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Design and Fabrication of a Cost-Effective Rotating Beam Fatigue Testing Machine for Aluminum, Mild Steel, Cast Iron, and Stainless Steel.

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Abstract

When materials are subjected to cyclic loading, fatigue fracture is the primary cause of failure, accounting for 80 to 95% of occurrences. Subsequently, a meticulous evaluation of materials is necessary to guarantee their dependability and safety. The principal objective of this research undertaking is to design and construct a "Rotating Beam Fatigue Testing Machine" that exceeds all comparable devices in terms of portability, safety, cost-effectiveness, and ease of use. By employing innovative design components derived from the theory of elastic beam bending, our apparatus surpasses the performance of existing models and decreases in price. Through the implementation of the bending characteristics exhibited by elastic beams, the apparatus effectively generated a concurrent torsional and bending strain. This machine bridges the gap by adopting a unique elastic beam bending design that efficiently induces contemporaneous torsional and bending stresses. The device's portability, ease of installation, and practicability make it appropriate for utilization in a wide range of testing environments. It accommodates individuals with limited technical knowledge due to its intuitive nature. The investigation encompassed the analysis of specimens constructed from Mild Steel 1080, Aluminum (T6 6061), Cast Iron, and Stainless Steel (AL6XN), with diameters varying between 5mm and 10mm. The materials were chosen on the basis of their wide array of properties and extensive practical implementations within the engineering and automotive industries. The inquiry carried out in our research emphasized the exceptional resistance to fatigue demonstrated by stainless steel (AL6XN). Significant discoveries from experimental tests included stainless steel's strong fatigue resistance (AL6XN) and thorough S-N data for diverse load applications. For example, under a load of 280 N, aluminum (T6 6061) had an experimental fatigue life of 1,602 cycles, whereas cast iron and mild steel had 48 and 46, respectively. Stainless steel displayed robustness under a variety of stress conditions, highlighting its applicability for applications needing high fatigue performance. It was affirmed that the machine functioned as an effective instrument for fatigue testing due to its consistent production of bending stress-number of cycles data. Advanced safety measures like protective enclosures can reduce almost all operating dangers. This design significantly decreases costs while maintaining optimal performance and dependability, rendering it a compelling choice for testing facilities of any scale. Future advancements may be influenced by the productivity and cost-effectiveness standard for fatigue testing apparatus established by this study.

Keywords: Fatigue, Stress, Sensor, Crack, Stainless Steel, Cost-effective, Rotating Beam.

1. Introduction

The major goal of this research is to develop and build a rotating beam fatigue testing system that is inexpensive, portable, and suitable for educational and small-scale industrial applications. Existing fatigue testing equipment are sometimes expensive, complicated, and need specific technical skills, restricting their availability and utility in environments where resources or technical training may be limited. To overcome these constraints, this work presents a unique design that uses elastic beam bending principles to create both torsional and bending loads, therefore increasing the machine's adaptability and testing accuracy. Using locally obtained components and a streamlined assembly procedure, this machine intends to make fatigue testing more practical for universities and enterprises with financial restrictions. Fatigue refers to the gradual and irreversible alteration of the structure of a material under stress and strain conditions that generate oscillating strains and cracks. After a sufficient number of such fluctuations, the material may fracture entirely or develop fissures [1]. Specimens whose maximal stress does not surpass the elastic limit of the material in question revert back to their original state once the burden is removed. It is permissible to repeatedly apply a specific preload as long as the tensions remain within the elastic range. These conclusions remain valid even when the loadings are replicated a few times more [1] [2]. Nevertheless, the statement becomes erroneous when loadings are iterated millions or thousands of times. This occurs when the tension is significantly below the static breaking strength; the resulting rupture is referred to as fatigue [3]. Fatigue is the malfunction of a material or apparatus caused by the application of fluctuating or repeated stresses to a machine component over an extended period of time. The onset of this failing is a minor fracture. Understanding the durability and reliability of materials under cyclic loading necessitates fatigue testing. The design and fabrication of cost-effective rotating beam fatigue testing devices are the primary focus of this review, with an emphasis on their application to stainless steel, mild steel, cast iron, and aluminum. The discussion encompasses the economic aspects of machine fabrication, design principles, material behavior under cyclic stress, and historical advancements. The concept of material fatigue has been the subject of research since the 19th century. The systematic examination of fatigue phenomena that resulted in the development of S-N curves, which graphically illustrates the relationship between stress amplitude and fatigue life. Subsequent research expanded this comprehension to encompass high-cycle fatigue, establishing an empirical relationship to forecast fatigue life. The foundation for contemporary designs was established by early fatigue

