iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 3 **Issue:** IV **Month of publication:** April 2015

DOI:

Volume 3 Issue IV, April 2015
ISSN: 2321-9653
International Journal for Research in Applied Science & Engineering Technology (IJRASET)

Ergonomics Design and Work Stress Output on Lever Type Borehole Mechanical Hand Pump

Ogunwede, O.I. [1], Prof. Abolarin, M.S[2], Olaiya .K.A. [3]
[1]Centre for Automotive Design and Development, Industrial Development Centre (IDC), Premises Samaru Zaria.
[2]Mech. Eng. Dept. F.U.T Minna, [3]Dept of Mech Eng Lagos State Polytechnic, Lagos.

Abstract: The use of lever type borehole handpumps (Indian Mark II and Afridev (RUWATSAN)) were found to impose undue fatigue and stress on the users. This leads to discomfort, and easily could lead to repetitive strain injury (RSI) causing chronic or permanent damage on the users when tapping water from borehole. This research work attempts to investigate the outcome of stress on the lever type handpump and an ergonomically rotary handpump that could help the workers to work for a longer hour within the Operational Health Safety (OHS) of the body systems. The results showed that the rotary handpump delivers less stress and can prevent musculoskeletal disorders (MSDS), such as low-back pain and knee problems.
Significance: The significance of this research work is to make pump manufacturers aware of the intrinsic implications of pump design and inter alia, boost the acceptability of borehole hand pumps.
Key words: Ergonomics, Stress, Borehole, Rotary, Lever, hand pump.

I. INTRODUCTION

The use of mechanically operated lever type borehole hand pump is on the increase in Nigeria since the community has no access to portable water supply due to erratic electricity supply and high cost of diesel for the pump station and water board to power the machineries for the supply of portable water to the community, (Ogunwede, 2011). The adopted lever type reciprocating hand pump in Nigeria was found short of ergonomics design thereby imposing unfavorable work-stress on the operators of the pump, (Ogunwede, 2011).
Ergonomics principle is based on designing of workstation/machine to fit the workers, rather than physically forcing the worker's body to fit the job (Zarif et al, 2007). Ergonomics consideration in machine and workplace design is vital to the worker's healthy living. If workstation is not ergonomically designed, workers may be exposed to undue physical stress, strain, over-exertion including vibration, awkward posture as shown in Plate 1. This can cause musculoskeletal disorders (MSDS), such as low-back pain and knee problems, loss of productivity due to work injuries and accidents. Poor workplace design can also lead to disabilities, low products quality and injuries (Zafir et al., 2007). Work injuries that have been reported relate psychological distress, decreased participation in daily living activities, physiological distress and negative effects on family well being (Kirsh and Mckee, 2003).

Plate1: Awkward posture of an operator on a lever type handPump

The term ergonomics is derived from two Greek words: "ergon", meaning work and "nomoi", meaning natural laws. (www.ergonomics.org). Ergonomics can therefore be defined as natural laws governing works design for better output without undue stress on the worker. Ergonomics can also be said to be the study of man-machine interface or work-human relationship, i.e., performance of work without undue stress on the human body or performance of work at maximum human comfort. This will not only increase productivity and improve tool life of the equipment concerned; it will equally help the workers to work for a longer hour within the Operational Health Safety (OHS) of the body systems (http://web.wit.ac.za).
Some of the human factors in ergonomics to be considered during work place design include:

A. Environmental factors

This factor dwells on the body response to the reactions in the environment, such as temperature and humidity, lighting, noise level, vibration, pollution, etc.

B. Anthropometry

This has to do with the anatomy of the body; i.e., the skeletal framework, joint and muscles, positioning of the arms and legs, range of movement and evaluation of the work relative to different work postures without undue stress.

C. Neuromuscular

This is the central mechanism of the body and the flow of information through the nerves to other sensory organs of the body that determines the work performance in the area of accuracy and judgment.

