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Ergonomic Evaluation of a Lathe Environment Using Energy Expenditure Prediction Program

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Abstract: — For evaluating a workstation, energy expenditure plays a vital role as far as the worker's safety, health, and efficiency of performing the task most effective and efficient manner is concerned. This study has been carried out for finding the energy expenditure by using Energy Expenditure Prediction Program Software. The energy expenditure was determined by observing and recording the activities during the operations on a lathe machine. In this work, the average metabolic energy rate is predicted by knowing the energy expenditure and task duration. The method used in this work is more accurate and feasible and less costly than laboratory techniques such as measurement of oxygen consumption, carbon dioxide production, etc. The technique used in this work provides an objective rate to gauge worker's fatigue. The study identifies the grade of physical work based on energy expenditure for various activities during the experiment and the activities having higher energy expenditure as compared to set limits by various agencies to be ergonomically designed. The findings of this study explored that during a lathe operation out of nine selected activities four activities namely loading of job, lathe machine tool setting and adjustments, rough facing, and unloading of finished job consumes more energy as compared to standards and therefore these activities should be emphasized the as for as ergonomic design of a lathe interface environment is concerned.

Index Terms **- Energy expenditure, Ergonomic design, Design tool, Lathe Machine, Lathe operations, Task duration, Worker fatigue,**

1. INTRODUCTION

A. Ergonomics

Ergonomics (or human factors) is the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data, and methods to design to optimize human well-being and overall system performance. Ergonomics is concerned with the "fit" between the user, equipment and, their environments. It takes account of the user's capabilities and limitations in seeking to ensure that tasks, functions, information, and the environment suit each user. To assess the fit between a person and the used technology Ergonomics draws on many disciplines in their study on human and their environments, including anthropometry, biomechanics, mechanical engineering, industrial engineering, industrial design, kinesiology, physiology, cognitive physiology. Ergonomics in its application has an interdisciplinary approach, with the ultimate objective of improving the level of comfort.

The branch of ergonomics can be divided into three broad categories: -

Physical ergonomics

Physical ergonomics is concerned with human anatomy, and some of the anthropometric, physiological, and biomechanical characteristics as they relate to physical activity. Physical ergonomic principles have been widely used in the design of both consumer and industrial products**.**

Cognitive ergonomics

Cognitive ergonomics is concerned with mental processes, such as perception, memory, reasoning, and motor response, as they affect interactions among humans and other elements of a system.

Organizational ergonomics

Organizational ergonomics is concerned with the optimization of socio-technical systems, including their organizational structures, policies, and processes. Relevant topics include communication, crew resource management, work design, work systems, design of working times, teamwork, participatory design, community ergonomics, cooperative work, new work programs, virtual organizations, telework, and quality management.

Skeletal muscles may be thought of as biochemical machines with chemical energy stored in adenosine triphosphate (ATP) going into the muscles and being converted to mechanical work and heat energy (Sherwood, 2012) and (Umberger, Gerritsen and Martin, 2003). In other words, the total metabolic energy expenditure will be transformed mainly into the sum of the work done by the joint actuator torques, heat energy dissipation, and basal metabolic energy. In the case of static loading – where the mechanical work done by the muscle is zero – the muscle energy is all dissipated as heat. Mechanical power is expressed as the product of joint actuator torque and joint velocity. The total mechanical power of the system is determined as the sum of the mechanical power of all the joints.

Ergonomists, applied physiologists, sports scientists, nutritionists, and epidemiologists require the estimates of activity patterns and energy expenditures. Methods generally used for measurement of energy expenditure are: -

- 'Gold Standard' Method
- Cosmed K4b2 (Rome, Italy) Portable Indirect Calorimeter
- Metamax (Borsdorf, Germany)
- Medgraphics VO2000
- Accelerometer
- Portable Metabolic Unit
- Pedometer
- Polar Heart Rate Monitor
- Doubly Labelled Water
- Multiple Inertial Sensors
- Motion Sensors
- Combined Heart Rate and Motion Sensor
- Combined Heart Rate and Questionnaire Methods
- Integrated Electromyography
- Pulmonary Ventilation Volume
- Thermal Imaging
- Flex-Heart Rate Method

Recent technological advancements in sensor technology along with the great progress made in algorithms have made accelerometers a powerful technique often used to assess everyday physical activity. Energy expenditure consists of the following three components: -

- Maintenance expenditure
- Diet-induced energy expenditure
- Activity-induced energy expenditure

B. Literature Review

A model of muscle energy expenditure was developed for predicting thermal as well as mechanical energy liberation during simulated muscle contractions (Umberger, Gerritsen and Martin, 2003). The muscle energy model was evaluated at varying levels of complexity, ranging from simulated contractions of isolated muscle to simulations of whole-body locomotion. In all cases, an acceptable, agreement was found between simulated and experimental energy liberation.

