4387[illegible]

TORSION FATIGUE SYSTEM FOR MECHANICAL CHARACTERIZATION OF MATERIALS

A Thesis Presented to the Faculty of the

Fritz J. and Dolores H. Russ College of Engineering and Technology

Ohio University

In Partial Fulfillment

of the Requirement for the Degree

Master of Science

Thesis
M
2000
HUSS

By

Hyder Hussain

Department of Mechanical Engineering

November, 2000

[illegible] 2/13/01

THIS THESIS ENTITLED

" TORSION FATIGUE SYSTEM FOR MECHANICAL CHARACTERIZATION OF MATERIALS"

by

Hyder Hussain

has been approved for the

Department of Mechanical Engineering

And

The Russ College of Engineering and Technology

Dr. Hajrudin Pasic, Professor
Department of Mechanical Engineering

Jerrel Mitchell, Interim Dean
Fritz J. and Dolores H. Russ
College of Engineering and Technology

ACKNOWLEDGEMENTS

I would like to express deep gratitude and sincere appreciation to my advisor, Dr. Hajrudin Pasic, for his exceptional guidance, valuable support, and encouragement throughout this project. I would also like to thank my defense committee members--Dr. Larry Snyder and Dr. Gregory G. Kremer--for their valuable time and suggestions. I would especially like to thank Dr. M. K. Alam, Moss Professor, for helping me through my graduate program and for his helpful suggestions throughout my degree program. I also like to thank Dr. Madhu Annapragada for helping me in various aspects of my project and for all the invaluable help that he provided in the design and development of the Torsion Fatigue System.

I also like to thank the Engineering Research Facility staff at Ohio University's Russ College of Engineering and Technology, especially Len Huffman, for all the help and support that he extended all along. Finally, I would like to thank my parents and friends for their love, understanding, and constant encouragement throughout this endeavor.

TABLE OF CONTENTS

List of Tables

List of Figures

Chapter: 1 Introduction

1.1 Fatigue Loading

Engineering applications of various structural materials involve a wide variety of operating conditions. Only rarely, however, are mechanical components and structural elements subjected to constant loads throughout their entire service history. The majority of components in motor vehicles, forging equipment, hoisting gear, and numerous other forms of machinery and structures experience variable loading conditions. This loading can result from vibration, fluctuating power or load requirements, non-uniform road surfaces, and repeated temperature changes, to mention only a few.

A repeated (cyclic) application of a 'safe' load from static design considerations may ultimately cause sudden and catastrophic failure. Such failures are referred to as fatigue failures. Unlike corrosion, wear, distortion, or creep, fatigue failures often give no prior indication of a deterioration in the performance or strength of the component or structure or warning of impending failure. The incidence of fatigue failures in engineering structures and equipment is widespread, and fatigue failures constitute the most common source of service failures in machinery and structures.

1.2 Challenges of Material Development

The quest for better materials has been going on since the dawn of time. Our earliest successes with materials depended largely on fortuitous experience and are seen more as an art, rather than a science. Recent years have seen a momentous change–the birth of a new materials age. In every area of science and technology, we find work being done to push back the boundaries of existing materials constraints to seek new freedom from the past. Everyday we find new materials applications that are challenging mankind to expand the existing horizons. Totally new approaches are required to solve such fundamental questions.

The demand for better materials has created a new revolution in materials development–the field of materials science. Some of our best scientific minds are banding together in an interdisciplinary effort to probe the basic nature of materials and the forces, which control their behavior. Industry research laboratories are seeking ways to improve processing, efficiency, and quality. Academic laboratories are seeking to discover and evolve new theories of materials and the impact of interrelationships with structural design.

The application of scientific principles, techniques, and instrumentation can resolve many questions across a wide spectrum of materials applications. Against this backdrop, a fatigue testing system was proposed to be developed for material characterization.

Fatigue properties are often most important because virtually all fabrication processes and most service conditions involve some type of mechanical loading.