D. Physiological

This is the response of the body system to external stimuli or the physical activities and stresses encountered. The energy expenditure during workload is been classified as spelt out in Table 1:

Table 1: Classification of workloads

	Workloads	Energy Expenditure (Joules)
i	Light (Office work)	2.5 – 5.0
ii	Moderate (Running, driving, etc)	5.0 -7.5
iii	Heavy	7.5 – 10.0
iv	Very Heavy	10.0 – 12.5

The term ergonomics is derived from two Greek words: "ergon", meaning work and "nomoi", meaning natural laws. (www.ergonomics.org). Ergonomics can therefore be defined as natural laws governing works design for better output without undue stress on the worker. Ergonomics can also be said to be the study of man-machine interface or work-human relationship, i.e., performance of work without undue stress on the human body or performance of work at maximum human comfort. This will not only increase productivity and improve tool life of the equipment concerned; it will equally help the workers to work for a longer hour within the Operational Health Safety (OHS) of the body systems (http://web.wit.ac.za).
Some of the human factors in ergonomics to be considered during work place design include:

E. Environmental factors

This factor dwells on the body response to the reactions in the environment, such as temperature and humidity, lighting, noise level, vibration, pollution, etc.

F. Anthropometry

This has to do with the anatomy of the body; i.e., the skeletal framework, joint and muscles, positioning of the arms and legs, range of movement and evaluation of the work relative to different work postures without undue stress.

G. Neuromuscular

This is the central mechanism of the body and the flow of information trough the nerves to other sensory organs of the body that determines the work performance in the area of accuracy and judgment.

H. Physiological

This is the response of the body system to external stimuli or the physical activities and stresses encountered. The energy expenditure during workload is been classified as spelt out in Table 1:

Table 1: Classification of workloads

	Workloads	Energy Expenditure (Joules)
i	Light (Office work)	2.5 – 5.0
ii	Moderate (Running, driving, etc)	5.0 -7.5
iii	Heavy	7.5 – 10.0
iv	Very Heavy	11.0 – 12.5

The essence of the above factors is to lower stress to the bearable minimum for sound healthy living during ergonomics system design. The higher the amount of energy expenditure during workload, the more is stress imposed on the body system.

Smith (1994) stated that stress is what happens when the body does not adjust to some new or additional internal or external stimulus. Kets de Vries (1979) pointed out that stress is as a result of imbalance between the demands of the environment and the ability of the individual to adapt. The experience of stress in the workplace or in operation of machine has undesirable consequences both for the health and safety of individuals and well being of the society. Work stress on lever type pump for the extraction of water from borehole can affect the operators in many ways, from lowering resistance to illness and depriving them of sleep, to interfering with their concentration so that more injuries and accidents occur. Measures of distress can be psychological (anxiety, depression, irritability), physiological (high blood pressure, changes in oxygen consumption, increase in heart beat rate, high muscle tension levels, etc) or behavioral (poor work performance, accidents, sleep disturbances, substance/drug abuse) (Zafir et al., 2007).

II. MATERIAL AND METHODS

A. Posture

Posture in the place of work can easily determines how well or how long a worker can perform. In recent years, ergonomists have attempted to define posture as a position that minimizes unnecessary static work and reduces the forces acting on the body (www.ergonomics.org). Workers could significantly reduce the risk of injury if they could adhere to the following ergonomic principles:

1) All work activities should permit the worker to adopt several different, but equally healthy and safe postures

2) Where muscular force has to be exerted, it should be done by the largest appropriate muscle groups available.

3) Work activities should be performed with the joints at about mid-point of their range of movement. This applies particularly to the head, trunk, and upper limbs.

The above conditions were considered during the handpump design and were found to reduce the stress imposed on users, reduce long queue at pump site, reduce pump failure rate. This enhances the acceptability of these pumps more easily in the host community.

B. Effects of Handpump Loading on Human-Body Mechanism

One of the most amazing things about the human body is the incredible range of movement and mobility it has. The day to day activity is accomplished by the muscles through the extraordinary and fascinating ability of converting chemical energy and energy stored in nutrients, into mechanical energy i.e. energy of movement. Muscles are often viewed as the "machines" of the body. They help move food from one organ to another to carry out physical movement. Overstretching of the muscle and excessive loading could lead to nervous breakdown (ThinkQuest, 1976).

C. Muscle Types

The muscles are divided into cardiac, smooth and skeletal. Cardiac muscles are involuntary and are found only in the heart. They are controlled by the lower section of the brain called the medulla oblongata, which controls involuntary action of the body. The heart cells come in long strips, each containing a single nucleus, one of the key factors that determines which of the three classes a particular muscle belongs. The main function of the muscle is to propel blood into circulation. Contraction of the cardiac tissue is caused by an impulse sent from the medulla oblongata to the Sino Arterial node (SA nerve) located at the right atrium (link-circulatory). The SA node is the pacemaker of the heart that initiates the heart beat. The rate of the contraction of the tissue is determined by the amount of impulse sent to the medulla oblongata as a result of the stress imposed on the nerves.

