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Ergonomic Study on Computerised Numerical Control Machine Operation

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Abstract **– Ergonomists play an important role in preventing and controlling work-related injuries and illnesses. Machine design, job structure, physical and mental strain experienced by the operators of Computerised Numerical Control (CNC) machines were studied in an engineering company. Data were collected based on study of the machines, interviews and questionnaires. The main objective of this study is to investigate ergonomics, occupational health and safety problems of CNC machine operators. One hundred and twenty two employees participated in the study and different types of CNC machines were taken up for the study. The study revealed that 45 percent of the employees reported of lower back pain, 44% of neck, 21% of upper-body pain, 61% of shoulders and 41% of leg. However, the employees expressed that their jobs are more challenging and interesting. Furthermore, the environmental working conditions were assessed to be more convenient than in conventional workplaces. The outcome of this study (1) generated a data-grounded conceptual framework for ergonomic decision-making and (2) assessed the adequacy of that framework for describing the decision-making of ergonomics practitioners.**

Keywords **– CNC Machines, Anthropometry, Ergonomics, Discomfort, MSDs, OHS, WLBD, WRMSDs.**

I. Introduction

Improving worker productivity and occupational health and safety (OHS) are the major concerns in Industries, especially in developing countries. Some of the common problems are improper workplace design, ill-structured jobs, mismatch between worker abilities and job demands, adverse environment, poor human–machine system design and inappropriate management programs. This leads to workplace hazards, musculoskeletal disorder (MSDs), mechanical equipment injuries and disabilities. These in turn reduce workers' productivity and product/work quality. Ergonomics or human factors application has been found to improve worker productivity, occupational health, safety and satisfaction. This has both direct and indirect effects on overall performance. It is believed that ergonomic deficiencies in industry are the root cause for workplace health hazards, low levels of safety, and reduced worker productivity and quality (Ashraf A. Shikdar and Naseem M. Sawaqed - 2004) [1]. Although ergonomics applications have gained significant momentum in developed countries, awareness remains low in developing regions. Ergonomic principles, if properly applied, can eliminate or reduce OHS problems in the workplace and enhance performance. In this paper application of ergonomics in improving OHS needs are explored for the Machining industry.

Work in the engineering industry involves diverse activities, safety and health hazards have been recognized in the literature and guidelines for exposure have been formulated (Hancock & Vasmatzidis, 1998) [2]. It is generally more effective to examine working conditions on a case-by-case basis when applying ergonomic principles to solve or prevent health and safety problems arising in industrial scenario. Effective application of ergonomics in work system design can achieve a balance between worker characteristics and task demands. This can enhance worker productivity, provide worker safety and physical and mental well being, and job satisfaction for the worker. Ergonomics can play an important role in reducing drudgery and improving user satisfaction in technology development (McNeill M and Westby A. 1999) [3]. As regards occupational health, stress and safety matters, advanced manufacturing technologies may obviously have good and bad effects (Parsons, 1987) [4]. Many studies have shown positive effects of applying ergonomic principles to the workplace - in machine design, in job design, and in environment and facilities design (Burri and Helander, 1991) [5]. Lack of skills in ergonomics, communication and resources are believed to be some of the major factors contributing to the poor ergonomic conditions and consequent increase in health and safety problems in the industry (Ashraf A. Shikdara and Naseem M. Sawaqed, 2004) [6]. However, there are still low levels of acceptance and limited applications in industry for the application of ergonomics system design (Konz, 1995) [7]. The compounding effect of job and/or workplace deficiencies will surpass the body's coping mechanisms, causing the inevitable physical symptoms, emotional stress, low productivity, and poor quality of work. (Ayoub M.A. 1990) [8]. It is a challenge for the management and designers to ensure that jobs remain demanding and interesting in the long run. (Pentti and Eva, 1991) [9]. Employees need to be trained systematically in ergonomics in order to improve ergonomic conditions and OHS and hence improve human performance. This would be beneficial to both employees and management.