1.3 Need for Fatigue Testing

Much of the present general awareness of the problem of fatigue failure in engineering components has resulted from several well-publicized and, unfortunately, catastrophic accidents involving ships, bridges, aircraft, etc. The task of the designer is usually one of compromise between conflicting requirements in terms of structural or mechanical efficiency, structural or mechanical integrity, and economy. The development of fatigue research, from the relatively simple experiments of Wohler in the 19th century [2] to the present complex test facilities, has been associated with a number of basic problems and expanding design requirements. These include:

- The inability of the more common mechanical tests--e.g., static tensile, impact and hardness--to provide adequate information or even any indication of fatigue behavior of materials under repeated loads.
- The importance of detail design under fatigue loading conditions. Stress analysis, either theoretical or experimental, can not only be complicated and expensive but may result in only a qualitative indication of fatigue behavior. Fatigue testing of components enables the influence of changes in detail design to be readily assessed.

- A need for information on the most fatigue prone regions and sequence of failures in a built-up structure so that realistic inspection and repair schedules can be established before the introduction of the item into service. In general, such information is best obtained from full-scale fatigue tests.
- The need to obtain an indication of fatigue performance at an accelerated rate compared with service experience, so that preventive modifications can be incorporated, if necessary, before failures occur in service.
- The need for more accurate or confident predictions of service life, safe life, or probability of fatigue failures under loading conditions similar to those likely in service.

1.4 Scope and Objective of Thesis

The control of fracture and fatigue has become a high priority of designers and materials researchers. Results from various fatigue testing methods have been used as a guide in the selection of materials for use under cyclic stress conditions. The key factors in performing such fatigue tests are specimen alignment, specimen surface conditions, and precision in setting and maintaining cyclic loading parameters and test frequency as high as possible. Against this backdrop, in 1995 a mini-fatigue testing system was developed at Ohio University's Russ College of Engineering and Technology under the guidance of Dr. H. Pasic to study the high and low cycle fatigue behavior of materials and small components in torsion. This fatigue system (with electro-servomotor and controller) enables test conditions to be accurately established. There was some contribution for the initial development of the 'Fatigue Testing System' by graduate students working under Dr. Pasic and the engineers and craftsmen at Ohio University, as well as the technician, Len Huffman. The current thesis extends that contribution by configuring the fatigue testing system to suit the fatigue testing requirements and by developing robust and flexible Windows-based fatigue testing software, which enables the fatigue testing system to perform high-and-low cycle fatigue testing in various modes (torque mode, displacement mode, etc). The goal was to provide a friendly GUI for controlling all aspects of the fatigue test for both high-and-low cycle fatigue testing and give the flexibility of automatic data collection, monitoring, analysis, and storage. The GUI (Graphic User Interface) has been developed using Visual Basic 5.0 software with RS232 standard as the serial port communication protocol between the terminal and the testing system. Various tests have been carried out on some specimens using the fatigue testing software, and the results have been analyzed and documented.

The following chapters elaborate more on the description, specifications, design and development of the torsion fatigue testing system developed by Dr. H. Pasic along with the author's contributions to the system configuration. They also discuss extensively the fatigue testing software package developed as part of this thesis and future extension to current research for developing bi-axial fatigue testing system. The content of this report is organized as follows. Chapter 1 is an introduction to fatigue testing and the current industry requirements for studying the fatigue behavior of materials. Chapter 2 presents literature review regarding fatigue mechanisms and factors affecting fatigue behavior of materials. Also discussed are the various fatigue testing machines available to carry out the tests and present the fatigue data. Chapter 3 is concerned with the summary of research and analysis done in terms of our testing requirements for fatigue testing and comparison of available systems for this purpose. Also given are the reasons why we opted to design our Torsion Fatigue Testing System with appropriate system configurations, machine characteristics, and production costs suited for our testing needs. Chapter 4 explains the architecture, configuration, and design of motion control system for the fatigue testing system, which includes the actuator, motor, feedback transducer, and controller. Chapter 5 discusses the testing software design issues and the procedure for conducting the tests in various modes using the testing software. Chapter 6 documents and analyzes the results obtained after conducting the high- and low-cycle fatigue tests using the fatigue testing software. Finally, Chapter 7 presents the conclusion of the thesis and the scope of future enhancements to the fatigue testing system and the associated software. Appendices A, B, and C provide detailed specifications for the motor, drive, and controller used for the motion control system of the testing system. Finally, Appendix D contains the source code for the software developed in Visual Basic 5.0 on Windows platform.

