Low Cycle and Finite Life Fatigue Experiment

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ABSTRACT

An experiment for examination of fatigue failure theories is presented for potential adaptation at undergraduate mechanical and civil engineering programs. The focus of the experiment is placed on Low Cycle and Finite Life Fatigue. Design of the experiment and its associated apparatus allows for both symmetric (fully reversed) and non-symmetric reversed loading with different magnitudes applied to an array of cantilever beams. Several scenarios using beams with different lengths, sections, stress concentrations, and materials are proposed for destructive/fatigue failure testing. Other specimen with interesting features may be easily added to the package if desired. The time factor for conducting fatigue testing in an educational environment has been incorporated in the design process. Availability of the blueprints of all components of the robust apparatus, its cost effectiveness, ease of manufacture, and a proposed outline of the experiment make it an ideal addition to the archives of experiments in undergraduate engineering programs.

I-INTRODUCTION

Laboratory experimentation is a critical final link for a thorough understanding and appreciation of scientific and engineering theories. Every possible effort should be made not to deprive the future engineers or educators from this vital component of their education [1]. It is therefore necessary to continue development of effective and efficient pedagogical methods and techniques for the engineering laboratory experience [2].

Laboratory apparatus is generally expensive due to low production levels, specialized features and significantly higher *Design Costs* built into the final cost. For example, the range of cost for a typical educational fatigue testing apparatus is from \$28,500 to \$32,500. These units are basically adaptations of the R. R. Moore Industrial Fatigue testing devices which cost in excess of \$100,000.

Such high costs may lead to lack of vital laboratory apparatus and in turn deprive the engineering students from being sufficiently exposed to important concepts such as verification of the theory through experimentation, interpretation and analysis of data and gaining sufficient background for designing experiments. However, if blueprints of the designs of a (desired) apparatus are available, and on site machining capabilities exists, a major cut may be expected in the final cost. Such designs and blueprints may be generated in-house in collaboration with undergraduate engineering students [3]. The authors hope that the colleagues in other engineering programs would find this effort worthy of potential adaptation in their program.

II- OBJECTIVES OF THE PROJECT

The following major objectives were set at the inception of the project;

- 1. To develop an experiment for examination of fatigue failure theories,
- 2. To create an opportunity for collaborative research and design efforts between engineering student(s) and faculty,
- 3. To generate a modular, cost-effective, reproducible apparatus with outstanding design characteristics,
- 4. To make all information necessary for fabrication of the apparatus and conducting the experiment available to engineering programs nationwide.

The authors invited three Junior engineering students (Andrew Maulbeck, Mary Anne Bitetto and Greg Conway) to collaborate with them in materializing the above goals. The parameters in successful implementation of the processes involved for achieving the above goals were comprehensively discussed, outlined and a preliminary Gantt chart was generated. Through ten weekly scheduled meetings, alternative designs for each of the components, subsystems and the overall integrated system were evaluated, chosen and optimized. It took another two weeks to fabricate, modify, and test the reliability and capabilities of the apparatus.

III- Background

Roark and Young define Fatigue as "the fracture of a material under many repetitions of a stress at a level considerably less than the ultimate strength of the material" [4]. In a fatigue test, the specimen may be exposed to equal or unequal alternating stresses. When equal positive and negative stresses are applied, it is said that the loading is fully reversed. In this situation, a critical location of the specimen will experience equal levels of both tensile and compressive stresses in one full cycle.

The benchmark for establishing the behavior of engineering materials under dynamic/fatigue loading is the "S-N" diagram. Here, "S" corresponds to the stress level and "N" to the number of cycles. Due to the uncertainties involved in material behavior and characteristics, a large number of specimens are tested at different stress levels for generating the "S - log N" diagram. Ideally, the main objective in such tests is two-fold. First, to establish (for a given material), up to what stress levels the material will enjoy an infinite life (Endurance Limit); and second, to correlate the number of cycles at different stress levels that a material will be able to go through before coming to failure.

The S-N diagrams for several engineering materials have been established as a result of comprehensive and highly time consuming tests. Generally, the results are more reliable for steel alloys compared to aluminum alloys. Low-cycle fatigue is defined on an S-N diagram as being approximately between zero and 1000 cycles. High-cycle fatigue is generally greater than 10^3 cycles. Finite life is assumed to be below 10^7 cycles [5]. A typical S-N diagram is shown in figure 1.



