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ENCLOSURES SOLUTIONS, STUDIES OF ACOUSTIC EFFECTIVENESS UNDER REAL CONDITIONS

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This reports presents examples of enclosures designed by the author and implemented in the industry. Their purpose is to limit the excessive noisiness of machines and installations that are situated outside of proeduction halls and of technological objects and increase the acoustic degradation of the environment. The results of verification studies executed in order to determine both the acoustic effectiveness of the enclosures applied and the limitation of the noise in the external environment obtained in acoustic protected sites in the neighbourhood of industrial objects are also discussed. The examples of implementation presented confirm the great usefulness and effectiveness of enclosures in anti-noise protection. This report contains also information about experimental studies conducted by the author in order to determine the influence of materials and constructional solutions on the acoustic effectiveness of enclosures. The results of research obtained are useful in designing improved constructional solutions of enclosures.

1. Introduction

An enclosure, which is the passive device of noise limitation, is often the only possible way to limit the sound radiation caused by acoustic active machines or their parts. Its particular importance consists in the fact that the noise level is reduced already in the direct neighbourhood of a noise source. It makes it possible to protect both workplaces situated closely in the case of the noise ocuring inside of production halls, and of objects in the external environment, i.e. in the direct neighbourhood of the border of an industrial plant in which a noisy machine works located outside of production halls. As the practice shows the enclosure plays an important role in the set of antinoise protection means applied for the limitation of the excessive arduosness of industrial noise influencing acoustic protected sites. Scientific works on the application of sound-absorbing and insulating enclosures have been executed for many years in numerous high-industrialized countries. These works or those that can be applied in the design of enclosures have been conducted in three directions:

• a theoretical direction based on the achievements of theoretical acoustics [e.g. 9, 10].

• a scientific direction consisting in the elaboration of computational methods, rules of the selection of sound absorbing and sound insulating materials, technical, functional and architectonic solutions, standards and instructions, as well as in practical applications of new solutions of limitation of the noise caused by a real individual machine or by series of types of machines and installations [e.g. 7, 10, 11, 12];

• a research direction consisting in the study of properties of sound absorbing and insulating materials and in the determination of the influence of material and structural factors on the acoustic effectiveness of enclosures, etc. [e.g. 8, 13];

The investigations executed in the Mechanics and Vibroacoustics Department during the last few years aimed at the elaboration of effective and modern structural solutions of enclosures, comparable to the solutions applied in countries having more experience in this field, such as USA, Great Britain or Germany. The verifying studies executed after application of the designed enclosures in the industry proved that the elaborated solutions were conformable with the international standards of acoustic, as well as exploitation requirements and realization esthetic.

At the Mechanics and Vibroacoustics Department extensive studies were also executed which were aimed at the determination of the influence of the material and structural solutions of enclosure elements on their acoustic characteristics. The studies on the determination of the influence of the following elements on the enclosure acoustic effectiveness deserve special attention: solution of contacts and joints of enclosure components, the kind of seals in the contacts and joints of enclosure walls, the material structure in the constructional solution of the wall and the way of the wall fastening to the frame of the supporting structure. The results of these studies should be treated as an extension of the results of the research works executed in other foreign scientific centers.

2. Solutions of enclosures

In the implementation practice four kinds of enclosures are applied [1, 2]; partial, partly closed, entirely closed and integrated enclosures. The following factors influence the kind of the constructional solution of the enclosure used: the type and principle of operation of the noisy machine, its production or technological process, requirements concerning the necessary acoustic insulation. The basic repartition of the enclosure is presented in Fig. 1.

The classification presented in Fig. 1 can be completed by other repartitions [3] after taking into account more detailed criteria, such as: the kind of the implemented constructional solution, thermic requirements concerning the enclosed machine, the access to the machine during repairs and the course of the production on technological process, the kind of the technological or production process carried out by the

