**DEVELOPMENT OF LABORATORY FATIGUE TESTING MACHINE**

**BY**

**OZULUOHA GIDEON**

**2014/1/54033EM**

**DEPARTMENT OF MECHANICAL ENGINEERING, SCHOOL OF INFRASTRUCTURE, PROCESS ENGINEERING AND TECHNOLOGY, FEDERAL UNIVERSITY OF TECHNOLOGY MINNA, NIGER STATE**

**NOVEMBER, 2019**

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**A PROJECT SUBMITTED TO THE DEPARTMENT OF MECHANICAL ENGINEERING, SCHOOL OF INFRASTRUCTURE, PROCESS ENGINEERING AND TECHNOLOGY, FEDERAL UNIVERSITY OF TECHNOLOGY MINNA, NIGER STATE. IN PARTIAL FULFILMENT OF THE REQUIREMNTS FOR THE AWARD OF BACHELOR DEGREE. (B.ENG) IN MECHANICAL ENGINEERING**

**NOVEMBER, 2019**

**DECLARATION**

I hereby declare that the work reported in this project was done by me under the fortunate supervision of Engr. Dr. O. Adedipe of the Department of Mechanical Engineering, Federal University of Technology Minna. The works of other researchers whether published or unpublished are referenced appropriately by means of references.

**………………………… ………………………**

OZULUOHA Gideon DATE

2014/1/54033EM

**CERTIFICATION**

This project work titled “Development of Laboratory Fatigue Testing Machine” was done by OZULUOHA Gideon and has been read and approved seeing that it meets the imperative requirement and standards for the award of Bachelor of Engineering (B.ENG) degree in Mechanical Engineering of the Federal University of Technology, Minna.

Engr. O. Adedipe …………………...............

Project Supervisor Signature & Date

Engr. Dr. S. A. Lawal ………………………………

Head of Department Signature & Date

……………………………. ………………………………

External Examiner Signature & Date

**DEDICATION**

This project work is dedicated to Almighty God for the Gift of life, sound health and endless protection upon my life, and to my Awesome Mother whose support and prayers has kept me going.

**ACKNOWLEDGEMENT**

My sincere gratitude goes to God and my amiable supervisor Engr. O. Adedipe whose suggestions and constructive criticism has made this work a success.

To my ever supportive Head of Department Engr. S. A. Lawal and the entire staff of the School of Infrastructure, Process Engineering and Technology (SIPET). I am most grateful for all your efforts that has helped me in fulfilling my ambition and academic pursuit. I will always be grateful for your contributions.

To my awesome parents, Mr. Onyeka Ozuluoha and Mrs. Margaret Ozuluoha who have spent their resources and finance to fund my academic pursuits and are always encouraging me in prayers. I am very grateful for your unforgettable impact to my life.

My warm appreciation goes to all my friends and the entire class of the Mechanical Engineering 2019. My journey in Federal University of Technology Minna would have been boring and difficult without you. Thank you all for enduring my flaws.

Lastly, my utmost gratitude goes to the Almighty God who has blessed me with creativity and the capacity to understand and excel in knowledge to achieve my pursuit. All of these would have been impossible without your Grace.

**ABSTRACT**

One of the most important factors that Engineers consider greatly when developing components, parts, structures and machines is its durability, as this will determine how long the components will last when in use before permanent failure. Unlike some other professions, failure in the field of Engineering has displayed fatal and unwanted outcomes.

Research has shown that more than 80% of the failures of modern materials and components are caused by fatigue, which is why fatigue failures are of great concern and should be tackled and reduced as much as possible.

Using the fatigue testing machine, the specimens were subjected to fatigue loading at various stress levels below the material’s ultimate stress and the number of cycles to failure were recorded. The test process was repeated with the stress level for each test reduced, hence different values for the number of cycles were obtained. A graph producing the S-N curve was then plotted with the stress on the y-axis and the number of cycles on the x-axis in order to obtain the relationship between the applied stress and the number of cycles.

The machine has been improved and modified such that its speed can be regulated using an automated keypad control. This has made possible the testing of the specimen at various speeds of the motor in order to compare the results obtained at different speeds. The machine has also been modified such that the motor stops automatically when the specimen fails and displays on the LCD the Number of cycles to failure.

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**NOMENCLATURE**

W Applied load acting on specimen

L Length of specimen

D Neck Diameter

I Second moment of inertia

E Modulus of rigidity

P Applied load

δmax Maximum deflection due to torque

H Heat generated by bearing

Θ Angular twist of the shaft

δb Deflection under peak load

Ni Crack initiation

Nf Final failure

Np Crack propagation

σmin Minimum stress

σmax Maximum stress

K Stress Magnitude

ni Number of Cycles

Ni Number of Cycles to failure

Si Constant stress

D Diameter

a Crack length

T Torque generated by the electric motor

poisson ratio

W loads

P Power lost

N Motor speed

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**CHAPTER ONE**

**1.0 INTRODUCTION**

**1.1 Background of The Study**

Fatigue is a failure that occurs in materials or machines due to the cyclic or periodic loading or stresses over an unpredictable period of time.

Many everyday Items or components are not loaded uniformly but rather non-uniformly with periodically changing loads that may even be well below the material’s yield point resulting into accumulation of damages which will eventually lead to failure over time. This manner of loading is obvious in certain systems like the transportation, construction systems.

In Transportation systems, certain components in Aircrafts, Trains, Automobiles and so many others experience periodically changing or fluctuating loads. For instance, Aircrafts experience different stresses during takeoff and in turbulence than on ground motion. This type of loading is termed fatigue loading and the response of materials to this to this manner of loading is called fatigue.

The axle in trains which is intrinsically a round beam is subjected to tensile stress at its bottom and compressive stress at it’s top. When the axle rotates half turn, there is change over time as the bottom becomes the top and vice versa, making the stress on an exact portion of the axle to change recurrently.

