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Research Article

An Ergonomically Sound Encapsulating System Application in an Automotive Stamping Press Line for Reducing Employee Noise Exposure

Yücel Can[1*]

[1]R&D Center, Oyak Renault, Bursa/Turkey (ORCID: 0000-0003-2086-2129)

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Abstract

Stamping press lines are among the highest noise sources in the automotive industry. The noise limits imposed by OSHA (Occupational Safety and Health Organization) force companies to keep employees away from these high-decibel noises. The most ergonomic and effective program for noise safety is to block the noise at the source. In this study, a press line of the Renault-Turkey automotive plant was enclosed with a novel foam-core sandwich structure to improve the comforts and ergonomics of the stamping press workshop environment. Three different encapsulating cases were applied: four sides circumferentially closed with soundproofing walls, five sides encapsulated with a closed top, and a gap-reduced case. For all three cases, the sound levels were measured in the stamping press workshop. The sound levels were reduced below 85 dB (A) in all cases. The performance of the encapsulating system was observed while producing two different parts. It was determined that this type of stamping press line should be encapsulated on all five sides to reduce the stamping workshop noise level. The four lateral sides' sound barriers were not sufficient to soundproof the press line. The small gaps and the die changing doors were very important in the all-five-sides encapsulated case.

Keywords: Soundproofing, Stamping press line, Sandwich structures, Workshop ergonomics, OSHA, Noise.

Çalışanların Gürültü Maruziyetini Azaltmak için Otomotiv Sac Şekillendirme Pres Hattında Ergonomik Bir Ses Yalıtım Sistemi Uygulaması

Öz

Sac parça üretiminde kullanılan pres hatları otomotiv endüstrisindeki en yüksek gürültü kaynakları arasındadır. OSHA (Mesleki Güvenlik ve Sağlık Örgütü) tarafından getirilen gürültü limitleri şirketleri çalışanlarının bu yüksek şiddetteki gürültüden uzak tutmaya zorlamaktadır. Gürültü güvenliği için en ergonomik ve etkili yöntem gürültüyü kaynağında engellemektir. Bu çalışmada, Renault Türkiye otomotiv fabrikasının bir pres hattı, pres atölyesi ortamının konforunu ve ergonomisini geliştirmek için yeni bir köpük çekirdekli sandviç yapısı ile tamamen kapatılarak ergonomik bir gürültü önleme uygulaması gerçekleştirilmiştir. Üç farklı kapatma tasarımı denenmiştir: a) Dört cepheden çevresel olarak kapatılmış gürültü önleme sistemi, b) Tavanı da kapatılan beş cepheli sistem ve c) açıklıkları azaltılmış beş cepheli kapatma sistemi. Her üç durumda da, pres atölyesinde gürültü seviyeleri ölçülmüştür. Tüm durumlarda gürültü seviyesi 85 dB (A) altına düşürülmüştür. Geliştirilen gürültü yalıtım sistemlerinin performansı iki farklı sac parçanın seri üretimi esnasında ölçümlenerek gözlemlenmiştir. Pres atölyesi gürültü seviyesini düşürmek için uygulama yapılan pres hattının beş cepheden kapatılmasının gerektiği tespit edilmiştir. Sadece dört yan cepheli kapatma sisteminin diğer ikisine göre daha başarısız olduğu görülmüştür. Beş cepheli kapatma sisteminde küçük açıkların dahi iyileştirilmesinin ses yalıtımına önemli katkısı olduğu tespit edilmiştir.