Chapter: 2 Fatigue of Materials

2.1 Introduction

This chapter reviews the fatigue mechanism and the factors affecting fatigue behavior of materials with special emphasis on design considerations for fatigue prevention. The subsequent topics also analyze various fatigue testing machines available to carry out the tests and present the fatigue data.

Fatigue is the progressive, localized, permanent structural change that occurs in materials subjected to fluctuating stresses and strains that may result in cracks or fracture after a sufficient number of fluctuations. Fatigue fractures are caused by the simultaneous action of cyclic tensile stress and plastic strain. In the absence of these conditions, fatigue cracking will not initiate and propagate. The cyclic stress starts the crack; the tensile stress produces crack growth (propagation). Although comprehensive stress will not cause fatigue, compression load may sometimes do so.

Fatigue cracking normally results from cyclic stresses that are well below the static yield strength of the material. Fatigue cracks initiate and propagate in regions where the strain is most severe. Because most engineering materials contain defects and thus regions of stress concentration that intensify strain, most fatigue cracks initiate and grow from structural defects. Under the action of cyclic loading, a plastic zone (or region of deformation) develops at the defect tip. This zone of high deformation becomes an initiation site for fatigue crack. The crack propagates under the applied stress through the material until complete fracture results [2]. On the microscopic scale, the most important feature of the fatigue process is nucleation of one or more cracks under the influence of reversed stresses that exceed the flow stress at the crack tip due to stress-concentration, followed by the development of cracks at persistent slip bands or at grain boundaries [4].

2.2 Fatigue Mechanism

2.2.1 Structural Features of F atigue

Studies of the basic structural changes that occur when a metal is subjected to cyclic stress have found it convenient to divide the fatigue process [2] into the following stages:

- Crack initiation – initial fatigue damage consisting of crack nucleation and crack initiation. This includes the early development of fatigue damage, which can be removed by a suitable thermal anneal.
- Slip-band crack growth – involves the deepening of the initial crack on planes of high shear stress. This frequently is called Stage I crack growth.
- Crack growth on planes of high tensile stress _ involves growth of well defined but still short (about 0.5mm) crack in direction normal to maximum tensile stress, usually called Stage II crack growth.
- Ultimate failure _ occurs when the crack reaches sufficient length so that the remaining cross section cannot support the applied load.

Fatigue crack can be formed before 10% of the total life of the component has elapsed, but this depends on a material and test condition. In general, larger proportions of the total cycles to failure are spent with the propagation in Stage II in low-cycle fatigue than in high-cycle fatigue, while Stage I crack growth comprises the largest segment for low-stress, high-cycle fatigue. If the tensile stress is high as in the fatigue of sharply notched specimens, Stage I crack growth may not be observed at all. The rate of crack propagation in Stage I is generally very low--on the order of angstroms per cycle, compared with crack propagation rates of microns per cycle for Stage II, which is 1000 times faster.

Fatigue cracks in smooth components are initiated on a free surface. Metal deforms under cyclic strain by slip on the same atomic planes and in the same crystallographic directions as in unidirectional strain. In the case of unidirectional deformation, slip is usually widespread throughout all the grains, but in the case of fatigue only some grains will show slip lines. Slip lines are generally formed during the first few thousand cycles of stress. Successive cycles produce additional slip bands, but the number of slip bands is not directly proportional to the number of cycles of stress.

