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ORIGINAL PAPER

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# Redesign of Work Space in Order to Reduce Noise Health Effects

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## ABSTRACT

**Introduction:** Noise represent an unwanted sound that endangers human health in multiple manners and in work setting causes reduction of productivity on one side, and increased waste on the other. Noise pollution occurs when the ear is exposed to the volume of sound that is disturbing, stressful or directly damaging hearing, but also acting on the organism as a whole. **Aim:** The aim of the article is to examine the vulnerability of workers working on the „press“ machine, and to carry out an analysis and examine the press operator workplace, then perform the noise spread measurement in the press operator work area and compare the current measurements with the permissible levels and analyze the time period of worker exposure, as well as presentation of the effects of noise on productivity and workers health. The aim of the article also includes the proposal for decrease of noise pollution. **Methods:** A noise analysis at the workplace of workers working on a „press“ machine was performed, which is exposed to a high impulse noise due to which the quality and quantity of production are reduced. For the purpose of calculating the noise level for one working day at the press operator site 1, 2 and 3, it is necessary to analyze the noise level in time. Operators spend most of their working hours at stations 1 and 3 where the measured noise level is  $L_{m1} = 94.7$  dB is taken, or at position 3,  $L_{m3} = 97.2$  dB. The measured noise level at these locations without the operation of the press is  $L_{m1} = 80.1$  dB, or at station 3 is  $L_{m3} = 80.1$  dB. **Results:** It was found that these operators working on the machine in question were exposed to a noise over the limit for more than three years. Their health problems that arise as a result of noise exposure are documented in their health charts. In order to achieve uninterrupted work at the press machine, during the eight hours shift, a noise correction is required to allow the equivalent sound level to fall within one day to the permissible 85

dB. In this regard, we consider the fact that we have known that the press produces a sound level of 110 dB, and that there is a reverberation (reflecting) sound. Given the technical characteristics of the plant, the reduction of the sound intensity of the source itself is not possible, so the suggestions of the technical solution will be based on reduced reflected sounds and to prevent the spread of direct sound to the operator. **Conclusion:** Workers are exposed to permanent noise during a working day, which produces a number of consequences for the health of the worker, but also the employer and the community. The imperative of the employer is to reduce the number of rejects, increase profitability and to have a positive impact on the health of the individual.

**Keywords:** Noise, medicine, productivity, remediation.

## 1. INTRODUCTION

Noise represent an unwanted sound that endangers human health in multiple manners and in work setting causes reduction of productivity on one side, and increased waste on the other. The noise is generated when the ear is exposed to the volume of sound that is disturbing, stressful or directly damaging the hearing but also acting on the organism as a whole (1).

The sensitivity to the noise depends on the characteristics of the noise, the individual characteristics of the person and the type and duration of exposure to the noise source (1,2). Noise is the main preventable cause of hearing loss (2,3,4).

Hearing loss can occur after acute exposure to very high noise and long-term exposure above 75-85 dB (damage to the ear or its parts may be short term, but permanent repetition of the effects of noise can become permanent) (5). Measurements have been established and legally

stipulated that the average noise level in the open space environment is around 35 dB, while for the conversation the noise level is 65 dB (6). In the case of intensive traffic, the noise produced intensity is in the interval of 90 dB to 120 dB, which is very painful for the human ear and can often result in damage, including loss of hearing or some other negative health consequences (6).