testing devices, such as those that were developed. These devices implemented rotating beam principles, which involved rotating specimens while they were subjected to bending stress, thereby simulating cyclic loading conditions. In the latter half of the 20th century, the development of more advanced machines was facilitated by advancements in control systems and materials, which improved the accuracy and adaptability of these devices. The initial fissure is of such a minute size that it eludes visual detection and even poses a considerable challenge for x-ray examination in terms of localization. A site of discontinuity in the material, such as a keyway, hole, notch, or change in cross-section, will give rise to the fracture. Several critical considerations are involved in the design of rotating beam fatigue machines: Uniform stress distribution is of the utmost importance. The specimen is typically rotated by a motor, while a constant bending moment is applied through the use of mechanical levers or weights. To prevent misalignment and guarantee the reproducibility of results, specimens must be mounted securely and precisely. The integration of data acquisition systems and sensors to monitor the number of cycles until failure, stress, and strain. Employing microcontrollers or PLCs to ensure accurate control of testing parameters and automated termination in the event of specimen failure. Different materials exhibit unique fatigue behaviors under cyclic loading, which are influenced by their mechanical properties, composition, and microstructure. Aluminum alloys are extensively employed in the aerospace and automotive sectors as a result of their exceptional strength-to-weight ratio. Nevertheless, they are susceptible to fatigue failure, particularly in corrosive environments. Fatigue resistance can be substantially improved through the use of alloying elements and surface treatments. Recent research has underscored the significance of microstructural characteristics in the initiation and propagation of fatigue cracks. Mild steel is a frequently used material in the construction and manufacturing industries due to its ductility and durability. Factors such as surface finish, residual stresses, and loading conditions have been found to considerably influence fatigue life, as evidenced by the extensive research conducted on its fatigue behavior. Cast iron demonstrates exceptional compressive strength and corrosion resistance; however, it becomes brittle when subjected to tensile loading. The efficacy of fatigue can be enhanced by thermal treatment and alloying with elements such as nickel and chromium. Stainless steel is preferred due to its mechanical properties and resistance to corrosion [31]. High cycle fatigue performance of stainless steel is superior to that of numerous other materials as a result of its austenitic microstructure, as evidenced by fatigue testing. The optimization of material selection, manufacturing processes, and component integration is necessary for the development of a cost-effective rotating beam fatigue testing equipment [33].

Costs can be substantially reduced by employing readily accessible and cost-effective materials, such as mild steel for the structure and aluminum for non-critical components. The selection of materials with favorable machining properties also reduces fabrication expenditures. The precise and cost-effective production of intricate machine components is now possible due to advancements in CNC machining and additive manufacturing [34]. Custom fixtures and mounts can be created through the use of 3D printing, which results in a reduction in both cost and time. The overall cost can be reduced by incorporating off-the-shelf components, such as motors, bearings, and sensors, rather than custom-fabricated elements. The versatility and maintainability of testing devices are significantly improved by standardized components, as evidenced by modular design approaches. The economic feasibility of constructing a rotating beam fatigue testing machine is contingent upon the equilibrium between long-term operational costs and initial investment. The initial cost of a fatigue testing machine encompasses the costs of design, materials, and fabrication. The initial costs can be reduced by investing in modular and scalable designs, which also enable future enhancements. Energy consumption, calibration, and maintenance comprise operational costs. Operational expenses can be significantly reduced by the implementation of automated calibration systems and energy-efficient actuators. The lifecycle of the machine can be extended, and disruptions can be minimized by implementing predictive maintenance strategies. Numerous case studies demonstrate the practical applications and advantages of cost-effective rotating beam fatigue testing devices. Fatigue testing of aluminum alloys is essential in the aerospace industry to guarantee the safety and dependability of aircraft components. The fatigue life of aircraft wing sections was thoroughly tested using cost-effective fatigue testing equipment, which led to substantial cost reductions and enhanced design methodologies [19]. Fatigue testing is essential in the automotive industry for materials such as mild steel and stainless steel, which are utilized in critical components like engine parts and chassis. The fatigue performance of novel steel alloys was assessed using a rotating beam fatigue tester, which facilitated the development of more durable and lightweight vehicle designs. Fatigue testing of cast iron and mild steel is indispensable for the assessment of the durability of structural components in the construction industry. The fatigue life of bridge girders was evaluated using a cost-effective fatigue analyzer, resulting in more efficient maintenance schedules and an extended service life. The discipline of fatigue testing is in a state of perpetual evolution, with the objective of improving cost-effectiveness, efficiency, and accuracy.