Figure 1 A Typical S-N Diagram. Curve A – Typical behavior of steel alloys in fatigue loading, Curve B – Typical behavior of Aluminum alloys in fatigue loading.

Ferrous materials usually show a definite breaking point on the S-N diagram around 10^6 cycles, whereas nonferrous metals show no such point. For nonferrous metals, a value of 5×10^8 cycles is usually assigned as the fatigue limit. There are several theories available for prediction of failure due to cyclic loading [6]. Depending on the situation at hand, the designer must apply the suitable theory as no one theory will optimally address all design requirement. However, all of them reflect on the fact that this type of failure is not yet completely understood and extra care must be taken when dealing with fatigue phenomenon. Shigley and Mischke present a rather comprehensive view of the issues involved with the variations of behavior of different materials in the fatigue analysis process [7]. The goal in the current experiment is to create and simulate the conditions that allow students to test the reliability of such (S-N) diagrams and gain a better understanding of the (statistical and probabilistic nature of) Fatigue Failure Theories.

IV- DESIGN OF THE EXPERIMENT AND ITS ASSOCIATED APPARATUS

The following criteria have been incorporated in the design of the experiment and the associated apparatus:

- Safety
- Simplicity and Practicality in Fabrication (at other institutions)
- Affordability/Control of Cost
- Use of Reliable Sources for Components
 - Durability
 - Use of Non-Corrosive & Aesthetically Pleasing Materials
 - Simplicity of Operation
 - NO use of Discontinued Parts/Components
 - Time Factor in Conducting the Experiment

The requirement of having a modular design and stopping the motor (when the specimen fails) presented some interesting challenges. Additionally, the size, weight, and other physical characteristics of the experiment were not defined at the inception of the project. This lack of constraints was a mixed blessing (for the students) since it did free the design process to vary these factors, but also removed these characteristics from being used as starting points in the process. Table (1) summarizes the parameters involved in the implementation of the project.

#	
	TYPE OF ACTIVITY
1	Brainstorming for Design of the Experiment and the Apparatus
2	Meeting Minutes and Progress Reports
3	Prototyping
4	Generation of Technical Drawings for all (Home Made) Components
5	Selection of (commercial) Components and Identification of Suitable Sources
6	Fabrication and Compilation of Notes on Best Approach for Machining
7	Electro-mechanical control system
8	Testing, Calibration, Generation of Data and Measure of Accuracy
9	Generation of the Laboratory Manual for the Experiment
10	Loading of All Necessary Information and Helpful Links on a CD (**)

 Table 1
 Parameters involved in the successful implementation of the project.

(**) This Information may be obtained from the first author.

V- MATHEMATICAL MODELING

To better appreciate the complexity of the fatigue phenomenon, mathematical models were generated, examined and used as a visual platform to decide on the degree of modularity of the apparatus. Further, they serve as indicators by which a laboratory coordinator/instructor may make more informed decisions about the time required for conducting the experiment/ demonstration. These models are presented in *Appendix (A)* [8].

VI- DESIGN OF THE COMPONENTS AND SUBSYSTEMS OF THE APPARATUS

The proposed Modular Fatigue Testing System is comprised of the following major components and subsystems.

- 1. Frame and the Cantilever Beam Support System/Stand(s),
- 2. Force Delivery linkage,
- 3. Counter and Motor Control system.

The role and design characteristics of each of these components are briefly discussed.

1. The Frame and Beam Support Stand

The Frame is constructed of MiniTec components due to their durability, cost effectiveness, and aesthetic appeal. MiniTec frames are capable of being rearranged to fit additional demands.

This modular nature allows for upgrading the system in the future by only purchasing a few additional components instead of purchasing a completely new frame. The frame allows for supporting and running two testing devices simultaneously. It is equipped with four locking casters (that also resist rotation). The modularity of its design allows for conducting many other experiments at different periods of a typical laboratory course and easy storage when not in use.