(Gunn *et al.*, 2004) investigated four self-paced household tasks (sweeping, window cleaning, vacuuming, and mowing), conducted in the subjects' homes and a standardized laboratory environment. Energy expenditure was predicted via indirect methods. The findings suggest that the aforementioned household chores can contribute to the 30 min. per day of moderate-intensity activity required to confer health benefits. However, the substantial between-subject variability in energy expenditure resulted in some persons performing these tasks at a light intensity. The significant metabolic equivalent (MET) differences between the home and laboratory emphasize the effects of 'environment and terrain' and the 'mental approach to a task' on self-paced energy expenditure. (Levine, 2005) reviewed and assessed metabolic needs, fuel utilization, and the relative thermic effect of different food, drink, drug, and emotional components for measurement of energy expenditure in humans. He recommended where high accuracy is required and sufficient resources are available, an open-circuit indirect calorimeter can be used, whereas when resources are limited and/or optimum precision can be sacrificed, flexible total collection systems and non-calorimetric methods are potentially useful if the limitations of these methods are appreciated. For detailed information on free-living subjects' factorial method is used. (Eric M. Przybyszewski, 2011) predicted energy expenditure from physical activity (PA), heart rate (HR) and anthropometry in female Indian tea pluckers. An energy expenditure (EE) prediction equation was generated using a branched method that first distinguishes time during normal workday activities (resting, plucking and walking) using accelerometer counts. Resting EE was estimated from age and weight, while minute-by-minute non-resting EE was estimated from HR and body mass index BMI. He concludes that energy expenditure can be accurately predicted with a branched equation based on the PA, HR, age, weight, and height for a specific population participating in a known set of activities. Very little is known about the longitudinal changes in energy requirements in late life. (Cooper *et al.*, 2013). The purposes of this study were to: (i) determine the energy requirements in late life and how they changed during a 7-year time-span, (ii) determine whether changes in fat-free mass (FFM) were related to changes in resting metabolic rate (RMR), and (iii) determine the accuracy of predicted total energy expenditure (TEE) to measured TEE. He concluded TEE, RMR and activity energy expenditure (AEE) decreased in men, but not women, from the 8th to 9th decade of life. The Dietary Reference Intake (DRI) equation to predict TEE was comparable to measured TEE, while the World Health Organization (WHO) equation over-predicted TEE in an elderly population. Non-calorimetric methods (Ocobock, 2014) for estimating energy expenditure are often used due to their ease of use and relative economy. These methods estimate energy expenditure through physiological variables that are related to energy expenditure such as heart rate and muscle activity. These methods have been standardized and validated using calorimetric methods. (Levine, 2005). Five different methods were also used like integrated electromyography, pulmonary ventilation volume, thermal imaging, flex-heart rate method and the doubly labeled water method. The model for predicting human total energy expenditure (TEE) (Ocobock, 2014), the Factorial Method, significantly underestimates actual TEE, particularly among highly active populations. In this study, the Allocation Model is presented for predicting TEE. Unlike the Factorial Method, the Allocation Model includes metabolic cost terms for both thermoregulation and the thermic effect of food, as well as using more accurate basal metabolic rate and activity cost estimations. The Allocation Model was tested using doubly labeled water and flex-heart rate measured TEEs of healthy, highly active adults. The results suggest the Allocation Model is a powerful new tool that should be used in place of the Factorial Method for estimating human TEE and can be used to analyze adaptations, life history strategies and differential energy allocation among highly active humans in natural environments.

C. Problem Statement

The worker on a Lathe machine spends a substantial amount of time while performing the machining operations. The work activities require physical effort like handling of materials, supply and movement of tools and work. Thus occupations like manufacturing often require workers to expend moderate to high levels of physical energy to perform jobs. Back injuries resulting from overexertion are common in most occupations. A high level of physical efforts may cause stress and strain. The factors which affect energy consumption are methods of work, work posture, work rate and tool design.

In this study, the energy expenditure was determined by observing and recording the activities during the machining operations on a lathe machine.

In this work the average metabolic energy rate is predicted by knowing the energy expenditure and task duration. The metabolic energy is calculated by dividing the job into tasks or activity elements.

Various cognitive tests were conducted before starting the experiment and based on the acceptable result, the subject was selected for determining and evaluating his energy expenditure on the lathe.

D. Design Tool Program and Energy Expenditure Prediction Program

Design Tools for Cognitive Tests

Cognitive tests are assessments of the cognitive capabilities of humans. Before experimenting, it is required to have a preliminary investigation for work assignments like: -

- Simple Reaction Time Experiment
- Choice Reaction Time Experiment
- Psychophysics – Line Length Judgment
- Fitts Tapping Task
- Short Term Memory Span
- Stroop Test
- Visual Inspection- Resister inspection

The subject for the experiment was selected based on these various cognitive tests. For the above cognitive tests, Design Tools Laboratory Software (*Benjamin W. Niebel and Andris Freivalds, 2001, Design Tools Laboratory Software for Methods, Standards, and Work Design (11th ed.) Programmed by Dongjoon Kong, Version 3.0.0*) was used.

Based on tests Fig.1,2 & 3., the experiment was started and then energy expenditure of lathe work environment was evaluated.