Materials endure less stresses when subjected to periodic loading compared to static loading. Even when materials are designed while satisfying mechanical strength criterion, it may fail due to fatigue. This is why many design disasters have occurred by simply neglecting the effects of fatigue.

Fatigue failure is most likely the most dangerous type of failure experienced by engineering components and materials. This is due to the fact that unlike failures resulting from static loading, fatigue failures occur without any prior warning, making them totally unpredictable.

This dangerous and sudden failure can lead to severe injuries and possibly loss of lives which is one of the main reason why we chose to devise an automated fatigue testing machine to test the fatigue of engineering materials and components thus, reducing the risk of failures and loss of lives.

When testing the properties of materials that relates to the stress-strain curve, the application of the load is done gradually in order to give enough time for the strain to take effect or develop fully while the testing is done until the material or specimen fractures. This one-time stress condition is known as a static condition.

However, in most cases the stresses induced are rather irregular and sinusoidal in nature making this type of stress condition a cyclic or repeated condition. Research has it that machines, materials and components fail mostly under this condition; yet unveils that the even the maximum stresses encountered by these specimens were below their ultimate strength.

**1.2 Stages of Fatigue Failure**

Fatigue failure in engineering materials and components occur mainly in three stages namely:

1. Crack initiation
2. Crack propagation
3. Final fracture

Both high and low cycle fatigue failures follow the same processes of fatigue failure upon non-uniform cyclic loading. The process initiates with micro-cracks which nucleates within the material and proliferates or spread gradually over time where a crack growth occurs along crystallographic planes in regions with the highest shear stresses.

After the initiation stage, when the crack attains an analytical size, they begin to propagate quickly along a direction perpendicular to the applied force. This propagation of the crack size continues over time until the material encounters ultimate failure usually in a crisp or inelastic manner.

**1.2.1 Crack Initiation:**

This stage is the most crucial stage in fatigue fracture. The most notable factor about this stage is that the effect of load action on the material which are irreversible occur as a result of repeated shear stresses. Over a large number of load(cyclic) application with time, there is an accumulation of micro-variations or small compounding changes known as accumulated damages.

This accumulated damages that occur in metals is the primary cause of fatigue fracture and it is apparent that if this change can be avoided, then fatigue failure will not occur.

**1.2.2 Crack Propagation:**

The propagation stage of fatigue is responsible for changing the direction of micro-cracks causing them to propagate perpendicular to the tensile stress experienced by the metal.

**1.2.3** **Final Fracture:**

As the proliferation of the cracks progresses, there is a reduction in the cross-sectional area of the specimen. This causes the material to weaken progressively until final and eventual fracture occurs. The manner of fracture could be either brittle (with a cleavage or inter-granular fracture surface) or ductile (with a dimpled surface) or a combination of both.

The manner of fracture depends on certain factors such as the metal involved, the level of stress, the environmental concerned etc.

**1.3 Fatigue Testing Machine**

A Fatigue testing machine is a machine that is designed to test the fatigue strength or fatigue life of a material by measuring the force that is exerted on the specimen over many cycles until the material fractures or fails.

**1.4 Classification of Fatigue Testing Machines**

The following are the classifications of fatigue testing machines:

**1.4.1 Classification Based On Purpose of the Test**

Depending on the purpose of test, Fatigue testing machine can be sub-divided into the following groups:

1. General purpose fatigue testing machine
2. Special purpose fatigue testing machine
3. Equipment for testing parts and assemblies

**1.4.1.1 General Purpose Fatigue Testing Machine**

The general purpose testing machine can be divided into two major categories as follows:

**1.4.1.1.1 Classification Based On Type of Stressing Method**

1. **Rotating Bending Testing Machine**

This machine produces a S-N curve identified as a rotating-bending or stress controlled fatigue data curve. This curve is produced by turning the motor at a constant revolution per minute or frequency. An unvarying static load resulting to a constant bending moment is exerted on the specimen to cause failure of the material. A stationary moment applied to a rotating specimen causes the stress at any point on the outer surface of the specimen to go from zero to a maximum tension stress, back to zero and finally to a compressive stress. Thus, the stress state is one that is completely reversed in nature.



**Figure 1.1: Rotating Bending Testing Machine [Callister, 1994].**

1. **Reciprocating Bending Test Machine**

This machine produces a S-N curve identified as a tension-compression, strain controlled fatigue data curve. This machine is capable of zero mean cyclic stresses by positioning the specimen clamping vice with respect to the mean displacement position of the crank drive.



**Figure 1.2 Reciprocating Bending Testing Machine [Collins, 1981].**

1. **Axial Loading (Push-Pull) Type Fatigue Tester**

When using this machine for testing, the sample or material is not subjected to bending but to axial (tensile or compressive) stresses. The test-specimen is held firmly at both

ends and then loaded periodically between two (maximum and minimum) values

.

**Figure 1.3 Direct-Force Fatigue Testing Machine [Collins, 1981].**

Other possible types, though not commonly used for testing are:

1. Torsion loading fatigue tester.

2. Combined bending and torsion fatigue tester.

3. Bi-axial and tri-axial loading fatigue tester.

**1.4.1.1.2 Classification Based On Source Of Stressing**

The following classification of fatigue testing machine is based on the principle behind the source of the test-force. Load produced by:

1. Mechanical deflection

2. Dead weight or constant spring force

3. Centrifugal force

4. Electromagnetic force

5. Hydraulic force

6. Pneumatic force

The choice of load source depends on certain factors such as the amount of applied force required, control systems available, cost, the needed frequency, and how close the test is to be simplified to the actual working loading in service.