The smooth muscles, like the cardiovascular muscles, are involuntary. They make up the internal organs, such as the stomach-hyper link, throat-hyper link, small intestine-hyper link, and all the others, except the heart. The skeletal muscles are the only voluntary muscles of the body; they are called the muscular system. They are all the muscles that move the bones to reveal external movement. Unlike either of the other two classes, skeletal muscles contain multiple nuclei because of its large size, being in strips up to a couple of feet long.

1) *Muscular System:* The muscular system, composed of over 600 muscles, comes in a variety of shapes and forms. Differences between each muscle are recognized by location, function, structure, and the way they contract.

2) *Muscle-Bone interactions (lever system):* A lever is a rigid bar on which a given load is moved with supporting help from a fulcrum. A fulcrum is a fixed-point on which a lever can move in different ways or angles. The whole muscular system interacts in this kind of way with the skeletal system-hyperlink. Given a load, the muscles pull the bone up or in any direction against the load. The joints-hyperlink usually seems to be the fulcrum on which the lever or bone moves as a result of the muscles contractions. Skeletal muscles can be broken down into groups based upon the type of movement they portray. The movement of the muscle is based upon the type of joint (hyperlink-Skeletal system) upon which the muscle works. Skeletal muscles generally work in pairs, one contract and stretch the other, and reverse its effects on the joint. For example, when the major arm muscle contracts the bicep contracts and the triceps extends. So as one muscle contracts, the other one extends as shown in plate 2.

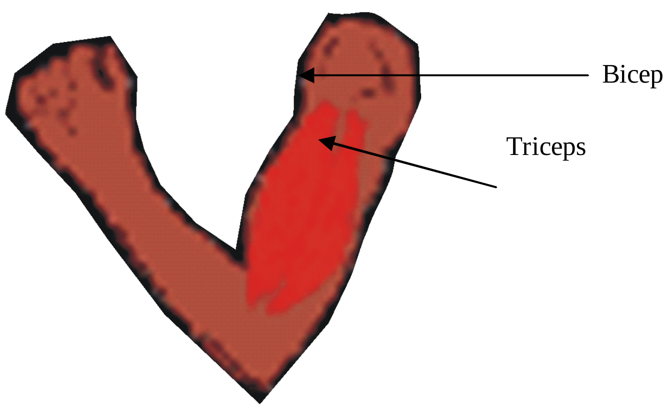


Plate 2: Low Band Width. (Source: ThinkQuest, 1976).

D. *Tendons and Ligaments*

As fascinating as they are, muscles alone can't do the job but with the help of tendons and ligaments. Muscles wouldn't be very useful alone because they don't directly connect to the bone, so even if they contract, they wouldn't be moving anything. Instead, muscles are connected to tendons, which are connected to the bones. When the muscles contract, they pull on the tendons, which in turn pull on the bone, and that causes movement. But without ligaments, that movement wouldn't be too useful because it would not be a direct movement. Without ligaments, instead of bones bending or rotating about each other when muscles contract, they would slide by each other. Ligaments are what hold the bones together. They connect at the ends of muscles and keep them from slipping and sliding, and force them to bend as shown in Fig. 2.13 (ThinkQuest, 1976).

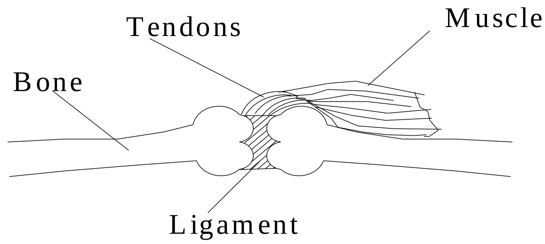
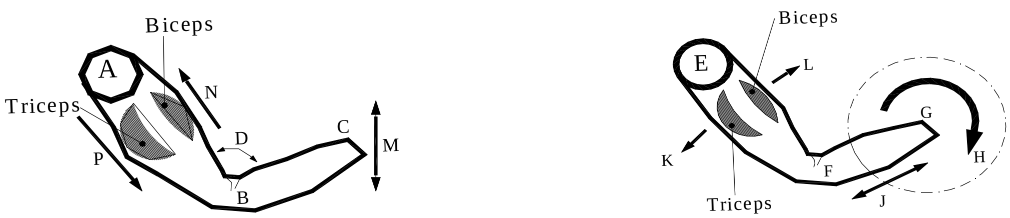


