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Design and evaluation of a modified drilling method

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ABSTRACT

The aim of the study was to develop a modified drilling method (MDM) for a bench drilling machine to enhance the drilling task performance. The MDM and the present drilling method (PDM) were evaluated for the subjects of varying age groups (21–30, 31–40 and 41–50 years) while performing the drilling task for different work durations (3, 6 and 9 min) in the sitting and standing working postures. The performance parameters used were metal removal rate (MRR) and perceived discomfort score (PDS). Drilling load required to perform the task and endurance time were also determined for both PDM and MDM. Thirty male subjects were selected to perform the drilling task on a mild steel block at a drilling speed of 700 rpm. The results of the study showed that there was an increase in MRR by more than 140% using MDM. PDS was also reduced appreciably at different body segments using the proposed system. The results of the study further revealed that there was a substantial decrease in the drilling load required to perform the task and a considerable increase in the endurance time.

1. Introduction

Several interventions have been suggested in the past for various manual tasks. Drilling performed using a bench drill machine is, however, one such task where no major modification has been reported so far. Drilling task being monotonous and repetitive in nature carries with it various health and safety related issues such as repetitive strain injury (RSI), musculoskeletal disorders (MSDs) etc. (Escorpizo, 2008; Walker-Bone and Cooper, 2005). The task of drilling on a bench drilling machine is performed in a straight upright posture. The hand moves down slowly from the shoulder height and exerts pressure on the workpiece to complete the process. The continuous repetitive motion of the hand and arm resulted in muscle fatigue and discomfort (Moore and Wells, 2005; Chung et al., 2005) leading to reduced efficiency and job dissatisfaction (Fellows and Freivalds, 1991). Working in an awkward posture might lead to the development of MSDs as hands should not remain above shoulder height for a long period of time continuously (Chaffin et al., 1999). Shoulder elevation greater than 60° during work was described as an awkward posture (NIOSH, 1997; Dasgupta et al., 2014). Lee et al. (2015) found that the upper limb experienced high fatigue when the task was performed at above the elbow height. Farooq and Khan (2014) showed that forceful exertion in an awkward postures increased the hazard of prevalence of MSDs. Awkward working postures were reported to be the foremost factor in the prevalence of MSDs (Burdorf et al., 1991; Muggleton et al., 1999). Hagberg et al. (1995) found MSDs to be the main occupational health quandary in the industrial world. The findings of the previous researchers assume significance in the light of the fact that a large proportion of the total workforce in the developing and underdeveloped countries is involved in drilling and other such tasks performed manually.

The factors like awkward posture and repetitive motion may be reduced to a greater extent using ergonomic interventions, if not eliminated completely. Since ergonomics is “the design and engineering of human–machine systems for the purpose of enhancing human performance” (Dempsey et al., 2000), an intervention might be termed as ergonomic if it eliminates or significantly reduces fatigue and enhances performance of the worker. Studies have shown that non ergonomic design might be responsible for poor performance and various other occupational issues (Khan and Muzammil, 2013; Arnetz et al., 2003; Das, 2000; Grandjean et al., 1983). An ergonomic design might reduce stress and utilise worker's capacity in a better way leading to increased productivity (Dempsey et al., 2004).

Bench drilling machine is widely used for drilling holes of various sizes in metals and non-metals. Drilling is a strenuous task that demands sustained downward push and a shoulder pull leading to the development of fatigue. Although the bench drilling machine is widely used in various industries, researches pertaining to the improvement in working method are in a rudimentary stage. No major modification/new intervention related to bench drilling task appears to have been reported so far. Hence it was the need of the hour to design an intervention which might help the worker performs the drilling task in a better way to enhance productivity. The objectives of the present study were (i) to evaluate the present drilling method (ii)design and fabricate a modified drilling method (MDM) with a view to perform the drilling

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task efficiently (iii) evaluate the developed system and (iv) compare the existing and proposed interventions.

2. Methodology

2.1. Drilling operation

Drilling is the process of making holes in a workpiece using a drill bit mounted in a tool holder on a bench drilling machine. A drill bit is a cylindrical bar having helical flutes and radial cutting edges. The rotating drill bit is fed against the stationary workpiece to perform drilling. The worker applies downward force to push the rotating drill bit into workpiece.

2.2. Subjects

Before selecting subjects for the experimental task, a survey was carried out to determine the age group of workers involved with the trade. The survey revealed that the majority of the worker's population was in the range of 20–50 years. Hence in the present research subjects falling in the observed age group were studied to investigate their drill task performance. The three age groups of workers namely 21–30, 31–40 and 41–50 years with ten subjects in each group were selected for the present study.