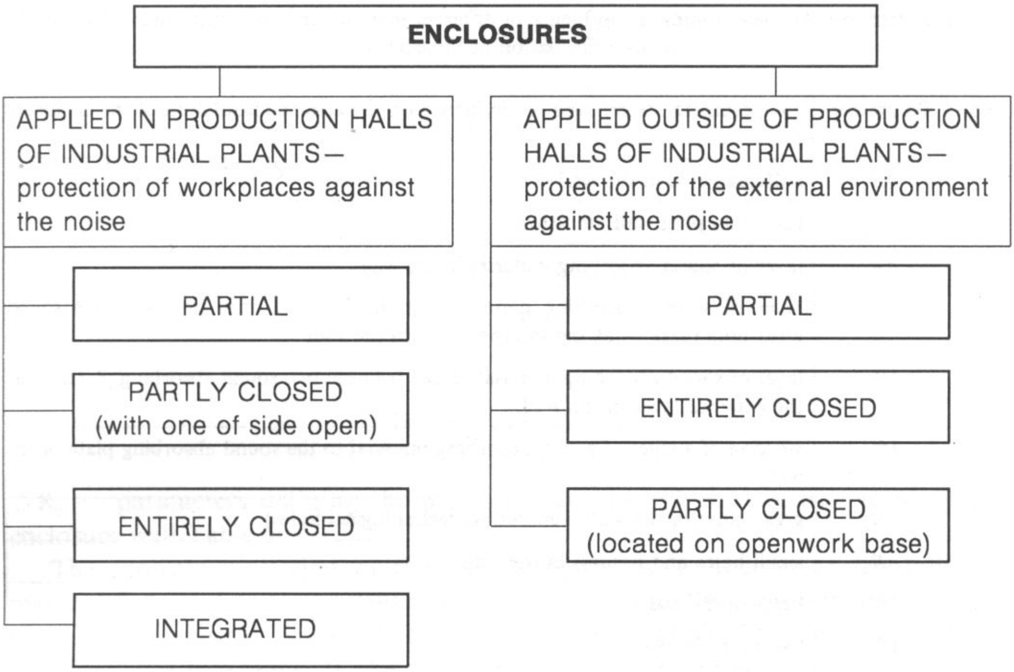


Fig. 1. General classification of enclosures.

enclosed machine, the required acoustic effectiveness of the enclosure, the application of automation elements in the constructional solution of the enclosure, the way of fastening of enclosure walls, the solution of the enclosure shape.

3. Parameters influencing the acoustic effectiveness of enclosures

A measure of the enclosure effectiveness is its acoustic insulation, D_{obud}, which indicates to what extend the enclosure protects against the penetration of the air vibration as well as the material vibration in the outside. The acoustic insulation of an enclosure depends first of all on the specific acoustic insulation R_s of its walls. Next, the value of the acoustic insulation of an enclosure wall depends on the physical properties of the material of which it is made and on its constructional features.

On the basis of the research results obtained up to the present it can be stated that the material and constructional factors occuring in the depending and production phases have an essential influence on the acoustic effectiveness of the enclosures. The following formula describes this relationship:

$$D_{\mathrm{obud}} = R_s + \sum_{i=1}^{13} \triangle R_i, \quad \mathrm{dB} \tag{3.1}$$

where R_s — specific acoustic insulation of the thin enclosure wall, dB.

Table 1. Parameters ΔR_i determining the influence of different material and constructional factors on the acoustic insulation of the enclosure

No.	Parameter	This parameter determines the influence on the acoustic insulation of the enclosure of:
1	ΔR_1	stiffening ribs in the wall
2	ΔR_2	layer dumping wall vibration
3	ΔR_3	layer of sound absorbing material in the wall
4	$\Delta R_{3.1}$	layer of sound absorbing material combined with a thin homogeneous sound absorbing plate — as the external layer in the wall
5	$\Delta R_{3.2}$	layer of sound absorbing material placed between two sound absorbing plates — as the external layer in the wall
6	$\Delta R_{3.3}$	sticking of a layer of sound absorbing material to the sound absorbing plate of the wall
7	ΔR_4	great holes in the wall (ventilating, technological holes)
8	ΔR_5	small holes and fissures in the wall
9	$\Delta R_{5.1}$	holes in the wall
10	$\Delta R_{5.2}$	fissurs in the wall
11	$\Delta R_{5.3}$	way of arrangement of holes (perforation) in the wall
12	ΔR_6	way of fastening of the wall to the supporting structure frame
13	ΔR_7	acoustic bridge in constructional solution of layer wall
14	$\Delta R_{7.1}$	linear acoustic bridges
15	$\delta r_{7.2}$	point acoustic bridges
16	ΔR_8	elastic properties of wall material
17	ΔR_9	constructional solution of complex wall — with an element of window or eyehole
18	ΔR_{10}	volume mass of sound absorbing material applied in constructional solution of the wall
19	Δr_{11}	solutions of contacts and joints of components
20	$\Delta R_{11.1}$	kind of joints between the walls
21	$\Delta R_{11.2}$	joints on the contact of doors, windows and flaps and their embrasures
22	$\Delta R_{11.3}$	fissures in joints between walls
23	ΔR_{12}	kind of seals in contacts and joints of the wall
24	$\Delta R_{12.1}$	seals in contacts of wall and enclosure supporting structure
25	$\Delta R_{12.2}$	seals in joints of walls
26	$\Delta R_{12.3}$	irregularity of seal holding down in the joint contact
27	$\Delta R_{12.4}$	sound transmission by the supporting structure
28	ΔR_{13}	material structure in constructional solution of the wall