Anahtar Kelimeler: Ses Yalıtımı, Pres Hattı, Sandviç Yapı, İşyeri Ergonomisi, OSHA, Gürültü

[*] Corresponding Author: R&D Center, Oyak Renault, Bursa/Turkey, ORCID: 0000-0003-2086-2129, yucel.can@renault.com

1. Introduction

The general effect of noise on the hearing of workers has been a topic of debate among scientists since the end of the 1960s, although it has been a known problem since the 18th century. (Brink et al., 2002; Mohammadi, 2008)The Occupational Safety and Health Administration (OSHA) requires the use of hearing protection at noise levels greater than 85 dB(A). Automotive, wood, textile, petroleum, utility, metal, print, and paper industries have the highest percentage of workers exposed to critical safety noise levels and higher.(Noweir, Bafail, & Jomoah, 2014) Medical studies and other sources of evidence indicate that noise problems cause physical and psychological disorders, undetected hearing loss or damage, and disruption, thus causing inefficient production and job performance. (Arezes, Bernardo, & Mateus, 2012; Mohammadi, 2008) Noise-induced hearing loss (NIHL) is among the ten leading occupational diseases and is very costly (Brink et al., 2002). Some of the cost estimates of NIHL compensation found in the literature are as follows: $100 million annually paid in Sweden, an average of $10,000 per hearing loss claim in Canada, and $200 million for the calendar year 1990 in the USA.2 Compounding the problem of predicting NIHL is the implementation of mandatory hearing conservation programs in most industries, including automobile manufacturing.(Berger, 1983; Brink et al., 2002) The noise resulting from the manufacture of automobile body parts constitutes the greatest environmental problem for the employees at a plant.(Brühl et al., 1994)

In automotive manufacturing factories, the primary manufacturing process is to shape the metal sheets using stamping press machines. The combination of the variously sized and arranged stamping press machines and robots constitutes a stamping press line. The stamping press motions by the addition of robotic part transportations produce high-level noises from the metal-to-metal impacts, compressed air releases, and noise from the pumps, gears, clutch, brakes, and motors.(Brueck et al., 2013) These undesired sounds are emitted around the press lines. The airborne noises are harmful to the health of the employees, especially those employees around the press lines. Moreover, the National Occupational Health and Safety Regulations also require companies to reduce in-plant noises. There are three airborne noise reduction methods applied by engineers in industrial plants: a) blocking the noise at the source along its path from the source to the receiver; b) blocking the path of the noise, such as using sound barriers; and c) wearing personal hearing protection to provide a passive means of self-protection. Personal hearing protectors are the most often used and cost-effective method of individual exposure control. However, due to the discomfort of wearing personal hearing protection, workers in noisy work environments do not always wear them correctly and consistently. This method also requires educating and motivating employees. (Hsu et al., 2004; Bockstael et al., 2013) In the present study, a noise reduction method to reduce employees' NIHL level is studied by encapsulating the noise source on all sides; the noise source is a stamping press line in the automotive manufacturing plant of Renault/Turkey. Although lowering the noise at the source is the most efficient noise control method for the stamping press line noise source cases(Hsu et al., 2004; Moreland & Minto, 1976; Sanders, M.S., McCormick, 1987), it has many difficulties and research parameters: a) the selected stamping press line has a high dimensional volume of 50 m x 7 m x 10 m; b) changing the stamping die requires many openings, such as guillotine doors, which cause noise diffusion; and c) in the press line, several sheet metal stamping press machines exist with various sizes and capacities. This system produces different frequencies, amplitudes and periods of airborne noise.

In the press line, stamping press machines work sequentially to shape a flat metal sheet into the final complex car body part by blanking, cutting and stamping the sheet metals. These shaped sheet metals are transferred by robots from one press machine to another one based on the engineered process. Due to the continuous and automatic manufacturing process, it is not possible to enclose each stamping press machine separately for noise reduction. The only option is to close all sides of the press line with sound absorber walls unless the room temperature increases. All sounds that originate from the stamping press actions and robotic part transfers stay inside the enclosed room and affect the other noises until the noises are absorbed by the noise absorber walls. The noise absorber walls take in the sound waves and dissipate the wave energy while converting some of the energy into heat, which reduces the sound transmission level and controls the noise level. However, some of the airborne noise transmits from the inside to the outside of the enclosed room through the plant. Currently, the most useful noise absorber wall materials are polymer foam-core sandwich materials and layered structures. The sandwich and layered structures can be designed to reduce the overall noise level over a wide frequency range. For instance, to absorb medium- and high-frequency noises, at least one layer of a porous sound-absorbing sheet comprising a sandwich structure is suggested. A layer with a high specific weight has soundproof properties and absorbs the low-frequency noise, and a layer of vibration damping properties deflects structural noise. (Iasnicu, 2013)