The Beam Support System/Stand is required to support the specimen in a cantilever mode. These are made of aluminum and may be used for other experiments. Figure 2 shows the frame, and the two stands used to run tests on two different specimens at the same time. In the shown instant, the upper fibers of the specimens on the left and right are experiencing tensile and compressive stresses respectively.



Figure 2 The Frame and the two Beam Support Stands used for running two different tests simultaneously.

2. Force Delivery linkage

Application of the force to the free end of the cantilever specimen is achieved through the use of a (simulated) 4-Bar Linkage. The Input link is a disc attached to a DC motor; the Coupler (the connecting rod) is a steel bar coupled to Heim joints at both ends; and the Output link is the specimen <u>itself</u>. This arrangement has proven to work satisfactorily. The input disc allows for several input lengths and the motor bracket may be adjusted for obtaining different combinations of desired alternating stresses. Figure 3 shows how the Force Delivery System has managed to create a fully reversed loading condition on an aluminum specimen.





Figure 3 Display of the force delivery in a fully reversed loading on an aluminum specimen with a circular discontinuity near the fixed end.

3. Counter and Motor Control system

A seven digit counter with magnetic sensors is used to measure the number of cycles to failure. Next, the problem of stopping the motor (as the part fails) had to be addressed. Using the geometry of the system, a method for capturing the event of *specimen failure* was devised. It was recognized that if the specimen failed, the connecting rod would have a tendency to fall either towards or away from the beam support. It was determined that regardless of how the specimen failed; the position of the rod would quickly travel outside of its normal pattern.

Because of this, a solution was chosen that places a limiting dimension on the horizontal travel of the connecting rod. Essentially, a pivoting fork was positioned around the connecting rod such that in normal operation, the connecting rod comes within 0.25" of the legs of the fork. When the specimen fails, however, the connecting rod falls into a leg, causing the fork to pivot. This pivoting motion is used to actuate micro-switches that are interfaced with a relay. Upon actuation of these switches, the relay cuts the power to the motor. This solution is tested, and reliably stops the motor (and in turn the counter) when the specimen fails. Figure 4 shows the left and right legs of the fork leaning against the micro-switches.



Fig. 4 Stopping Mechanism. Upon failure of the Specimen, the Connecting Rod will cause the Pivoting of the Fork which in turn activates the relay to shut the motor.

Figure 5 shows the 7-digit digital counter which is activated by a magnetic sensor package coupled with the rotating disc (input link) and the motor bracket.



Figure 5 The Counter and the Sensors. The cylindrical magnet housed on the input link (the rotating disc) triggers the sensor (attached to the motor bracket) carrying signals to the digital counter.

VII- EXPERIMENTAL PROGRAM AND COLLECTION OF DATA

The collection of data initiated since second week of December (2004). A significant number of specimens have been tested so far in the test program. This process has revealed some promising data. Several materials have been selected so far in the test program. Table (2) reflects on the properties of these materials. Figure 6 shows a sample of three aluminum alloy specimens with different geometries. Figure 7 shows two samples with Dog-Bone geometries (of which one has a discontinuity). The table in *Appendix (B)* is an abridged listing of the test results so far.

Although the testing program has resulted in some promising data, in general, the tested specimens consistently fail at higher number of cycles than those predicted by text book models. The authors speculate that this may be due to the combinational effects of the statistical/ conservative nature of the text book models and the conservative listings of the strength of materials in tables. We obtained a 1/8" x 1" x 6 ft. bar of Aluminum 6061-T6 with certification. *The (average) Ultimate and Yield strength values listed on the certificate (S_U = 47.34 kpsi, S_Y = 44.16 kpsi) of this bar are considerably higher than those listed in conventional/text book tables (S_U = 45 kpsi, S_Y = 38-40 kpsi). This is a critical issue in that when running the experiment, the factors of safety against the Ultimate and Yield strengths are set in the range of 1.1, 1.15, 1.2, 1.25, etc. Consider the following scenario.*

If the actual Yield strength is 45 kpsi and a listed table/book value of 40 kpsi is used say with a factor of safety of 1.15; *in reality a factor of safety of about 1.3 is in effect*. The (HIDDEN) actual difference in this case may offset the result by tens of thousands of additional (unexpected) cycles. The tested specimens (machined) from the certified bar have shown significantly better results compared to the non-certified samples.

