REDUCING MANUFACTURING PROCESS NOISE WITH INNOVATIVE DAMPING MATERIALS TO ENHANCE SAFETY IN HUMAN-MACHINE INTERACTION

R.P. Lukodono*, A.T. Hardian, B. Indrayadi, R. Ardianwiliandri

Departemen Teknik Industri, Fakultas Teknik, Universitas Brawijaya, 65145, Indonesia.

*Corresponding Author's Email: rio_pl@ub.ac.id

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ABSTRACT: The auditory disturbances that are generated during various manufacturing operations present significant hazards to the overall health, safety, and productivity of workers, particularly in environments where the complex interactions between human operators and machine systems are of paramount importance. The occurrence of noise levels that are deemed excessive, surpassing the regulatory threshold of 85 dB for an 8-hour working period as delineated in the relevant Government Regulation, can result in detrimental auditory impairments, diminished levels of concentration, and an overall decline in work performance and efficiency among employees. Empirical investigations have shown that welding threading machines are responsible for producing the most elevated noise levels, reaching an alarming 86.1 dB, which effectively highlights the urgent need for targeted and effective noise reduction measures to be implemented in these settings. This study endeavors to rigorously examine the effectiveness of innovative damping materials, including but not limited to acrylic, polyurethane foam, and rockwool, in mitigating the adverse effects of excessive noise that are typically encountered during various manufacturing processes. By employing these advanced materials, the research aims to significantly improve safety conditions and enhance the quality of interactions between human operators and machine systems within the manufacturing environment. The most effective combination of damping materials consisting of acrylic, rockwool, and polyurethane foam successfully reduced noise levels by 12.66%, demonstrating its potential to enhance worker safety in high-noise environments.

KEYWORDS: Manufacturing; Damping material; Noise; Human-machine interaction; safety

1.0 INTRODUCTION

One of the occupational health and safety (OHS) factors identified as a challenge in manufacturing environments is the comfort of the workplace. Noise levels from machinery are often deemed excessive, potentially disrupting employees during their tasks and, over time, adversely affecting their health. Noise is defined as unwanted sound, including irregular sounds generated by transportation and industrial activities over prolonged periods. Prolonged exposure to noise pollution has significant long-term effects on human health [1,2], impacting both physical and psychological well-being [3–5]. These findings support prior studies highlighting the role of ergonomic discomforts such as musculoskeletal strain and ventilation issues in shaping perceived comfort and satisfaction among transport and industrial system users[6]. Table 1 presents the results of noise level measurements from various machines in the manufacturing setting.

Table 1: Noise measurement result

Sampling	*Welding Threading Machine* (dB)
1	88
2	85
3	85
4	88
5	87.2

Table 1 shows the measurements and the company's assessments indicate that the noise level of the welding threading machine exceeds the Threshold Limit Value (TLV) established in the Regulation of the Minister of Manpower and Transmigration (PERMENAKER) No. 5 of 2018 on noise control [7]. According to this regulation, noise levels should remain within the specified threshold to ensure compliance and safeguard worker health and safety. Research indicates that noise levels below 85 dB are generally considered safe and do not significantly increase the risk of high-frequency hearing loss, especially when hearing protection is used effectively[8]. The urgency to address this issue arises from the significant health risks posed by exceeding the TLV, highlighting the critical need to implement effective noise control measures to safeguard workers.

The welding threading machine is used for welding and threading processes on metal shells. The metal shell in spark plugs serves to secure the spark plug to the cylinder head in the engine and acts as a conductive material with excellent thermal conductivity. The machine is operated under the supervision of an operator, whose primary responsibilities include ensuring that the materials processed meet the specified dimensions and monitoring the machine's operation. Figure 1 illustrates the condition of the welding threading machine.