$$R_3 = \sum_{j=1}^{3} \triangle R_{3j}, \quad dB$$

$$R_5 = \sum_{j=1}^{3} \triangle R_{5j}, \quad dB$$

$$R_7 = \sum_{j=1}^{2} \triangle R_{7j}, \quad dB$$

$$R_{11} = \sum_{j=1}^{3} \triangle R_{11j}, \quad dB$$

$$R_{12} = \sum_{j=1}^{4} \triangle R_{12j}, \quad dB$$

$\triangle R_i$ — parameters defining the increase (decrease) of the acoustic insulation of enclosure wall Table 1.

The acoustic insulation of the enclosure wall is a function of the following material factors: the volume density of the wall material, the longitudinal modulus of elasticity, the internal loss coefficient in the wall material, the Poisson's ratio, the wall thickness, the frequency of the incident sound wave, the void ratio of the wall material.

The following constructional factors that influence the acoustic insulation characteristics of the enclosure wall should be mentioned the acoustic homogeneity or heterogeneity of the wall, the acoustic homogeneity or heterogeneity of the wall surface, the type of joints and the way of fastening of the wall to the circuit, the tightness of the wall on the entire surface etc.

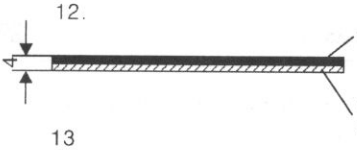
4. Study of the material and constructional solutions on the acoustic effectiveness of enclosures

The important acoustic effectiveness, a large range of applications the only possible way to limit the noise in many cases — these are the arguments for the application of enclosures in industrial plants, as well as for further studies of new improved material and constructional solutions. The author has executed many experimental studies [3] in order to determine the influence of the material and constructional factors on the acoustic effectiveness of enclosures. The research work included:

1. Investigations of the influence of the solutions of contacts and joints of enclosure components taking into account:

a) the influence of the kind of joints between the walls,

b) the influence of the joints on the contact of doors, windows and flaps and their embrasures, 12.



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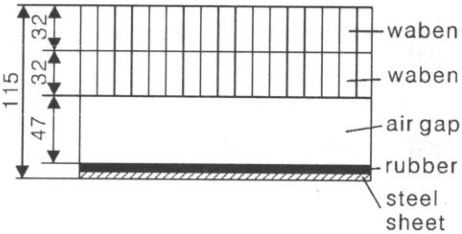

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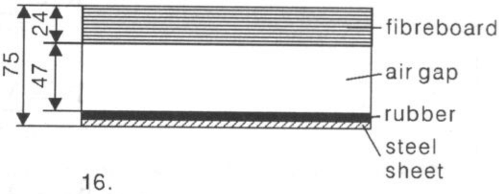

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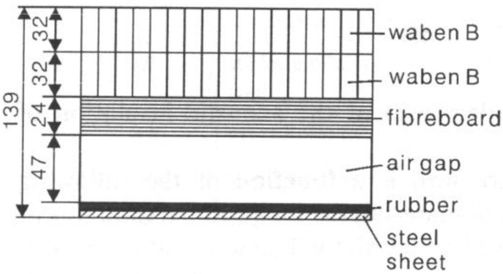

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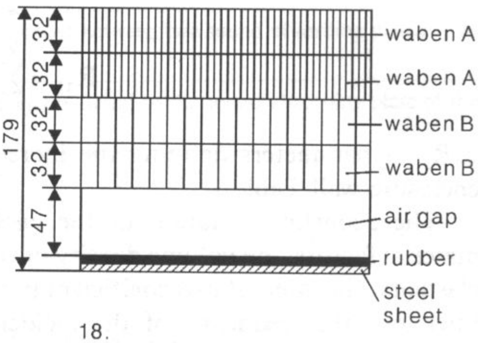