Because of the unforeseen circumstances (explained above), the testing program will continue until the best possible choices of materials and geometries are established for a better controlled environment. The interested parties may freely contact the first author for most updated and recommended procedures and choices of materials.

VIII- OBSERVATIONS and RECOMMENDATIONS

The following is a listing of the interesting observations made up to this point in the process:

- 1. All solid specimens failed at the edge support,
- 2. All specimens with discontinuities (near the fixed end) failed at the discontinuity,
- 3. All specimens with Dog-Bone geometry failed at the smaller sections near the fixed end,
- 4. Certified specimens fail at values closer to the predicted ones than the non-certified ones,
- 5. Steel specimens fail at values closer to the predicted ones than the Aluminum samples,
- 6. Failure of all specimens was abrupt-no warning,
- 7. The test results may be considered as Accurate but certainly not Precise.

The major obstacle to overcome is to reduce the number of cycles required for failure. This may be achieved by further examination of the text book models/equations and ascertaining materials that do not suffer from a large standard deviation from the expected mean.

The following recommendations may be made at this stage of the task:

- 1. Avoid the use of thin sections as the variation in results is quite troublesome-(do not use sections with a thickness less than 1/8" for Steel and no less than 1/4" for Aluminum),
- 2. Work with specimens that have a Length to Width Ratio of $12 \le L/W \le 15$,
- 3. To avoid Edge Effect, use Dog-Bone geometry if possible,
- 4. Select motors that provide a reasonable combination of power and RPM,
- 5. If you choose to work with aluminum, don't set it as the base metal for the experiment,
- 6. Try to obtain material with certification as this may save you a great deal of time,
- 7. If possible, run a complete tensile test on a sample of the bars used for the specimens,
- 8. Exercise the safety precautions in this experiment to the full extent,
- 9. Obtain the most updated results and recommended procedures from the authors,
- **10.** Share your findings and Alternative Solutions with the authors so that they may share them with other interested parties.

Material	Ultimate Strength, [S _U] (psi)	Yield Strength, [S _Y] (psi)	FatigueBrinellEndurance Limit,Hardness,[S'e][HB](psi)500 Kg Load;10 mm Ball		Modulus of Elasticity, [E] (psi)
Aluminum 6061-T65 Certification Available	45,000	40,000	14,000	95	10,000,000
(Alclad)	(42,000)	(37,000)	(Not Available)	(Not Available)	
Aluminum 5052-H32 (AVOID)	33,000	28,000	17,0000	60	10,000,000
(Alclad)	(25,000)	(21,000)	(Not Available)	(Not Available)	•
Aluminum 6063-T5	27,000	21,000	10,000	60	10,000,000
Steel 1018-HR (Hot Rolled) Recommended	58,000	32,000	(Not Available)	116	29,000,000

 Table 2
 Text book/Table Listing of the Properties of the Materials Tested with the Apparatus.



Figure 6 Samples of Specimens with Different Geometries.



Figure 7 Two Specimens with Dog-Bone Geometries.

IX - WHAT IS AVAILABLE TO THE INTERESTED PARTIES

The following materials are available to those colleagues who may be interested in the reproduction of the apparatus and the use of this experiment:

- 1. Complete set of (most updated) blueprints of all home made components of the apparatus,
- 2. Comprehensive list of all commercial components and materials, their cost, and sources,
- 3. Most updated results and recommended procedures.

The above information may be obtained from the first author. A (preliminary) breakdown of the cost of the apparatus is shown in *Appendix (C)*. A sample Laboratory Handout for the experiment is included in *Appendix (D)*.

X - CONCLUSIONS

The major objectives listed in *section II* have been achieved in this project. It is believed that in comparison with the commercially available counterparts of the proposed design and experiment, an alternative solution is offered to those colleagues who may be interested in adapting this proposed experiment and apparatus. This approach is beneficial for all parties involved; the researching/collaborating student(s), underclassmen who would benefit from such experiments and the enthusiastic instructors/laboratory coordinators who may be fighting with budgetary issues. The major remaining obstacle is the better understanding of why the experimental number of cycles are not falling within acceptable range of the predicted ones. So, further examination of the text book models/equations and search for ascertaining materials that do not suffer from a large standard deviation from the expected mean must continue.