Polymer foams are two-phase materials in which a gas is dispersed in a continuous macromolecular phase.(Rodríguez-Pérez, 2005) Polyolefins are tough, flexible, and resistant to chemicals and abrasions, and foams made from polyolefins inherit these properties. Although polyolefin foams were developed relatively recently compared with polyurethane or polystyrene foams, they are used in almost every industry. Areas of application include packaging, sports, leisure, toys, thermal insulation, automotive, military, aircraft, buoyancy or cushioning.(Eaves, 2004)

Entirely encapsulating the noise source causes the sound level intensity to be isolated inside the soundproofed volume. The gaps become more important than in the one-side-open case in this kind of soundproofing application by increasing the sound transmitted through the gaps. In the one-side-open case, the sound is emitted through the open side, and the intensity of the noise level in the soundproofed volume is not as high as the all-sides, sound-insulated case.(Asakura and Sakamoto, 2013; Shimizu and Koizumi, 2015)

There are limited studies presented in the literature about in-plant noise encapsulating devices. (Moreland and Minto, 1976; Radičević et al., 2012; Moreland, 1984) Moreland and Minto (1976) performed a study on in-plant noise reduction using acoustical barriers around a motor-generator noise source. In their application, the sound barrier was subjected to only a few desired areas, which were personnel-occupied locations near the machine.

In this study, a soundproofing application of the stamping press line in an automotive company was presented. Noise levels were measured for three different cases at a stamping workshop: a) Four lateral sides soundproofing walls, b) All five sides encapsulated with soundproofing walls along with the top, c) The gaps closed. The sound level before and after the encapsulation was measured around the press line, and noise maps were obtained according to the distance from the noise source. The effects of many openings, such as the press line observation windows, the sheet metal parts entrance, exit gaps, and guillotine doors for die setup operations, were considered for noise reduction.

2. Material and Method

The main soundproofing material used was a DurSolex® PE (Durfoam/Turkey) based foam sandwich structure. The material sound performances are given of various densities. The chopped foams were mixed and hot pressed at approximately 130˚C to shape a flexible block in a mold. This material is a composite of chopped PE foams thin slices and used as a sandwich core material. The sandwich soundproofing material was bonded with three different high-density polymer solid layers and the chopped PE foam core layer. Figure 1 shows the soundproofing panel with steel back face and soundproofing polymer sandwich foam. The soundproofing material section is shown in Figure 1 with a scaled view of the section. In Figure 2 the sound absorption measurement results were presented for two different sandwich materials with open side measurement for comparison. The vertical axis of these figure shows the sound level measurements, and the horizontal axis shows the frequency of the noise. As a result of these measurements, a combination of the PETex+HDPE+UHDPE foams for the soundproofing material was selected for the noise encapsulation, which reduced the sound transition by more than 20 dB(A).