The effects of noise on the cardiovascular system on the occurrence of hypertension, ischemic heart disease and stroke have been demonstrated, but the noise also affects the autonomic nervous system, which regulates the work of the cardiovascular system (2,7,8). Also, noise affects the values of diastolic blood pressure, the heart rate, and release of catecholamine and glucocorticoids, which also has a negative effect on the cardiovascular system (7,8). It has an influence on blood lipid concentrations, blood viscosity, and hence the atherosclerotic process (9), and can be indicated as a risk factor for ischemic heart disease (7,8,9). Influence on blood glucose values (7), may also be related to diabetes mellitus (10), and a true dysregulation of the endocrine system (also affects adrenaline, noradrenaline, cortisol and gonadotrophin) and increases the stress of the body) (2). Evidence and impact of noise on cognitive abilities (11) were demonstrated. All of the above indicates a significant effect on noise in the work environment. Given that the productivity of a person is the very core of business, ensuring adequate working conditions is imposed as an employer's imperative for profitability. Narrow health is both short-term and long-term in both the employer and the health system. Better health conditions and positive lifestyle risk factors are associated with workplace productivity loss (12). Job satisfaction is one of the basics of good business (13), and prevention is the imperative of modern health care (14).

## 2. AIM

The aims of this article are:

- Investigate the vulnerability of workers working on the „press“ machine;
- Conduct an analysis and examine the workplace of the press operator;
- Perform noise measurement at the press operator workstation and compare current measurements with permissible levels;
- Analyze the workers exposure time;
- To show the character and quantity of noise impacts on productivity and health of the workers;
- Provide remediation proposals for noise reduction.

## 3. METHODS

A noise analysis at the workplace of workers working on a „press“ machine was carried out, who are exposed to a high impulse noise due to which the quality and quantity of production are reduced. The study was done in the factory CIMOS CASTING, Zenica, Bosnia and Herzegovina. The noise was measured by the integrated averaging sound level meter CIRRUS CR:811B. The respondents were operators who worked on the presses (three stations, three workers per station, were working in three shifts (total number per press is 9 workers, and total number of workers is 27). Ac-

ording to the technical documentation the press produce noise of 110 dB (near these presses there are also other machines that are part of the technological process and generate additional noise, which explains the total noise measured at the level of 118.2 dB). The additional noise of the machines in the environment was not taken into account for calculations due to the fact that it is planned to carry out their repairs and to bring their noise levels to the allowed limits. The noise intensity of the other machines is of a magnitude 7% of the primary noise source.

## 4. RESULTS

It has been determined that these workers who have been working on a given machine have been exposed to noise above limit for three years (Figure 1). Their health problems that arise as a result of noise are documented in their health records.

### 4.1. Workplace description

The press as a device itself produces a noise of 110 dB. Between the press and the operator, there are physical barriers that prevent direct sound from reaching the working place of the operator. However, these barriers are not enough to protect the worker from high pulses, sound impact at work, summed up with background noise, and appropriate security measures are required to ensure maximum workplace productivity during the working day.

Figure 2 shows the noise spreading plan by means of the contour lines in the working area of the press machine and