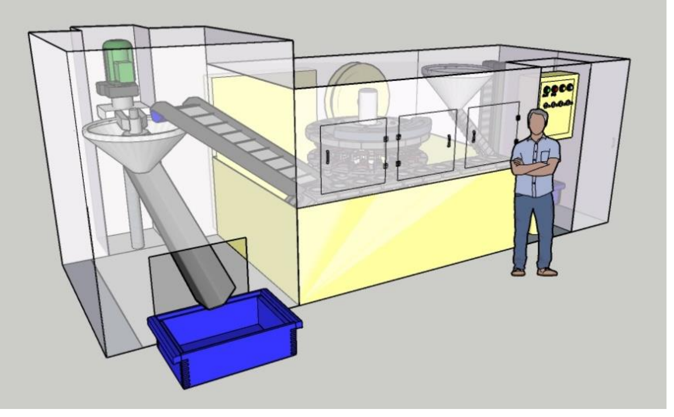

Figure 1: Welding Threading Machine

Several measures have been proposed to reduce noise levels in industrial environments, including the application of noise barriers, the provision of hearing protection devices for workers, and the installation of noise warning signs [9]. In another study., the use of noise dampers made from materials such as mahogany wood panels, coconut coir, egg cartons, styrofoam, and plywood effectively reduced noise levels by 21 dB—from an initial machine noise level of 95 dB to 70 dB[10].

In addition to conducting noise level measurements, companies often provide annual medical checkups to monitor worker health. One of the key examinations included in these checkups is the audiometry test, which evaluates the auditory function of employees. Another measure taken is the provision of hearing protection devices (HPDs) in the form of earplugs, supplied annually to machine operators. The purpose of earplugs is to protect operators' hearing and ensure a sense of safety and comfort. Earplugs are small devices inserted into the ear canal to reduce noise exposure [11]. There are two main types: insert type and muff type. Insert types can be generic or custom-shaped and are made from materials such as foam, plastic, or fiber. Muff types involve foam or liquid-filled cushions attached to headbands or helmets [12]. Earplugs can reduce noise levels by up to 22 dB [13], although reductions of 8-30 dB have been reported, depending on proper fit and usage. Despite their benefits, earplugs have several limitations: they are less effective at noise levels above 100 dB, cannot be used by individuals with ear infections, are prone to being misplaced due to their small size, and require regular maintenance to ensure hygiene [14]. These factors highlight the importance of comprehensive noise control measures in industrial environments.

Based on the discussion above, it can be concluded that current noise control measures in the manufacturing environment, including the provision of hearing protection devices (HPDs) such as earplugs, remain insufficiently effective. This is evidenced by the occurrence of conductive hearing issues identified through routine audiometric testing. These findings underscore the critical need for more effective noise mitigation strategies, particularly for high-noise machinery such as the welding threading machine. Although numerous studies have explored the use of noise dampers in general industrial contexts, limited attention has been given to applications that address the specific noise characteristics of welding threading processes. For example, several studies have investigated bulk recycled materials such as rubber and textile fibers using impedance tube testing, the sound absorption properties of wood charcoal across different grain sizes and heat treatments [15], and the performance of hemp and polyurethane foam at various thicknesses [16], demonstrating promising results for natural fiber-based materials [17]. However, these studies did not extend to machine-level testing or examine layered combinations of materials in operational environments. Thus, empirical research that applies and evaluates multilayer damping systems directly on functioning industrial machines remains limited. Moreover, most prior studies focused on single-material evaluations, leaving a notable gap in the systematic analysis of hybrid damping configurations that may provide enhanced acoustic performance under real-world manufacturing conditions.

The objective of this research is to reduce noise from the welding threading machine by implementing noise dampers. This study addresses a significant research gap by evaluating the performance of selected damping materials, namely acrylic, polyurethane foam, and rockwool, in various combinations specifically tailored for this machine. Furthermore, the study seeks to develop noise reduction strategies that do not solely rely on human discipline in using earplugs, ensuring a more sustainable and effective solution to workplace noise issues. The novelty of this research lies in the experimental comparison of different damping configurations on actual production equipment and its emphasis on passive noise control measures, which remain underexplored in current literature.