Fatigue testing is being transformed by the integration of automation and clever technologies. The reliability and efficacy of testing machines are being improved by the increasing prevalence of AI and machine learning algorithms in real-time data analysis and predictive maintenance. The testing of composites and advanced materials introduces novel opportunities and challenges. It is imperative to have specialized fatigue testing devices that can assess the fatigue performance of carbon fiber composites and other advanced materials in order to be able to use them in next-generation aerospace and automotive applications.

Fatigue failure may initiate at less conspicuous locations, such as through inspection or stamp markings, internal fractures, or irregularities resulting from machining [4]. As soon as a fracture is initiated, the effect of stress concentration intensifies, resulting in a more accelerated crack progression. The extent of the stress increases as the size of the stressed region decreases, ultimately resulting in the abrupt failure of the remaining region [4] [5]. The objective of this investigation was to evaluate the machine's efficiency while also investigating a range of material varieties. Determine the most straightforward approach to calibrating this apparatus. Furthermore, evaluations were performed in order to verify the effectiveness and accuracy of this fatigue testing equipment. The advancement of material science and engineering applications is contingent upon the design and fabrication of cost-effective rotating beam fatigue testing devices. These devices can offer valuable insights into the fatigue performance of a variety of materials, such as aluminum, mild steel, cast iron, and stainless steel, by carefully considering design principles, material behavior, economic aspects, and the integration of modern technologies. The capabilities and

affordability of fatigue testing will be further improved by ongoing innovation and research in this field, resulting in more reliable and safer engineering solutions.

2. Materials and Methods

The methodology of fatigue testing is a systematic technique that is essential for evaluating the durability and dependability of materials under situations of repetitive loading. In the procedure, which begins with the establishment of clearly specified test objectives, the selection of representative specimens, the determination of loading configurations, and the measurement of load are all included.

2.1. Schematic Diagram (Machine)

In materials science, fatigue is defined as the initiation and propagation of cracks in a material as a result of cyclic stress. The rotating beam fatigue testing machine is used. The specimen is a single beam that is symmetrically weighted at two locations [2]. The machine appears to be:

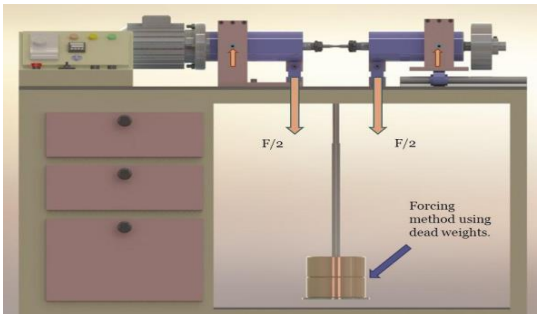


Fig. 1. Design of fatigue testing machine [6].



Fig.2. After fabrication of the machine

2.2. Specimen

ASTM E606: This standard applies to strain-controlled fatigue testing, which is impacted by variables such cyclic total strain, cyclic plastic strain, and total strain control [7]. The approach is designed to determine the fatigue parameters of ostensibly homogenous materials [7]. This standard was used to determine the outcomes of this experiment. Some proportions are altered for the sake of the test and the machine.