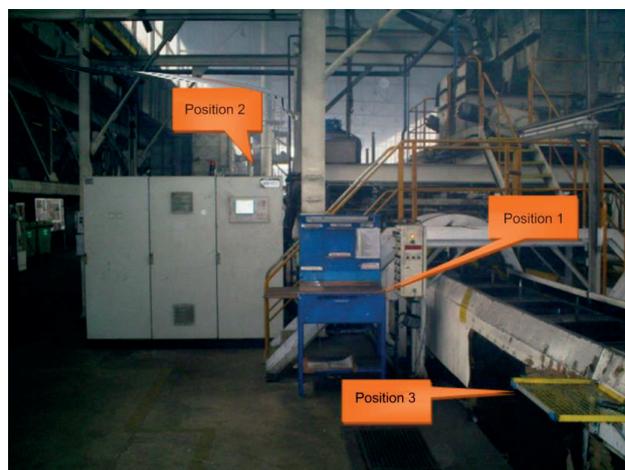


Figure 1. The workplace of the press operator

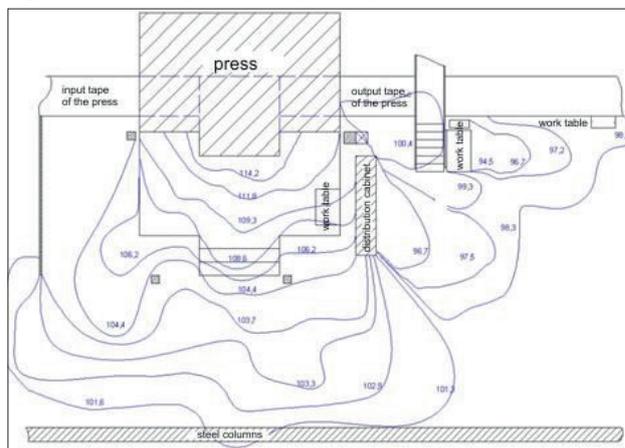


Figure 2. Noise distribution plan

the operator working in that work area.

Measured noise values for station 1 are 118.2 dB, and exceed the permitted limit, as well as at station 2 (124.9 dB) and station 3 (108 dB) (slight).

#### Station 1.

The sound level at the catalogue value for the press is 110 dB. The distance between station 1 and the center of the noise source is 5 meters. The sound wave decrease for  $r$  is calculated according to the following pattern:

$$M = 20 \log (r / 5 r) = 20 \log (1 / 5) = -13.97 \text{ dB} \quad (1)$$

$$L_{m1} = L_{start} - \Delta L = 110 - 13.97 = 96.03 \text{ dB} \quad (2)$$

Physical barriers between the station 1 and the sound source cause diffraction and reflection. The diffraction at position 1 generates an audible shadow, which reduces the intensity of the sound. When reflecting, one part of the energy bounces from substrate or physical barrier while the other part of the energy passes through the barrier.

The extent to which energy will be diverted from the barrier, and the extent to which it passes depends will depend on the power of the material, or its ability to transfer the sound.

The reflexion of the sound results in a reverberation, that is to the indirect noise that increases the intensity of the noise, as mentioned earlier. By entering energy into the barrier material, an absorption of one part of the energy becomes transformed into heat energy. The rest of the energy passes through the barrier.

The barriers between the sound source and stations number 1 and 3 are of a material that is a poor sound isolator, and there are large openings between the barriers, which reduces their noise protection capability. The noise level in the sound shadow behind the barrier will be reduced by about 4% (due to the reflection and absorption of one part of the noise).

The expression (1) and (2) represent a mathematical record of the noise intensity from the barrier between the operator and the press.

$$L_{mir} = (L_{start} - \Delta L_4) - 4\% = 110 - 13.97 \quad (3)$$

$$L_{mir} = (110 - 12.04) - (97.96 \cdot 4 / 100) = 94.04 \text{ dB}, \quad (4)$$

where

$L_{mir}$  – calculated sound intensity level at position 1. without background noise

$\Delta L_4$  – calculated sound intensity level at a distance of 4 meters.

$$\Delta L_4 = 20 \log (1 / 4) = -12.04 \text{ dB} \quad (5)$$

$$L_4 = 110 - 12.04 = 97.96 \text{ dB} \quad (6)$$

We aggregate the total sound intensity level at station 1 with the background noise:

$$L_{m1} = 10 \log (10^{0.1 \cdot L_{min}} + 10^{0.1 \cdot L_{pos}}) = 10 \log (10^{0.1 \cdot 94.04} + 10^{0.1 \cdot 8.01}) = 94.17 \text{ dB} \quad (7)$$

where it is

$L_{pos} = 80.01 \text{ dB}$  the measured background noise value

$L_{m1}$  – calculated sound intensity level at station 1.