Standing is a common working position required for most of the operations in machining. Standing within limited areas for long periods of time intensifies musculoskeletal fatigue and body discomfort. These include lower extremity fatigue, pain, swelling and discomfort, venous blood pooling, low-back pain, and whole-body fatigue (Dempsey, 1998; Grandjean and Hunting, 1977) [10], [11]. Many incidences of low-back pain have been associated with prolonged standing of four hours or more per day (Jorgensen, et al., 1993; Magora, 1972) [12]. Prolonged standing can also cause the joints in the spine, hips, knees, and feet to become temporarily immobilized or locked. This immobility can subsequently lead to rheumatic diseases due to degenerative damage to the tendons and ligaments (Bernard, 1997) [13]. Machine operators and others whose jobs are characterized by prolonged standing commonly report these problems. Various solutions to reduce these problems have been proposed in literature. The main concern of work system design is usually the improvement of machines and tools. However, design of work place system as a whole is not considered in many places. Neglect of ergonomic principles brings inefficiency and discomfort to the workforce.

The main objective of this study is to investigate ergonomics, occupational health and safety problems faced by the operators working in CNC machines and to suggest suitable engineering solution to prevent the occupational health hazard. The methodology for investigating ergonomics, and OHS issues in the industry require collection of data based on checklist that include questions on: (1) Dimensions of the machines, (2) Details of the employees, (3) OHS issues, (4) Ergonomic issues, and (5) Environmental factors. Regarding safety issues, the employees were asked questions about the injury if any and absenteeism. The ergonomic issues have questions regarding worker complaints on health and safety such as back pain, upper body pain, fatigue and stress. The environmental factors have questions on the perception of heat, noise and light.

II. Anthropometry, Biomechanics

Designers and human factors specialists incorporate scientific data on human physical capabilities into the design of systems and equipment. Human physical characteristics, unlike those of machines, cannot be designed, but have to be incorporated while designing the systems or equipment. Anthropometric data are more appropriate when they are derived from a survey of the existing worker population of interest and shall be used in the design of systems, equipment (including personal protection equipment), clothing, workplaces, passageways, controls, access openings, tools, etc. The human interface with other system components needs to be treated as objectively and systematically as other interface and hardware component designs. Application of appropriate anthropometric and biomechanics data are important while designing systems and equipment for human usage.

Limiting design dimensions, such as reach distances, control movements, display and control locations, test point locations, and handrail positions, those restricts or are limited by body or body part size, shall be based upon the 5th percentile data for applicable body dimensions. As per the MIL-Standard 1472 D (MIL-STD-1472D, 1989) [14]. all clearance and dimensions like passage of the body or parts of the body must accommodate or allow passage of whole body or parts of body as the case be for 95 percent of persons, that is 95th percentile of data on anthropometric shall be used.

III. Work Related Musculoskeletal Disorders (WRMSD)

Musculoskeletal disorders are not sudden "injuries", but are rather "illnesses" that develop gradually over a time, aggravated by repeated exertions or movements of the body.. WRMSDs are characterized by the symptoms of pain, numbness, stiffness, and eventually weakness, depending on the type of disorder and body location. WRMSD symptoms are task dependent. Video display unit (VDU) operators, for example, have reported musculoskeletal symptoms in the upper extremities, neck and shoulders. WRMSDs increase with work stress or job strain and may be mediated, in part, through excess muscle tension.

Awkward postures are postures that when used repetitively or for prolonged periods result in increased risk of fatigue, pain or injury. These postures are sustained either actively by muscle contractions or passively by compressive or tensile loads on bones, muscles, tendons, ligaments, etc. (Chaffin et al., 1984) [15]. Muscle contractions require energy and produce waste products of metabolism. If the contractions are of sufficient magnitude, the blood supply to the muscles is reduced, limiting the supply of oxygen and other nutrients and allowing waste products to build up which leads to fatigue and pain in the muscles (Astrand et al., 1986) [16]. Passive loading stresses the tissues and may result in strain. This tissue strain may lead immediately to feelings of pain or numbness or may accumulate over time and result in tissue damage. Table I lists some of the adverse health effects associated with awkward lower extremity, trunk and neck postures. Work-related Low Back Disorders (WLBD) control is an important issue in occupational health. Several epidemiological studies have proved that musculoskeletal disorders and workload are related (Bernard, 1997; Hales and Bernard, 1996) [17], [18]. Workers of CNC machines frequently perform tasks which have potential for WLBD.