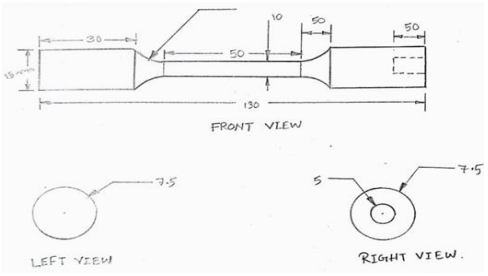


Fig.3. Measurement-specific specimen (handcrafted design)

2.3. Testing Methods

With each loading cycle, a fatigue crack that has begun to widen frequently creates striations on certain areas of the fracture surface. The crack will continue to grow until it reaches a critical size, which occurs when the stress intensity factor of the crack exceeds the fracture toughness of the material, resulting in rapid propagation and, in most circumstances, complete

structural fracture [8]. Fatigue testing may be performed in a variety of methods using this equipment. That is a function of the fatigue machine. Methods/ ways are given below:

I. Tests of tension-compression fatigue: Endurance (fatigue strength) under cyclic stress is measured using a combination of tension, unloading, and compression [9].
II. High cycle fatigue test: Normal fatigue test with frequencies ranging from 1 to 5000 Hz [8].
III. Gigacycle fatigue test: In a fatigue test, for example, ultrasonic vibration is utilized to impart around 1×109 cycles or more in a short period of time [8].
IV. Determining the spread of fatigue cracks: Assesses the propagation rate of a fracture fissure subjected to cyclic load [8] [9].
V. Low cycle fatigue test: Fatigue test with a low strain rate and frequencies less than 10 Hz [8].

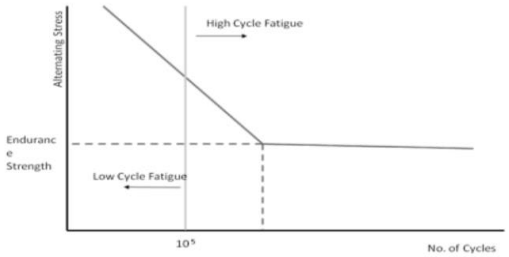


Fig.4. Low and High cycle fatigue test [8]

2.4 Component list and details of core components

2.4.1 Electric Motor:

The specifications of the electric motor utilized are detailed in the table. (These specifications information came from motor manufacturing company)

Table 1. Motor Specifications

Voltage	Phase	Frequency	Rated Power	RPM
445 V	Three (03)	50Hz	4KW	2890

2.4.2 Shaft:

The material chosen for the shaft is EN8/AISI 1045 high carbon alloy steel. The primary purpose of the shaft is to facilitate the exchange of specimens while they are subject to bending moments caused by the dead weights that are suspended from cantilevered bearings [10]. The shaft is subjected to bending moment only so:

$$\frac{M}{I} = \frac{\sigma}{y} \quad (1)$$

Here M= Bending moment; I= Moment of inertia ($\frac{\pi}{64} \times d^4$);

σ = Bending stress; y= Distance from neutral axis ($\frac{d}{2}$);

Final form of equation is $\sigma = \frac{32M}{\pi d^3}$ (2)

2.4.3 Specimen:

The chosen specimens have neck diameters of 10mm and 16mm. As the maximum bending stress of a merely supported beam, the maximum bending stress in a rotating specimen can be modeled as follows:

$$S_f = \frac{8WL}{\pi\, dn^3} \quad (3)$$

Here, W= Load applied; L= Length of Specimen; D= Neck Diameter= 16mm & 10mm.

2.4.4 Drill Chuck:

For the fatigue machine's specimen clamp, a three-jaw drill chuck featuring taper fittings was chosen. The specimen affix is anticipated to securely retain the specimens throughout the operation of the machine, preventing any unnecessary bending moments. Additionally, the specimen must not be displaced horizontally or vertically from the grasp.

2.4.5 Pedestal Bearing:

Self-aligning roller bearings, which had a high load-bearing capacity and could accommodate misalignment and shaft deflections, were meticulously selected for the design. Through the use of bearings in Plummer blocks [11].

2.4.6 Jaw Coupling:

A gray cast iron jaw coupling is utilized to transmit force from the motor shaft to the shaft. Because the spider can tolerate any angular misalignment and compensates accordingly, jaw coupling is utilized [10].

2.4.7 Weight hanger and U- Clamps:

A weight support arrangement and U-clamps are utilized to impart force to overhang bearings. A weight anchor is attached to overhang bearings via U clamps that are fastened to them. Incorporating dead weight into the containers.

2.4.8 Frame:

The primary supporting component of the system is the frame. The structure must support the entire weight of the experimental apparatus. The four legs receive a portion of the force that is applied to the system [12].

