise. In this way absorbers cover a bigger space angle than by the centre in noisy sources, and therefore a lower number of absorbers are required. Reduced indirect (reverberating) component of noise results in increased "acoustic comfort", better understanding of speech and it is also easier to assess where the noise comes from, which is often an important factor for ensuring general safety at work in the workroom.

4. Reduction of noise level by increasing sound absorption

Table 2 presents the sound-absorption characteristics of selected materials for coating of machine workroom free surface. Table 3 shows the variant solutions.

Table 2 Absorption characteristics of materials selected for the acoustic treatment of machine workroom

Material	Absorption coefficient α						
	125	250	500	1000	2000	4000	8000
Polyurethane mass	0.26	0.44	0.74	0.94	0.88	0.99	0.97
"Azma" AD panels with absorber	0.4	0.95	0.95	0.85	0.78	0.77	0.78
Acoustic resonators "Guca" AR-2V/AR-4V	0.82	0.82	0.55	0.34	0.20	0	0.20
Linoleum	0.02	0.03	0.04	0.05	0.05	0.05	0.05

Table 3 Variant solutions to reduce noise levels in the machine workroom

	Wall	Wall	Ceiling	Floor	Door
Surface [m²]	4	65	37.4	37.4	11.15
Variant 1	plastered	AZMA	AZMA	linoleum	polyurethane mass
Variant 2	plastered	GUCA	GUCA	linoleum	polyurethane mass

Modeling of the identical acoustic characteristics of the workroom was done in acoustically treated space of machine workroom, as in acoustically untreated workroom. The modeling results are shown in Figure 8.

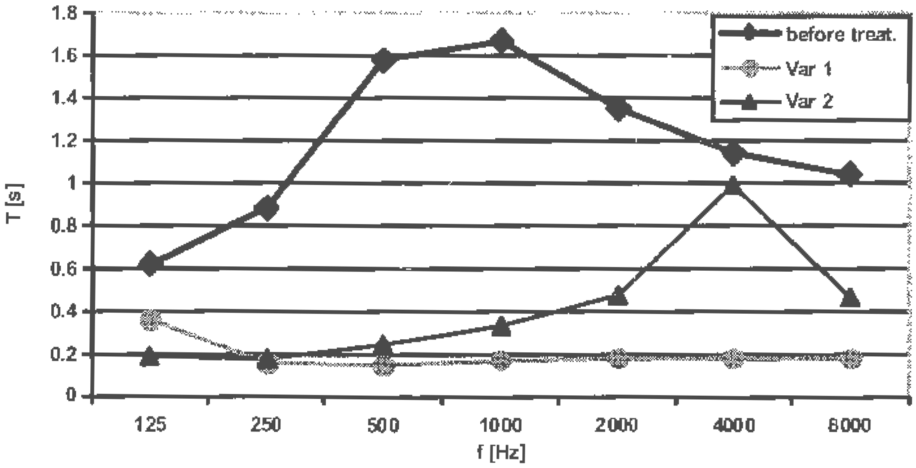


Fig. 8 Reverberation time of acoustically treated machine workroom

In case of acoustically treated machine workroom, sound field simulation was performed in the xy-plane at a height of z=1.5m. The simulation results are shown in Figures 9 and 10.