The subjects selected were students and employees of the Mechanical Engineering Department, Zakir Husain College of Engineering and Technology, A.M.U., Aligarh (India). They performed the experimental task voluntarily and no reward was paid to them. They were all novice with no previous experience in the trade of drilling. The subjects selected were healthy, right handed with no previous history of neuro-muscular disorder. An informed written consent was obtained from the subjects who participated in the studies.

2.3. Independent and dependent variables

The independent variables selected were age group of the workers (at three levels: age group 1 (21–30 years), age group 2 (31–40 years) years and age group 3 (41–50 years)) work duration (at three levels: viz. 3, 6 and 9 min) and working posture (at two levels: standing and sitting) while the dependent variables used were metal removal rate (MRR) and perceived discomfort score (PDS) on a 100 mm visual analogue scale (Khan et al., 2010). A randomized full factorial experiment was designed for the present investigations. A total of 36 conditions (3 age group x 3 work duration x 2 working posture x 2 operation method) with 10 subject on each condition leading to 360 experimental conditions were investigated. The operation method i.e. PDM and MDM were taken as independent variable. Table 1 summarizes factors and their levels used in experiment design.

The work durations for the drilling operation were selected on the basis of a survey carried out in the industries where the drilling task was being carried out in a major way. The survey revealed that the workers were performing the drilling task continuously for a maximum period of 8–9 min while the minimum task duration was 3–4 min. Accordingly, the durations selected were 3, 6 and 9 min.

Table 1
Summary of full factorial experiment design.

Factors	Operation Method	Age Group	Subjects in each Age Group	Working Posture	Work Duration
Levels	2	3	10	2	3
Total number of Experimental Conditions	360				

MRR, which may be defined as the volume of material removed per unit time, was calculated using the following relationship.

$$MRR = Volume\ of\ metal\ removed\ /\ Work\ duration\ (minutes) \quad (1)$$

$$MRR = \left(\frac{\pi d^2}{4} h\right)/t\ (\mathrm{mm^3/minute}) \quad (2)$$

where d and h are the diameter of the drill bit and depth of the drilled hole in mm respectively and t is the drilling time duration in minutes for which drilling task was performed.

PDS levels were obtained using visual analogue scale (Carey and Gallwey, 2002; Ozucelik et al., 2005; Farooq and Khan, 2014). PDS Score Sheet (Corlett and Bishop, 1976; Ozucelik et al., 2005) was used for different body segments on a 10 point scale. A value '0' on the scale indicated no fatigue while '5' signified appreciable fatigue. A value of 10 referred to a condition where the subject could no longer continue with the task.

2.4. Experimental task and procedure

The subjects of various age groups performed the drilling task for different work durations in standing and sitting working postures. A training session was organized for the subjects to get them familiarised with the task before carrying out the actual experimentation. The experimental task was performed in the Production Engineering Laboratory, Department of Mechanical Engineering, AMU, Aligarh (India). The subject was asked to drill a hole of 6 mm diameter, on a bench drilling machine, in a mild steel block (750 mm × 750 mm x 250 mm). During the experimentation the drilling speed was maintained at 700 rpm. A 6 mm diameter drill bit made up of high speed steel was used for making holes. Each subject was provided a fresh drill bit for drilling holes to keep the sharpness of the cutting edges at the same level. The subjects performed the drilling task for 3, 6 and 9 min duration in both standing and sitting working postures. A rest of at least 15 min in between the two sets of experimental investigations for each subject was provided.

2.5. Working environment

Generally an industry/workshop has many kinds of machines where assorted types of tasks are performed. These machines generate appreciable amount of noise which may exceed the acceptable limits recommended by OSHA. A noise level meter (Pulsar make: Model 33) was used in the present study to measure the level of equivalent noise (L_{eq}). Proper illumination level was maintained as per the recommendations of Health and Safety Executive (HSE, 1997). All experimental investigations were carried out at an ambient temperature of 25–35 °C.

2.6. Present drilling method (PDM)

The PDM of a bench drilling machine consisted of three straight handles each at 120° with spherical knobs at the end as has been shown in Fig. 1. Subject applied the required downward pressure using these handles to carry out the task. During the drilling process, the hand arm system of the subject remained in a straight position above the shoulder height almost for the entire duration of the task.

2.7. Modified drilling method (MDM)

The MDM was designed and fabricated in the Workshop, Mechanical Engineering Department, using a gear train mechanism. The gear train mechanism was used to eliminate the existing elevated position of shoulder during a drilling task and reduce reach distance (Das et al., 2007). The gear train mechanism used in MDM also facilitated the upper extremity of the arm to remain close to the worker's body. It was designed to help keep the arm of the worker in a most