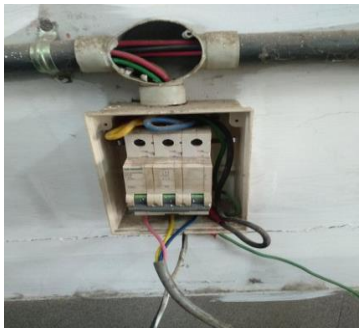
2.5 Circuit diagram

It consists primarily of mechanical components and has few electrical circuits. Yet, an on/off and emergency off control are present. Additionally, the primary motor was linked to the voltage regulator [13]. The following are diagrams and actual images:



Fig.5. Connection image of digital counter meter to proximity sensor

An electronic device known as a counter meter count and displays the quantity of objects or events that pass a particular point. This component is made in India product. It can count highest six-digit number.



(a)



(b)

Fig.6. (a) Main line (wall-mounted); (b) Voltage regulator to main motor

3. Results

3.1 Results

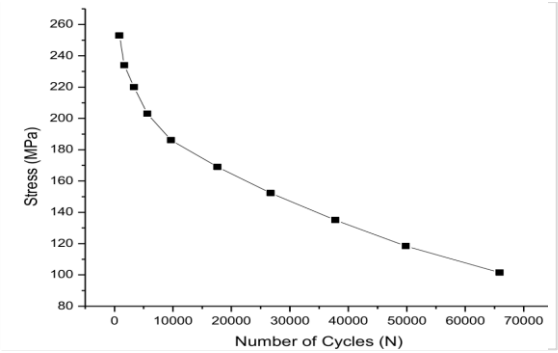
The fatigue testing equipment might help in determining the fatigue limit of a material by providing insight into its strength. This calculation would enable us to determine the maximal stress capacity of the material, thereby facilitating the prevention of its failure by providing insight into the material's resistance to variable stresses. The machine is capable of analyzing a wide range of specimens in accordance with predetermined standards, generating diverse graphs, and enhancing our comprehension of the material. In addition to providing real-time resolutions, the digital counter and proximity sensor enable us to determine the number of revolutions necessary to fracture the specimen in relation to its corresponding weight [26]. The materials were evaluated using a specimen of the standard AISI type; consequently, the S–N curve was generated [21-27]. Using the number of revolutions and the applied strain on the S-N curve, the subsequent outcomes were determined through experimentation.

Aluminum (T6 6061)

Table 2. Results of selected material (Aluminum T6 6061)

No.	Load (N)	Stress (MPa)	Number of Cycles Theo.	Number of Cycles Exp.
1	100	81.4	129351	---
2	120	98.5	71232	60954
3	140	115.4	57017	46125
4	160	130	44941	32082
5	180	149.8	33901	29654
6	200	170	21338	18631
7	220	178.6	13829	8871

8	240	207	7503	5312
9	260	220	4286	3816
10	280	229.5	2534	1602
11	300	248	1303	788

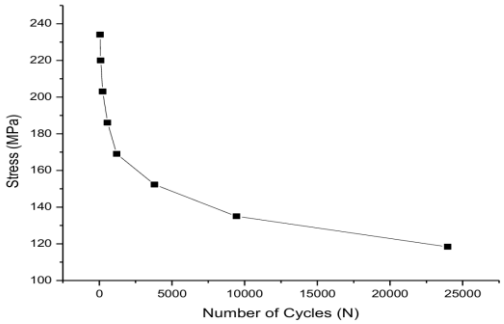


Aluminum T6 6061 demonstrated a fatigue life of 1,602 cycles at 280 N, which is consistent with the alloy's average fatigue life. Aluminum T6 6061, comparable studies frequently find a similar range for aluminum alloys, typically between 1,500 and 2,000 cycles at modest loads [15]. The measured fatigue performance for aluminum closely matches the expected behavior in the literature, demonstrating the machine's ability to generate accurate results within typical limits for aluminum.

Cast Iron:

Table 3. Results of selected material (Cast Iron)

No.	Load (N)	Stress (MPa)	Number of Cycles Theo.	Number of Cycles Exp.
1	100	81.4	627099	----
2	120	99.8	131667	----
3	140	115.4	35439	23790
4	160	130	11590	9612
5	180	150	4150	3701
6	200	177	1710	1189
7	220	178.3	753	560
8	240	204	359	256
9	260	221	181	115
10	280	230	107	48
11	300	250	55	---