Based on the measured measurements and the computer calculation for the press operator number 1, there is a noise over the limit and it amounts to:

$$L_{over\_m1} = L_{m1} - L_{allow} = 94.17 - 85 = 9.17 \text{ dB} \quad (8)$$

#### Station 2.

No significant noise levels reductions are possible for this location, as the press produces a noise of 110 dB, which

is higher than the permissible (85 dB). However, the sound that produces the press in the moment of impact is reflected by the massive steel poles facing opposite the press as well as the ceiling. Reflected values are obtained by combining with direct sound:

$$L_{m2} = 10 \log (10^{0.1 \cdot L_{r1}} + 10^{0.1 \cdot L_{r2}} + 10^{0.1 \cdot L_{po\check{c}}}) = 10 \log (10^{0.1 \cdot 11} + 10^{0.1 \cdot 11} + 10^{0.1 \cdot 11}) = 114.7 \text{ dB} \quad (9)$$

Noise level above the permissible limit at station 2 is high:

$$L_{over\_m2} = L_{m2} - L_{allow} = 114.7 - 85 = 29.7 \text{ dB} \quad (10)$$

#### Station 3.

Station 3 is further away from the station 1, but it also comes out of the sound shadow that is created by physical barriers. The sound level at this location is caused by background noise, direct sound of the press, as well as reflection of the same or indirect sound.

The calculated direct sound intensity level at position 3, without background noise effects, is:

$$\Delta l = 20 \log (r / 8 r) = 20 \cdot (-0.903) = -18.06 \text{ dB} \quad (11)$$

$$L_{m3r} = L_{start} - \Delta L_4 = 110 - 18.06 = 96.03 \text{ dB} \quad (12)$$

Sound intensity level, combined with background noise, is:

$$L_{m3u} = 10 \log (10^{0.1 \cdot L_{m3r}} + 10^{0.1 \cdot L_{pos}}) = 10 \log (10^{0.1 \cdot 96.03} + 10^{0.1 \cdot 8.1} + 10^{0.1 \cdot 9.2}) = 97.5 \text{ dB}, \quad (13)$$

where it is

$L_{pos} = 81.01 \text{ dB}$  – the measured background noise value,

$L_{m3}$  – calculated sound intensity level at station 3,

$$L_{over\_m3} = L_{m3} - L_{allow} = 97.5 - 85 = 12.5 \text{ dB} \quad (14)$$

### 4.2. Operator exposure to noise during the working day

For the purpose of calculating the noise level for one working day at the press operator station 1, 2 and 3, it is necessary to analyze the noise level in function of time. Operators spend most of their working hours at stations 1 and 3 where the measured noise level at  $L_{m1} = 94.7 \text{ dB}$  is taken, or at position 3,  $L_{m3} = 97.2 \text{ dB}$ . The measured noise level at these locations without the operation of the press is  $L_{m1} = 80.1 \text{ dB}$ , or at position 3 is  $L_{m3} = 80.1 \text{ dB}$ . Consequently, workers are exposed to permanent noise during the working day.

In normal operation, the press can produce 140 molds per hour, which is 2 to 3 molds per minute. The duration of one stroke took 4 seconds. Based on this, it is possible to calculate the time of the sound levels at the work of one person on a daily basis. The most unfavorable case for a worker is that press work at maximum intensity, which would be 1.120 hits in 8 hours of operation.

The number of press strikes, multiplied by the duration of the produced sound, gives a time interval of 4,480 seconds, or 1h 14min and 40s. The rest of the working hours workers are exposed to the background noise. That part of the time interval can be expressed so that by the total working time of 8 hours we subtract the time in which workers are exposed to the noise of the press, which is 6h 46min and 20s.

The noise rate for each station will depend on the noise level and exposure time in those places. The noise dose to which the worker is exposed during the working day at stations 1, 2 and 3 is:

#### For the station 1.

$$L_{rt} = 10 \log [1 / 8 \cdot (1.24 \cdot 10^{9.45} + 6.75 \cdot 10^{8.1})] = 90.84$$