**1.5 Problem Statement**

1. In our everyday life, components and materials fail due to irregular stress patterns which ultimately leads to failure over time, making fatigue failures a critical area that requires intense research in order to reduce these failures to the minimal.
2. There is deficiency in the knowledge of how fatigue failures occur in engineering materials in most Tertiary institutions in Nigeria. This problem can be traced to the inadequate testing machines.
3. Research has it that fatigue failure is responsible for at least 80% of the failures that occur in engineering materials and components.

**1.6 Aim and Objectives**

The aim of this project work is to design, fabricate and automate a fatigue testing machine.

**Objectives**

1. To modify and design a cost effective automated fatigue testing machine.
2. To create an efficient and automated fatigue testing machine that can test different specimens at variable speeds.
3. To obtain and evaluate the S-N curve obtained from the experiment while interpreting the curve.

**1.7 Justification of The Project**

The project design solves one of the major failure issues in the field of engineering in Nigeria. A cost effective, efficient and automated fatigue testing machine will help in solving practical engineering failure problems. The automation of the machine will make possible the testing of different metals at different speeds, thus reducing the risk of failure and increasing the level of practical knowledge of the fatigue phenomenon amongst Nigerian students at large.

**1.8 Scope of The Project**

In the design of this project, a review of available literatures on the subject context was made to design and fabricate an electro-mechanical driven fatigue testing machine with automated controls to improve on the practical and theoretical learning of fatigue failures of engineering materials, while focusing on the minimization of cost, size, efficiency, and ease of operation.

**1.9 Limitations of The Project**

The limitations are as follows:

1. It is limited to test only small sized specimens due to the portability of the machine.
2. It is designed to enhance the learning process.
3. It is driven electromechanically.

**CHAPTER TWO**

**2.0 LITERATURE REVIEW**

**2.1 History of Fatigue Testing**

**Beginning in the first half of the 19th century, metals and materials were discovered to fail mechanically due to repetitive stresses well below their yield strength. The theory was agreed upon that metals were tired, hence giving birth to the “fatigue” phenomenon.**

**In 1829 Wilhelm August Julius Albert,** a German mining administrator, observed, studied, and reported on the failure of mine hoist cables resulting from repeated small loadings, this is first known recorded account of metal fatigue.

**Jean-Victor Poncelet,** described metal as being “tired” at military school at Metz during his lectures in 1839.

**In the early 1840s William John Macquorn Rankine discovered that railway axles had failed due to progressive proliferation of a brittle crack from a shoulder or stress concentration of the shaft when he examined many broken railways.**

**In 1849, E.A. Hodgkinson was commissioned by the British Government to study the fatigue of cast and wrought iron used in railway bridges. After his study, He described fluctuating bending experiments on beams deflected at midpoints recursively by a rotating cam.**

**F. Braithwaite derives the term “fatigue” using it to describe the failure of metals as a result of sinusoidal loadings in his report.**

**Sir William Fairbairn a Scottish Engineer (1789 - 1874)** was one of the first to conduct systematic investigations into the failures of structures such as bridges, mills, and boilers. At the request of the UK Parliament in 1861 he conducted research into metal fatigue by raising and lowering a 3ton mass onto a cylinder of wrought iron 3 million times before it fractured and showing that a static load of 12ton was needed to achieve the same result. Partially funded by the Board of Trade he built large scale testing set ups for his studies of the effects of repeated loading of wrought iron and cast iron girders, demonstrating that fracture could occur by crack growth from incipient defects, a problem now known as fatigue.

**August Wöhler (1819 - 1914) was a German engineer.** He is remembered chiefly for his systematic work on metal fatigue. His work is the first to systematically characterize the fatigue behavior of materials using S-N curves or Wöhler Curves. He developed a machine for repeated loading of railway axles, and showed clearly that fatigue failure occurs by crack growth from surface defects until the load can no longer be supported. In 1870 he summarizes his work on railroad axles, and concludes that cyclic stress range is more important than peak loads and introduces the concept of endurance limit. Wöhler was a member of the Technical Committee of the Verein Deutscher Eisenbahnverwaltungen, and favored the introduction of state-approved classifications for steel and iron. He also called for the founding of facilities for materials testing and testing equipment. He took part in teaching the theoretical and practical training of testing methods, but left the application and implementation of these to his assistant. With the construction of equipment for testing fatigue, Wöhler broke new ground in terms of methodology and testing technology, and had a significant impact on modes of thought in the technical disciplines.

**Sir James Alfred Ewing KCB - Knight Commander of the Order of the Bath - (1855 - 1935)**

**was a Scottish engineer and physicist popularly recognized for his work on the magnetic properties of metals. He examined and named the phenomenon called Hysteresis. He was the first to come up with the proposal that fatigue failures were initiated by microscopic defects or slip bands in 1903 after studying the crystalline structure of metals.**

**In 1945 M. A.. Miner popularizes A Palgrin's (1924) linear damage hypothesis as a practical design tool. It is now commonly referred to as Miner's rule.**Miner's Rulestates that where there are k different stress magnitudes in a spectrum, Si (1 ≤ i ≤ k), each contributing ni(Si) cycles, then if Ni(Si) is the number of cycles to failure of a constant stress reversal Si, failure occurs when:

http://www.wmtr.co.uk/images/What_Is_Fatigue_Testing_clip_image016.jpg  
  
C is experimentally found to be between 0.7 and 2.2. Usually for design purposes, C is assumed to be 1.

