proceedings

Proceeding Paper

Evaluation of Vibration Emission Values of Nailers: Can an Automatic Test Stand Be Used Instead of Human Operators? †

Maxime Vincent [1,*], Thomas Padois [1,2], Marc-André Gaudreau [3], Thomas Dupont [1] and Pierre Marcotte [2]

[1] Département de Génie Mécanique, École de Technologie Supérieure, Montréal, QC H3C 1K3, Canada; thomas.padois@etsmtl.ca (T.P.); thomas.dupont@etsmtl.ca (T.D.)
[2] Institut de Recherche Robert-Sauvé en Santé et en Sécurité du Travail, Montréal, QC H3A 3C2, Canada; pierre.marcotte@irsst.qc.ca
[3] Département de Génie Mécanique, Université du Québec à Trois-Rivières, Trois-Rivières, QC G8Z 4M3, Canada; marc-andre.gaudreau@uqtr.ca
* Correspondence: maxime.vincent.1@ens.etsmtl.ca
† Presented at the 15th International Conference on Hand–arm Vibration, Nancy, France, 6–9 June 2023.

Abstract: To protect workers, it is necessary to characterize the noise and vibration emissions value of nailers. Standardized characterization methods exist but require three trained human operators, which leads to a dispersion in the results and a difficult implementation. An automatic test stand (ATS) was developed to characterize those values without the participation of human operators. It is proposed here that we compare the results obtained by the two methods. Preliminary results suggest that further refinement of the ATS is needed to better mimic the biodynamics of the human hand–arm and that a larger number of operators would be required for validation.

Keywords: nailers; power tools; impact vibrations; shocks; hand–arm vibration; automatic test stand

Citation: Vincent, M.; Padois, T.; Gaudreau, M.-A.; Dupont, T.; Marcotte, P. Evaluation of Vibration Emission Values of Nailers: Can an Automatic Test Stand Be Used Instead of Human Operators? *Proceedings* **2023**, *86*, 20. https://doi.org/10.3390/proceedings2023086020

Academic Editors: Christophe Noël and Jacques Chatillon

Published: 12 April 2023

1. Introduction

Portable nailers are power tools widely used in the construction industry since they permit efficient and accurate fastening of wood structures. Unfortunately, nailers also produce high levels of impact noise and vibration, which can represent a significant risk to develop hearing loss or hand–arm vibration syndrome. That is why it is important to choose and design nailers that produce low levels of noise and vibration emissions value (VEV) to prevent potential injuries. A first good step would be to simplify the methods to evaluate noise and vibration emissions value.

The ISO 28927-13:2022 standard presents a method for evaluating the VEV of fastener driving tools such as nailers [1]. The procedure requires three trained operators to fasten 50 nails each in a standardized piece of pine wood, which is particularly long and expensive. Therefore, an automatic test stand (ATS) was previously developed to simplify and to reduce the cost of VEV measurement [2,3]. Apart from the VEV characterization, the ATS was also used to determine noise emission values [2,4] and to localize nailers' noise sources [2,5]. The ATS VEV were compared with the VEV obtained with the three human operators for seven different portable nailers using the *Wh* weighted RMS acceleration (ISO 5349-1 standard [6]). However, an epidemiological study has suggested that the band-limited *hF* frequency weighting, which considers a higher frequency content, is more appropriate for assessing the risk of developing vibration-induced white finger [7]. Another study has also shown that three human operators, as specified by the ISO 10819:2013 standard [8], were insufficient to determine the vibration transmissibility of gloves [9].

In this paper, it is proposed that we compare nailers' VEV as RMS and peak *hF* weighted accelerations measured with the three human operators (ISO 28927-13:2022 standard) and with the ATS.

2. Materials and Methods

Seven different nailers were used for the study: PR1, PR2, PB1, PB2, PB3 refer to pneumatic nailers; GB1 refers to a gas (butane) one; and EB1 to an electric one. The conditions of the measurements with the human operators followed the ISO 28927-13:2022 standard, with three operators fastening 10 nails over 30 s for 5 repetitions, for a total of 50 nails by operators or 150 nails for each tested nailer.

The ATS was composed of an aluminum frame above the test setup proposed in the ISO 28927-13:2022 standard, as shown in Figure 1. The nailer handle was attached to a moving support, which consists of a greased slider restricting nailer motion to the vertical direction. A remote trigger was designed to pull the trigger of the nailer. For both ATS and human operator measurements, a triaxial accelerometer (PCB 356B20) was rigidly attached to the nailer body, as close as possible to the operator's hand. The acceleration signal was acquired with a sampling frequency of 51.2 kHz.