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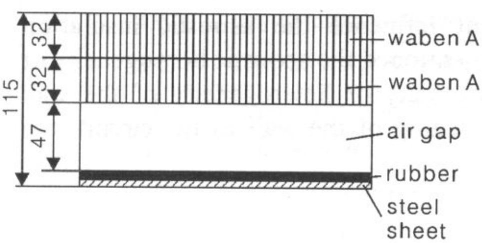

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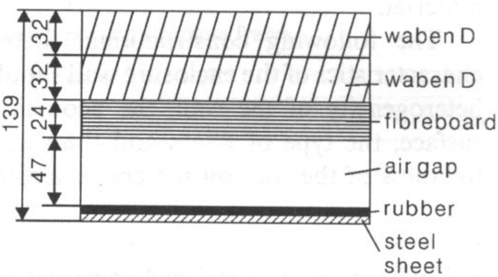

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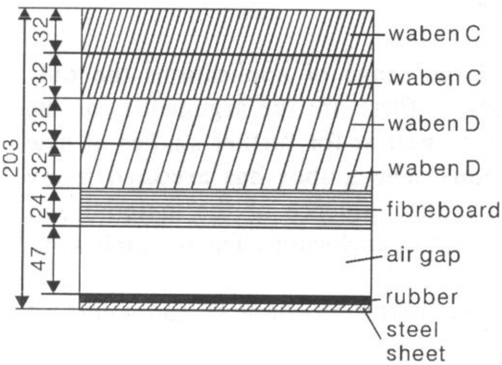

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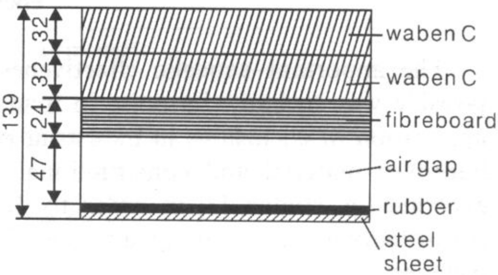

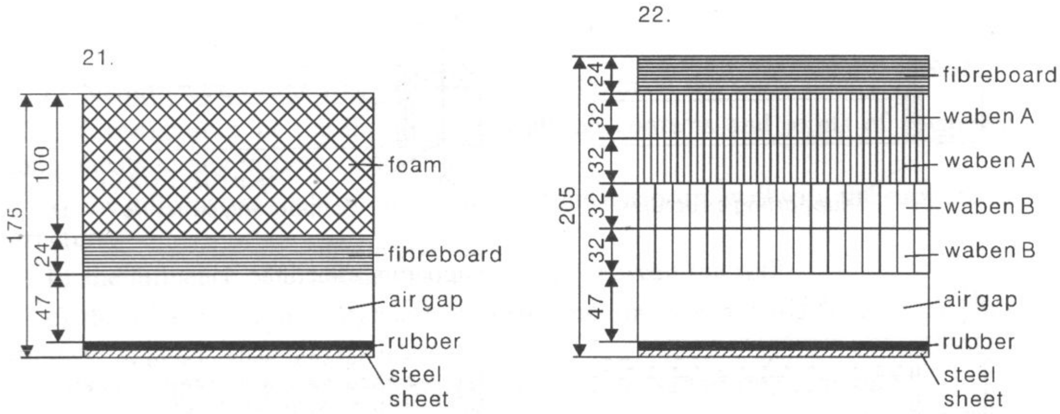

Fig. 2a. Schemes of variants of layer walls used in the experimental research of the influence of the wall material structure on the acoustic insulation of an enclosure.