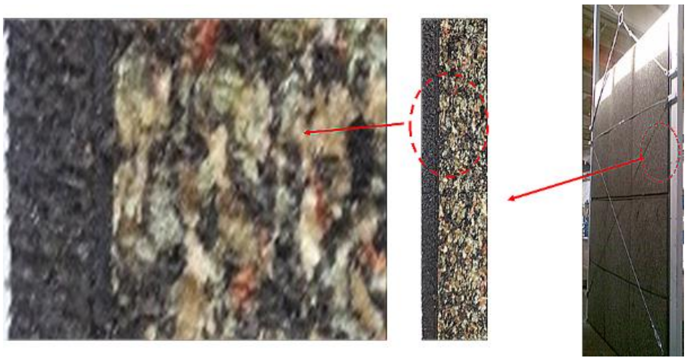

Figure 1. The soundproofing wall and sandwich panel section

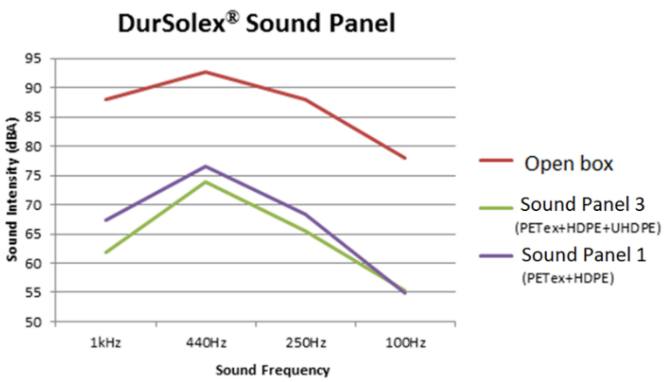

Figure 2. The sound absorption of the sandwich panels.

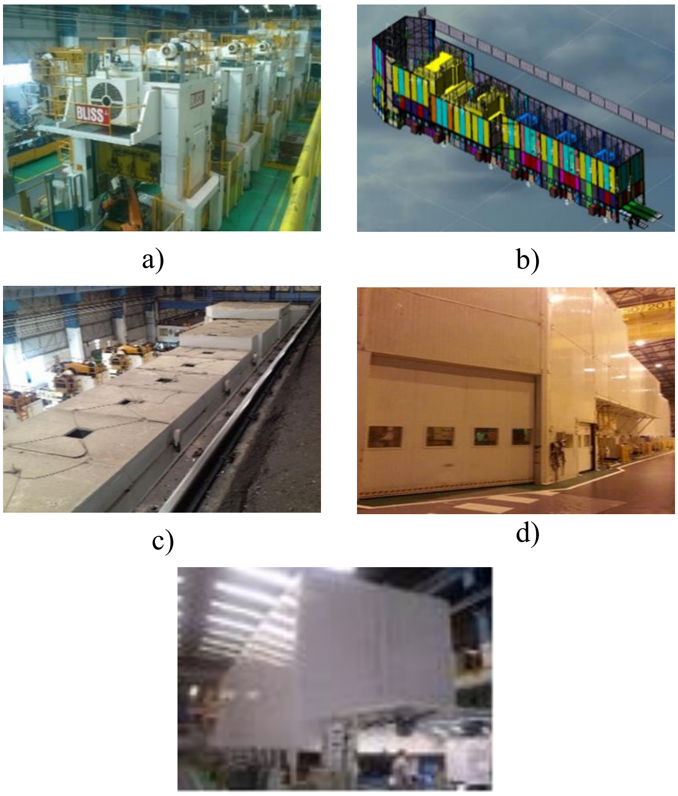

Figure 3. The stamping press line encapsulating system: a) Original press line b) Encapsulating system design cad model c) Circumferentially noise encapsulating application d) Top closing system e) Guillotine doors and their gaps.

The developed soundproofing panel walls were used in the designed press line encapsulating system. This encapsulation design is shown in Figure 3. Figure 3a shows the stamping press line photo before encapsulating. The press line consists of five mechanical sheet metal stamping presses with different widths and heights. In the first design (Figure 3b), the soundproofing walls surrounded the press line.

The mechanical press noises were also transmitted by mechanical vibrations through the floor. All 28 measurement points were carried out after closing the soundproofing walls. The noise level variations were reviewed after lateral encapsulation (Figure 3b). Then, a soundproof design improvement was developed by closing the top of the lateral encapsulated system (Figure 3c). After this upgrade, a new noise level measurement was performed. The desired level of noise reduction to the proposed level was still not achieved. The problem was analyzed, and the high noises were observed around the part exit and guillotine doors, which are needed for die changing. There were some observed gaps and openings around these points. In the last improvement, the size of these gaps was substantially reduced (Figure 3d and Figure 3e).