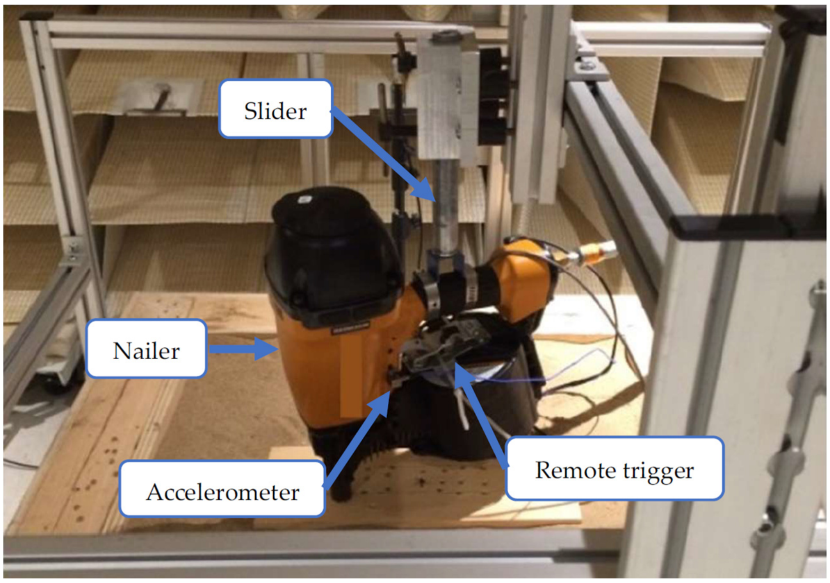

Figure 1. The automatic test stand above the ISO 28927-13:2022 test stand [2].

For the ATS, 10 nails were fastened for each nailer [2]. The acceleration signals were digitally filtered by the band limiting *hF* (or flat_h) weighting, as defined in the ISO/TS 15694 technical specification [10]. It consists in a flat band-pass filter with unity gain in the 6.3–1250 Hz frequency range. For each nailer, the 3-s RMS weighted (*hF*) acceleration for a single impact $a_{hF,\,3s}$, the weighted peak value $a_{hF,PEAK}$, and the crest factor *CF* were computed from the acceleration signals for both the three human operators and the ATS, following Equations (1)–(3). In these equations, *T* is the measurement period, a_{hF} is the *hF* weighted RMS acceleration, $a_{hF}(t)$ is the *hF* weighted acceleration time signal, and *n* is the number of single impact (nail):

$$a_{hF,\,3s} = a_{hF}\sqrt{\frac{T}{3n}}, \tag{1}$$

$$a_{hF,PEAK} = max_{0\leq t\leq T}|a_{hF}(t)|, \tag{2}$$

$$CF = \frac{a_{hF,\,PEAK}}{a_{hF,3s}}. \tag{3}$$

The data obtained with the three human operators were averaged and the standard deviation was computed. For the ATS, the average and standard deviation were computed over the 10 nails. The relative difference was calculated to compare the results between the human operators and the ATS.

3. Results

The 3-s RMS, peak value, and crest factor of the *hF* weighted acceleration along the predominant z_h vertical direction are presented in Figure 2.

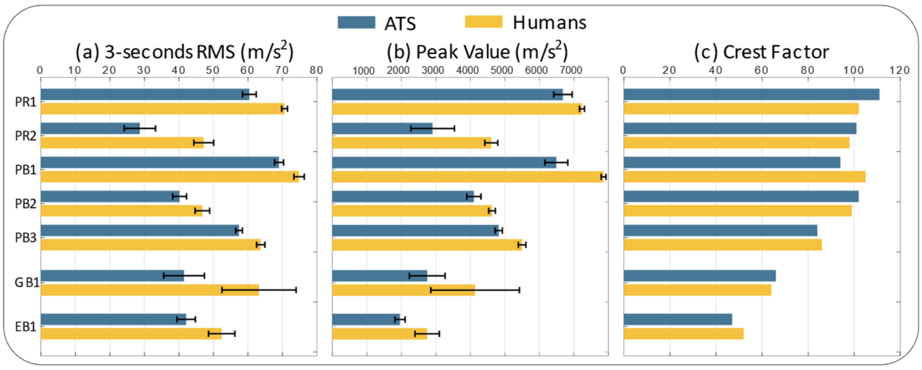

Figure 2. VEV obtained for the seven tested nailers comparing human operators and the ATS over the z_h direction: (**a**) 3-s RMS acceleration *hF* weighted; (**b**) peak acceleration *hF* weighted; and (**c**) crest factor with the mean of the three human operators and the ATS. The standard deviation is displayed as the error bar.