Fig. 1: Muscle-bone Connection

When the hand lift up and drop down load as shown in Fig. 2 (a), the amount of contraction and extension of the bicep and triceps becomes very high and causes stress, as compared with the contraction and extension of the bicep and triceps during winding or rotational motion of the hand that causes less stress, as shown in Fig. 2 (b).



(a) Vertical motion (b) Radial motion

Fig. 2: Contraction of Triceps and Biceps

The hands in Fig. 2 (a), (b), are pivoted at Point A and E respectively. As the hand in Fig. 2 (a), lifts load vertically upwards or downwards through direction M, there is a change of angular direction at D causing the biceps to contract and triceps to extend depending on the direction of M. As indicated, this creates undue stress on the biceps and triceps through contraction and expansion of the muscles. The change of direction in Fig. 2 (b), is rather linear (J), when the hand lifts the load through a radial motion (H), the biceps and triceps flex in the direction of L and K, which reduces the amount of contraction and extension of the biceps and triceps, which causes less stress in the muscle. This explains why the human hand is fatigued when load is lifted through a vertical direction (M) as compared with the load lifted through rotational or winding motion (H). Typically, this is the experience the mechanically operated borehole handpump users go through when tapping water using the lever type of handpumps like the Indian Mark II and Afridev series, which makes the users get tired easily and have to improvise a relief measure as shown in plate 1, to proffer solution to the problem of fatigues being experienced, that has never been met.

E. Design of Radial Mechanism

The physical problems associated with prolonged use of the lever pump, do not end with the odd twinge discomfort, but they can easily extend to repetitive strain injury (RSI) causing chronic or permanent damage (Beckett, 1995). In terms of everyday use, an ergonomic mechanism is one which not only allows the user to complete task, but will also actively facilitate the task. A radial mechanism with gearing system was designed to incorporate some bearings to reduce frictional effects as the crank of the system rotates the gears. The gearing of the mechanism was designed to amplify the reciprocating motion of the pump, which in turn improved the rate of discharge that minimizes the stress of the user.

F. Ergonomics Analysis of Radial and Lever Mechanism

In order to determine which of the pump head mechanisms (Developed pump head and Indian Mark II head) was less stressful, a statistical sample based on time for the discharge of a quantity of a volume of water was collected to test the difference between the two pumps.

According to Yode (1999), when there is need to test for the difference between two population means; two types of statistical analysis are used. The Z-test is used for large sample size (n>30), and the t-test, for small sample size (n<30). Therefore, for this analysis, a t-test was adopted due to the small sample size based on the hypothesis developed.

Volume 3 Issue IV, April 2015
ISSN: 2321-9653

1) The Research Hypothesis

H_O: There is less stress developed with Radial mechanism than Lever mechanism.

H_1: there is more stress developed with Radial mechanism than Lever mechanism.

According to Nworgu (1998), the t-ratio is calculated with a formula:

$$t = \frac{\overline{X}_1 - \overline{X}_2}{\sqrt{\frac{\sigma_1^2+\sigma_2^2}{n_1+n_2}}} \qquad 2.1$$

Where:

$\overline{X}_1$ = Mean for Dev. Pump head

$\overline{X}_2$ = Mean for Indian Mark II pump head

n_1 = number of observation for Dev. Pump head

n_2 = number of observation for Indian Mark II pump head

$\overline{\sigma}_1$ = Standard deviation for Dev. Pump head

$\overline{\sigma}_2$ = Standard deviation for Indian Mark II pump head

Note $\overline{X}_1 = \frac{\sum X_1}{n}$ 2.2

$$\overline{\sigma}_1 = \sqrt{\frac{\sum(x_1-\bar{x}_1)^2}{n_1}} \qquad 2.3$$

$$\overline{\sigma}_2 = \sqrt{\frac{\sum(x_2-\bar{x}_2)^2}{n_2}} \qquad 2.4$$

df = degree of freedom = $(n_1 + n_2 - 2)$ 2.5

At 0.05 level of significance for a two tailed test and the degree of freedom (df), the calculated t-test value was compared with the critical or table value and a conclusion was drawn on the hypothesis of H_O and H_1.