**In 1954, L.F. Coffin and S.S. Manson illustrated fatigue crack growths in the crack tips**. The Coffin-Manson relation describing low-cycle fatigue in terms of strain in the material, and is independently published by S. S Manson In 1953 and by L. F. Coffin in 1954. **http://www.wmtr.co.uk/images/What_Is_Fatigue_Testing_clip_image018.jpg.**

**In the face of initial skepticism and popular defense of Miner's phenomenological approach** P. C. Paris in 1961 proposes methods for predicting the rate of growth of individual fatigue cracks.  
**P. C. Paris, M. P. Gomez and W. E. Anderson**derive relationships for the stage II crack growth with cycles N, in terms of the cyclical component ΔK of the Stress Intensity Factor K.  
  
http://www.wmtr.co.uk/images/What_Is_Fatigue_Testing_clip_image020.jpg  
Where "a" is the crack length and "m" is typically in the range 3 to 5 (for metals). This is often referred to as Paris' Relationship.  
**This relationship was later modified** to make better allowance for the mean stress, by introducing a factor depending on (1-R) where R = min. stress/max stress, in the denominator.

**In 1968 Tatsuo Endo and M. Matsuiski devised a rainflow-counting algorithm** and apply it to Miner's rule enabling its reliable use in cases involving random loads. The methodology has progressed to a very sophisticated level with various software packages available. **ASTME 1049** Section 5.4 (standard practices for cycle counting in fatigue analysis: Rainflow Counting and Related Methods) is often referenced as a standard for this method.

**2.2 Fatigue Literature Review**

Fatigue failure was defined by **F. Braithwaite as the failure of a material due to repeated loading or alternating stresses considerably below the ultimate strength of the material.**

Over time, some methods have been put in place for analyzing and determining the fatigue strength of various engineering metals. The relationship between stress amplitude and number of cycles it can execute before failure also known as the S-N curve derived by wohler. where “S” denotes the stress level and “N” is the number of cycles. As stress amplitude decreases, the number of cycles to failure increases and vice-versa.

As a result of the irregularities involved in the characteristics of materials, Materials are tested at different stress levels to obtain their S-N curve with the objective of establishing the Endurance Limit of the material and secondly, to compare the number of cycles the material will undergo at different stress levels before final failure.

**2.3 Types of Fatigue Testing**

1. **High Cycle Fatigue Testing:** are fatigue tests that generally run 100,000 or more cycles. They are used for materials that experience stress levels that are relatively low and where deformation and change in shape or size of a material as a result of an applied force is primarily elastic in nature.
2. **Low Cycle Fatigue Testing:** are fatigue tests that generally run less than 100,000 cycles. They are commonly used for materials in application where stress levels are extremely high and plastic deformation can often occur as a result of fatigue stresses.

The principal distinction between high cycle fatigue and low cycle fatigue is the region of the stress-strain curve where the repetitive application of load and the resultant deformation or strain is taking place. Both methods are performed using different techniques. Low cycle fatigue testing is performed using the strain controlled method where specific magnitude of strain is applied to the test specimen per cycle. Whereas traditional high cycle fatigue testing is stress controlled, meaning that a constant load is applied throughout the duration of the test.

1. **Axial Fatigue Testing:** is a cyclic loading type of fatigue testing in which a specimen can be subjected to tension and compression repeatedly until failure. In this type of test, Flexural or torsional may be applied repeatedly until the point of failure.

**CHAPTER THREE**

**3.0 MATERIALS AND METHODS**

The Materials used in the fabrication and development of the automated fatigue testing machine includes: Electric Motor (1hp), Chucks, Bolts and Nuts, Square pipes, Shaft, Flat wood, Load hanger and sensor.

**3.1 Material Design and Considerations**

The Materials and components used in the development of the machine were carefully selected with the aim of developing a durable and equally efficient device. The Materials were selected based on the following factors:

1. Availability of the Material.
2. Cost of the Material.
3. Size and weight.
4. Physical appearance.
5. Safety
6. Resistance to corrosion.
7. Strength and durability.

**3.2 Components and Materials Used**

**1. Electric Motor**

An electric motor is an electro-machine that converts electrical energy into mechanical energy thereby driving components. An Induction motor with a power of 1hp is used in the development of the fatigue testing machine.



**Figure 3.1: Electric Motor**

**2. Bearing**

A roller bearing is selected to be used in the machine in order to reduce friction between the shaft and other moving parts.



**Figure 3.2: Bearing**

**3.** **Microcontroller (Arduino Uno)**

The Arduino Uno is a microcontroller board that is used to automate and control machines and other hardware. It comprises of an Integrated Development Environment(IDE) that runs on a computer system through which code can be written and transferred to the Arduino board.

The IDE runs on a simpler model of C++ programming language called C for arduino



**Figure 3.3: Microcontroller (Arduino Uno)**

**4. Keypad Controller (4 By 3)**

This component is the hardware that represents the interface between the machine and the user. The Keypad accepts inputs from the user and passes this input to the microcontroller for processing.



**Figure 3.4: 4 by 3 Keypad Control**

**5. Liquid Crystal Display(LCD)**

The LCD is a flat panel display that displays the user input from the Keypad and also displays the Number of Cycles to failure. Its display depends on the data received from the microcontroller.



**Figure 3.5: Liquid Crystal Display**

6. **Aluminium and Mild Steel Specimens**



**Figure 3.6: Mild steel (left) and Aluminium(right)**

Other Components Used Include:

1. Step down Transformer
2. Filter Capacitor
3. Bridge rectifier
4. Voltage regulator
5. Optocoupler
6. Continuity Sensor
7. Triac

**3.3 Design Calculations**

**3.3.1 Machine Capacity**

The diameter of the test specimen is 6mm. Usually, It is assumed that the machine would be used to test some high strength steel at stress levels close to the yield stress. For mild steel AISI 1080, with an ultimate yield stress of 585Mpa assuming Tresca’s criterion, the shear yield stress is given as 400Mpa. The required torque is expressed as:

T = π/16 × τ ×d3

Where, T = Torque generated by the electric motor.

d = Diameter of the specimens

τ = Shear stress

Since the diameter of the specimen is 6mm; T = × 400 × 63  = 16.964Nm

**3.3.2 Diameter of the Shaft**

Recall that: T = π/16 × τ ×D3

Hence, D =

D =

D =

A minimum shaft diameter of 25mm is used for the design. This is to ensure that the shaft can withstand greater heat and shock from many tests without failing.

