**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 criteria, 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

**GENERAL PURPOSE FATIGUE TESTING MACHINE**

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

**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 11 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 12 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

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Figure 13 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.

**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.

**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.

**AIMS AND OBJECTIVES**

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

**Objectives**

1. To create and evaluate a S-N curve obtained from the experiment while interpreting the curve.
2. To create and design a cost effective automated fatigue testing machine.
3. To create an efficient automated fatigue testing machine that helps in determining the fatigue life and fatigue strength of a metal.

**JUSTIFICATION OF THE PROJECT**

The project design solves one of the major failure issues in engineering field in Nigeria. A cost effective and efficient fatigue testing machine with the added feature of automation will go a long way to help in solving practical engineering failure problems and confirming the various fatigue strength of various engineering metals. Thus reducing the risk of failure and increasing the level of practical knowledge of the fatigue phenomenon.

**SCOPE OF THE PROJECT**

In the design of this project, a review of available literature 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.

**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 phenomenon “metal fatigue“.**

**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. He also developed a test machine for conveyor chains used in the mines.

**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 flunctuating 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 3 tonne mass onto a cylinder of wrought iron 3 million times before it fractured and showing that a static load of 12 tonne 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. **ASTM E 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 WHY CREATE OUR OWN CUSTOMISED FATIGUE TESTING MACHINE**

Of Course,There already exists commercial and educational fatigue testing machines that are even highly efficient. But these machines are extremely expensive with their price ranging from $10,000 to $32500 due to their dependability and reliability. This has led to the lack of fatigue testing machines in Nigerian institutions which is needed to effectively transmit practical fatigue strength knowledge to the students.

The Goal is to produce a similar blueprint of these machines more affordable and highly effective fatigue testing machine which is fully functional and modified for easy operation in order to accelerate the running of tests in Nigerian Institutions and Industries.

**2.3 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.

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###### s–n images for some materials will go here ######################

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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 100,000 or less 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 maybe 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 (1 hp), Chucks, Bolts and Nuts, Square pipes, Shaft, Flat wood, Load hanger, Counter 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.

3.1.1 Components of the Machine

1. ELECTRIC MOTOR

An electric motor is a device