III. RESULTS AND DISCUSSION

Tables 3.0 and 3.1 were the data collected during the test of the developed pump head mechanism and the Indian Mark II pump head mechanism. For a reciprocating pump, the volume discharge per stroke is constant depending on the fatigue of the user. If the user is less fatigue, a higher volume of water is delivered in lesser time than when fatigue and stress set in.

Table 3.0, Readings from Rotary Pump head Mechanism

S/No.	Number of Stroke	Time (Sec)	Volume (Ltr)
1	12	9.48	4
2	12	9.52	4
3	12	9.31	4
4	12	7.61	4
5	12	7.37	4
6	12	7.60	4
7	12	8.01	4
8	12	8.09	4
9	12	7.67	4
10	12	7.36	4
		$\sum = 82$ Secs.	40 Ltrs.

From table 3. total time taken to pump 40 ltrs with the pump head under development was 1.37min. This indicates the discharge rate for the pump is 29.2ltrs/min.

Note: discharge or flow rate, Q = $AV = \frac{vol}{time}$

i.e. $Q = \frac{40}{1.37} = 29.2$ ltrs/min.

Table 3.1, Readings from Indian Mark II Pump head Mechanism

S/No.	Number of Stroke	Time (Sec)	Volume (Ltr)
1	12	13.85	4
2	12	13.39	4
3	12	13.03	4
4	12	13.80	4
5	12	13.95	4
6	12	14.18	4
7	12	14.36	4
8	12	16.03	4
9	12	15.14	4
10	12	15.16	4
		$\sum = 142.89$	40

From table 3.1, total time taken to pump 40 ltrs with the Indian Mark II pump head was 2.3815 min. This indicates the discharge rate for the Indian mark II pump is 16.8 ltrs/min.

Comparing the discharge rate of the rotary pump head the mechanism with the discharge rate of the Indian Mark II pump head, it is vivid that the discharge rate for the rotary pump head mechanism developed was better. This is made clear on the graph in Fig. 3. This also indicate that the stress encountered using the rotary pump head is less than the stress on the Indian mark II pumphead when tapping the same volume of water from the borehole per unit time.

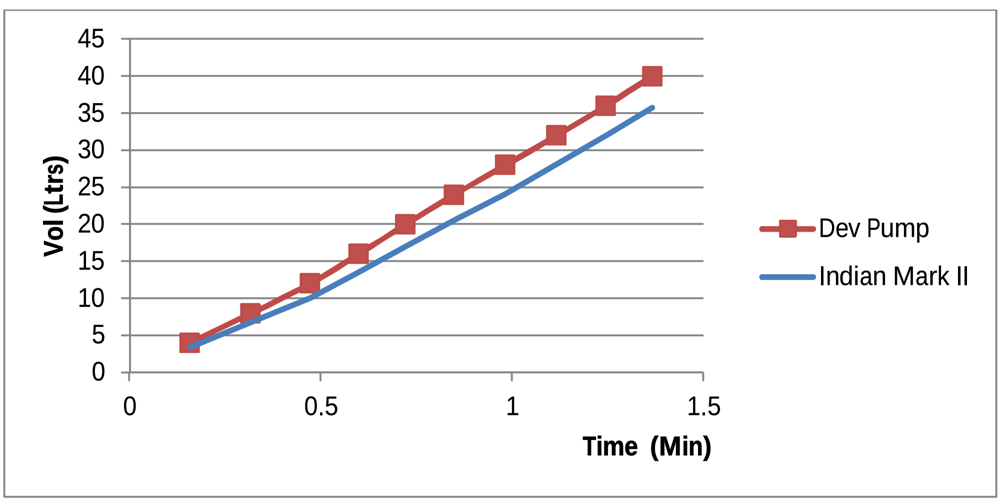


Fig. 3: Pump Head Performance

A. Ergonomics design of work stress analysis of Radial and lever Pump Head Mechanism

With reference to Tables 3.0 and 3.1, the statistical readings based on time taken to deliver a specific volume of water per number of stroke are as enumerated in Table 3.2.