Fig. 1. Simple Reaction Time Experiment

Fig. 2. Choice Reaction Time Experiment

Fig. 3. Short Term Memory Span Test

Energy Expenditure Prediction Program (EEPP)

Advantages of using EEPP

The EEPP software: -

- Is easy to understand and apply to your materials handling jobs, is non-technical in operation,
- Provides objective values to gauge worker safety, make comparisons, and design improvements,
- Is less expensive and often more feasible than laboratory techniques,
- Is more accurate than pulling standard energy expenditure values from published tabular data, and
- Provides a summary value to compare with NIOSH guidelines.

EEPP Information

The Energy Expenditure Prediction Program™ (EEPP) predicts metabolic energy expenditure rates by summing up the energy requirements of small, well-defined work tasks that comprise the entire job. The resulting estimate is much more precise than a single table value depicting an entire job, and the required job analysis procedure is accordingly more tedious, but computerization (e.g. EEPP) has made this type of analysis feasible. This method allows energy expenditure analysis of existing jobs as well as simulated, non-existent jobs. This ability to simulate workplaces is important in the job design process. This method also identifies specific work tasks that contribute heavily to an overall high job energy expenditure rate, which facilitates job redesign activities.

The metabolic prediction model (Garg, Chaffin and Herrin, 1978) is based on the assumption that a job can be divided into tasks or activity elements. The energy expenditure requirements for each task can be added together to determine the energy expenditure of the entire job. The energy expenditures of the tasks are calculated using prediction equations derived from empirical data. The information for each task needed to compute these energy requirements includes: the force exerted, distance moved, frequency, task posture, lifting technique for lifting tasks, and the time needed to perform the tasks. Gender and body weight, two worker factors, are also needed. The average metabolic energy expenditure rate for the job is then predicted as the average (over time) of the sum of the energy requirements of the individual tasks, plus the energy required to maintain various body postures. The prediction model is described by the following equation:

Ejob = Ebasal + S(Etaskj / Ttaskj)

Where:

E_{job} = average energy expenditure rate of the job (Kcal/min)

E_{basal} = metabolic energy expenditure rate necessary to maintain basal metabolism and posture (Kcal/min)

E_{taskj} = net metabolic energy expenditure of the j^{th} task in steady-state (Kcal)

T_{taskj} = time duration of the j^{th} task (min.)
As the equation shows, the energy expenditure prediction model has two basic components: -
Energy expenditure is necessary to maintain non-work-related body energy requirements, and
Net energy requirements of the various work tasks.

The first component depends upon the energy required for posture maintenance. The energy requirement is a function of gender, body weight, and body posture. The model can accommodate three different body postures: standing, standing bent over and sitting.
The second component is the net metabolic energy expenditures for the various tasks that comprise the entire job. The model accommodates many different work tasks, including both static and dynamic work. The prediction of the energy expenditure of the separate tasks is a function of various factors, as was previously mentioned. Much of the data needed for this methodology can be collected from industrial engineering time and motion studies or from predetermined time systems. (Benjamin W. Niebel and Andris Freivalds, 2001) provides further information.
The accuracy of this prediction procedure depends upon several factors, including: -

(1) The completeness and accuracy of the division of the job into tasks (the job analysis must be correct);
(2) The availability of a prediction equation that precisely describes the task that has been identified;
(3) The accuracy of the task equation itself.

Program Inputs

- Subject's gender and weight;
- List of activity elements (e.g. Lift, push, carry); and
- Parameters specific to activity elements (e.g. Frequency, weight of load, distance carried).

Program Outputs

- Listing of activity elements with their corresponding energy expenditure;
- Calculation of the total energy expenditure rate for the job in Kcal/minute or METS; and
- Data can be viewed on-screen, printed, or written to a file for later recall or for inclusion in a report.

Task Elements

- Posture Tasks:
  - Standing
  - Standing bent
  - Sitting
- Incremental Tasks:

(1) Lifts or lowers:
Stoop - knees straight, back bent
Squat - knees bent, back straight
Semi squat - knees and back bent
Arm lift - Hands above 32 inches
One-handed - Hands above 32 inches
(2) Walks:
Level surface
Inclined surface
(3) Carries or holds:
Arm's length at sides
Against waist at sides
(4) Pushes or pulls:
Horizontal direction
Forward direction
(5) Handwork - General:
Light (writing)
Heavy (gear assembly)
(6) Arm work - Lateral:
180 degrees - one or both hands
90 degrees - standing
90 degrees - sitting one or both hands
(7) Arm work - Horizontal:
Standing
Sitting
(8) Arm work - General:
Light one hand (filing metal)
Light both hands (planning wood)
Heavy one hand (hammering nails) Heavy both hands (upholstering)

The following screenshot in **Fig. 4.** example illustrates EEPP after the data has been entered.