Extensive structural studies [2] of dislocation arrangements in persistent slip bands have brought much basic understanding to the fatigue fracture process. The Stage I crack propagates initially along the persistent slip bands. In a polycrystalline metal, the crack may extend for only a few grain diameters before the crack propagation changes to Stage

II. By marked contrast, the fracture surface of Stage II crack propagation frequency shows a pattern of ripples or fatigue fracture striations. Each striation represents the successive position of an advancing crack front that is normal to the greatest tensile stress. Each striation is produced by a single cycle of stress. The presence of these striations unambiguously defines that failure was produced by fatigue, but their absence does not preclude the possibility of fatigue fracture. Since Stage II cracking does not occur for the entire fatigue life, it does not follow that counting striations will give the complete history of cycles to failure.

Stage II crack propagation occurs by a plastic blunting process that is illustrated in Figure 2.1. At the start of the loading cycle, the crack tip is sharp (Figure. 2.1a). As the tensile load is applied, the small double notch at the crack tip concentrates the slip along planes

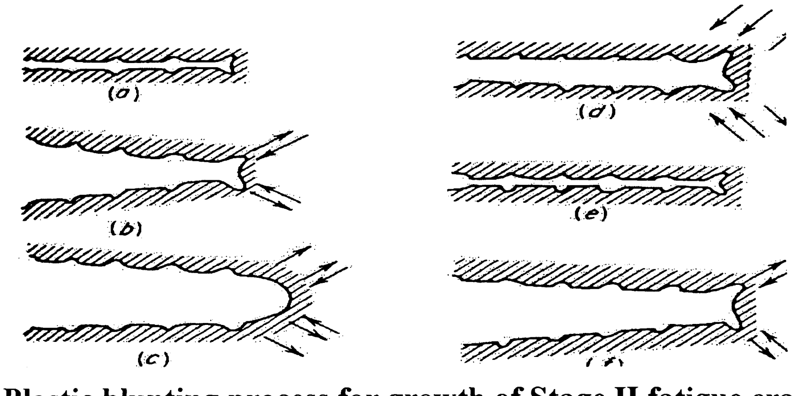


Figure 2.1 Plastic blunting process for growth of Stage II fatigue crack [6]

at 45° to the plane of the crack (Figure 2.1b). As the crack widens to its maximum extension (Figure 2.1c), it grows longer by plastic shearing and, at the same time, its tip becomes blunter. When the load is changed to compression, the slip direction in the end zones is reversed (Figure 2.1d). The crack faces are crushed together and the new crack surface created in tension is forced into the plane of the crack (Figure 2.1e), where it partly folds by buckling to form a resharpened crack tip. The resharpened crack is then ready to advance and be blunted in the next stress cycle.

2.2.2 Fatigue Nomenclature

The 'fatigue' sequence shown in Figure 2.2 is typical of many service loading sequences experienced by components and structures. In a number of cases, the variation of stress (or load) with time may be approximated by a sinusoidal type of loading sequence (Figure 2.2) which, in fact, is the type of sequence produced by many commercial fatigue testing machines. However, some service conditions--particularly those involving low cyclic frequencies and repeated impact--involve distinctly non-sinusoidal types of sequence. Some modern fatigue testing machines can closely simulate or even reproduce exactly the complex service load history of components or structures.

Irrespective of the nature of the applied forces and the shape of the loading cycle, there are a number of common parameters which can be used to define the stress cycle [1]. In Figure 2.2, nomenclature relating to the common features of the stress cycle--i.e., alternating stress amplitude (S_a), stress range ($2S_a = S_r$), maximum stress (S_{max}), minimum stress (S_{min}), and mean stress (S_m) - are self-evident. To define the stress cycle completely, it is necessary to specify at least two of the four parameters--$S_{max,}$ S_{min}, $S_{a,}$

and S_m. The usual convention is that tensile loading is denoted as positive and compressive loading is denoted as negative.