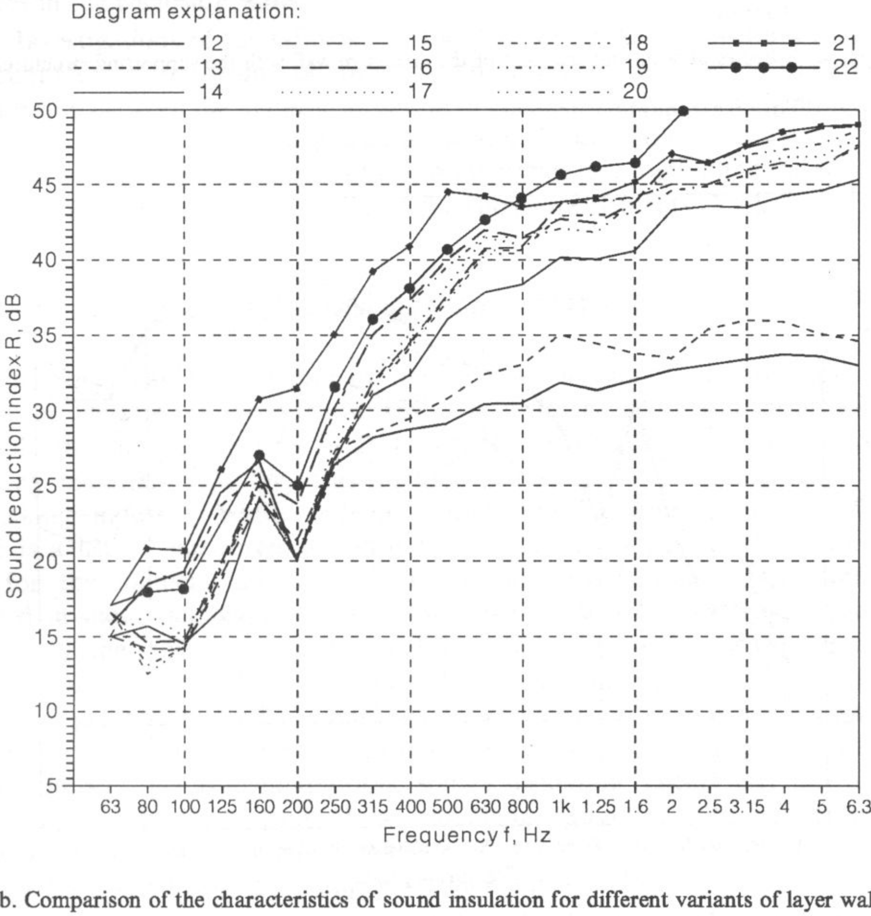

Fig. 2b. Comparison of the characteristics of sound insulation for different variants of layer walls of the enclosure.

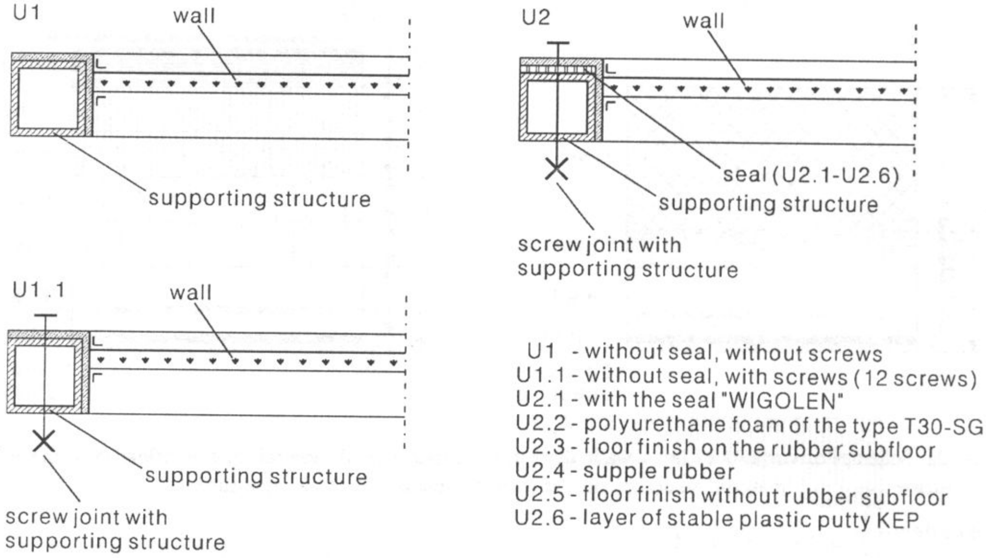

Fig. 3a. Schemes of seals and the joint of the enclosure wall with the supporting structure.