**3.3.3 Design for Bearing**

Pressure on Bearing P

P =

Where

A = Area of the shaft = πr2

P = Pressure on Bearing

W = Applied load

**Power loss (due to friction), Pf**

Pf =

Where T = frictional torque = 0.667×W×

N = speed of the motor in rpm

Recall that = 0.29, Poisson’s ratio

T = 0.6667 × 350 × 0.0125 × 0.29 = 0.8459Nm

Pf  =  = 124.021W

Pf = 0.124KW

Heat Generated by the bearing, H = Pf × 60

H = 0.124 × 60 = 7.44

Bearing 1 and 2 bears a maximum load of;

= = 300.8N

Hence, Average shear stress =

= = = 306N/m

Bearing 5 and 6 bears a load of;

= = 308.32N

Hence, Average shear stress =

= = = 314N/m

**3.3.4 The Angular Twist of the Shaft Transmitting Torques Under Full Load Capacity**

θ = × L ×

Where G = modulus of rigidity = 80×103N/mm

θ = × 164 × =

**3.3.5 Bending stress for long and short shaft**

=

δ =

where I = Moment of Inertia **=**

I = = 19174.76mm4

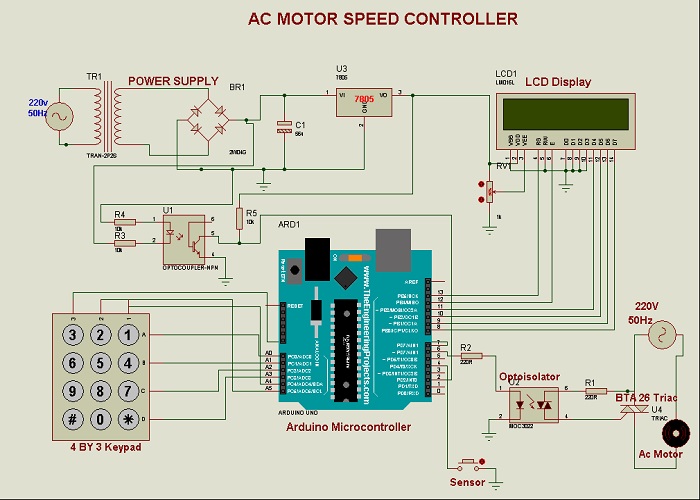
**y = = =** 12.5mm

Hence; δ = = 32N/m

Bending stress for the long and short (driven) shaft are the same, since their diameters are the same.

* 1. **Electronic Circuit diagram**

The electronic circuit diagram shows the various electrical components and their interconnections to each other.

****

**Figure 3.7: Electronic Circuit Diagram**

The circuit diagram contains six major sections namely:

1. **Power supply:**

Alternating Current at 220V and 50Hz is provided to the system, but the voltage of 220V is way too much for the microcontroller and other components as the microcontroller requires just 5V. Hence, a Step down transformer is used to step down the voltage to 12V. A Bridge rectifier converts the alternating current to Direct Current since the microcontroller requires Direct current which is further purified using a Filter capacitor. The voltage regulator keeps the voltage in the circuit stable at 12V. The Optocoupler, Microcontroller, Opto-isolator and the LCD all source their voltage from the Voltage regulator.

1. **Microcontroller (Arduino Uno):**

The microcontroller processes all the user inputs and displays on the LCD. The microcontroller communicates with the components of the circuit in order to know what action to take.

If the program criterion is met, the microcontroller signals the Opto-Isolator to turn on the motor.

1. **Keypad Control:**

The keypad is responsible for accepting user input and passing this input data to the microcontroller for processing.

1. **Sensor (Continuity sensor):**

The sensor checks for continuity in the machine so that the motor automatically stops running when the specimen fails.

1. **Feedback/Optocoupler:**

The Optocoupler detects the current motor speed and modifies the frequency or speed of the motor based on the user input. The Varying of the motor speed is done by the Triac (BTA26) in order to avoid the heating of the microcontroller.

1. **LCD (Liquid Crystal Display):**

The LCD is responsible for displaying the user input and the Number of cycles to failure.

* 1. **Machine Programming and codes**

#include <TimerOne.h> // Avaiable from http://www.arduino.cc/playground/Code/Timer1

#include <Keypad.h>

#include <LiquidCrystal.h>

LiquidCrystal lcd(5,6,7,8,9,10);

const byte ROWS = 4; //four rows

const byte COLS = 4; //three columns

volatile boolean zero\_cross=0; // Boolean to store a "switch" to tell us if we have crossed zero

int AC\_pin = 11; // Output to Opto Triac

int dim = 0; // Dimming level (0-128) 0 = on, 128 = 0ff

int inc=1; // counting up or down, 1=up, -1=down

int m = 0, n = 0, a = 0, o = 0, d = 0;

int freqStep = 75; // This is the delay-per-brightness step in microseconds.

char keys[ROWS][COLS] = {{'1','2','3', 'A'},{'4','5','6', 'B'},{'7','8','9', 'C'},{'\*','0','#', 'D'}};

byte rowPins[ROWS] = {A0,A1,A2,A3}; //connect to the row pinouts of the keypad

byte colPins[COLS] = {A4,A5,13,12}; //connect to the column pinouts of the keypad

char KEYS[5];

char key;

int i = 0, PWM, RPM, tracker = 0, currentposition=0;