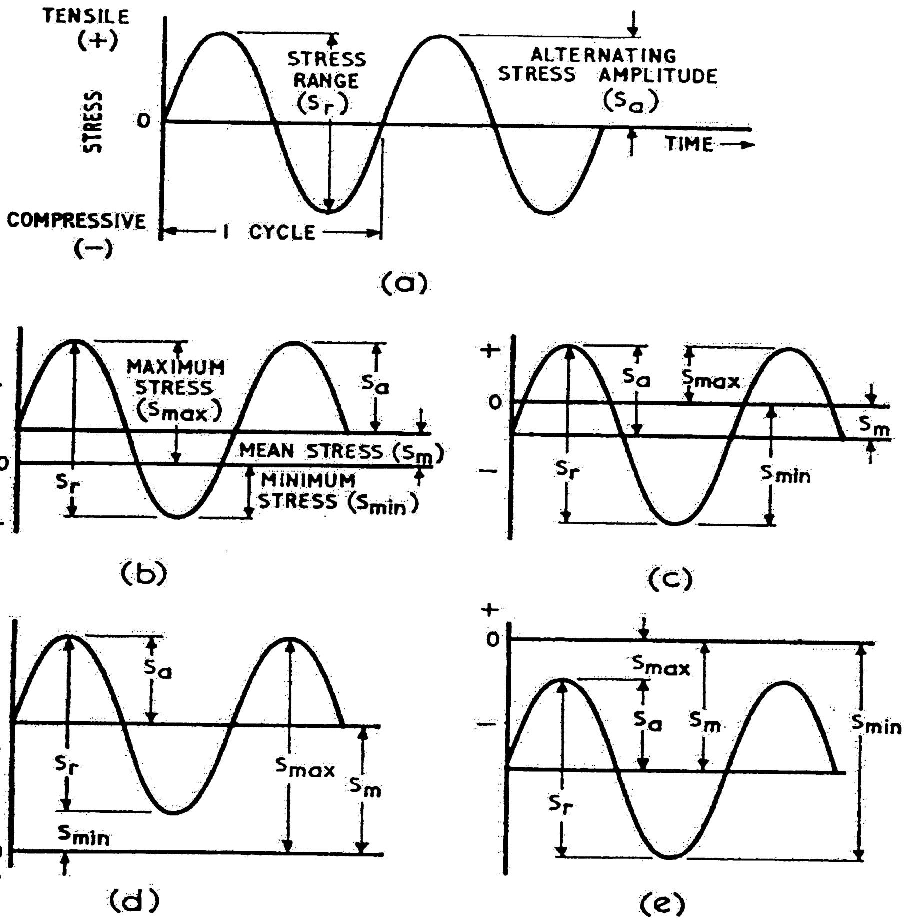


Figure 2.2 Types of stress or load cycles [1]

The meaning of these stresses is as follows:

- S = nominal stress – the stress calculated on the net section by simple elastic theory, disregarding the influence of notches and other geometric discontinuities.

- S_u = ultimate tensile stress (U.T.S) – the ratio of the maximum load sustained in a static test divided by the original net cross-section area.

- R = stress ratio – the algebraic ratio of the minimum stress to the maximum stress in one fatigue cycle; i.e., $R = S_{min}/S_{max}$. For completely reversed stress (i.e., zero mean stress) conditions, R = -1, while if the minimum stress of the cycle is zero, then R= 0. A value of R between 0 and +1 indicates a non-reversed or fluctuating tensile stress.

- A = stress ratio – the ratio of the alternating stress amplitude and the mean stress of the fatigue cycle; i.e. $A = S_a/S_m = 1- R/1+R$.

- N = fatigue life – the number of stress cycles causing failure under given loading conditions. The endurance is usually expressed as decimal fractions or multiples of 10^6 cycles.

- n = stress cycles endured – the total number of cycles applied up to any stage during the fatigue test.

- C = cycle ratio – the ratio of the stress cycles (n) applied at a given stress level to the average fatigue life (N) at that stress level, based on the fatigue curve; i.e., C = n/N.

- S_N = fatigue strength – the value of the stress level at which the fatigue life (which may be statistically determined) is N cycles. The fatigue life should always be stated and, as well as, the mean stress or another parameter to define the type of stress cycle.

- S_D = fatigue limit – the value, which may be statistically determined, of the stress condition below which a material may endure an infinite number of stress cycles.

- Fatigue Ratio – the ratio of the fatigue limit (S_D) or fatigue strength (S_N) to the ultimate tensile stress (S_U); i.e., S_D/S_u or S_N/S_u.