A picture of the press line before the sound encapsulation is shown in Figure 3a, and the workshop layout technical drawing with the encapsulated press line and noise level measurement points are given in Figure 4. In this figure, the stamping workshop layout drawings are shown, and the sound encapsulated press line is indicated by a thick rectangular frame. This stamping workshop has five press lines and one try-out press. The data acquisition was performed when only the studied press line was in operation, indicating that the other press lines and machines in the workshop were not active. Therefore, encapsulating performance was fully measured. Measurement points 1 to 14 are next to the encapsulation wall. The results for these points were used to compare the near-field noise level to the press line and the soundproofing performance. The other points (15 to 28) were selected to measure the far-field soundproofing effectiveness. During the sound level measurements, sheet metal body-in-white parts were produced in the press line, as shown in Figure 5. Figure 5a and Figure 5b show the Part A and Part B respectively. Part A is manufactured using 4 active stamping press machines in the press line. However, Part B is produced using 5 active stamping press machines in the same press line. It can be understood from these pictures, Part B is more complex than Part A and needs more stamping operations to obtain the final shape. Therefore, these two different parts were selected to understand the effect of the active stamping press machines in the press line to the noise level.

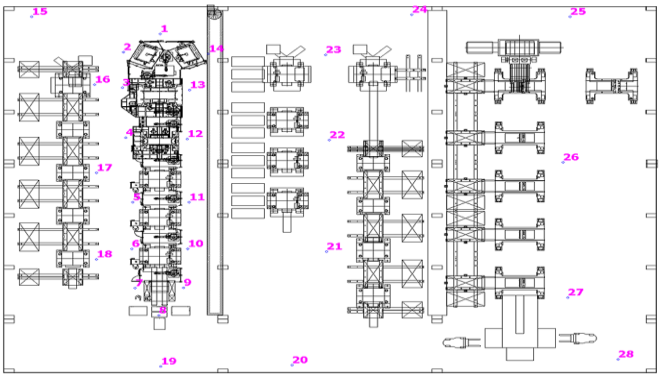

Figure 4. Noise measurement locations in the workshop.

a)

b)

Figure 5. The parts for noise measurement a) Part A b) Part B

The sound level measurements were performed at 28 points before and after the encapsulation during only the operation of the studied press line in the workshop. The noise level in the workshop can be described as short period, steady noises that originate from continuous press ram impact motions. The noise measurements were obtained using the SVANTEK SV102 portable noise measurement device. This device is a noise dosimeter. It can measure noise exposure in accordance with the ISO9612.

3. Results and discussion

The noise measurements before encapsulating the press line are mapped in Figure 6. The maximum sound level around the center zone of the studied press line was 103 dB(A). The sound levels around the press line were almost all higher than 92 dB(A). The minimum noise level was measured in the far field, measurement points 24 to 28, and was between 83-85 dB(A). These points are a minimum of 35 m from the working press line and have many line-of-sight obstructions, such as other press lines. The roof on the stamping press line has conventional covering plates. This press line produces very high noise levels, and the noises are emitted all around the stamping workshop.

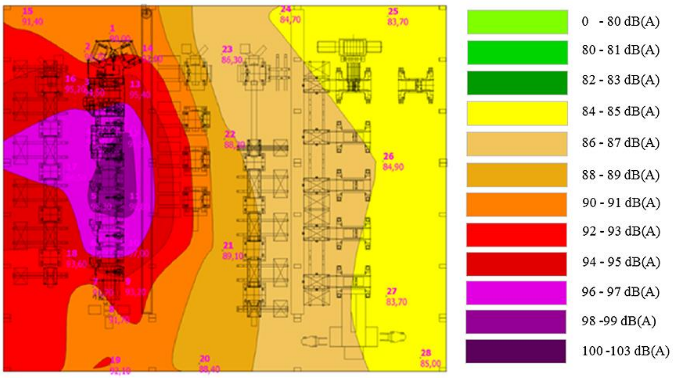

Figure 6. The noise map in the workshop before encapsulation.