The results show that the 3-s RMS *hF* weighted acceleration and the peak value are always underestimated with the ATS. However, the *CF* are similar, which means the ratio between RMS and peak values is preserved. The relative differences between the 3-s RMS *hF* weighted acceleration obtained with the human operators and the ATS range from 8% for the PB1 nailer to 39% for the PR2 nailer. Differences for all other nailers are below 20%, except for the GB1 and PR2 nailers, which are also associated with the largest variabilities in the weighted 3-s RMS and peak accelerations. The nailer with the lowest relative difference ratio between both the 3-s RMS *hF* weighted acceleration and the weighted peak acceleration is the PB3 nailer, with 10% and 12%, respectively.

To further investigate those differences between the averaged human operators and the ATS, the one-third octave band spectrum of the *hF* weighted acceleration is computed. VEV for the PR2 and GB1 nailers, comparing the ATS with the three human operators, are presented in Figure 3. The PB3 nailer is displayed as a reference.

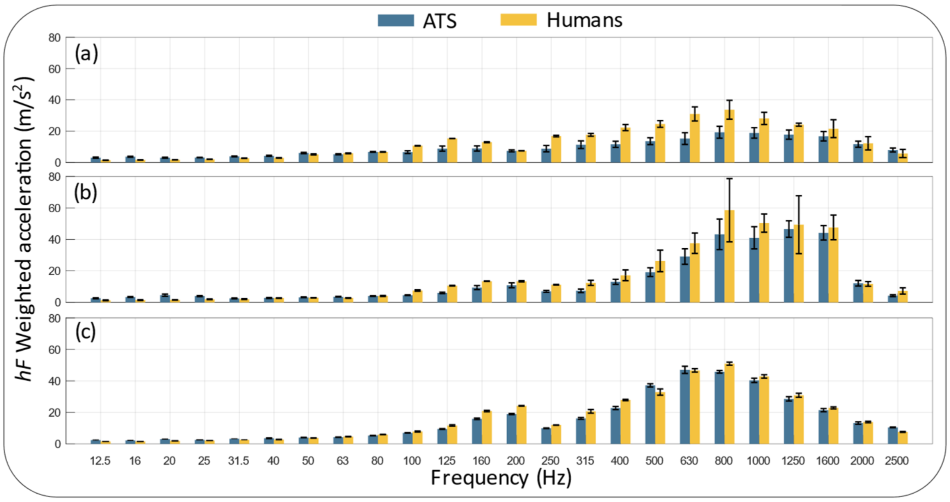

Figure 3. One-third octave band spectrum of the mean *hF* weighted acceleration for (**a**) PR2 nailer, (**b**) GB1 nailer, and (**c**) PB3 nailer, with the mean of the three human operators and the ATS. The standard deviation is displayed as the error bar.

The one-third octave band spectrum obtained with the PR2 nailer (Figure 3a) shows a good agreement between the ATS and human operators in the low frequency until 200 Hz. For higher frequencies, the spectrum magnitude increases for both operators and ATS as well as the difference between them. The highest values are in the 400–1600 Hz frequency range, which justify the use of the *hF* weighting. Similar observations can be made for the GB1 nailer (Figure 3b). For the human operators, it is worth noting that the error bar (i.e., the standard deviation) is very large (i.e., in the 400–1600 Hz frequency range), which demonstrates a large variability between the operators. In comparison, the PB3 nailer (Figure 3c) shows good agreement between the ATS and the human operators for the entire frequency spectra. The VEV measured with the ATS are always underestimated compared to the VEV measured with human operators. This could be attributed to the design of the ATS itself, which restricts the motion to the vertical axis only. In addition, the VEV of some nailers could be more sensitive to the human biodynamic coupling, which was not considered in the ATS design. The large intersubject variability also suggests that three operators could be insufficient to determine nailer VEV accurately.