//initialize an instance of class NewKeypad

Keypad keypad = Keypad( makeKeymap(keys), rowPins, colPins, ROWS, COLS);

void setup() {

// put your setup code here, to run once:

lcd.begin(16,2);

pinMode(AC\_pin, OUTPUT); // Set the Triac pin as output

Timer1.initialize(freqStep); // Initialize TimerOne library for the freq we need

Timer1.attachInterrupt(dim\_check, freqStep);

//Serial.begin(9600);

lcd.clear();

lcd.setCursor(0,0);

lcd.print(" Single Phase AC");

lcd.setCursor(0,1);

lcd.print("Motor Controller");

delay(2000);

lcd.clear();

}

void zero\_cross\_detect() {

zero\_cross = true; // set the boolean to true to tell our dimming function that a zero cross has occured

i=0;

digitalWrite(AC\_pin, LOW); // turn off TRIAC (and AC)}

// Turn on the TRIAC at the appropriate time

void dim\_check() {

if (zero\_cross == true) {

if (I >=dim) {

digitalWrite(AC\_pin, HIGH); // turn on light

i=0; // reset time step counter

zero\_cross = false; //reset zero cross detection

}

else {

i++; // increment time step counter

}}}

void loop() {

// put your main code here, to run repeatedly:

if (i == 0){displayscreen();}

keypod();

if(key == 'A'){

getkeys();

a = 0;

currentposition = 0;

keypod();

keypod();

keypod();

keypod();

PWM = atoi(KEYS);

delay(400);

Load1\_on();

a = 0, currentposition = 0;

keypod();

if(KEYS[0] == '\*' && PWM < 2801){

if(d == 0){

attachInterrupt(0, zero\_cross\_detect, RISING); // Attach an Interupt to Pin 2 (interupt 0) for Zero Cross Detection

d++; }

lcd.clear();

dim = map(PWM, 0, 2800, 128, 1);

delay(18);

n = n-1;

for (m; m>=0;m--){

for (n; n>=0;n--){

for (o = 60; o>= 0; o--){

i = 4;

lcd.setCursor(0,0);

lcd.print("Speed:");

lcd.setCursor(7,0);

lcd.print(PWM);

lcd.setCursor(0,1);

lcd.print("Time:");

lcd.setCursor(8,1);

print2digits(m);

lcd.setCursor(10,1);

lcd.print(":");

lcd.setCursor(11,1);

print2digits(n);

lcd.setCursor(13,1);

lcd.print(":");

lcd.setCursor(14,1);

print2digits(o);

delay(999);

lcd.clear();

}

}

}

lcd.clear();

lcd.setCursor(0,0);

detachInterrupt(0); // disable power

lcd.print(" Motor Stopped ");

dim = 128;

digitalWrite(AC\_pin, LOW);

delay(2000);

i = 0, d = 0; }

else{

lcd.clear();

lcd.setCursor(0,0);

lcd.print("..INVALID RPM...");

lcd.setCursor(0,1);

lcd.print("Enter RPM < 2800");

delay(2000);

i = 0;

}

}

else{

lcd.clear();

lcd.setCursor(0,0);

lcd.print("Press F1 to Enter");

lcd.setCursor(0,1);

lcd.print("....New RPM.....");

delay(1000);

i = 0;

}

//char key = customKeypad.getKey();

//getkeys();

}

int keypod(){

//lcd.clear();

do

key = keypad.getKey();

while(!key);

// Serial.println(KEYS[i]);

KEYS[currentposition] = key;

lcd.setCursor(a + 11,1);

lcd.print(key);

currentposition++;

a++;

if (currentposition > 5)currentposition = 0;

//

}

int getkeys(){

lcd.clear();

lcd.setCursor(0,0);

lcd.print("AC Motor Control");

lcd.setCursor(0,1);

lcd.print("Enter RPM: ");

delay(100);

}

//\*\*\*\*\*\*\*\*DISPALAY FUNCTION!!!\*\*\*\*\*\*\*\*\*\*\*\*\*//

void displayscreen()

{

lcd.setCursor(0,0);

lcd.println("Press F1 to Ente");

lcd.setCursor(0 ,1);

lcd.println(" RPM and start ");

}

void print2digits(int number) {

if (number >= 0 && number < 10) {

lcd.write('0');

}

lcd.print(number);

}

/\*............................PROGRAMMING LOAD1............................. \*/

int Load1\_on(){

KEYS[0] = 0;

KEYS[1] = 0;

KEYS[2] = 0;

KEYS[3] = 0;

a = 0, currentposition = 0;

lcd.clear();

lcd.setCursor(0,0);

lcd.print(" ENTER LOAD ON ");

lcd.setCursor(0,1);

lcd.print("Time: ");

keypod();

keypod();

m = atoi(KEYS);

lcd.setCursor(13,1);

lcd.print(":");

a = 3;

KEYS[0] = 0;

KEYS[1] = 0;

KEYS[2] = 0;

KEYS[3] = 0;

currentposition = 0;

keypod();

keypod();

n = atoi(KEYS);