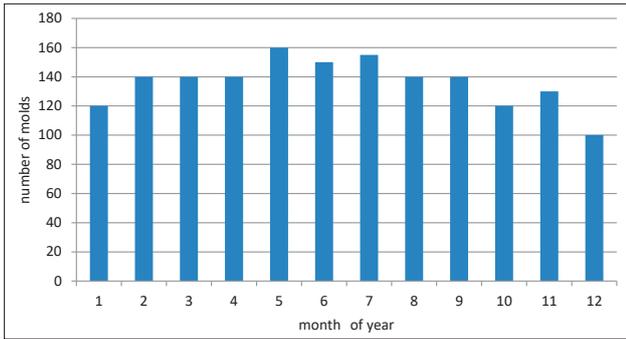


Figure 3. Production of molds before workplace repair

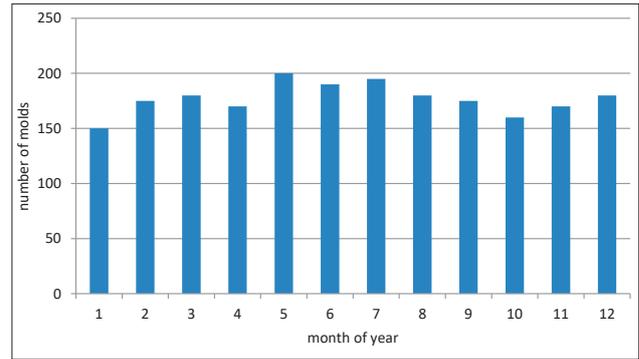


Figure 4. Production of molds after workplace repair

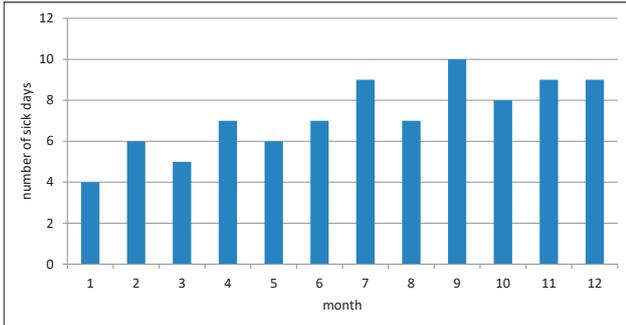


Figure 5. Monthly number of sick days before workplace repair

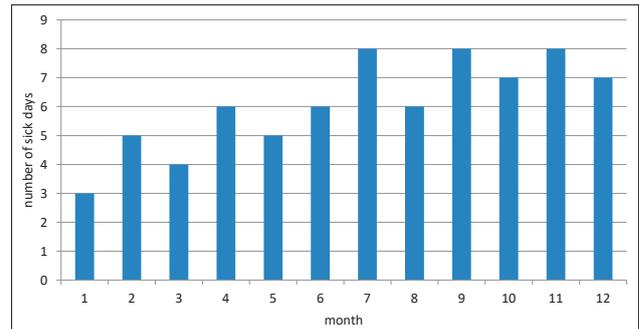


Figure 6. Monthly number of sick days after workplace repair

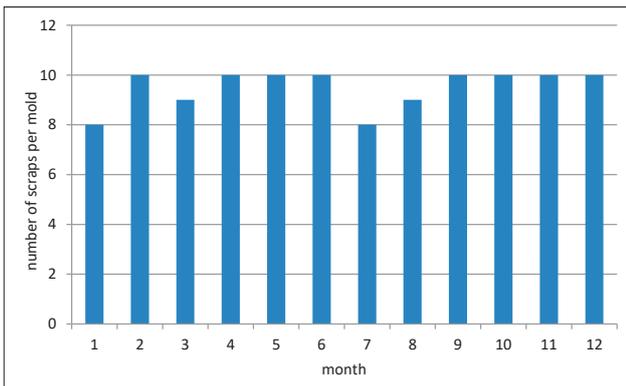


Figure 7. The monthly average of rejects per mold before workplace repair

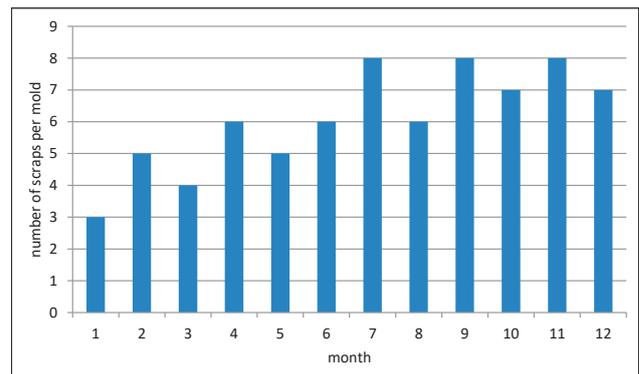


Figure 8. The monthly average of rejects per mold after workplace repair

dB (15)

Due to the eight-hour working time during one shift, the operator at station 1 receives a noise dose of 400% greater than the allowed one. Optimal working hours for this job would be 2 hours a day. In that time, the worker would receive a permissible dose of noise prescribed for one day.

**For the station 2.**

$$L_{r2} = 10 \log [1 / 8 \cdot (1.24 \cdot 10^{11.42} + 6.75 \cdot 10^{8.1})] = 105.85 \text{ dB} \tag{16}$$

Thus, workplace 2 represents a zone with a critical noise level. For this noise value in this workplace, the worker can be exposed for 15 minutes during the working day.

**For the station 3.**

$$L_{r3} = 10 \log [1 / 8 \cdot (1.24 \cdot 10^{9.7} + 6.75 \cdot 10^{8.1})] = 91.88 \text{ dB} \tag{17}$$

At eight-hour working time, the operator at station 3 receives a noise dose of 500% higher than the allowable. The optimal working time recommended for this workplace during the day would be 2 hours a day. In order to ensure the permissible noise level for this workplace, noise repairs should be carried out to achieve limits up to 85 dB.