Table I. Adverse health effects associated with various postures

Posture	Adverse Health Effects
Stationary standing	Compression neuropathies
Using a foot pedal	Pain in the low back, hip and knee
Kneeling	Increased heart rate
Squatting	Compression neuropathies
Sitting with Back support	Compression neuropathies
Sitting without Back support	Low Back pain
Mild flexion/trunk	Increased heart rate, Back Pain
Severe flexion/trunk	Increased heart rate, Back Pain
Twisted/bent/trunk	Back pain
Mild flexion/neck	Neck pain and stiffness
Severe flexion/neck	Pain in the neck, upper back and arms neck pain and stiffness
Twist/bent/neck	Neck and shoulder pain headache
Extension/neck	Neck pain and stiffness

IV. Case Study- CNC Machines

A list of CNC machine work centers on which the present study was performed is given in Table II.

Table II. List of CNC work centers studied

CNC Machine Type	No of work centre studied
Lathe	31
Bending machines	8
Boring Machine	10
Turning Centre	9
Drilling Machine	6
Gas Cutting Machine	4
Edge Preparation machine	4
Welding Machine	2
Press Brake	1

Though CNC machines may help in reducing the work force and increase the production rate, there are some ergonomic and health related problems associated with these machines. The CNC machines consist of control panel attached with display which are used in performing initial operations in the machine and view the program respectively. In some machines the control panel and the display unit is fixed on the machine itself, pendent type arrangement is used in some machines and in some machines fixed on a stand separately away from the machines. The positioning of these parts are very important in these machines to reduce the repetitive motions and to prevent ergonomic and health related problems to the operators like back pain, neck pain, shoulder pain and eye strain. Initial analysis/ understanding of existing set up was done through check list distributed to 122 operators. During the survey assurance was given that the data collected will be used only for the study purpose and to make improvement in the work area only and not to take any action against the operator. This helped in colleting the realistic data.

Interviews have been conducted on all the 75 CNC machines operators, two operators for each machine and the findings are recorded.

Table III Employee Data

Sl. No	Parameter	Mini	Max	Mean	SD
1	Age < 40	23	38	27.40	3.895
	Height (cm)	156	175	164.88	4.774
2	Age < 41-49	43	49	47.34	1.548
	Height (cm)	155	190	164.75	6.193
3	Age < 50-59	50	59	53.04	2.659
	Height (cm)	150	178	163.23	6.325
4	Overall Age	23	59	45.08	10.155
	Overall Height	150	190	164.21	5.964

The data analyzed were indicated specific ergonomic problems exist in most of the work centers. The employees age ranged from 23 to 59 years with a mean of 45.08 and a standard deviation of 10.155. The height of the tallest operator is 190 cm and the shortest operator is 150 cm with a mean of 164.21cm and a standard deviation of 5.964 (Table III).

V. Comparison with Anthropometric Recommended Data

The analysis could only be concluded by comparing the data with the anthropometrically recommended data. The anthropometrically recommended value is taken from the book "National Ergonomic Database for the Indian Male population" given by the Industrial design centre of Indian Institute of Technology, Bombay (1992) [19]. 95th and 5th percentile values recommended are considered for comparison wherever applicable. For example operator heights, height of the control panel are to be corresponding to 5th percentile.

Table IV and V list the deviations of the actual values on the machines compared to anthropometric recommended values.

Table IV. Comparison for Control panel height with Anthropometric recommended Values of Elbow height.

Sl. No.	Machine Type	Actual Value (cm)	Anthropometric recommended Value (cm)	Variation
1	Edge Preparation	150.0	95.6	54.4
2	Machining	145.0	95.6	49.4
3	Gas Cutting	125.7	95.6	30.1
4	Press Brake	125.5	95.6	29.9
5	Turning	120.0	95.6	24.4
6	Drilling	118.5	95.6	22.9
7	Lathe	118.3	95.6	22.7
8	Welding	111.3	95.6	15.7
9	Boring	110.0	95.6	14.4
10	Bending	103.5	95.6	07.9

Table V. Comparison for the top of Display with Anthropometric recommended Values of Eye height.

Sl. No.	Machine Type	Actual Value (cm)	Anthropometric recommended Value (cm)	Variation
1	Edge Preparation	186.0	143.4	42.6
2	Machining	161.4	143.4	18.0
3	Gas Cutting	160.5	143.4	17.1
4	Press Brake	159.0	143.4	15.6
5	Turning	156.2	143.4	12.8
6	Drilling	156.0	143.4	12.6
7	Lathe	150.9	143.4	07.5
8	Welding	150.0	143.4	06.6
9	Boring	147.8	143.4	04.4
10	Bending	145.3	143.4	01.9

VI. Discomfort Study

Postural discomfort/pain is one of the crucial problems of the workers in CNC centers. Corlett and Bishop's method of body mapping (1976) [20], is one of the most commonly and widely accepted methods of obtaining information about body pain fig. 1. This method of discomfort assessment is inexpensive, sensitive and suitable for field work Several researchers have used this method to identify the sites of pain and their intensities in varying tasks. This is used for assessing the pain level.