2.0 METHOD

2.1. Initial Measurements

The study began with field observations and discussions with production floor employees to identify dominant sources of workplace noise. Preliminary assessments revealed that the welding threading machine produced consistently high noise levels. To validate this, noise measurements were conducted on nine welding threading machines using a Krisbow KW06-290 sound level meter, in accordance with SNI 7231:2009. Figure 2 illustrates the sound level meter used in this study.

Figure 2: Sound level meter

Using the instrument illustrated in Figure 2, each measurement session lasted 1 minute, with readings recorded at 5-second intervals. The sound level meter was placed 30 cm from the machine, aligned at a 70˚–80˚ angle, and positioned at operator ear height to simulate realistic noise exposure. Measurements were taken between 10:00 AM and 12:00 PM. This approach aligns with established acoustic measurement protocols found in prior studies with similar device settings to assess noise characteristics[18].

Noise measurements were performed twice for each machine: the first before installing the dampers and the second after installation. The collected data was then analyzed to determine which welding threading machine exhibited the highest noise level. That machine was selected for further noise reduction interventions. In the subsequent phase, dampers were designed specifically for that machine.

The materials selected for the dampers were based on their ability to absorb sound energy, a critical factor in reducing noise levels in industrial environments. Sound-absorbing materials are widely used in acoustic rooms, recording studios, educational institutions, and other settings where noise mitigation is essential [16]. Furthermore, several studies emphasize that these materials work by converting vibrational energy into heat, thereby effectively reducing resonance and improving acoustic comfort [19,20]. This methodological framework was designed to ensure measurable, repeatable, and real-world applicable results in evaluating passive noise control solutions.

2.2. Material selection

Three materials were selected based on their physical and acoustic characteristics, as well as their practicality for industrial application. Acrylic (3 mm) is a transparent thermoplastic with a density of 1.17–1.20 g/cm^3[21], commonly used as a protective shield. It offers structural rigidity but is limited in acoustic damping, making it suitable as a support layer in multilayer configurations. Rockwool, a mineral fiber derived from volcanic rock, is known for its high sound absorption, thermal resistance, and non-flammability. It operates by converting kinetic sound energy into thermal energy [10], making it effective for absorbing mid-to-high-frequency sounds. Polyurethane foam is a lightweight polymer made from polyol and isocyanate, with a density of 36 kg/m^3 and a porous structure that enables the dissipation of low-frequency sound energy [22,23]. The combination of these materials allows for layered damping panels that address a broad range of industrial noise frequencies. Additional selection criteria included availability, cost-efficiency, thermal stability, ease of fabrication, and compatibility with existing machine surfaces to ensure both acoustic effectiveness and practical feasibility in real industrial environments.

2.3. Damping Panel Design

The damper design served as a reference during the fabrication process and guided the development of the experimental setup. This study introduces a novel methodological approach by experimentally implementing multilayer damping configurations directly onto operating industrial machinery an application rarely addressed in prior studies, which often rely on lab-scale simulations [24]. hree panel configurations were constructed for comparative analysis: configuration A (0.3 cm acrylic + 2.5 cm rockwool), configuration B (0.3 cm acrylic + 2.5 cm polyurethane foam), configuration C (0.3 cm acrylic + 1.25 cm rockwool + 1.25 cm polyurethane foam). Each panel measured 40 cm × 30 cm (1,200 cm^2) and was developed to systematically evaluate acoustic behavior under varied material compositions. Acrylic accounted for approximately 10% of the total thickness, while the remaining portion consisted of single or hybrid damping materials. This configuration strategy enables a direct comparison between dual-layer and triple-layer panels under actual working conditions, capturing operational variability often excluded from controlled experimental designs [25]. By bridging the gap between theoretical material performance and real-world application, the methodology provides a validated empirical basis for passive noise control in high-noise manufacturing environments.