Figure 7 shows the first soundproofing application of the press line (see Figure 3a) application results. In the first step, only the lateral sides of the press line were closed using the panels that are shown in Figure 3b, is an isometric view of the CAD model and the constructed panel wall shown in Figure 1. In this encapsulating application, there is still one gap for the produced part exit, an open top, and gaps between the guillotine doors and the soundproofing wall panel. As shown in the sound map, after the press line was surrounded with an 8 m high sound insulation wall, the noise level measurements at location numbers 5 and 11 were 85 dB(A). This zone was the maximum noise level in the initial case. Thus, the maximum noise generated by the press line was reduced by more than 18 dB(A). These points were exterior and next to the encapsulating wall. While the noise level was reduced next to the encapsulating wall, a bit far-field noise level from the wall did not decrease to the same extent (~ 5 dB(A)). The reason is that the top of the press line was open and the sounds are emitted from the source to the outside of the surrounded region through to the angled stamping workshop roof. These sound

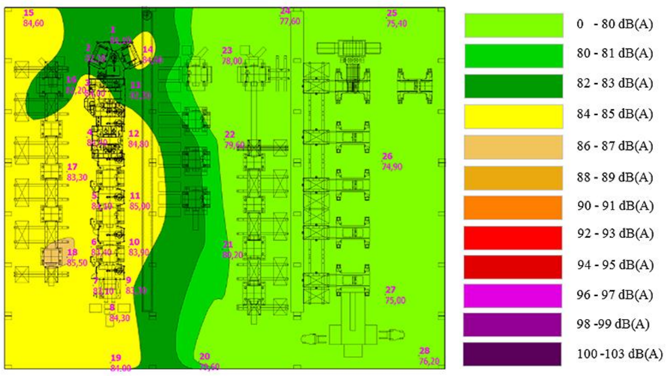

Figure 7. Noise map for enclosed four Lateral sides.

waves are reflected through a bit far region of the press line. The left side of the press line has a higher noise level than the right side for both the initial and surrounded case since the left side has a rigid concrete wall from the workshop building and the emitted sound through the left side is reflected from the rigid wall. The measurement point 18 has an additional pipeline air leakage sound. Therefore, this point has a higher sound level at a given time.

Figure 8 presents the noise level map for the top-closed case with the soundproofing panel. The focused measurement points 10, 11 and 12 near the soundproofing wall had noise levels that were unexpectedly higher than the top-open case. The top encapsulation caused the sound energy to intensify and produced a higher noise level inside the encapsulated cabinet. This intensive noise transmission from the soundproofing wall and the gaps increased (see Figure 3c). The zone close

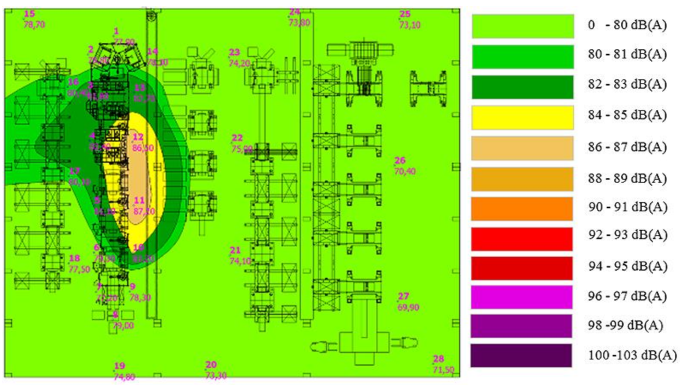

Figure 8. Sides and top enclosed while door gaps are open.