The intensity of pain was measured by asking the worker to rate the intensity of pain for the various parts of the body at regular intervals namely, before the starting of work, before mid morning tea, before lunch, before afternoon tea and at the end of work. Various rating scales can be used to measure the intensity of the pain such as Verbal rating scale, Visual analogue scale, Numeric rating scale and Graphic rating scale.

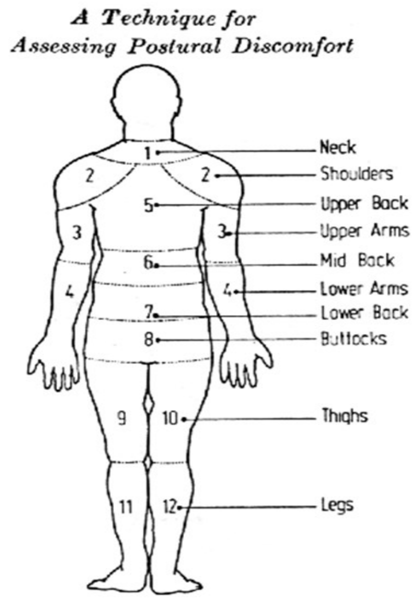

Fig. 1. Body part Discomfort mapping

In this study a numerical rating scale rated from 0- for no pain to 4- for extreme pain was used as it can be easily explained to workers and easy to understand. Also the data from this scale can be easily analyzed as the intensity of pain was given in terms of whole numbers. A table based upon this rating scale was developed which can rate the intensity of pain for different parts of the body at regular intervals.

Pain ratings for different numbers are as follows:

0- No pain.
1- Minimal pain.
2- Moderate pain.
3- Severe pain.
4- Extreme pain.

The workers were asked to give their pain rating according to the scale given for each part of the body at regular intervals namely, Start of the shift, before morning tea break, before lunch, after lunch, before afternoon tea break and end of the shift.

VII. Analysis of Results on Worker Health Complaints

Employees having pain in various parts of their body are shown in fig. 1. It is observed that 45 percent of the employees have lower back pain, 44% of neck, 21% of upper-body pain, 61% of shoulders and 41% of leg. These are clear indications of ergonomic deficiencies in the work system design.

Fig. 2, 3 and 4 shows the mean pain level at different body parts during different time intervals for the age groups below 40, 40 – 49 and 50 – 59 respectively. The maximum pain level was reported at the end of the shift and worst affected body parts are shoulder, neck and lower back in all the age groups.

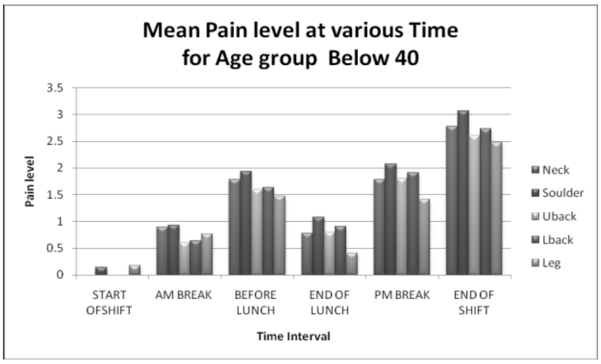

Fig. 2. Mean Pain level at various times for age group below 40

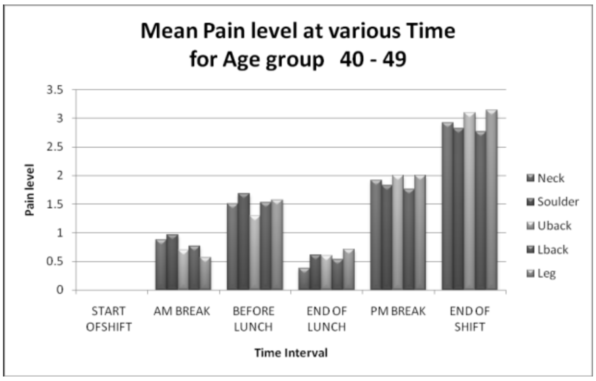

Fig. 3. Mean Pain level at various times for age group Between 40 and 49.