2.4. Leq analysis

The equivalent Continuous Noise Level (Leq) formula, or equivalent continuous sound level, is a metric used to represent varying noise levels over time by averaging the energy of fluctuating sound levels into a single value. This approach is particularly useful in environments where noise levels are not constant, allowing for a comprehensive assessment of noise exposure[26]. The Leq formula calculates the average sound level over a given period by integrating the sound pressure levels, which are typically measured in decibels (dB), over time. This integration accounts for the fluctuating nature of noise, providing a single value that represents the overall exposure level. The formula for calculating Leq is as follows [27].

$$\text{Leq}=10\ \text{Log}\ \{\frac{1}{T}\left[t_1 \text{ x antilog}\left(\frac{L_1}{10}\right)+t_2 \text{ x antilog}\left(\frac{L_2}{10}\right)+\ldots\ t_n \text{ x antilog}\left(\frac{L_n}{10}\right)\right]\} \quad (1)$$

L_1: Sound pressure level during period t_1
L_n: Sound pressure level during period n
T: Total time (t1 + t2 + … + tn)

This formula enabled quantitative comparison of damping performance for each configuration under dynamic operating conditions.

3.0 RESULT AND DISCUSSION

3.1 Current Noise Evaluation

After conducting noise level measurements, data on the noise levels of the welding threading machines were obtained. The collected data was then processed using the equivalent continuous noise level formula (1) to determine the overall noise exposure. The following calculation and Table 2 provide an example and the results of a calculation using the Leq formula for the welding threading machine.

Table 2: Leq Calculation Results

Machine ID	Repetition	Leq (dB)	Average
2A	1	85.1	85.2
	2	85.2	
	3	85.3	
5	2	85.2	85.4
	3	85.3	
	3	85.4	
4	1	85.3	85.2
	2	85.2	
	3	85.2	
6	1	88.6	88.4
	2	88.6	
	3	88	
7	1	85.4	85.2
	2	85.2	
	3	85	
8	1	85.6	85.8
	2	85.9	
	3	85.9	
1	1	86.8	86.6
	2	86.4	
	3	86.6	
3	1	87.6	87.6
	2	87.6	
	3	87.4	
2	1	85.4	85.6
	2	85.7	
	3	85.6	

3.2 Chamber Design for Welding Threading Machine

After identifying the noise levels of the welding threading machine and selecting the materials to be used, a re-measurement was conducted on the machine. The purpose of this redesgin is to determine the extent to which the selected dampers can reduce noise levels. The design was carried out in three tests on the welding threading machine number 6, as it produced the highest noise levels among the welding threading machines. The first test utilized a combination of acrylic and rockwool, the second test combined acrylic and sound-absorbing foam, and the final test incorporated all three materials.

i) Chamber using Acrylic and Polyurethane Foam material

In this first design, acrylic material with a thickness of 0.3 cm and zigzag-patterned polyurethane foam with a thickness of 2.5 cm were used. Figure 3 shows the material installation and the results of the noise level measurement from the first test.

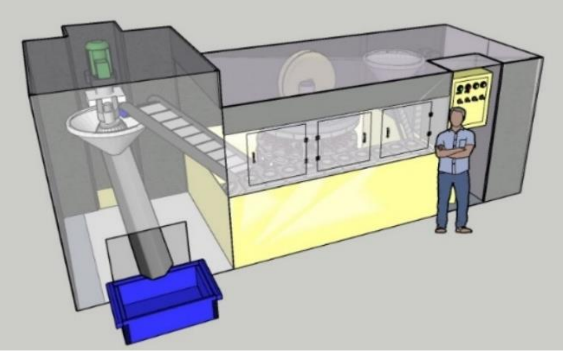

Figure 3: Welding threading machine damper using polyurethane foam

ii) Chamber using Acrylic and Rockwool material

In the second design, acrylic material with a thickness of 0.3 cm and rockwool with a thickness of 2.5 cm were used. Figure 4 are the images of the material installation and the results of the noise level measurement from the second test.