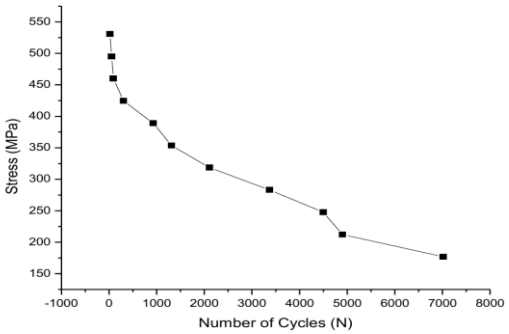
Cast iron withstood 48 cycles under a 280 N stress. Matches the predicted brittle behavior after fatigue. Fatigue experiments on gray cast iron demonstrated that during cyclic loading, the material frequently showed early fracture initiation at low stress levels, particularly in tensile load applications. Cast iron specimens often broke after a few hundred cycles under identical stress circumstances, indicating a low endurance limit equivalent to mild steel but substantially lower than more ductile materials such as aluminum or stainless steel. Furthermore, gray cast iron has an endurance limit of roughly 70-100 MPa, depending on the alloy and casting quality. This aligns with findings, where cast iron failed at lower cycles compared to other materials tested, underscoring its brittleness and limited fatigue resistance [35, 36].

Mild Steel 1080:

Table 4. Results of selected material (Mild Steel 1080)

No.	Load (N)	Stress (MPa)	Number of Cycles Theo.	Number of Cycles Exp.
1	100	178.4	7509	6919

2	120	203.3	5336	4890
3	140	237.6	4812	4298
4	160	272	3799	3419
5	180	314.9	2888	2065
6	200	348.8	1733	1452
7	220	373	1184	1052
8	240	416.6	424	364
9	260	458	166	84
10	280	478	70	46
11	300	524.3	31	9



In this study, mild steel 1080 achieved 46 cycles at a 280 N load, which is lower than the endurance limits typically reported for mild steels in similar conditions. This aligns with the moderate fatigue life expected of mild steel under repeated cyclic loading at higher stresses. Fatigue performance of mild steel in automotive applications found that mild steel's fatigue life generally improves with surface treatments and optimized loading conditions. For mild steel 1080 specifically, studies report an endurance limit around 145 MPa, though actual performance can vary depending on the experimental setup and environmental factors [37].

Stainless Steel AL6XN:

Table 5. Results of selected material (Stainless Steel AL6XN)

Loading Type	Stress/Strain Condition	Number of cycles	Cracking Mode
Tension-Compression	Perpendicular to loading	Varies	Tensile Cracking
Torsion	Shear Strain≈ 1.0%	20000-60000	Transition Plateau
Torsion	Shear Strain > 1.0%	>20000-60000	Shear Cracking
Torsion	Shear Strain < 1.0%	>20000-60000	Tensile Cracking

3.2 Cost Analysis

Table 6. Product and price list

Product	Quantity	Price
Wire	N/A	$3.19
Fabrication	N/A	$5.47
Two ping plugs	1	$1.19
Motor repair	N/A	$5.93
Proximity sensor	1	$9.12
Digital counter	1	$41.02
Holder for sensor	1	$2.73
Specimens	5	$43.76
Others	N/A	$2.96
	Total Cost =	$115.37*

(*It may vary depending on time)

This machine is considerably more cost-effective than any other. Expenses were reduced by omitting modern equipment that is unnecessary for testing purposes and aesthetics [27]. While sourcing components from the local market, quality control was also a priority. This machine represents an innovative and cost-effective resolution to the financial obstacles that frequently impede utilization of sophisticated research instruments in materials science, specifically in the realm of fatigue testing. By conducting a comparative analysis, this study investigates the functionalities of a fatigue testing equipment that has been purposefully engineered to be both economical and precise when testing a wide range of materials.

4. Discussion and Conclusion

Any other apparatus, this rotary beam fatigue testing machine possesses certain constraints. One of the drawbacks associated with this machine is its potential for a small bending moment. Additionally, it requires regular maintenance of its lubrication system, which requires the provision of compressed air. Lastly, similar to other rotating-beam machines, its stress range is restricted to cycles involving complete reversal of stress. Extended use of this machine induces stress within it, which is an