Table 3.2: Statistical analysis of Radial and Lever Pump Mechanisms

No. of Readings	X_1	X_2	$X_1 - \bar{X}_1$	$(X_1 - \bar{X}_1)^2$	$X_2 - \bar{X}_2$	$(X_2 - \bar{X}_1)^2$
1	9.48	13.85	1.28	1.64	-0.43	0.18
2	9.52	13.39	1.32	1.74	-0.89	0.77
3	9.31	13.03	1.11	1.23	-1.25	1.56
4	7.61	13.80	-0.59	0.35	-0.48	0.23
5	7.37	13.95	-0.83	0.69	-0.33	0.11
6	7.60	14.18	-0.6	0.36	-0.1	0.01
7	8.01	14.36	-0.19	0.04	0.08	0.01
8	8.09	16.03	-0.11	0.01	1.75	3.06
9	7.65	15.14	-0.55	0.30	0.86	0.74
10	7.36	15.16	-0.84	0.71	0.88	0.77
	$\sum X_1 = 82$	$\sum X_2 = 142.9$		$\sum = 7.07$		$\sum = 7.44$

From eqn. 2.2, $\bar{X}_1 = \frac{\sum X_1}{n}$

Where n = 10.

From eqn. 2.3, $\bar{\sigma}_1 = \sqrt{\frac{\sum(x_1 - \bar{x}_1)^2}{n_1}} = \sqrt{\frac{7.07}{10}} = 0.84$

And from eqn. 3.56, $\bar{\sigma}_2 = \sqrt{\frac{\sum(x_2 - \bar{x}_2)^2}{n_2}} = \sqrt{\frac{7.44}{10}} = 0.86$

From eqn. 2.4, $t = \frac{\sum(\overline{X_1} - \overline{X_2})}{\sqrt{\frac{\sigma_1^2 + \sigma_2^2}{n_1 + n_2}}} = \frac{8.20 - 14.28}{\sqrt{\frac{0.84^2 + 0.86^2}{10+10}}} = \frac{-6.08}{\sqrt{\frac{0.71+0.74}{10+10}}} = \frac{-6.08}{\sqrt{0.145}} = \frac{-6.08}{0.38}$

∴ t = -15.97.

From eqn 2.5, Degree of freedom df, = $(n_1 + n_2) - 2$

= (10 + 10) – 2 = 18

Comparing the calculated t-test value with the critical or table value at 0.05 level of significance for two tailed test and 18 df, the table value of t is equal to 2.101.

The decision here is that, the Ho is accepted since the calculated value of t (-15.97) is less than the table value of t (2.101).

The results of the test suggest that there is less stress developed with Radial mechanism than Lever mechanism.

REFERENCES

[1] Beckett R. (1995). Are you Sitting Comfortably? Facilities. 13(12): 26-27, http://eprints.utm.my

[2] http://web.wit.ac.za. Industrially Developing Countries (IDC), Ergonomics Centres, Literature Review. Date cited: 26/11/2009.

[3] Kets de Vries, M.F.R., (1979). Organizational Stress: A Call for Management Action. Sloan Management Review. 21(1): 3-14

[4] Kirsh B. and Mckee P, (2003). The Needs and Experience of Injured Workers: A participatory Research Study. Work. 21: 221-231, in Jurnal Kemnusiaan bil.9,Jun 2007. Ergonomics Design on the Work Stress Outcomes by Zafir et al. (2007). http://eprints.utm.my/8126/1/ZMMakhbul2007-Ergonomics_Design_On_The_Work.pdf

[5] Nworgu.B.G (1998). Educational Research, Basic Issues and Methodology, Wisdom Publishers Oweri.

[6] Ogunwede O (2011). Development of Radial Pumping Mechanism for Effective Borehole Operations, M.Eng Thesis, Federal University of Technology, Minna, Niger State, Nigeria.