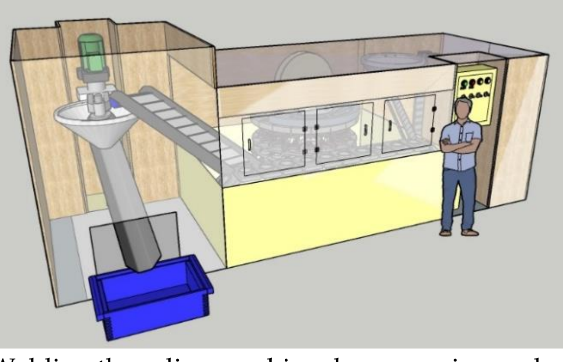

Figure 4: Welding threading machine damper using rockwool

iii) Chamber using Acrylic, Rockwool, and Polyurethane Foam material

In the third design, acrylic material with a thickness of 0.3 cm, rockwool with a thickness of 2.5 cm, and zigzag-patterned polyurethane foam with a thickness of 2.5 cm were used. Figure 5 are the images of the material installation and the results of the noise level measurement from the third test.

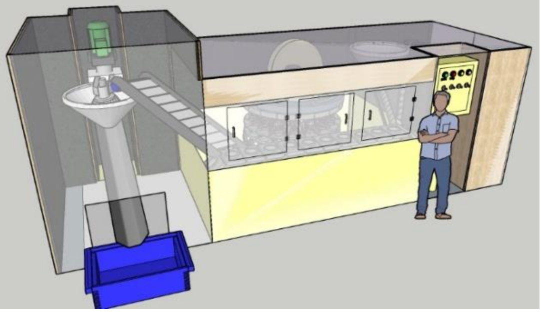

Figure 5: Welding threading machine damper using rockwool and polyurethane foam

3.3 Calculation of Noise Reduction Effectiveness

The noise reduction effectiveness stage is carried out after obtaining noise level measurement data and Leq calculations following the installation of dampers. Equation (2) is used to calculate the noise reduction effectiveness. Table 3 presents the results of the damper reduction effectiveness.

$$\text{Reduction Effectiveness} = \frac{K_{DP} - K_{BP}}{K_{DP}} \times 100\% \quad (2)$$

Table 3: Calculation results of damper reduction effectiveness

Material	Repetition	Reduction effectiveness	Average
Acrylic and polyurethane foam	1	1.57%	1.63%
	2	1.70%	
	3	1.61%	
Acrylic and rockwool	1	10.46%	10.63%
	2	10.81%	
	3	10.63%	
Akrilik, rockwool, polyurethane foam	1	12.75%	12.66%
	2	12.58%	
	3	12.64%	

From the calculations conducted in the previous section, the Leq value before installing the dampers was 88.4 dB. In the first test, using acrylic and polyurethane foam, the Leq value was 87.0 dB, with a noise reduction effectiveness of 1.63%. In the second test, using acrylic and rockwool, the Leq value was 79.0 dB, with an effectiveness of 10.63%. Meanwhile, in the third test, using acrylic, rockwool, and polyurethane foam, the Leq value was 77.2 dB, with a reduction effectiveness of 12.66%. The most effective damper was the combination of acrylic, rockwool, and polyurethane foam, as it reduced the noise level to 77.2 dB with a reduction effectiveness of 12.66%. The spark plug company has planned to install dampers on all machines in the production area, starting in 2025. In addition to installing dampers, it is recommended to improve protective measures by replacing personal protective equipment, such as earplugs, tailored to the standards for Asian workers' ears and upgrading the quality of the earplugs.

These findings confirm the superior effectiveness of multilayer damping configurations under actual industrial conditions. The configuration combining acrylic, rockwool, and polyurethane foam achieved the highest reduction in noise levels (12.66%), outperforming other dual-layer setups. The success of this combination highlights the potential of material layering strategies not only for laboratory applications but for practical noise mitigation in active manufacturing environments. This real-world validation underscores the novelty of the study's approach and provides measurable evidence for the feasibility of passive noise control through hybrid material design.