To the left side of the soundproofing wall did not show the same sound increase after the top was closed. Since there are not any guillotine doors on the left side. However, most of the stamping workshop noise level was reduced below 80 dB (A).

Figure 9 shows the noise map after the final improvements. In this case, the height of the ending side opening (needed for the produced parts to exit the press line) was reduced by 300 mm by adding new soundproofing panels. Additionally, the guillotine doors were originally designed to work safely with a 100-mm offset between the soundproofing wall and the guillotine door panel. It was observed that this distance produced a high-level noise emitting from the inside to the outside of the encapsulated volume. These offset distances were reduced to 5 mm in the improved design. As shown in the noise map, the maximum noise level of 83.3 dB(A) was measured around the noise measurement

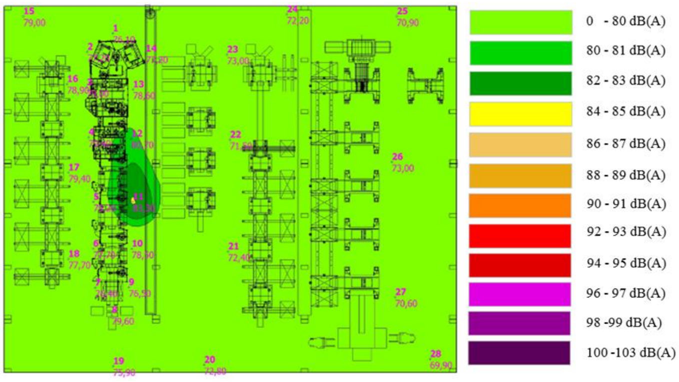

Figure 9. Sides and top enclosed while the door gaps are closed.

point 11. After these improvements, the noise level in the stamping workshop decreased by more than 5 dB(A) next to the soundproofing wall.

Moreover, at the right side of the soundproofing system, only a 2 dB(A) noise reduction was observed due to the guillotine doors. Furthermore, in the far field, there were not any reduced effects after the final improvements. The noise level comparisons at each measurement location for all cases are shown in Figure 10. In this figure, each point describes a certain measurement location. These locations are shown in Figure 4 on the stamping workshop section plan. The straight line shows the OSHA limit value, which indicates the limits for the critical workers' continuous exposure to the noise level for 8 hours. This value is a limit for hearing loss to start. The figure shows the following cases:

Case 1: Initial noise levels in the stamping workshop.

Case2: Press line encapsulated four lateral sides by soundproofing panels.

Case 3: Press line four lateral sides and top closed (All five sides closed).

Case 4: Guillotine door gaps and part exit opening narrowed.