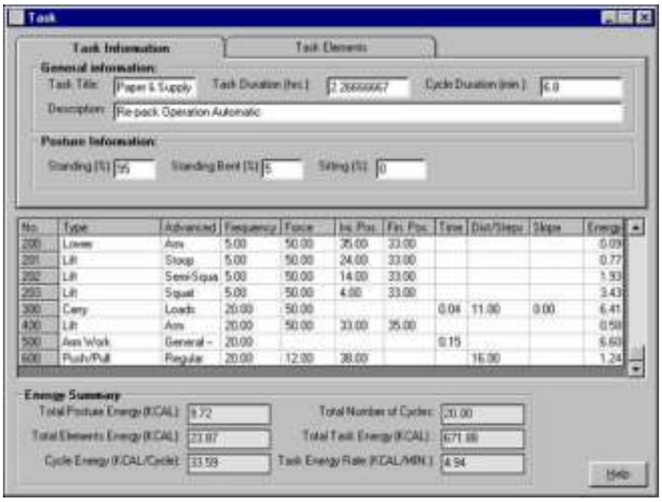

Fig. 2. Screenshot of EEPP showing task information

2. EXPERIMENTAL SET UP AND PROCEDURE

A. Experimental Setup

The literature revealed that for carrying out experimental investigations, it is best to perform in the work field of industrial environment to incorporate utmost realistic conditions and achieve precise results. The experiment was conducted at **Osama Machines Ltd, Aligarh (India).**

The experimental setup comprised of the following components: -

1. A conventional Lathe Machine
2. Vernier Caliper
3. A heavy cylindrical job of mild steel weighing 84 kg
4. Clamp, jigs and fixtures
5. Single point cutting tool
6. Coolant
7. Boring tool
8. Rack
9. Drills of different sizes
10. Video Camera for recording Task

The conventional lathe machine environment includes the lathe machine, a heavy cylindrical job of about **84 kg**. The material selected is of mild steel having a density of **7.85 g/cubic cm**. The initial dimension of the workpiece is of diameter **232 mm** and length as **255 mm** and the initial volume of job **is 10779.68404 cubic cm** and a rack of suitable dimension used for keeping tools was used as shown in **Fig.5.** The experiment was performed in **Osama Machines Ltd, Aligarh (India).** The working environment conditions like temperature, sound level and illumination level were tested. The average dry bulb temperature was **29.25 ˚C** and the average wet-bulb temperature was **25.5 ˚C**. The illumination level maintained was **230 LUX** on m/c and **30 LUX** on the working area. Sound level throughout the experiment is recorded and is found within the acceptable range **as 110dB (Max), 97dB (Normal) and 108 (Peak)** and verified by the Design Tools Laboratory Program (Benjamin W. Niebel and Andris Freivalds, 2001).

As shown in **Fig. 6.** the operator is standing in front of the lathe machine at a comfortable distance for experimenting.

The Schematic diagram of the experimental setup employed in the experimental investigation undertaken in the present work is shown in **Fig 5.** and **Fig 6.**

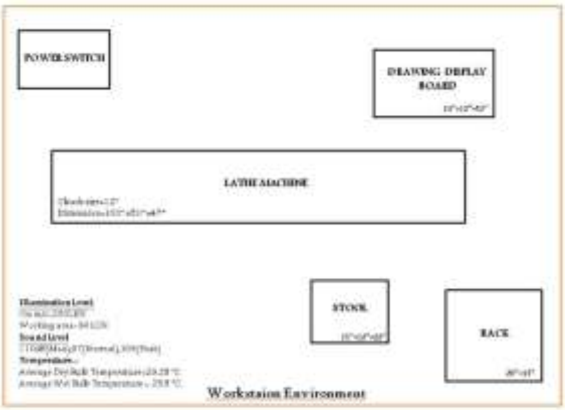

Fig. 5. Schematic diagram of the workstation environment employed in the experimental investigation undertaken in the present work

Fig. 6. Experimental setup

B. Subject

The subject for the experiment was selected based on various cognitive tests. For this cognitive test, Design Tools Laboratory Software (Benjamin W. Niebel and Andris Freivalds, 2001) was used. The findings of these tests have resulted from an average simple reaction time of **0.3898 sec**. and its standard deviation as **0.0293**.

Through the same test, it was recorded that the average choice reaction time and corresponding standard deviation **0.01097**. In the short memory span test, the subject was asked to enter five-digit numbers after **20** seconds the result obtained was the length as 5 and the number of correctly recalled as 5, which implies that the response was **100%**. This result indicates that the subject selected for the concerned experiment is successful in the short-term memory test and fit for the concerned task.

The age of the subject was **52 yrs. old** and height were **165 cm** having experience of **9 years** working on lathe machine.

Based on tests, the experiment was started and then energy expenditure of lathe work environment was evaluated.

C. Experimental Procedure

After conducting the cognitive tests on the subject and before starting the experiment, the subject was given sufficient instructions to perform the job. A heavy workpiece of dimension **ϕ232mm x 255 mm** length of mild steel was selected. The operations performed on the workpiece for energy expenditure measurements were **Loading, Facing, Turning, Drilling, Boring, Finishing and Unloading**. The activities like **machine ready** and **switch on**, **setting and adjusting, loading, unloading, execution** and **switching off** the machine were recorded through a Sony HD video camera.