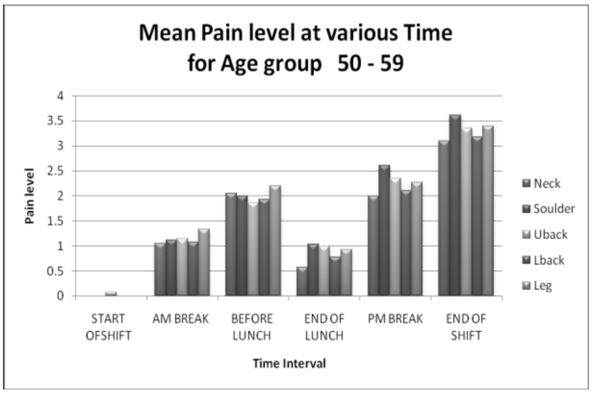

Fig. 4. Mean Pain level at various time for age group between 50 and 59.

The analysis revealed that except at the start of the shift, at different time intervals employees felt musculoskeletal fatigue and body discomfort in various body parts. Though the arm, legs, lower back, upper back, shoulder and neck are the affected body parts, shoulder and neck are the main body parts predominantly affected. This is due to the level difference of the display and controls from anthropometrically recommended values for the region.

At the end of the shift the mean score of the pain level of age groups below 40 is 2.74(SD 0.732), 40 to 49 is 2.85 (SD 0.612) and 50 to 59 is 3.30 (SD 0.785) (Table VI). due to the positioning of display also the pain increased with time of operations during the day of work.

Table VI. The mean score of the pain level

Age Group	Start of Shift	AM Break	Before Lunch	After Lunch	PM Break	End of Shift
40 & below	0 SD 0.	0.74 SD 0.594	1.66 SD 0.733	0.74 SD 0.712	1.77 SD 0.751	2.74 SD 0.732
41- 49	0 SD 0	0.87 SD 0.484	1.53 SD 0.710	0.42 SD 0.577	1.83 SD 0.55	2.85 SD 0.612
50 & above	0 SD 0	1.08 SD 0.463	1.97 SD 0.649	0.84 SD 0.665	1.97 SD 0.807	3.30 SD 0.785

According to the questionnaires and field survey we found the positions of displays and control panels are the prime factors of introducing discomforts to the operators in using CNC machines. Most of the machines taken up for the study have their displays situated above the anthropometrically recommended values of 143.4 cm (for the Indian population) This is resulted in pain at neck and lower back.

The comparison of actual position of control panels in the machines studied with the anthropometrically recommended values revealed that there are much above the recommended value of 95.6 cm this has resulted in pain at shoulder, neck and lower back.

The mean pain level analysis reveals that the pain level at the end of the shift is the maximum at all body parts. Also operators in the age group 50 – 59 are the worst affected.

VIII. Conclusion

It is observed that the level of discomfort increases irrespective of age group. It is further observed that older age groups tend to report more discomfort, and that the most discomfort is reported by the age group 50 years old or older. A slight improvement was seen after the 30-minute lunch break. Compared with the production it was noticed that before lunch it was high and reduced gradually. Increase in discomfort as the shift progresses may be a contributor to this decrease in productivity, and this needs to be verified rigorously.

The CNC machines consist of control panel attached with display but the placement in the machine plays a vital role in contributing the discomfort. In some machines the control panel and the display unit is fixed on the machine itself, pendent type arrangement is used in some machines and in some machines fixed on a stand separately away from the machines, each will have its own effect on the operator. In addition to the position of the display and controls.

The present study established that, the discomfort is related to the position of the control panel and display, although the relationship is not the same across body parts. The mean pain level analysis reveals that the pain level at the end of the shift is the maximum at all body parts. For display the difference in the anthropometric value resulted in pain at neck and lower back, and for control panel resulted in pain at shoulder, neck and lower back.

IX. Recommendations

If the control panel and the displays are to be separated from the single panel and the height of the control panel and displays of the CNC machines to be maintained as recommended by the anthropometric values for the geographic locations, then most of the discomforts experienced by the CNC operators could be reduced.

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