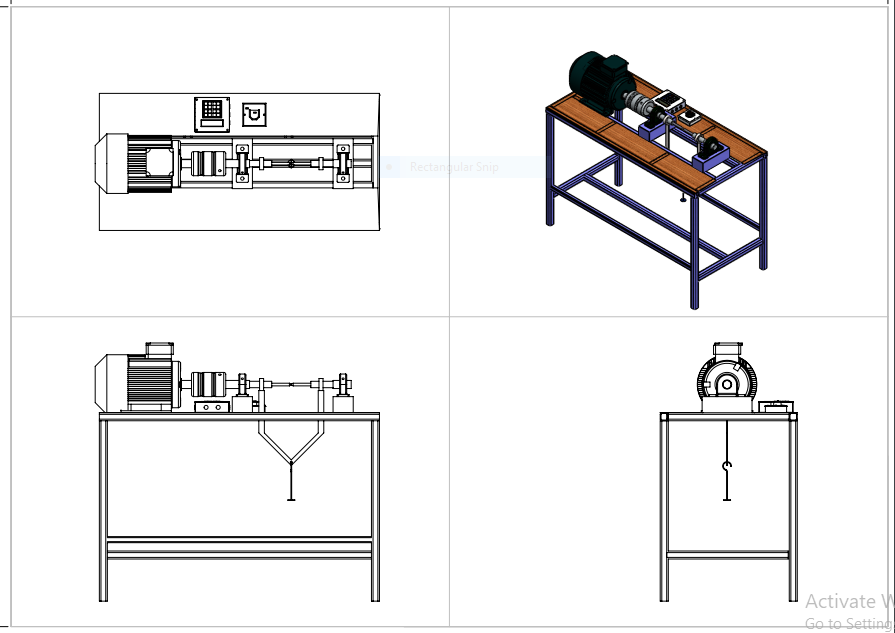
//currentposition = 0;

a = 0;

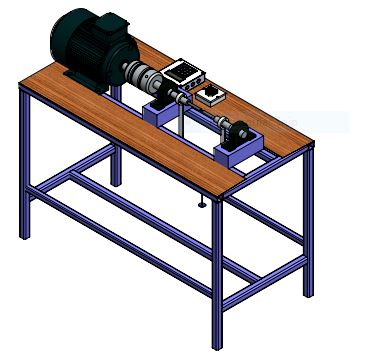
delay(100);

}

**3.6 Final Assembly**



**Fig 3.8: Various views of the assembled machine**

****

**Fig 3.9: Isometric view of the fatigue testing machine**

**CHAPTER FOUR**

**4.0 RESULTS AND DISCUSSIONS**

**4.1 Deflection**

Deflection is the degree of deviation or displacement of a structural element from its initial unloaded position under the application of load or force. This structural element could be a beams, slabs, shafts, columns, rods and so many others.

It is vital to study the deflection a material undergoes in order to comprehend the fatigue of that material due to the fact that most materials undergo deflection to a point before they snap or fail.

The repeated loading and unloading pattern involved in fatigue loading comprises successive deflection of the material since the material displaces from its original position and returns back to this same position as the material is subjected to a fluctuating load

Deflection of a beam is expressed mathematically as :

.

Where L = length of the shaft

P = applied load

E = modulus of rigidity (mild steel) = 200Gpa = 200 × 10,3 N/mm

I = second moment of inertia

1. Deflection for an applied load of 200N

= 0.24mm

1. Deflection for an applied load of 175N

= 0.21mm

1. Deflection for an applied load of 150N

= 0.18mm

1. Deflection for an applied load of 125N

= 0.15mm

1. Deflection for an applied load of 100N

= 0.12mm

1. Deflection for an applied load of 75N

= 0.09mm

1. Deflection for an applied load of 50N

= 0.06mm

1. Deflection for an applied load of 25N

= 0.03mm

**Table 4.1: Deflection of Shaft at Different Applied Loads**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| S/N |  | Load (N) |  | Deflection (mm) |
| 1 |  | 200 |  | 0.24 |
| 2  3  4  5  6  7  8 |  | 175  150  125  100  75  50  25 |  | 0.21  0.18  0.15  0.12  0.09  0.06  0.03 |

Source: Researchers Result 2019.

From the results obtained in table 4.1, it can be concluded that the applied load and the deflection exhibit a linear relationship such that the deflection increases as the applied load increases.

**4.2 Maximum Deflection Due to Torque**

The maximum deflection due to torque is expressed mathematically as:

δmax =

Where I = second moment of Inertia

I = = 19174.76

E = modulus of rigidity

M = 49332

δmax =

**4.3 Bending stress**

τ

where, L = length of the test specimen

D = Diameter of the neck

W = applied load on the specimen

1. Bending stress for an applied load of 200N:

τ = 212.22MPa

1. Bending stress for an applied load of 175N:

τ = 185.65MPa

1. Bending stress for an applied load of 150N:

τ = 159.15MPa

1. Bending stress for an applied load of 125N:

τ = 132.60MPa

1. Bending stress for an applied load of 100N:

τ = 106.08MPa

1. Bending stress for an applied load of 75N:

τ = 79.56MPa

1. Bending stress for an applied load of 50N:

τ = 53.05MPa

1. Bending stress for an applied load of 25N:

τ = 26.52MPa

**Table 4.2: Observation of Aluminium at Various Loads**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| S/N |  | Load(N) |  | Bending stress (Mpa) | Number of Cycles |
| 1 |  | 200 |  | 212.22 | 373 |
| 2  3  4  5  6  7  8 |  | 175  150  125  100  75  50  25 |  | 185.65  159.15  132.60  106.08  79.56  53.05  26.52 | 933  1727  2567  3966  5367  6953  8400 |

Source: Researchers Result 2019.

**Table 4.2: Observation of Mild steel at Various Loads**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| S/N |  | Load(N) |  | Bending stress (Mpa) | Number of Cycles |
| 1 |  | 200 |  | 212.22 | 5950 |
| 2  3  4  5  6  7  8 |  | 175  150  125  100  75  50  25 |  | 185.65  159.15  132.60  106.08  79.56  53.05  26.52 | 11750  35570  47680  62580  77600  89550  97750 |

Source: Researchers Result 2019

**Figure 4.1: S-N Curve for Aluminium**

**Figure 4.2: S-N Curve for Mild steel**

From the table 4.2 and 4.3, It can be observed that as the applied load increases, the Number of cycles to failure decreases and vice versa. Also a non-linear relationship exists between the bending stress and the number of cycles. If a material is subjected to a stress level above its ultimate stress, the material fails even before completing a single cycle.