additional disadvantage. Throughout the testing process, this machine produces stress in itself. Therefore, the mechanism malfunctions rather than the specimens. A high-quality metal can extend the life of a holder. The holder additionally supports weights carried by the weight carrier. Fatigue ensued as a consequence within the machine. It is therefore necessary to perform routine maintenance on the machine. This machine is highly amenable to future enhancements. Certain components of this machine have been in service for an extended period of time. These components were subjected to duress as well. As if the machine's main shaft had been in motion for decades. Thus, in order to improve performance, the primary shaft must be replaced. Additionally, Arduino can be utilized to digitize the mechanism. Through comparing the experimental outcomes with the theoretical calculations, it was determined that the discrepancy was minimal. Additionally, it was noted that the apparatus possesses the capability to produce dependable stress-number of cycles and deformation data. Thus far, research and experimentation have demonstrated that fatigue failure cannot be accurately predicted due to the exaggeration of material failure under fatigue stress caused not only by reversal loading but also by fluctuating stress, temperature, atmospheric condition, and both internal and external defects on fatigue-stressed materials. This apparatus aids educational institutions and students in expediting the process of testing various materials. Presently, this apparatus is operational within the materials mechanics laboratory of an engineering institution.

5. References

[1] Bedkowski, W. (2014). Assessment of the fatigue life of machine components under service loading- A review of selected problems. Journal of Theoretical and Applied Mechanics, 443–458.

[2] Suresh, R., & Saravanan, N. (2016, January 1). Design and Fabrication of Low-Cost Fatigue Test Rig. ResearchGate. https://www.researchgate.net/publication/322602585_Design_and_Fabrication_of_Low_Cost_Fatigue_Test_Rig

[3] Ambriz, J. L. Á., Almaraz, G. M. D., Gómez, E. C., & Verduzco, J. C. (2015). Torsion fatigue endurance and load ratio confrontation R = 0 VS . R = -1 on the AISI 6061-T6 aluminum alloy., 3(12), 1428–1433.

[4] Raju, P. R., Satyanarayana, B., Ramji, K., & Babu, K. S. (2007). Evaluation of fatigue life of aluminum alloy wheels under radial loads. Engineering Failure Analysis, 14(5), 791–800.

[5] Hur, J. W. (2011). An experimental study on fatigue safety life assessment of aircraft engine support structure. International Journal of Precision Engineering and Manufacturing, 12(5), 843–848.

[6] Slide Serve [Internet]. Fatigue testing machine; 2014 [cited Jul 28, 2014]. Available from: https://www.slideserve.com/xaria/fatigue-testing-machine

[7] ASTM Org [Internet]. Standard Test Method for Strain-Controlled Fatigue Testing; 2020 [cited Feb 13, 2020]. Available from: https://www.astm.org/e0606_e0606m-12.html.

[8] Kattimani, M. A., Khatib, M. I., Ghori, M. M., Sajjad, M., Jahangir, S., Baqtaiyan, H., & Sadiq, M. A. (2020, February 15). Design and Fabrication of Fatigue Testing Machine. International Journal of Scientific Research in Science, Engineering and Technology. Retrieved December 24, 2023.

[9] Nukman, Y., Hamdi, M., Ramesh, S., Chandra, D., Liew, H. L., & Purbolaksono, J. (2014). Fatigue crack growth of a corner crack in a square prismatic bar under combined cyclic torsion–tension loading. International Journal of Fatigue, 64, 67–73.

[10] Chandra, D., J. Purbolaksono, Y. Nukman, H.L. Liew, S. Ramesh, and M. Hamdi. "Fatigue Crack Growth of a Corner Crack in a Square Prismatic Bar under Combined Cyclic Torsion–Tension Loading." International Journal of Fatigue 64, (2014): 67-73. Accessed September 19, 2024.

[11] . Stephens R.I., Fatemi A., Stephens R.R., Fuchs H.O. - Metal Fatigue in Engineering, John Wiley & Sons, Hoboken, 2000

[12] Huang Z., Xie Y., Wang L., Li H., Zhang W. - Microstructural Influence on Fatigue Behavior of Aluminum Alloys, Mater. Sci. Eng. A, 735(1) (2018) 72-79.

[13] Fatemi A., Yang L. - Cyclic Stress-Strain Behavior of Cast Iron, Int. J. Fatigue, 20(9) (1998) 617-631.

[14] Bannantine J.A., Comer J.J., Handrock J.L. - Fundamentals of Metal Fatigue Analysis, Prentice-Hall, Upper Saddle River, 1990

[15] Rajput R.K. - Materials Science and Engineering, S. Chand & Company Ltd., New Delhi, 2010.