The recording was done for continuously **3 days** on working hours for about **19 hours**. After recording each task, software name **Energy Expenditure Prediction Program (EEPP)** was used to analyze the energy rate. For this, the job work was divided into 9 tasks and each task was further divided into various elements. **Task1** consists of **4** elements, **Task2** consists of **4** elements, **Task3** consists of **5** elements, **Task4** consists of **1** element, **Task5** consists of **6** elements, **Task6** consists of **9** elements, **Task7** consists of **27** elements, **Task8** consists of **2** elements and **Task9** consists of **9** elements. The energy expenditure for various tasks was determined using Energy Expenditure Program (EEP) software. The heavy workpiece which was used for the experiment has been shown in **Fig. 7 (a).** and **Fig. 7 (b).** which shows the initial and final dimensions of the job in the 3-D Model &Actual view respectively.

A final 2-D model dimension of the workpiece geometry (2D) used for the measurement of energy expenditures is shown in **Fig 8.**

The recorded time of every element is entered in the EEPP. The weight of the operator, the weight of the job and the postures of the operator for every task element like a stoop, squat, sitting standing, push, pull, handwork, arm work, etc. are entered. After entering every detail of all Task Elements, EEPP calculates the Total Posture Energy, Total Elements Energy, Cycle Energy, Total Task Energy and Task Energy Rate.

The Energy Expenditure detailed report is generated by the program for every task which is then used for analyzing the result.

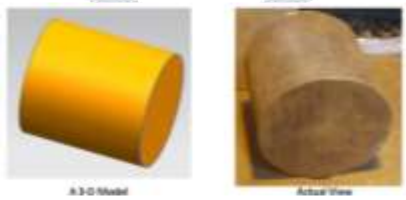

Fig. 7. (a). Mild Steel Job (Initial)

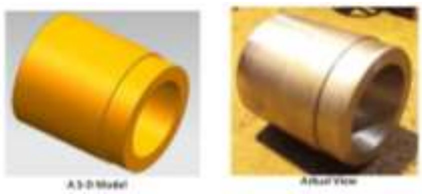

Fig. 7. (b). Mild Steel Job (Final)

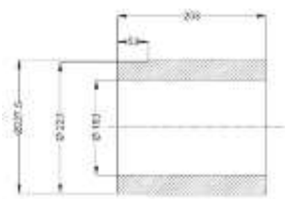

Fig. 8. The workpiece (2D) used for energy expenditure measurements

Some of the pictures taken while experimenting with of all the task operations regarding the present study have been shown below in **Fig 9.**

Fig. 9. Subject performing the task

The following **Table 1** shows the task description: -

Table 1. Task Elements for determining the energy expenditure

TASK NO	TASK NAME	NO. OF ELEMENTS	NAME OF ELEMENTS
1	MACHINE READY	4	Cleaning M/C
			Setting m/c parts to make it ready
			Switching on the m/c main supply
			Checking running m/c
2	LOADING	4	Holding job on hands
			Lifting job to chuck
			Carrying load to the m/c
			Holding job while loading on chuck
3	MACHINE SETTING	5	Centering of job
			Setting drill tool on the tailstock
			Next miscellaneous setting (drill tool + lamp)
			Arranging and setting drawing display board (machine off)
			Changing belt of pulley
			Rough facing
4	ROUGH FACING	1	Turning job
5	TURNING	6	Measuring diameter and miscellaneous setting
			Sharpening the cutting tool + setting tool post(machine off)
			Supervisor telling about drawing (m/c off)
			Facing acing operation
			Cleaning chips from job, tool and machine(m/c off)
			Setting drilling tool a
6	DRILLING	9	Drilling job
			Setting cutting tool and tool post
			Turning
			Setting drilling tool b
			Drilling
			Changing drilling tool
			Drilling
			Cleaning chips and removing drill tool
			1st Step Boring Of 38mm
7	STEP BORING (depth of cut=5mm)	27	2nd Step Boring Of 43mm
			3rd Step Boring Of 48mm
			4th Step Boring Of 53mm
			5th Step Boring Of 58mm
			6th Step Boring Of 63mm
			7th Step Boring Of 68mm
			8th Step Boring Of 73mm
			9th Step Boring Of 78mm
			10th Step Boring Of 83mm
			11th Step Boring Of 88mm
			12th Step Boring Of 93mm
			13th Step Boring Of 98mm
			14th Step Boring Of 103mm
			15th Step Boring Of 108mm
			16th Step Boring Of 113mm
			17th Step Boring Of 118mm
			18th Step Boring Of 123mm
			19th Step Boring Of 128mm
			20th Step Boring Of 133mm
			21st Step Boring Of 138mm
			22nd Step Boring Of 143mm
			23rd Step Boring Of 148mm
			24th Step Boring Of 153mm
			25th Step Boring Of 158mm
			26th Step Boring Of 160mm
			Setting and adjustment of tool

			Finishing facing operation
8	FINISHING	2	Finishing turning operation
			Carrying job on rack
9	UNLOADING	9	Lowering job to rack
			Measuring dimension of job
			Walking back to m/c
			Un-mounting tools from m/c
			Place the tools on the proper place
			Walking back to m/c
			Cleaning M/C
			Power switch off

The energy expenditure for the various task and their respective elements was determined using EEP program after inputting the recorded data. The EEP analyzes and determines the average metabolic energy rate of the task by knowing the energy expenditure of the time duration of the task.