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REFERENCES

- 1. Sepahpour, B., "Design of an Affordable Model Laboratory for Mechanical and Civil Engineering Programs", *Proceedings of ASEE 2003 National Conference, Nashville, TN, June 2003.*
- 2. Sepahpour, B., Clark, E. and Limberis, L. "Modular Lumped Mass Experiment", *Proceedings of* ASEE 2004 National Conference, Salt Lake City, Utah, June 2004.
- 3. Sepahpour, B., "Involving Undergraduate Students in Design of Experiments", *Proceedings of ASEE 2002 National Conference, Montreal, Canada, June 2002.*
- 4. Young, W. C. and Budynas G. <u>Roark's Formulas for Stress and Strain, Seventh Edition.</u> McGraw Hill, 2002.
- 5. Ugural, Ansel C. <u>Mechanical Design: An Integrated Approach. International Edition.</u> McGraw Hill Higher Education, 2004.
- 6. Juvinal, R. C., and Marshek, K. M. <u>Fundamentals of Machine Component Design. Third Edition</u>. John Wiley & Sons, 2000.
- 7. Shigley, J. E. and Mischke, C. R. Standard Handbook of Machine Design. McGraw Hill, 1986.
- 8. Shigley, Joseph E. Mechanical Engineering Design, Third Edition, McGraw Hill, 1980.

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Appendix A:

Approximate Stress Equations

From Mechanics of Materials;

General Equation:

$$\sigma_{bending} = \frac{Mc}{I}$$

$$\delta = -\frac{PL^{3}}{3EI} \rightarrow \frac{-3\delta EI}{L^{3}} = P$$

$$M = PL = \frac{-3\delta EI}{L^{3}} L = \frac{-3\delta EI}{L^{2}}$$

$$c = \frac{h}{2}, \qquad I = \frac{1}{12}bh^{3}$$

$$\sigma_{bending} = \frac{Mc}{I} = \frac{\left(\frac{-3\delta EI}{L^{2}}\right)\left(\frac{h}{2}\right)}{(I)} = \frac{-3\delta Eh}{2L^{2}}$$

It is interesting to note that this equation is independent of the width. For wide Beams a correction factor must be used. However, for the recommended sizes in this experiment, this is not necessary.

Sample Data:

Material: Aluminum 6061-T6 with certification.

The (average) Ultimate Strength, $S_U = 47.34$ kpsi, The (average) Yield strength, $S_Y = 44.16$ kpsi, Modulus of Elasticity, E = 10,000 kpsi, Thickness, h = 0.25" Width, b = 1.0" Deflection, $\partial = 1.0$ "

L Effective	σ _{Bending}
(in)	(psi)
10.0	37,500
9.75	39,400
9.50	41,500
9.375	42,700
9.25	43,800
9.125	45,000
9.0	46,300
8.875	47,600

Appendix A (Continued):

Equations for Number of Cycles to Failure

For fully reversed bending, $\sigma_m = 0$. So, Bending stress would be equal to Alternating stress as:

$$\sigma_{alternating} = \frac{3\delta Eh}{2L^2}$$

The Number of cycles may be predicted (for steel specimen) by:

$$N = \frac{10^{-(b/m)}}{S_e^{(1/m)}},$$

where
$$m = \frac{1}{3} \log \left(\frac{0.9 S_u}{S_e}\right)$$
$$b = \log \left(\frac{(0.9 S_u)^2}{S_e}\right)$$

Sample Data [8]:

Material: Steel with:

Ultimate Strength, $S_U = 385$ Mpa, Endurance Limit, $S_e = 112$ Mpa, Required Life: N = 70,000 Cycles, What Stress range/ fatigue strength (S_f)is acceptable?