3.4 Discussion

The study evaluated the performance of different noise-damping material combinations, revealing notable variations in effectiveness. Acrylic and polyurethane foam achieved only marginal noise reduction, with a decrease in Leq to 87 dB and an effectiveness of 1.63%. In contrast, a combination of acrylic and rockwool significantly reduced noise levels to 79 dB, achieving an effectiveness of 10.63%. The most effective solution was a combination of acrylic, rockwool, and polyurethane foam, which reduced the noise level to 77.2 dB, with an effectiveness of 12.66%. These results support prior findings that combining materials like rockwool and polyurethane can address both airborne and structure-borne noise [28]. Alternative materials such as electrospun fibers or recycled composites may also offer effective solutions with different trade-offs [15,24]. Thus, while previous studies have demonstrated the potential of these materials in laboratory environments, this study expands that understanding by testing them under realistic production conditions.

In this regard, the study also aimed to evaluate the feasibility of applying multilayer damping configurations directly in an active industrial setting, rather than under controlled laboratory conditions. Such an approach offers additional insights into how acoustic materials behave under machine-induced vibration, real-time operation, and varying environmental factors. Compared to earlier research, which typically evaluated sound absorption in static or simulated settings, the current findings provide a more contextual understanding of passive noise control in practical applications. That said, the scope of this research was limited to a single machine type in one production setting, which may constrain the broader applicability of the results. Additionally, the long-term performance of the tested materials under industrial conditions, such as exposure to heat, moisture, or wear, was not assessed. Future studies should explore a broader range of industrial settings, evaluate additional materials with advanced noise absorption properties, and consider the durability and maintenance requirements of noise-damping solutions. These additional investigations would be valuable for strengthening the evidence base and refining passive acoustic strategies for diverse manufacturing environments.

4. CONCLUSION

The study of noise levels in the production area of a spark plug company has provided valuable insights into effective noise reduction strategies and the performance of various damping materials. Based on the results of the noise study in the production area of a spark plug company, the following conclusions can be drawn. Noise level measurements were conducted using a Krisbow KW06-290 sound level meter, following SNI 7231:2009 standards. The sound level meter was placed 30 cm from the machine, with the microphone positioned perpendicular to the machine at a 70-80 degree angle. Measurements focused on the welding threading machine, with machine number 6 recording the highest noise level at 88.4 dB. The noise-damping materials tested included 0.3 cm thick acrylic, 2.5 cm thick rockwool, and 2.5 cm thick zigzag-pattern polyurethane foam. In the first test, a combination of acrylic and polyurethane foam achieved an Leq of 87 dB, reducing noise by 1.63%. The second test, using acrylic and rockwool, resulted in an Leq of 79 dB, with a noise reduction effectiveness of 10.63%. The third test, combining acrylic, rockwool, and polyurethane foam, achieved the highest noise reduction, with an Leq of 77.2 dB and a 12.66% effectiveness. Future studies should explore alternative damping materials with greater effectiveness to reduce noise to safer levels, particularly for machines like welding threading that produce high noise levels. Additionally, optimization of material combinations, thicknesses, and installation methods could further improve noise reduction performance. It is also recommended to assess the long-term durability and economic feasibility of these damping solutions in industrial environments.

AUTHOR CONTRIBUTIONS

R.P. Lukodono: Conceptualization, Methodology, Analysis, Supervision, Writing- Original Draft Preparation; A.T. Hardian: Data Curation, Validation; B. Indrayadi: Validation, Analysis; R. Ardianwiliandri: Writing-Reviewing and Editing.

CONFLICTS OF INTEREST

The manuscript has not been published elsewhere and is not under consideration by other journals. All authors have approved the review, agree with its submission and declare no conflict of interest on the manuscript.

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