3. RESULT AND ANALYSIS

A. Result

An overview of the literature about of on studies on human performance using energy expenditure in the context of Context lathe environment indicated that either no or little consideration has been given to this area in researches conducted previously. On the other hand, the use of lathe machines all over the world is increasing day by day. Today a very large size of the workforce is associated with the work on lathe machine tools. Human-machine interaction is already playing a vital role across the entire production process, from planning individual links in the production chain right through to designing the finished product. Innovative technology is made for humans, used by and monitored by humans. The products therefore should be reliable in operation, safe, cost-effective, accepted by personnel and last but not least, energy expenditure will be well within the permissible limit. This interplay between technology and user, known as human-machine interaction, is hence at the very heart of industrial production. Keeping in view these considerations, the present study was designed to explore how energy expenditure can be determined in a Conventional Lathe Environment using the Energy Expenditure Prediction program. Further, the study also aimed to compare the determined energy expenditure with standards set by various agencies.
The summary and detailed report of every task was generated using the EEP program after inputting the recorded data.
The result obtained after providing all information to the program has been shown in Table 2 which indicates the energy expenditure measurements for various tasks on lathe machine ready for operation, loading of the job, movement from rack to machine and loading workpiece, tool and machine setting, task operation execution like facing turning drilling boring, finishing and unloading workpiece and movement from machine to rack and machine switch off.

Table 2. Energy Expenditure measurements summary through energy expenditure prediction program for single workpiece

TASK TITLE	No. of Elements	Task Duration	Cycle Duration	Total Posture Energy	Total Elements Energy	Cycle Energy	Task Energy Rate	Total Task Energy
		(minutes)	(hours)	(Kcal)	(Kcal)	(Kcal/cycle)	(Kcal/min)	(Kcal)
TASK 1	4	10	0.1667	21.8	5.31	27.11	2.71	27.12
TASK 2	4	7	0.1167	16.38	64.11	80.49	11.5	80.51
TASK 3	5	25	0.4167	55	22.93	77.93	3.12	77.94
TASK 4	1	4	0.067	8.77	0.80	9.57	2.39	9.62
TASK 5	6	89.32	1.4886	195.79	30.05	225.84	2.53	225.83
TASK 6	9	59	0.983	129.09	36.62	165.71	2.81	165.66
TASK 7	27	936.72	15.612	2053.27	431.35	2484.62	2.65	2484.65
TASK 8	2	20	0.333	43.84	4	47.84	2.39	47.79
TASK9	9	10	0.1667	23.4	60.85	84.25	8.43	84.27

TASK	Description
TASK 1	Make lathe machine ready for operation
TASK 2	Loading of the heavy job on chuck
TASK 3	Machine and tool setting and adjustments
TASK 4	Performing rough facing operation
TASK 5	Turning operation
TASK 6	Drilling operation
TASK 7	Step boring
TASK 8	Finishing operation
TASK 9	Unloading the job to rack and switch off the main supply

TASK PORTFOLIO

Job Duration(hours)	19.35
No. Of Tasks	9
Job Energy(kcal)	3203.39
Job Energy Rate(kcal/min)	2.76

Table 2 indicates the energy rate and total energy expenditures in a discrete production environment during lathe machine ready for operation as 2.71 kcal/min and 27.12 kcal respectively, loading of the heavy job on chuck as 11.5 kcal/min and 80.51 kcal, machine and tool setting and adjustments 3.12 kcal/min and 77.94 kcal respectively, performing the rough facing operation as 2.39 kcal/min and 9.62 kcal respectively, turning operation as 2.53 kcal/min and 225.83 kcal respectively, drilling operation as 2.81 kcal/min and 165.66 kcal respectively, step boring as 2.65 kcal/min and 2484.65 kcal respectively, finishing operation as 2.39 kcal/min and 47.79 kcal respectively and unloading the finished job to rack and switch off the main supply 8.43 kcal/min and 84.27 kcal respectively. The total energy expenditure for the complete job is 3203.39.14.69 kcal and the job energy rate is 2.76 kcal/min.
Further actual detailed report generated by the Energy Expenditure Program software for every task has been added to analyze the result in Appendix.
A human-machine chart listing all the elements performed by an operator and the operations performed by the machine showing the corresponding idle and working times for each has been shown in Table 3.
Table 3 shows a Human-Lathe machine interaction chart. The Chart indicates the working of human as 23.3% and idle time percentage as 76.07%.

Also, the chart includes the Lathe Machine working percentage as 85.06% and idle time percentage as 14.94%.

Table 3. Human-Lathe machine chart for a job.