**4.3. Noise reduction**

In order to achieve uninterrupted work of the press, during the eight hours shift, a noise correction is required to allow the equivalent sound level to fall within one day reduced to the permissible 85 dB. In this regard, we consider the fact that we have known that the press produces a sound level of 110 dB, and that there is a reverberation (reflecting) sound.

Given the technical characteristics of the plant, the reduction of the sound intensity of the source itself is not possible, so the suggestions of the technical solution will be based on reduced reflected sounds and to prevent the spread of the direct sound to the operator station.

Proof of sound reverberation through Sabin's formula is shown in the following calculations.

From Figure 2, it can be seen that preventing the direct spreading of the sound wave to the operator's stations is taken by the provided barrier. This barrier should have such soundproofing properties that, when the sound wave reaches it, it needs to reduce part of the reflected energy directed towards the work area where the operator serves

the press. In this case, it should be borne in mind that by contact of the sound with the acoustic barrier occurs even after the sound diffraction.

In order to make the sound shadow in both places behind the barrier, the height of the wall should be high enough.

Based on Figure 5, there is an analytical proof of sound reverberation after noise correction.

$$A_{\text{str}} = 20 \cdot 40 \cdot 0.8 = 640 \text{ m}^2 \quad (18)$$

$$A_{\text{floor}} = 10 \cdot 30 \cdot 0.08 = 240 \text{ m}^2 \quad (19)$$

$$A_{\text{wall}_1} = [(5 \cdot 80) \cdot 0.73 + 30 \cdot 80] \cdot 0.4 = 1,076.8 \text{ m}^2 \quad (20)$$

$$A_{\text{wall}_2} = [(15 \cdot 80) \cdot 0.4 + 15 \cdot (40 - 30)] \cdot 0.73 + 100 \cdot 0.7 = 675.09 \text{ m}^2 \quad (21)$$

$$A_{\text{barrier}} = 28.39 \cdot 0.9 + 3 \cdot 0.03 + 15 \cdot 0.73 = 36.59 \text{ m}^2 \quad (22)$$

$$A = A_{\text{str}} + A_{\text{floor}} + A_{\text{wall}_1} + A_{\text{wall}_2} + A_{\text{barrier}} = 2,552.48 \text{ m}^2 \quad (23)$$