4. Conclusions

According to the VEV comparing the ATS with the three human operators (ISO 28927-13:2022 standard), the ATS could offer a good alternative to the human operators, while it also simplifies the procedure and reduces the number of nails required to obtain the VEV. However, for two of the seven tested nailers, large differences were shown between the VEV measured with the human operators and the ATS, as well as high intersubject variabilities. These large intersubject variabilities suggest that three operators are insufficient to characterize nailer VEV. In addition, the design of the ATS, which does not consider the hand–arm biodynamics to impact vibrations, could generate VEV underestimations between the ATS and human operators. For now, more research is needed to understand the differences between the VEV measured with the ATS and with the human operators and to improve the human representativity of the ATS; an ATS with better human representativity is necessary to improve the determination of nailer VEV and noise emission values, as well as to help manufacturers build safer tools with lower levels of noise and vibration.

Author Contributions: Methodology, M.V., T.P., M.-A.G., T.D. and P.M.; writing—original draft preparation, M.V. and P.M.; writing—review and editing, M.V., T.P., M.-A.G., T.D. and P.M.; supervision, T.P., T.D. and P.M.; project administration, M.-A.G., T.D. and P.M.; funding acquisition, M.-A.G., T.D. and P.M. All authors have read and agreed to the published version of the manuscript.

Funding: The project was funded by Institut de recherche Robert-Sauvé en santé et en sécurité du travail (project # 2018-0024) and by Mitacs (project # IT 27303).

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and approved by the Ethics Committee of École de technologie supérieure.

Informed Consent Statement: Informed consent was obtained from all the subjects involved in the study.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. *ISO 28927-13*; Hand-Held Portable Power Tools Test Methods for Evaluation of Vibration Emission Part 13: Fastener Driving Tools. International Organization for Standardization (ISO): Geneva, Switzerland, 2022.
2. Gaudreau, M.A.; Marcotte, P.; Laville, F.; Padois, T.; Boutin, J. *Cloueuses Portatives: Développement de Méthodes de Diagnostic Vibratoire et Acoustique*; IRSST: Montreal, QC, Canada, 2018; ISBN 978-2-89797-031-4.
3. Marcotte, P.; Gaudreau, M.A.; Laville, F.; Padois, T. Characterization of Nail Guns Impact Vibration. In Proceedings of the 26th International Congress on Sound and Vibration, Montréal, QC, Canada, 7–11 July 2019; pp. 1132–1138.

4. Gaudreau, M.A.; Padois, T.; Laville, F.; Marcotte, P. Noise and Vibration Measurement of Framing Nailers: Development and Validation of a Mechanized Test Bench. In Proceedings of the 46th International Congress and Exposition on Noise Control Engineering, Hong Kong, China, 27–30 August 2017.
5. Padois, T.; Gaudreau, M.A.; Marcotte, P.; Laville, F. Identification of Noise Sources Using a Time Domain Beamforming on Pneumatic, Gas and Electric Nail Guns. *Noise Control. Eng. J.* **2019**, *67*, 11–22. [CrossRef]
6. *ISO 5349-1*; Mechanical Vibration—Measurement and Evaluation of Human Exposure to Hand-Transmitted Vibration—Part 1: General Requirements. International Organization for Standardization (ISO): Geneva, Switzerland, 2001.
7. Bovenzi, M.; Pinto, I.; Picciolo, F.; Mauro, M.; Ronchese, F. Frequency Weightings of Hand-Transmitted Vibration for Predicting Vibration-Induced White Finger. *Scand. J. Work Environ. Health* **2011**, *37*, 244–252. [CrossRef] [PubMed]
8. *ISO 10819*; Mechanical Vibration and Shock—Hand-Arm Vibration—Measurement and Evaluation of the Vibration Transmissibility of Gloves at the Palm of the Hand. International Organization for Standardization (ISO): Geneva, Switzerland, 2013.
9. Hamouda, K.; Rakheja, S.; Dewangan, K.N.; Marcotte, P. Fingers' Vibration Transmission and Grip Strength Preservation Performance of Vibration Reducing Gloves. *Appl. Ergon.* **2018**, *66*, 121–138. [CrossRef] [PubMed]
10. *ISO/TS 15694*; Mechanical Vibration and Shock—Measurement and Evaluation of Single Shocks Transmitted from Hand-Held and Hand-Guided Machines to the Hand-Arm System. International Organization for Standardization (ISO): Geneva, Switzerland, 2004.