S.No	HUMAN(MIN)	TASK	TASK ELEMENT	TIME(MIN)	MACHINE TIME(MIN)
1	5	MACHINE READY	Cleaning M/C	5	5
	3		Setting M/C Parts To Make It Ready	3	3
	1		Switching On The M/C Main Supply	1	1
	1		Checking Running M/C	1	1
2	3	LOADING	Holding Job On Hands	3	3
	0.167		Lifting Job To Chuck	0.1667	0.1667
	2		Carrying Load To The M/C	2	2
	2		Holding Job While Loading On Chuck	2	2
	8		Centering Of Job	8	8
	9		Setting Drill Tool On Tail Stock	9	9
	3		Next Miscellaneous Setting (Drill Tool + Lamp)	3	3
	3		Arranging And Setting Drawing Display Board (Machine Off)	3	3
	2		Changing Belt Of Pulley	2	2
4	4	ROUGH	Rough Facing	4	4
5	0	TURNING	Turning Job	57	57
	8		Measuring Diameter And Miscellaneous Setting	8	0
	4		Sharpening The Cutting Tool + Setting Tool Post(Machine Off)	4	0
	4		Supervisor Telling About Drawing (M/C Off)	4	0
	11		Facing Operation	11	11
	6		Cleaning Chips From Job, Tool And Machine(M/C Off)	6	0
6	4	DRILLING	Setting Drilling Tool A	4	0
	5		Drilling Job	5	5
	2		Setting Cutting Tool And Tool Post	2	0
	2		Turning	2	2
	6		Setting Drilling Tool B	6	0
	12		Drilling	12	12
	2		Changing Drilling Tool	2	0
	24		Drilling	24	24
	2		Cleaning Chips And Removing Drill Tool	2	0
7	0	BORING	1St Step Boring Of 38Mm	23	23
	0		2Nd Step Boring Of 43Mm	24	24
	0		3Rd Step Boring Of 48Mm	13	13
	0		4Th Step Boring Of 53Mm	17	17
	0		5Th Step Boring Of 58Mm	21	21
	0		6Th Step Boring Of 63Mm	23	23
	0		7Th Step Boring Of 68Mm	21.15	21.15
	0		8Th Step Boring Of 73Mm	34	34
	0		9Th Step Boring Of 78Mm	39	39
	0		10Th Step Boring Of 83Mm	36	36
	0		11Th Step Boring Of 88Mm	39	39
	0		12Th Step Boring Of 93Mm	22.11	22.11
	0		13Th Step Boring Of 98Mm	34	34

B. Analysis

The analysis was done by comparing the measured energy expenditure with the standard energy expenditure for different grade of physical work based on energy expenditure level (assuming a reasonably fit adult male) adapted from the American Industrial Hygiene Association,1971.

The Comparison of energy expenditure for every task with standard data has been shown in **Table 4** below: -

Table 4. Comparison of energy expenditure of task with standard data

TASK	ENERGY EXPENDITURE (kcal/min)	Standard Energy Expenditure (kcal/min)
Task1-M/C READY	2.71	2.5
Task2-LOADING	11.5	10
Task3-M/C SETTING	3.12	2.5
Task4-ROUGH FACING	2.39	1.6
Task5-TURNING	2.53	2.5
Task6-DRILLING	2.81	2.5
Task7-BORING	2.65	2.5
Task8-FINISHING	2.39	1.6
Task9- UNLOADING	8.43	7.5

STANDARD DATA	
TYPE OF WORK	**ENERGY EXPENDITURE (kcal/min)**
REST (SITTING)	1.5
VERY LIGHT WORK	1.6-2.5
LIGHT WORK	2.5-5.0
MODERATE WORK	5.0-7.5
HEAVY WORK	7.5-10.0
VERY HEAVY WORK	10.0-12.5
UNDULY HEAVY WORK	GREATER THAN 12.5

A graph in **Fig. 10.** has been plotted to compare the measured and standard energy expenditure during tasks of the experiment. (For discrete production environment)

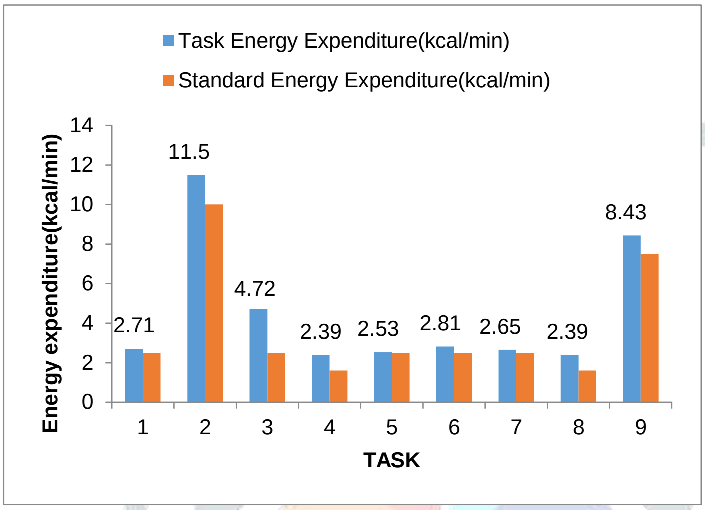

Fig. 10. Graph for comparison of measured and standard energy expenditure during tasks of the experiment

4. DISCUSSION AND CONCLUSION

The World Health Organization (WHO) and the Occupational Safety and Health Administration (OSHA) consider work-related energy expenditure to have multi-factorial causes. Management and workers are greatly concerned with the working environment, ergonomics, the quality of work and occupational safety and health. Developments in information and communication technologies and specialized work requiring repetitive tasks have resulted in a need for human-machine interface design from an energy expenditure point of view.

This study presented an effective approach for the evaluation of a lathe environment using an energy expenditure prediction program. For various tasks, a detailed report through software was generated for the analysis. Based on the present study for a discrete and mass production environment, the following concluding remarks are drawn:

(i) The energy expenditure of **Task1** i.e. during **lathe machine ready for operation** determined through energy expenditure prediction program is **27.12 kcal** and the energy rate is **2.71 kcal/min**. This energy is not so much as compared to standards; therefore, it is concluded that less attention is needed for this task

(ii) The energy expenditure of **Task2** i.e. during loading **of heavy job** determined through energy expenditure prediction program is **80.51 kcal** and energy rate is **11.5 kcal/min.** This energy is so high as compared to standards, and therefore it is concluded that further ergonomic design of the lathe environment is required.

(iii) The energy expenditure of **Task3** i.e. during **lathe machine tool setting and adjustments** is 77.94 kcal and the energy rate is 3.12 kcal/min. This energy is very high as compared to standards, therefore it is concluded that the concerned task needs to be ergonomically designed.

(iv) The energy expenditure of **Task4,** i.e. during rough **facing** determined through the energy expenditure prediction program is **9.62 kcal** and the energy rate is **2.39 kcal/min**. This energy is high as compared to standards, therefore it is concluded that further ergonomic design of the lathe environment is required.

(v) The energy expenditure of **Task5** during **turning** determined through the energy expenditure prediction program is **225.83 kcal** and the energy rate is **2.53 kcal/min**. This energy is within limits as compared to standards, therefore it is concluded that no attention is required for the operation and it is ergonomically alright.

(vi) The energy expenditure of **Task6** during drilling is **165.66 kcal** and the energy rate **is 2.81 kcal/min**. This energy is not so much high as compared to standards, therefore it is concluded that the concerned task is in within limits and less attention is needed.

(vii) The energy expenditure of **Task7, i.e. during step boring** is **2484.65 kcal** and the energy rate is **2.65 kcal/min**. This energy is below as compared to standards; therefore, it is concluded that the concerned task needs less attention.

(viii) The energy expenditure of **Task8, i.e.** during **finishing operation** determined through energy expenditure program is **47.79 kcal** and energy rate **is 2.39 kcal/min**. This energy is approximately equal to as compared to standards, therefore it is concluded that the task need to be ergonomically designed.

(ix) The energy expenditure of **Task9, i.e.** during **unloading of finished job** determined through energy expenditure prediction program is **84.27 kcal** and the energy rate is **8.43 kcal/min**. This energy is high as compared to standards, therefore it is concluded that further ergonomic design of the lathe environment is required.

Priority of designing the task ergonomically will be given to the task having higher energy expenditure as compared to other tasks so that the safety of the worker and his health can be maintained. The below table shows the remark and priority for every task: -

TASK	TASK NAME	ACTUAL ENERGY EXPENDITURE (Kcal/min)	Standard Energy Expenditure (kcal/min)	Difference b/w Actual & Standard	Remark	Priority
1	**M/C READY**	2.71	2.5	0.21	Less attention	**5**
2	**LOADING**	11.5	10	1.5	Ergonomic design require	**1**
3	**M/C SETTING**	3.12	2.5	0.62	Ergonomic design require	**3**
4	**ROUGH FACING**	2.39	1.6	0.79	Ergonomic design require	**8**
5	**TURNING**	2.53	2.5	0.03	Ergonomically designed	**7**
6	**DRILLING**	2.81	2.5	0.31	Less attention	**4**
7	**STEP BORING**	2.65	2.5	0.15	Less attention is require	**6**
8	**FINISHING**	2.39	1.6	0.79	Ergonomic design require	**9**
9	**UNLOADING**	8.43	7.5	0.93	Ergonomic design require	**2**

5. FUTURE SCOPE FOR THE STUDY

The study was conducted in a limited time frame, better results can be obtained if conducted over a long range of time with many workers and for many workpieces to see the effect with a large number of trials also it would reduce the error of acquaintance. Furthermore, the study can be done in a mass production environment to evaluate and determine the energy expenditure of many workers. In this way better results will be obtained and further ergonomic design can be possible.

The study can help to keep the energy expenditure within bounds and recommended limits. It can help to improvise the method of work, work posture, methodology, work rate and also tool design so as to reduce the fatigue, failure, injuries, WMSD's, overexertion etc.

In this way, the health of worker, his strength, and endurance could be maintained and finally the better ergonomic workstation can be suggested.

This method can be used to find the energy expenditure of any task because it is cheap and more accurate and feasible than any other techniques so it can be used for any work environment.

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