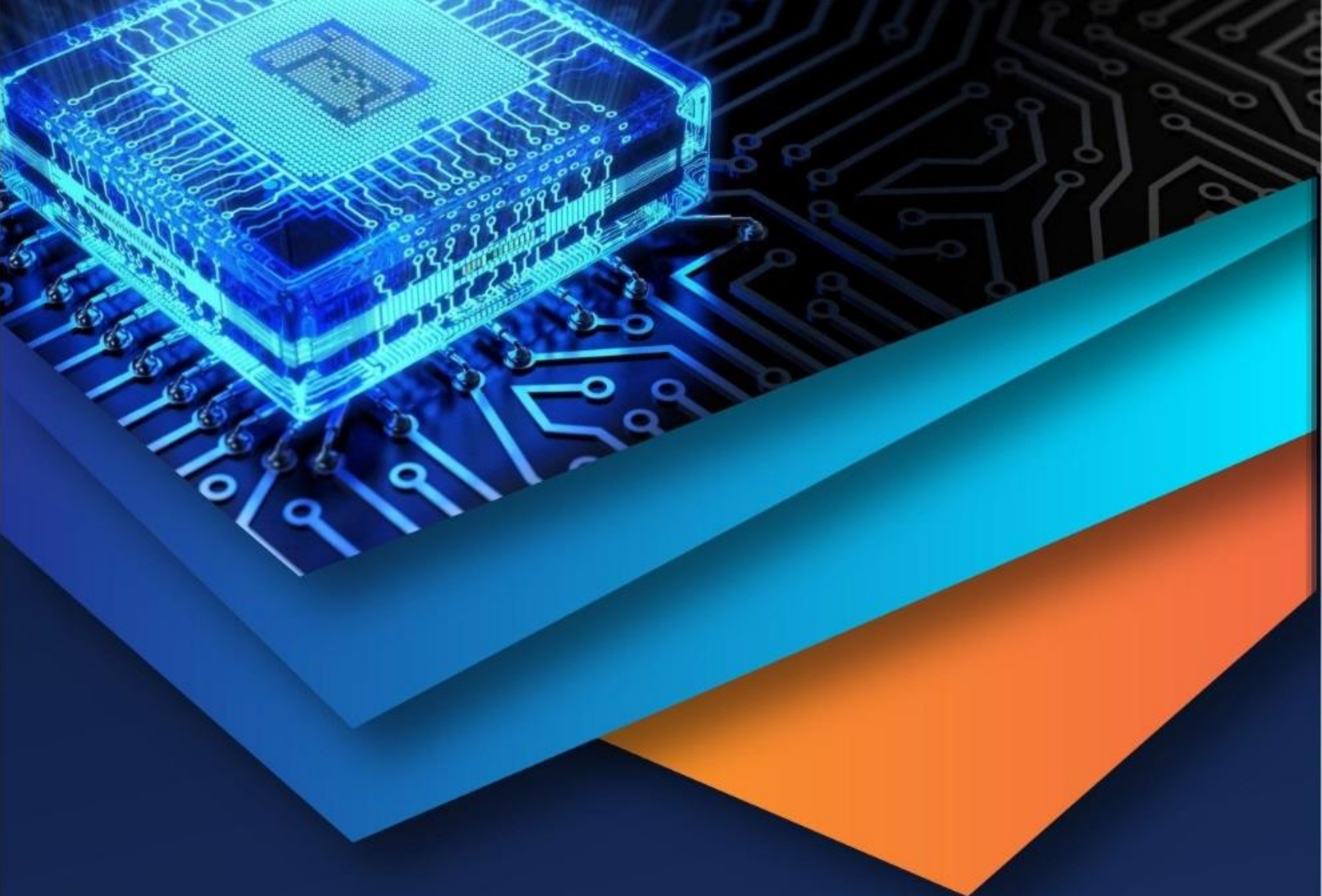
[7] Smith, S.L., (1994). Combating Stress. Occupational Hazards. 56(3): 57-59.

[8] ThinkQuest (1976). Oracle Education Foundation, http://www.library.thinkquest.org.

[9] www.ergonomics.org. Posture, Movement and Ergonomics. Dec. 16, 2009. 8:00:44AM

[10] Yode Omotosho (1999). College and University Statistics, NPS Educational Publishers limited. Trusthouse, South West Ring Road, P.O.Box 62, Ibadan. PP 147-145.

[11] Zafir Mohammed Makhbul, Durrisheh Idrus, Mat Rebi Abdul Rani, (2007). Ergonomics Design on the Work Stress Outcomes. Jurnal Kemamustaan bit. 9. http://eprints.utm.my.



10.22214/IJRASET

INDEX COPERNICUS
45.98

IMPACT FACTOR:
7.129

IMPACT FACTOR:
7.429

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY