

Influence of Vibro-isolator Attachment for a Jackhammer to Reduce Vibration Discomfort



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Abstract Jackhammers are widely used in the construction industry to break up rock, pavement and concrete. They are generally powered by compressed air, electric motors, or hydraulics and can generate a large force for drilling and demolition. However, while they are an efficient tool for this purpose, they also pose a serious danger to the worker, due to the vibrations transmitted. Prolonged exposure to these vibrations can cause ailments such as vibration white finger, Raynaud's disease and carpal tunnel syndrome (CTS). The objective of this research is to design and fabricate a vibro-isolator attachment to damp and absorb the range of harmful vibrations transmitted to the occupant. The attachment is clamped on top of the jackhammer and makes use of two helical springs in parallel to reduce the higher amplitude vibrations. Handles are provided above the springs for the user to grip the attachment and hence, the jackhammer. The new design, setup feels worker much less hand-arm vibration without reducing the downward drilling force of the jackhammer. Hence, the newly designed vibration isolation, attachment reduces the hand-arm vibration, and the jackhammer can be operated at full power without compromising on the health of the occupants.

Keywords Vibro-isolator · Jackhammer · Carpal tunnel syndrome · Design of springs

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1 Introduction

A large magnitude of vibrations is transmitted to the hand-arm system while using hand-operated tools. The variety of occupations like construction, industry, agriculture and medical applications are repeatedly using the hand-operated vibration tools. Continuous usage of vibrating tools transmits vibrations to the hand-arm system which leads to discomfort and pain [1] and also such vibrations lead to Carpal Tunnel Syndrome (CTS) and Hand-Arm Vibration Syndrome (HAVS) [2]. The level of vibration transmitted from the hand-operated tools are evaluated by various researchers such as grass trimmer (4.5–11.3 m/s²) [3], rock drill (24–25 m/s²) [4], pneumatic hammer (30 m/s²) [5], and orbital sander (3.9–7.3 m/s²) [6]. Improper design and continuous exposure may lead to a combination of muscular, circulatory, neurological, bone and joint disorders [7, 8]. Vibration exposure for a single day A (8) has been categorized by European Union (2005) based on that the exposure limit value and action value should be 5.0 m/s² and 2.5 m/s², respectively [9].

In order to overcome the hand-arm vibration, the assessment methods used for vibration measurement and its guidelines are drawn by ISO 2001 (International Standard Organization). The frequency-weighted vibration total value (ahv) was evaluated by combining the vibration acceleration of all three directions. The vibration measurement axes were suggested by ISO 5349-1 (2001); Zh-axis as the longitudinal axis from the third metacarpal bone; the Yh-axis perpendicular to the Xh and Zh axes; Xh-axis perpendicular to the Zh-axis [10]. Vibration injury was assessed between 8–1000 Hz of the working frequency. The vibrations in the frequency range of 6–20 Hz are more harmful to humans, but the effect of vibration decreases with the increase of frequency [11].

The response from human for vibration was depended on four factors such as direction of vibration, magnitude of vibration, exposure time and duration [12]. Other factors influenced hand-arm vibration transmission are forces of grip and push, posture of hand and contact area between the hand and handle. In order to estimate the hand-transmitted vibration objective and subjective measurements were followed by several researchers. The perceptions of workers in the workplace were evaluated by subjective measurements using observation and questionnaire methods [13, 14]. Subjective measurement accuracy is based on the honesty of the subjects [2]. Subjective measurements are very easy to estimate the hand-arm transmitted vibration. In objective measurements, the data obtained are duration of hand-arm vibration exposure, frequency of the vibration and magnitude of vibration. However, objective measurements are more accurate and required expensive sensory devices with experienced operators. The measurement accuracy of the objective method depends on biodynamic response of the humans, working environment, working conditions, tool condition and activity of the work [15]. In order to predict the hand-arm vibration health effects, Poole and Mason [16] combined both objective and subjective measurements.

Improved design of handles and accurately designed handles can provide safety and comfort during work, increase performance and decrease disorders [17]. Anti-vibration coatings were given to the handles in order to reduce the vibration and the vibration reduction was evaluated in the hand-arm system [18]. Alphin et al. (2013) considered the effect of handle diameter to overcome the vibrations transmitted to the hand-arm system [19]. Influence of shape and size was considered by Tony et al. to develop the human hand based handles and the vibration was reduced up to 14% than the traditional cylindrical handles [20]. The effect of handle diameter was simulated by Tony et al. (2019) using hybrid finger model and FE analysis [21]. The objectives of the present study are (1) to develop a vibro-isolator attachment for jackhammer by considering the design calculations, (2) to evaluate the effect of vibro-isolator in vibration reduction.

2 Materials and Methods

2.1 Subjects and Jackhammer Specifications

Six male subjects between the age group of 21–30 years, and who were free from musculoskeletal disorders, volunteered to participate in this experiment. Table 1 (a) and (b) shows the anthropometric descriptions of the participants and jackhammer specifications in detail. The detailed description of experimental procedure was explained for every subject before the experiment was initiated.

Table 1 Description of anthropometric measurements and jackhammer specifications: **a** Characteristics of subjects. **b** Jackhammer characteristics

Characteristics	Mean	S.D	Range
Age (years)	28	6.48	21–30
Height (cm)	164	3.92	152–170
Weight (kg)	76	4.89	61–79
Middle finger length (mm)	192	3.86	182–191
Thumb finger length (mm)	110	3.66	103–116
Grip diameter (mm)	52	2.65	44–52
Characteristics	Specifications		
Make	Bosch GSH 11 E		
Power rating	1500 W		
Impact rate	900–1890 bpm		
Impact energy	16.8 J		
Weight P ₀	266.7119 N		

2.2 Design Calculation of Springs

The presence of spring as a damper in the attachment to the handle will help reduce the vibrations considerably and also help avoid the various health hazards caused due to excessive vibrations. In order to design a spring as a damper, spring parameters to be considered such as arrangement of spring, number of springs, diameters of inner (D_i), wire (d) and mean (D), number of turns (n), spring index (C) and compressive force (P) of each spring. The calculated spring index was used to evaluate the Wahl stress factor (K) and found as 1.148 from the graph. The important parameters for designing the spring is shear stress (τ), deflection (y), and stiffness (q) were calculated using Eq. (1), (2) & (3) as 237.77 N/mm², 22.415 mm, and 5.949 N/mm, respectively.

$$\tau = \frac{8KPC}{\pi d^2} \quad (1)$$

$$y = \frac{8PC^3n}{Gd} \quad (2)$$

$$q = \frac{Gd}{8C^3n} \quad (3)$$

2.3 Three-Dimensional Handle Attachment Design

Considering the design parameters of springs the handle with spring attachment was designed using modelling software SOLIDWORKS 2016®. The various parts were first modelled individually and finally assembled to create the attachment. There are three distinct parts in the assembly. The springs are rested on the top surface of the bottom part and enclosing the cylinders projecting from the surface. Then the top part is added to the assembly. The axis of the solid cylinder and hollow cylinder are made coincident and one of the side surfaces of the top and bottom part is also made coincident. Now the top part is constrained in two directions and can move only in one direction. The top part is then moved downwards until it is in contact with the top of the spring. Then it is fixed in position. The damping attachment is assembled as shown in Fig. 1.

2.4 Fabrication of Handle

The aluminium block of dimensions 210 × 130 × 20 was purchased then; the block was measured and milled to the dimensions 200 × 120 × 20. Two holes were drilled in the block at a distance of 55 mm from the smaller edge, a distance of 60 mm from

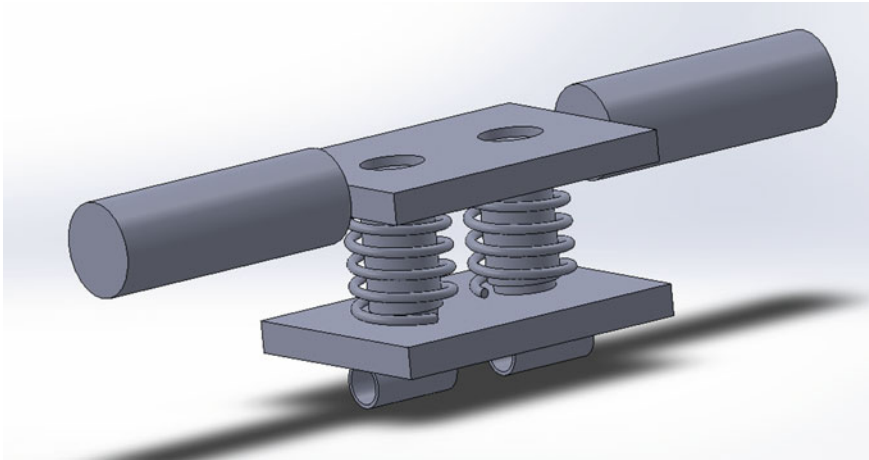


Fig. 1 Three-dimensional handle attachment design

the longer edge and of diameter 29.9 mm. Then, the aluminium block of 15 mm thickness is taken and milled so that it too has a length of 200 mm and a breadth of 120 mm. On the 20×120 mm faces of the slab, holes of 8 mm diameter were drilled using a vertical (manual) drill machine. These holes were of a depth of 45 mm.

Two aluminium rods of length 125 mm and diameter 34 mm are taken and were machined (faced and turned in lathe) to a diameter of 32 mm and a length of 120 mm. Then, the plates are drilled (centrally) with a 6 mm bit to obtain a 6 mm hole. The hole diameter is increased to 8 mm by means of boring process. The springs are placed over the mild steel rods centered on them.

Then, the hollow aluminium tubes are placed on either face (20×140) of the aluminium slab and are screwed in using 8 mm Allen bolts of length 130 mm. Now, the 20 mm thick slab is placed over the 15 mm thick slab so that the MS rod slides in and out of the MS tube. The two parts are locked together when a cotter is placed in the hole in the MS rod. The handle setup with spring attachment is shown in Fig. 2.

2.5 Experimental Procedure

The two aluminium blocks are placed on top of each other with the spring placed over the mild steel rods centered on them. The two aluminium blocks are locked together when a cotter is placed in the hole in the MS rod. The attachment is then placed over the handle of the jackhammer as shown in Fig. 3.

The vibrations were recorded at the base of the handle and at the wrist of each subject. The accelerometer was attached using the lightweight strip to avoid the measurement errors according to the ISO 5349-2 standard. Once the subject found the correct posture the experiment was initiated and the vibrations were measured

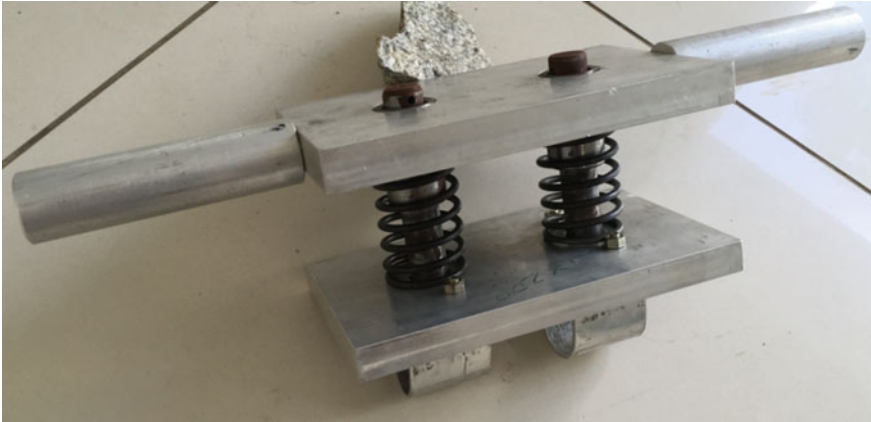


Fig. 2 Fabricated handle attachment setup



Fig. 3 Experimental studies with vibro-isolator attachment

up to 0-1000 Hz. IBM SPSS Statistics v.20 software[®] package was used to store all the acquired data.

3 Results and Discussions

A tri-axial accelerometer was used to determine the amplitude of vibrations with and without the attachment. These values at selected frequencies are tabulated below Table 2. Time-domain and frequency domain data was stored using this experiment. Time-domain data gives the relation between time and frequency. The below values of the amplitude of vibration, with and without the attachment, a graph is plotted is shown in Fig. 4. This graph is a plot of frequency domain that relates between frequency and amplitude.

Table 2 Experimental data

S. No	Frequency in Hz	Amplitude before damping in mm	Amplitude after damping in mm
1	150	11.97	7.89
2	200	8.42	1.30
3	300	25.84	2.00
4	350	17.31	4.30
5	400	55.41	2.45
6	500	16.49	0.99
7	600	6.53	1.38
8	700	27.91	2.22
9	800	11.39	1.83
10	900	8.18	3.0
11	1000	11.48	0.80

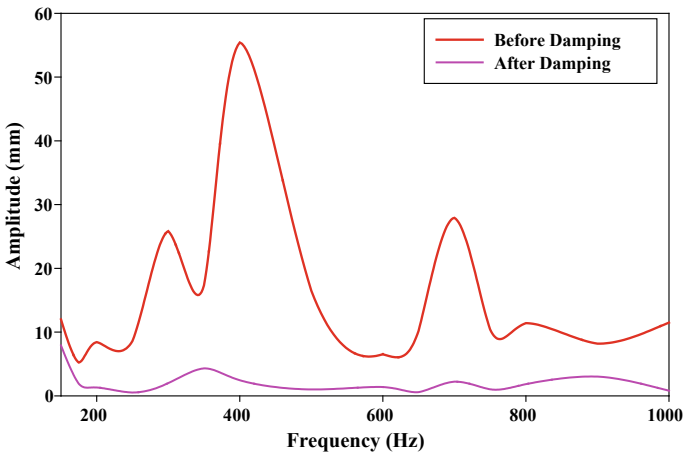


Fig. 4 Amplitude and frequency distribution

The graph denotes the amplitude of vibration before and after the attachment. Thus, a vibration-damping attachment for a jackhammer was designed and fabricated with the necessary dimensions. The aluminium slabs were accurately machined by milling. The solid and hollow mild steel cylinders were machined by turning and finished by cylindrical grinding. The fabricated attachment successfully damps the vibrations from the jackhammer as evidenced by the above graph. From the graph, we infer that the damping effect is not the same for all the frequencies. The damping is more for some frequencies and lesser for some other frequencies. The amplitude of vibration is greatly reduced in the region of frequency around 400 Hz. The results were in good agreement with experimental analysis conducted for ergonomic handle shapes [20].

It is also very effective in the region 700 Hz and in the region around 300 Hz as illustrated by the graph. From the graph and from the experiments, we inferred that the attachment was not effective in the lower frequency range (frequency less than 150 Hz). A similar response was found by the various researchers in order to control the vibrations below 150 Hz. The static gripping analysis of hybrid finger model was in good agreement with the experimental results [21, 22].

4 Conclusions

Thus, the vibro-isolator attachment for a jackhammer was successfully designed and fabricated. Experimental trials were conducted which signify successful damping of the vibrations from a jackhammer. This attachment reduces the risk of ailments that occur due to prolonged exposure to the vibrations from a jackhammer. The fact that the attachment is relatively inexpensive serves to highlight the feasibility of the product. Hence, using this attachment, the operator can use the jackhammer for longer durations of time without any risk to his wellbeing.

Ethical Approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional ethics and research committee (Dr. S. Sali-vahanan, Dr. V.E Annamalai, Dr. A. Kavitha). The participants gave their concerns for experiments and publications.

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