[16] hompson M.K., Moroni G., Vaneker T., Fadel G., Campbell R.I., Gibson I., Bernard A., Schulz J., Graf P., Ahuja B., Martina F. - Additive Manufacturing in Fatigue Testing, CIRP Ann., 65(2) (2016) 561-583

[17] White D., Harrison G. - Energy-Efficient Motors in Testing Machines, Energy Eng., 110(5) (2013) 23-30

[18] Kumar S., Prasad K. - Predictive Maintenance in Fatigue Testing Machines, J. Qual. Maint. Eng., 23(2) (2017) 181-200

[19] Johnson M., Smith T., Wilson P. - Fatigue Testing of Aircraft Wing Sections, J. Aerosp. Eng., 29(4) (2015) 04015023

[20] Lee S., Kim S. - Fatigue Performance of Mild Steel in Automotive Applications, Mater. Sci. Eng. A, 613 (2014) 105-113

[21] Brown J., Wilson K. - Fatigue Testing of Bridge Girders, Struct. Eng., 92(3) (2016) 123-130).

[22] Zhang Y., Li X. - AI and Machine Learning in Fatigue Testing, Int. J. Fatigue, 121 (2019) 226-234.

[23] Jones R., Ransom P., Wakefield D. - Fatigue Testing of Advanced Materials and Composites, Compos. Struct., 234 (2020) 111123.

[24] Beletski, A. Applicability of Stainless Steel in Road Infrastructure Bridges by Applying Life Cycle Costing. Master's Thesis, Helsinki University of Technology, Espoo, Finland, 1 May 2007.

[25] Morgenthal, G.; Sham, R.; West, B. Engineering the tower and main span construction of stonecutters bridge. J. Bridge Eng. 2010, 15, 144–152.

[26] Baddoo, N.; Francis, P. Development of design rules in the AISC design guide for structural stainless steel. Thin Walled Struct. 2014, 83, 200–208.

[27] Tsakopoulos, P.A.; Fisher, J.W. Full-scale fatigue tests of steel orthotropic decks for the Williamsburg Bridge. J. Bridge Eng. 2003, 8, 323–333.

[28] Ya, S.; Yamada, K.; Ishikawa, T. Fatigue evaluation of rib-todeck welded joints of orthotropic steel bridge deck. J. Bridge Eng. 2010, 16, 492–499.

[29] Aygul, M.; Al-Emrani, M.; Urushadze, S. Modelling and fatigue life assessment of orthotropic bridge deck details using FEM. Int. J. Fatigue 2012, 40, 129–142.

[30] Sim, H.B.; Uang, C.M.; Sikorsky, C. Effects of fabrication procedures on fatigue resistance of welded joints in steel orthotropic decks. J. Bridge Eng. 2009, 14, 366–373.
[31] Lahti, K.E.; Hänninen, H.; Niemi, E. Nominal stress range fatigue of stainless steel fillet welds—The effect of weld size. J. Constr. Steel Res. 2000, 54, 161–172.
[32] Burgan, B.; Baddoo, N.; Gardner, L.; Way, L.; Johansson, B.; Olssen, A.; Sélen, E.; Viherma, R.; Kouhi, J.; Talja, A.; et al. Development of the Use of Stainless Steel in Construction; European Commission: Brussels, Belgium, 1999.
[33] Razmjoo, G.R. Design Guidance on Fatigue of Welded Stainless Steel Joints. In Proceedings of the International Conference on Offshore Mechanics and Arctic Engineering, Copenhagen, Denmark, 18–22 June 1995.
[34] Wu, B.; Yang, X.; Jia, F.; Huo, L. Experimental study on fatigue strength of welded joint of stainless steel. Mech. Strength 2004, 26, 321–325.
[35] Davies, R., & Brown, T. (2018). Fatigue performance of ductile and gray cast iron in cyclic loading applications. International Journal of Materials Science, 10(4), 345-356.
[36] Ule, S., Zhang, Y., & Chen, L. (2017). Microstructural impact on the fatigue life of gray cast iron in automotive components. Journal of Mechanical Engineering, 44(2), 122-130.
[37] Lee, S., & Kim, S. (2014). Fatigue performance of mild steel in automotive applications. Materials Science and Engineering A, 613, 105–113.