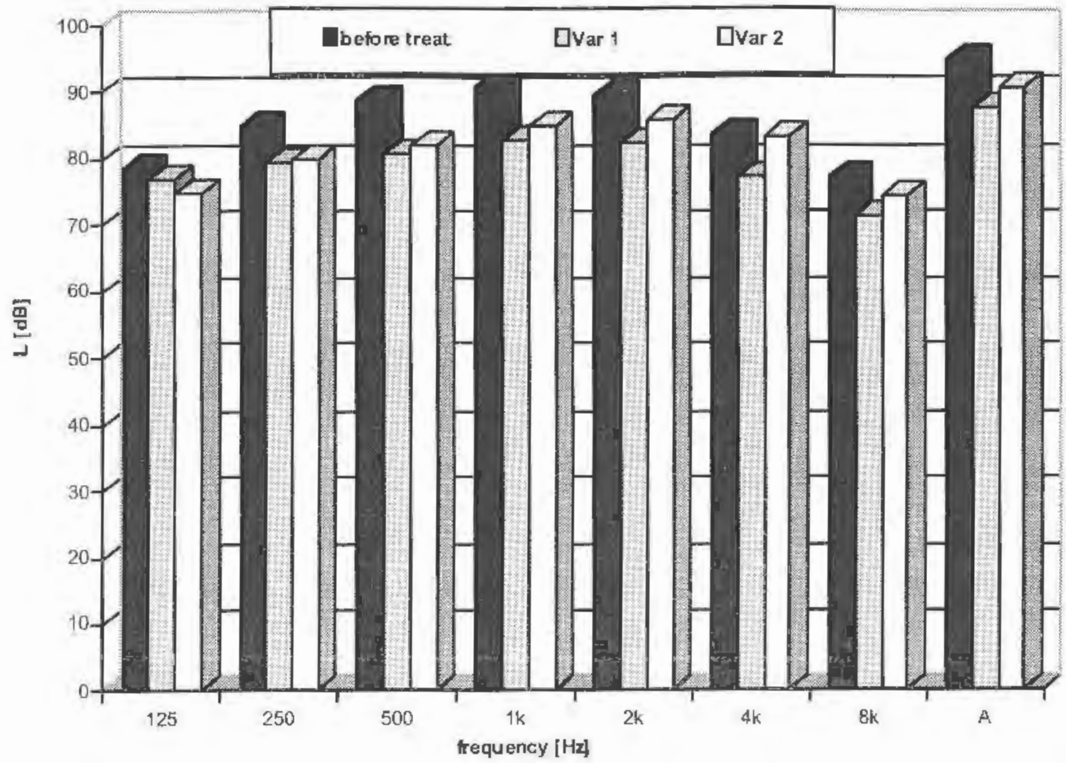
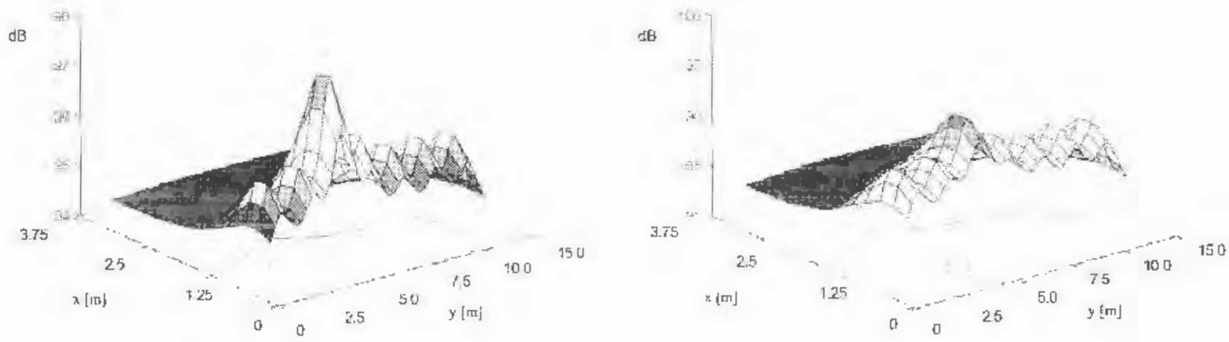


Fig. 9 Octave spectrum of the average noise level in the machine workroom at z=1.5m



before treatment after treatment

Fig. 10 3-D presentation of spatial distribution of noise levels before and after acoustic treatment at z=1.5m

5. Conclusion

Acoustic absorbers did very well in practice. They resulted in reduced reverberation time, reduced level of noise and much better understanding and communication of workers in the workroom.

In addition, by the acoustic treatment of working space using various materials, significant reduction of noise outside the working premises is achieved, which affects the quality of the environment. This is especially important if such facilities are located near residential buildings.

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