Calculated values for: m = 0.163 b = 3.029 $S_{f} = 173 Mpa$

Appendix: B

Specimen	D I M.	Effective Length	Deflection	Cycles (N)	Elapsed Time	Discontinuity	Point of Failure
Aluminum 6063-T5	1/8" x 1"	5.5"	±0. 4775	79,150	≈ 12.6 hrs. @104.7 RPM	None	@ Support
Aluminum 6063-T5	1/8" x 1"	5.5"	±0. 4775	108,450	≈ 17.25 hrs. @104.7 RPM	None	@ Support
Aluminum 6063-T5	1/8" x 1"	5.5"	±0. 4775	117,770	≈ 18.7 hrs. @104.7 RPM	None	@ Support
Aluminum 6063-T5	1/8" x 1"	5.5"	±0. 4775	91,800	≈ 14.61 hrs. @104.7 RPM	1/8" Hole with center 1" from support	@ Hole
Aluminum 6063-T5	1/8" x 1"	5.5"	±0. 4775	108,890	≈ 17.33 hrs. @104.7 RPM	1/8" Hole with center 1" from support	@ Hole
Aluminum 6063-T5	1/8" x 1"	5.5"	±0. 4775	45,850	≈ 7.3 hrs. @104.7 RPM	1/4" Hole with center 1" from support	@ Hole
Aluminum 6063-T5	1/16 "x 1"	4.6875"	±0. 4775	134,500	≈21.4 hrs. @104.7 RPM	None	@ Support
Aluminum 5052-H32	1/16 "x 1"	4.25"	±0.5031	361,000	≈ 65.15 hrs. @110 RPM	None	@ Support
Aluminum 5052-H32	1/16 "x 1"	4.25"	±0.5031	417,150	≈ 63.2 hrs. @110 RPM	None	@ Support
Aluminum 5052-H32	1/16 "x 1"	4.25"	±0.5031	648,000	≈ 98.2 hrs. @110 RPM	None	@ Support
Aluminum 5052-H32	1/16 "x 1"	4.25"	±0.5031	265,850	≈40.3 hrs. @110 RPM	1/4" Hole with center 1" from support	@ Hole
Aluminum 5052-H32	1/16 "x 1"	4.25"	±0.5031	782,190	≈ 118.5 hrs. @110 RPM	1/8" Hole with center 1" from support	@ Hole
Aluminum 6061-T65	1/8" x 1"	4.4375	±0. 4775	1,975	≈ 0.2 hrs. @104.7 RPM	None	@ Support
Aluminum 6061-T65	1/8" x 1"	4.625"	±0.5031	22,106	≈ 1.6 hrs. @234 RPM	None	@ Support
Aluminum 6061-T65	1/8" x 1"	6.50"	±0.5031	516,360	≈ 71.7 hrs. @120 RPM	None	@ Support
1018 HR Steel	1/8" x 1"	7.25"	±0.5031	44,360	≈ 3.2 hrs. @234 RPM	None	@ Support
1018 HR Steel	1/8" x 1"	7.5"	±0.5031	117,580	≈ 8.4 hrs. @234 RPM	None	@ Support
1018 HR Steel	1/8" x 1"	8"	±0.5031	305,360	≈ 21.75 hrs. @234 RPM	None	@ Support

 Table B-1
 Abridged Collected Data.

Appendix: C

Parts List and Breakdown of the cost

Part	Part No.	Quantity	Price (\$)
Steel Rod	L0001	1	10.50
Heim Joint	L0002	2	7.50
Nuts	L0003	2	-
Head Clamp	L0004	1	~40.00
Screws (Head Clamp)	L0005	2	-
Alternate Deflection Mechanism (Frame)	L0006	1	~40.00
Alternate Deflection Mechanism (Beam)	L0007	1	~40.00
DC Gear-motor	D0001	1	118.00
Disc	D0002	1	~30.00
Motor Mount	D0003	1	~30.00
Motor Base plate	D0004	1	~40.00
Bolts (Motor Mount)	D0005	4	-
Counter	C0001	1	50.00
Reed Switch	C0002	1	6.99
Counter Bracket	C0003	1	~30.00
Relay	P0001	1	4.29
PC Board	P0002	1	1.79
Micro Switch	P0003	2	2.69
Switch Pivoting Fork	P0004	1	~10
Switch Mounting Plate	P0005	1 ~20	
		Total Cost:	525 / (1 unit) 850 / (2 units)

- 1. Overall Cost of the Materials and Components \leq \$ 900
- 2. Frame \leq \$ 1050
- 3. Beam supports (2) \leq \$150
- 3. Required Machining and Assembly Time:
 - I Average Machining: About 18 hours (28 for two units)
 II Above Average Machining: About 5 hours (8 for two units)
 III Assembly of Frame and Components: About 6-8 hours

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Laboratory Handout for Low Cycle Finite Life Fatigue

Objectives:

To gain familiarity with fully reversed bending fatigue. To learn how to create and evaluate S-N diagrams. To verify fatigue equations using test data.