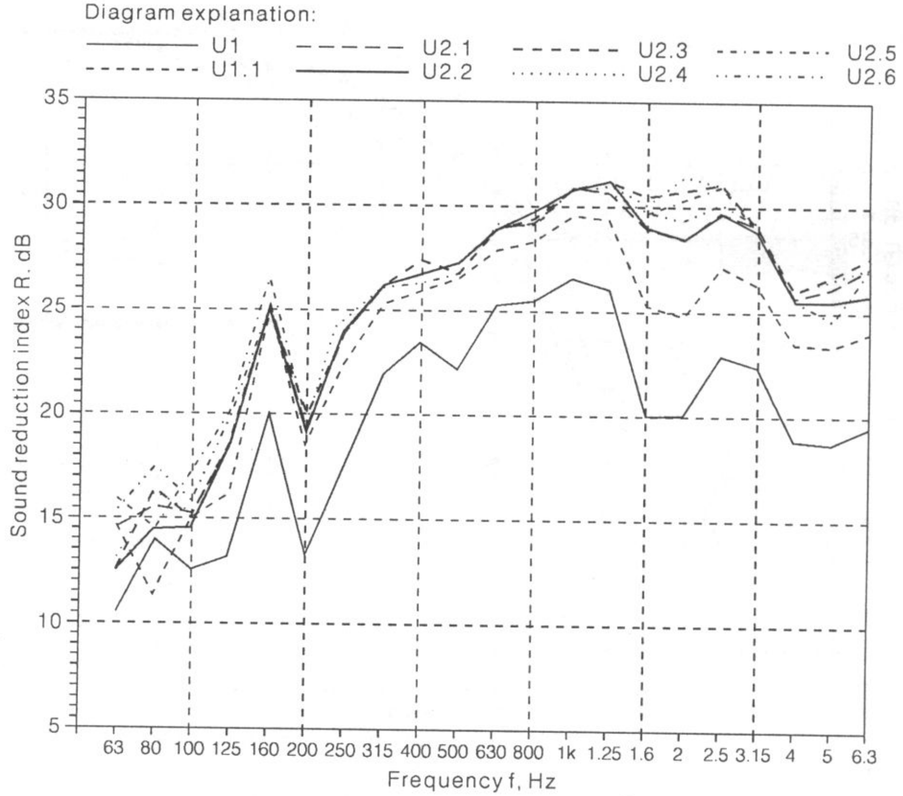

Fig. 3b. Comparison of the characteristics of sound insulation for different kinds of seals in contacts and joints of enclosure elements.

c) the influence of the fissures in the joints between the walls.

2. Investigations of the influence of seals on contacts and joints of enclosure components taking into account:

a) the influence of seals on the contacts of the enclosure wall with the supporting structure,

b) the influence of the seals in the contacts between the walls,

c) the influence of the roughness of the seal holding down in the point of the joint contact,

d) the influence of the sound transmission of the supporting structure,

e) the influence of the way of fastening the enclosure wall to the frame of the supporting structure.

3. Investigations of the influence of the constructional solutions of holes and fissures in the enclosure walls.

4. Investigations of the influence of the structure of the enclosure wall material.

Examples of the results of investigations executed in order to determine the relationship between the material structure of enclosure wall and its characteristics of sound insulation, R [3, 5], are presented in Figs. 2a and 2b.

Figures 3a and 3b present one of the results of the investigation of the effect of the seal kind on the contacts and joints of the enclosure elements [3, 4].

5. Practical appliation of enclosures

Enclosures can be applied in many noisy machines and devices situated inside or outside of production halls in different industrial branches. It is possible to apply enclosures in factories of heavy industry, chemical industry, building materials industry, glass-making industry, woodworking industry, papermaking industry, textile industry, food industry and others. In Table 2, there is a list of enclosures designed by the author as part of the work carried out for the industry of the Mechanics and Vibroacoustics Department and applied in industrial plants emitting excessive noise to the external environment caused by the noise sources situated in open air, outside or productive and technological objects. The enclosures listed in Table 2 were either the only antinoise protection applied limiting the emission of the environment up to admissible values or they entered into a complex set of applied passie protections noise dumpers, acoustic adaptation, sound insulating shields etc. the total implementation of which enabled to satisfying results in the improvement of the acoustic climate of the environment.

Figures 4 and 5 present examples of the applied enclosures.