If the bending stress or stress amplitude is decreased, the material will undergo more number of cycles before it fails. Decreasing the bending stress further will result to more number of cycles before failure and the trend continues in this manner until it gets to a certain limit where even the number of cycles to failure increases greatly such that it approaches infinity. At this limit, the material takes very long time to fail or it never fails infinitesimally. This limit is known as Endurance limit below which it is safest to operate the material.

Engineers always try to design their components effectively by keeping the stress level that is been employed below its endurance limit, that way the component will take longer time before encountering failure.

**4.4 Cost of Machine**

This cost entails the total cost involved in completing and producing the fatigue testing machine. The cost is subdivided into three categories:

1 Cost of Materials

2 Cost of Labour

3 Overhead Cost

**4.4.1 Cost of Materials**

The cost of the materials is in accordance with the current market price

Table 4.4 shows the specification of the material for the machine as well as the cost as at 2019.

**Table 4.4: Machine Cost Analysis**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| S/N | PARTS | QUANTITY | Cost per Unit | COST (N) |
| 1. | AC Motor (1hp) | 1 | 2 | 3,000 |
| 2. | Mild steel square Pipe (60mmX60mm) | 3 | 3500 | 10,500 |
|  |  |  |  |  |
| 5. | Mild steel shaft (25X1000mm) | 1 | 3,500 | 3,500 |
|  |  |  |  |  |
| 7. | Ball bearings (25mm) with the housing | 1 | 2,000 | 2,000 |
| 9. | Chuck | 2 | 3,500 | 7,000 |
| 10. | Bolts and Nuts (13mm diameter) | 16 Pairs |  | 1,500 |
| 11. | Load Hanger | 1 | 300 | 300 |
| 12. | Test Specimens (Aluminium, 12mm diameter and 90mm long) | 8 |  | 10,000 |
| 12. | Test Specimens (Mild steel, 12mm diameter and 90mm long) | 8 |  | 8,000 |
|  |  |  |  |  |
| 14. | Micro Controller (Arduino Uno) | 1 | 30,000 | 30,000 |

**SUB-TOTAL 75,800**

**4.4.2 Cost of labour**

The labour cost is normally taken as 20% of the material cost.

Labour cost = = N 15,160

**4.4.3 Cost due to overhead**

The overhead cost is usually 10% of the material cost.

Overhead cost = = N 7,580

**4.4.4 Total Cost**

Total cost = material cost + labour cost + overhead cost

= 75,800 + 15,160 + 7,580 = N 98, 540

**CHAPTER FIVE**

**5.0 CONCLUSION AND RECOMMENDATION**

**5.1 Conclusion**

The automated fatigue testing machine makes possible the analyzing of the stress and fatigue characteristics of engineering metals with ease and an improved efficiency. The machine was modified such that the speed of the motor can be varied in order to allow testing of metals at different speeds for different materials.

A graph of stress to number of cycles graph also known as S-N Curve was plotted for both Aluminium and Mild steel after result was obtained. The experimental result was compared to the work ad result of other researchers. The results obtained showed an average degree of correlation to the work of other researchers, this may be due to the effect of temperature, size of the machine and materials, vibrations, surface quality of specimen and other environmental conditions surrounding the test.

The machine was also modified such that the machine stops automatically when the specimen fails and then returns the number of cycles to failure on the LCD of the machine.

The test and research conducted on Aluminium and Mild steel for this project shows that fatigue failure cannot be exactly predicted due to the fact that the material failure are not just affected by its repeated loading but by some other factors such as its Number of cycles, temperature, atmospheric conditions, surface quality, and internal and external defects such as notch, inclusion, stress concentrations and non-homogeneity.

We can approximately conclude that the results obtained correlates with the laid down values obtained by previous researchers and scholars.

**5.2 Recommendation**

The following are the recommendations made in order to improve the accuracy of the result obtained and ease the operation of the machine

1. Electric motors with higher specifications (at least 2hp) should be used in order to reduce the duration of testing specimens.
2. More tests can be carried out various materials (at least three) while comparing the results obtained to that of other researchers.
3. A stronger load hanger should be used to allow the use of higher loads when testing.

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[www.fatiguetesting.com](http://www.fatiguetesting.com)

**APPENDIX**

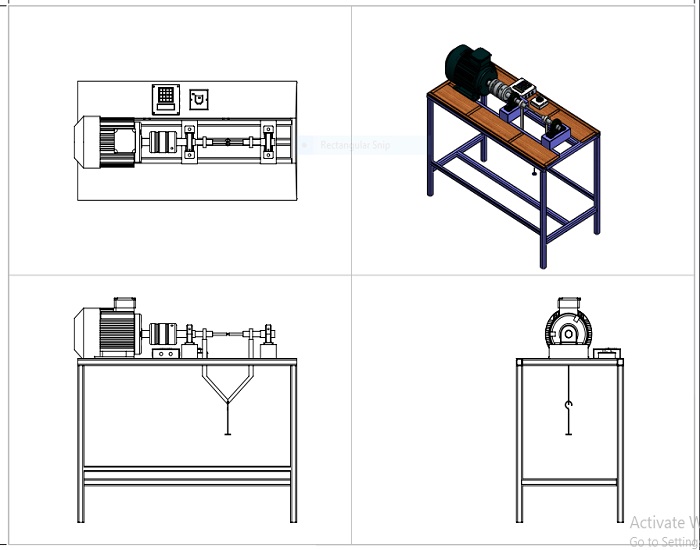


PLATE I: Orthographic view of the fatigue testing machine



Plate II: Top View Of The Fatigue Testing Machine



Plate III: Aluminium Specimens Plate IV: Mild Steel Specimens



PLATE V: Failed specimen due to fatigue loading