Equipment:

Frame Fatigue Tester Apparatus

Materials:

I - Three (3) steel / aluminum bars (for Low Cycle)

II - Three (3) steel / aluminum bars (for Finite Life)

- III Two (2) steel / aluminum bars (for examining the effects of Stress Concentration)
- One (1) having a 1/8 inch diameter hole with its CENTER at ³/₄" from the support,
- One (1) having a 1/4 inch diameter hole with its CENTER at $\frac{3}{4}$ " from the support.

Relevant Equations:

 $\sigma_a = \frac{3\delta Eh}{2L^2},$

where σ_a is the alternating stress, δ is deflection, E is the modulus of elasticity, h is the height of the beam, and L is the effective length of the beam

$$\frac{\sigma_a}{S_e} + \frac{\sigma_m}{S_u} = \frac{1}{n},$$

and σ_a is the alternating stress, σ_m is the mean stress, S_e is the endurance limit, S_u is the ultimate strength, and *n* is the factor of safety

$$N = \frac{10^{(b/m)}}{S_e^{(1/m)}}, \text{ where } m = \frac{1}{3} \log \left(\frac{0.9S_{ut}}{S_e}\right) \text{ and } b = \log \left(\frac{(0.9S_{ut})^2}{S_e}\right)$$

where N is the approximate number of cycles to failure, S_e is the endurance limit, and S_{ut} is the ultimate strength

Safety:

Caution! Please be sure to wear safety goggles while examining the specimen during testing. The beam may behave violently upon failure.

Experiment Procedure:

- 1. First, make sure the counter has been set to zero and the power to the motor is off.
- 2. Take the solid specimen, and install it in the fatigue tester. Use an effective length of 5.5 inches. Slide the support over to fit the beam. When the beam has been initially set up, tighten the screws on the clamp so that the beam fits snugly inside. Make sure that the beam is aligned in the center and perpendicular to the support before tightening the screws.
- 3. Calibrate the tester. Holding the support down (do not secure it to the frame yet), *turn the disk so that the heim joint and rod are vertically in-line with the disk's central axis.* The beam should be at its maximum deflection. Readjust the support to do this, if necessary. Holding the support in that position, turn the disk all the way around, ensuring that the rod will not hit either leg of the switching fork during normal operation. Once everything is in order, secure the support to the frame tightly.
- 4. Slide the front and rear plexi-glass protective covers over the apparatus.
- 5. The beam is now ready to be tested. Note the time before you start.
- 6. Put your safety goggles on BEFORE pressing the Power button.
- 7. While the beam is being tested, calculate the alternating stress and approximate number of cycles to failure for each of the specimens. Use a factor of safety of 1.1 against the Ultimate strength (for Low Cycle) and 1.1 against Yield strength for finite life). Create a table that includes these calculated values as well as columns for the experimental data. (The instructor might choose to include this step as part of a Pre-Lab Exercise instead.)
- 8. When the specimen fails, note the time and the number of cycles to failure.
- 9. Tabulate the results of the test(s) and calculate the percent <u>Difference</u> for the expected (theoretical) number of cycles.
- 10. Remove the specimen from the fatigue tester.
- 11. Repeat Steps 1 through 7 for each of the other specimens with the following adjustment. Change the factor of safety to 1.15, 1.2, 1.25, 1.3, etc. (Either for Low Cycle or Finite Life cases) and include the specimens with discontinuities (if desired).
- 12. Plot the result on an S-N diagram. Compare the results to an existing S-N diagram for the specified material.

Discussion Questions

- What are some of the causes for Fatigue Failure of materials?
- Comment on the statistical nature of fatigue failures.
- Define Endurance Strength and Endurance Limit and Compare them with each other.
- What can be done to minimize the possibility of Fatigue Failure and still conceive a product that is competitive in today's international markets?