Table 2. List of enclosures implemented in the industry in the years 1991 – 1994

No.	Noise source Kind of enclosure (Number of items)	Implementation place (Year of implementation)	Acoustic insulation of enclosure D_{Aobud}, dB	Noise limitation effect obtained in the environment ΔL_{Aeq}, in dB
1	Unit of four fan water coolers Entirely closed (1)	Krakowskie Zakłady Teleelektroniczne „TELKOM-TELOS" w Krakowie (1991)	10.0	14.0
2	Unit of four pumping engines Partly closed (4)	Przedsiębiorstwo Eksploatacji Rurociągów Naftowych „PRZYJAŹŃ" w Płocku Przepompownia Ropy ST-3 w Górach k/Płocka (1993)	23.0	17.0
3	Unit of two fans of flue gas draught and dust collection plants in the boiler house Entirely closed (2)	Krakowskie Zakłady Przemysłu Owocowo-Warzywnego w Krakowie (1993)	26.0	18.0
4	Unit of three fans of flue gas draught in the boiler house Entirely closed (3)	Okręgowa Spółdzielnia Mleczarska w Pajęcznie (1993)	25.0	30.0
5	Station of two air compressors in the boiler house Entirely closed (1)	Okręgowa Spółdzielnia Mleczarska w Pajęcznie (1993)	30.0	30.0
6	Unit of two condensors in the refrigerating engine room Entirely closed (1)	Okręgowa Spółdzielnia Mleczarska w Pajęcznie (1993)	23.0	30.0
7	Unit of two equalizing tanks in the air compressor room Entirely closed (1)	Zakłady Przemysłu Lekkiego „WIGOLEN" S.A. w Czestochowie (1994)	29.0	21.0

Fig. 4. Entirely closed enclosure (with noise dumpers on the exhaust holes) protecting the unit of two condensers in the Okręgowa Spółdzielnia Mleczarska in Pajęczno.

Fig. 5. Unit for partly closed enclosures (on openwork base) protecting the pumping engines in the Przepompownia Ropy ST-3 in Góry k/Płocka.

6. Studies of acoustic effectiveness of enclosures

The value of the acoustic insulation D_{obud} [1], is a measure of the acoustic effectiveness of the enclosure. The difference between the mean value, L_{pm1} (measured in dB), of the acoustic pressure levels at all the measurement points during the work of a machine or device without enclosure and the mean value, L_{pm2} (measured in dB), of those levels at the same points during the work in an enclosure, at frequencies of the central octave bands ranging from 63 to 8000 Hz, is defined as the acoustic insulation value of the enclosure. The acoustic insulation of an enclosure can be determined also by means of a parameter D_{Aobud} (defined as the difference of A sound level L_A before and after application of the enclosure). The required effectiveness of the enclosure is directly related to the limitation of the noise emission to the external environment, i.e. to the acoustic preserved teritority in the neighbourhood of an external noise source for which the antinoise protection in the form of an enclosure was applied. Therefore, the studies of the acoustic effectiveness of enclosures are executed simulatneously with the studies of the acoustic climate in the environment. Table 2 presents the results of studies of acoustic environment at the most unfavourable point of the influence of industrial noise of the border of a factory or within the acoustic zone preserved.

7. Conclusion

As the presented review of the completed implementation works shows, enclosures still have an important application in the set of passive protections limiting industrial noise. The enclosures used in many industrial plants proved to be very useful. Enclosures can be applied as the individual protections or they can be an element of a set of several sound insulation means applied together. It is a way to considerable improve the limiting of the influence of industrial noise on the environment.

Experimental studies executed in order to elaborate new improved material and constructional solutions of enclosures proved that:

— the decrease of the assumed acoustic insulation of the enclosure D_{obud}, in spite of the choice of walls with appropriate acoustic insulation R_s, can be caused by the influence of the material and constructional factors which are formulated as a function of the parameters ΔR_i defining the increase or decrease of the acoustic insulation of the wall. The identification and determination of the parameters ΔR_i makes it possible to avoid a decrease in the acoustic insulation of the enclosure, D_{obud}, and thereby to fulfill of the requirements concerning the desired effectiveness of the enclosure.

— the knowledge of the parameters ΔR_i enables to design effective enclosures by selection of appropriate sound-absorbing and sound-insulating materials for the enclosure walls and also by the design of technical solutions of enclosure elements that are correct from the acoustic point of view.

The author is going to adress his experimental studies in the future to the elaboration of a new material and constructional solution of the barrier wall with acoustic insulation increased in comparison with the solutions applied now. The wall will be designed to construct integrated enclosures. Those enclosures, that have been rarely in use up till now, are one of the components of the frame of a noisy machine or from the entire machine frame appropriately elaborated from the acoustic point of view. The elaborated of preliminary assumptions for the design of a new generation of the frames for selected machines, characterized by an increased vibroacoustic energy absorption, will be further extension of the planned research.

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