Room volume

$$V = a \cdot b \cdot h \text{ [m}^3\text{]} \quad (24)$$

$$V = 30 \cdot 20 \cdot 35 = 21,000 \text{ m}^3 \quad (25)$$

$$T_r = (0.16 \cdot V) / (4 \cdot m \cdot V + A) \quad (26)$$

$$T_r = (0.16 \cdot 21,000) / (0.0119 \cdot 21,000 + 2,552.48) = 1.1 \leq 1.1 \text{ s} \quad (27)$$

The success of the workplace remediation is manifested through increased productivity of the workforce, reduction of their sickness, and reduction of the rejects produced while working at the press.

Figures 3 and 4 shows that the average production of the mold before the repair of the workspace per month was 140 pieces per hour, while after repair it was 177 pieces per hour. This is about 20% increase compared to production before remediation.

Figures 5 and 6 shows that the average monthly number of days of sick leave before workplace repair was 7.3 days, while after repair it was 6.1 days.

This is about 17% reduction compared to production prior to remediation.

As can be seen in Figures 7 and 8, the average presence of the rejects before the repair of the work space was 12 pieces per hour, and after the repair it was 9 pieces per hour. This is about 20% reduction compared to the condition before the remediation.

## 5. DISCUSSION

Exposure to unwanted sound or noise, adversely affects people's health. In doing so, the sound level above 85 dB is generally considered to be industrial noise. In the production hall of the casting plant at the operator station, the measured sound level is significantly exceeding the permissible value.

In this study, the average measured annual production of molds is 140 pieces per month. Then, the average number of days of sick leave was recorded for one month during the year and it was 7.3 days. After that, average scrap values were recorded during the year and they amounted to 12 pieces per month. Since there is a link between the noise and the above conditions, there is a need to reduce the noise as it negatively affects the health of the worker, and thus the productivity and the quality and quantity of the production.

The operator station it very demanding to work. In addition to the background noise, the noise is evident and the

noise of the press, which is also the biggest noise producer. Due to the daily eight hours exposure to the effect of this noise, some workers have been exposed to adverse effects on the hearing, as well as the appearance of psychosomatic effects. As a result of these effects, workers are not able to perform their workload in full capacity, which is directly reflected in the reduction of the efficiency of the production process.

In order to prevent more damage to the health of the worker, but also to the productivity, noise reduction had to be made. The proposed solution resulting from the analyzes made and implemented in the production hall has greatly reduced the noise and adjusted the sound level to the prescribed level, or to a tolerable level for humans. In this respect, it has been shown that post-remediation productivity increased on a monthly basis by an average of 177 pcs, the number of sick leave decreased to a monthly level averaging 6.1 days, and that rejects decreased average on a monthly level of 9 pieces.

Study of the effects of noise on cardiovascular, endocrine, gastrointestinal systems is the sphere of interest in many studies, and are the source and proven negative effects of noise (2,6,7,8). It is a fact that the prevention of noise, or the repair of noise, and the use of protective equipment must be imperative both to the employer and to the worker himself, through the prism of self-consciousness about the concept of its health.

## 6. CONCLUSION

The employer's imperative is to provide a sound level bearable for the human being, bearing protective equipment, which would increase productivity, reduce the number of sicknesses leave, and thus exploit the individual, and reduce the number of rejects, increase profitability and positively affect not only the health of the individual, but the health system as a whole.

- **Author's Contribution:** F.V., S.B., E.B. and I.M. gave substantial contribution to the conception or design of the work and in the acquisition, analysis and interpretation of data for the work. Each author had role in drafting the work and revising it critically for important intellectual content. Each author gave final approval of the version to be published and they agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.
- **Conflicts of interest:** There are no conflicts of interest.
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