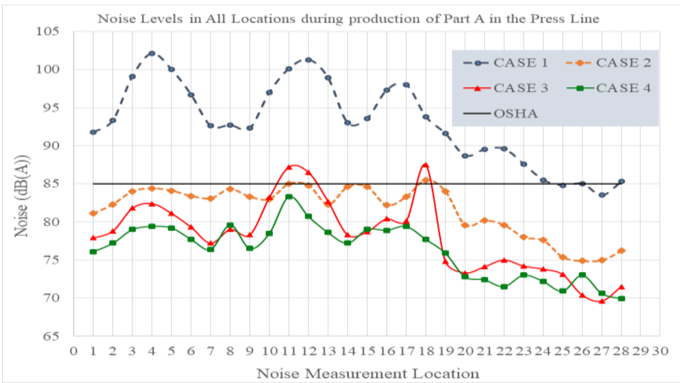

Figure 10. The noise level variation depends on the location

As shown in Figure 10, the circumferentially encapsulated case (Case 2) shows a noise level that is below the OSHA critical limit except for a few points (locations), but the mean value of all points is very close to the health limit. In that case, the soundproofing application required more improvements. Therefore, the top of the circumferentially enclosed press line was also closed by the soundproofing panels. In this enhancement, the noise levels were clearly reduced, except for a few locations. In contrast to the expectations, measurement points 10, 11, 12 and 13 had noise levels that increased by different percentages. As shown in Figure 4, these points are close to the guillotine doors of the system. It was observed that the gap between the guillotine doors and the soundproofing panels was at a 120-mm offset due to constructive needs. Moreover, after closing the top of the system, the noises were reflected from the encapsulating system cap and sound densification occurred inside the encapsulated system. These intensifications inside the encapsulated system caused more noise to transmit from the gaps. The noise level increase at point 18 indicated that the noise came from the air pipeline leakages. After this observation, this leakage problem was fixed. In the final improvement, the gaps between the guillotine doors and soundproofing walls were reduced from 120 mm to 5 mm. This improvement is denoted as Case 4. After these ameliorations, the noise levels were reduced under the OSHA limit in all locations of the stamping workshop.

The effects of the stamping product type and the number of stamping press machines in the press line on the soundproofing performance were investigated by producing two different parts. The part geometries are shown in Figure 5 as Part A and Part B, which require 4 and 5 active stamping press machines in the press line, respectively. As shown in Figure 11, measured noise level outside of the encapsulation during two different parts production (Part A and Part B) were almost same, although the generated noise levels were not same inside the encapsulation. The Pearson coefficients were used to obtain a correlation between two curves. In this study, the Pearson calculations were performed using MS Excel software. The more detailed information about the Pearson correlation coefficients R and R^2 can be seen in the literature. (Asuero et al., 2006) For Figure 11, R-value was calculated as 99%, and the R^2 value was obtained as 98%. That means these two curves were in a good match. However, as mentioned above, Part B was produced using one more stamping press machine than Part A, which was located at the end of the press line and next to the end of the line opening. This position corresponded to measurement point 8. In that case, the maximum noise variation during Part A and Part B production was observed at this point. Finally, Part B generated 4 dB(A) noise more than Part A.

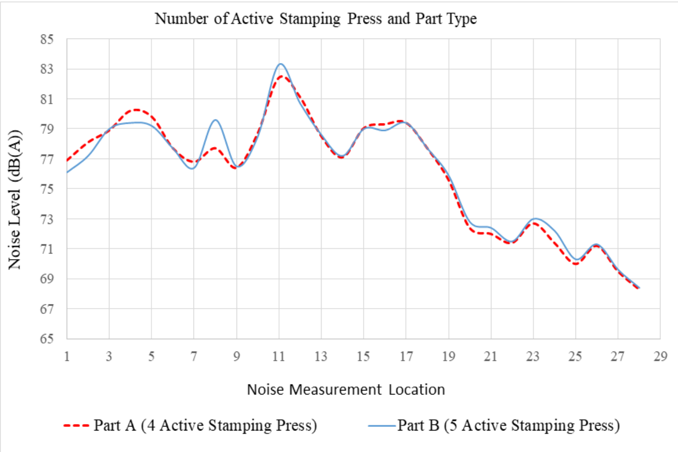

Figure 11. The noise level according to the press number.

4. Conclusions

The observed results can be concluded as follows:

1) The noise reduction was achieved by blocking the noise at the source through encapsulating the entire stamping press line to obtain employees' hearing comfort by conforming to OSHA regulations.

2) In the all-sides-encapsulated system, openings and small gaps become more critical in reducing noise levels. The noise transition from the gaps increased in the all sides encapsulated systems. The noise level increased and intensified inside the all-sides-encapsulated system

3) The noise level outside of the encapsulated system does not depend on the number of active stamping press machines in the press line. However, it does depend on the distance from the mandatory gaps and the openings of the noise sources.

4) The noise level outside of the encapsulated system can be reduced under the OSHA limits by circumferentially encapsulated systems. However, this kind of soundproofing system can be a solution when only one press line exists in the stamping workshop. If more than one press line work, the noise level can exceed the critical workshop noise limit by combining sound waves by generating each of one.

5) Designed soundproofing sandwich panel has shown same noise reduction performance all around the encapsulating noise system.

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