2.2.3 Cyclic Stress-Controlled vs. Cyclic Strain-Controlled Fatigue

Many engineering components must withstand numerous load or stress reversals during their service lives. Depending on a number of factors, these load excursions may be introduced either between fixed strain or fixed stress limits; hence, the fatigue process in a given situation may be governed by a strain- or stress-controlled condition.

One of the earliest investigations of stress-controlled cyclic loading effects on fatigue life was conducted by Wohler, who studied railroad wheel axles that were plagued by an annoying series of failures. Several important facts emerged from this investigation, as may be seen in the plot of stress versus the number of cycles to failure (a so-called S-N diagram) given in Figure 2.4.

First, the cyclic life of an axle increased with decreasing stress level, and below a certain stress level it seemed to possess infinite life; hence, fatigue failure did not occur. Secondly, the fatigue life was reduced drastically by the presence of a notch. These

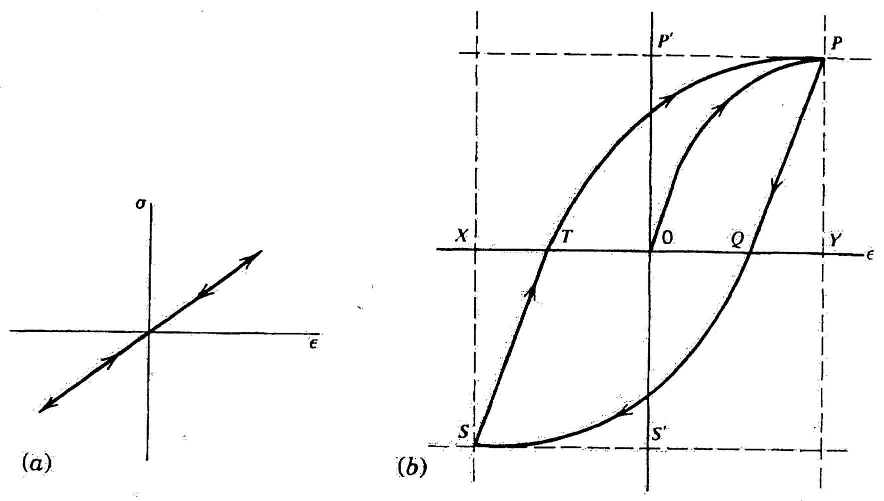


Figure 2.3 Hysteresis loops for cyclic loading in (a) Ideally elastic material and (b) Material undergoing elastic and plastic deformation [2].

observations have led many current investigators to view fatigue as a three-stage process involving initiation, propagation, and final failure stages. When design defects of metallurgical flaws are pre-existent, the initiation stage is shortened drastically or completely eliminated, resulting in a reduction in potential cyclic life.

Localized plastic strains can be generated by loading a component that contains a notch. Regardless of the external mode of loading (cyclic stress or strain controlled), the plasticity near the notch root experiences a strain-controlled condition dictated by the much larger surrounding mass of essentially elastic material. Scientists and engineers at SAE and ASTM have recognized this phenomenon and have developed a strain-controlled test to evaluate cumulative damage in engineering materials.

Cyclic strain-controlled fatigue (rather than stress-controlled) is found in thermal cycling, where a component expands and contracts in response to fluctuations in the operating temperature or in a reversed bending between fixed displacements. By monitoring strain and stress during a cyclic loading experiment, the response of the material can be clearly identified. For example, for a material exhibiting stress-strain behavior involving only elastic deformation under the applied loads, a hysteresis curve like that shown in Figure 2.3 is produced. The material's stress-strain response is retraced completely; that is, the elastic strains are completely reversible. For the behavior involving elastic-homogeneous plastic flow, the complete load excursion (positive and negative) produces a curve similar to Figure 2.3 that reflects both elastic and plastic deformation. The area contained within the hysteresis loop represents a measure of plastic deformation work done on the material. Some of this work is stored in the material as cold work and /or associated with configurational changes (entropic changes), such as in polymer chain realignment; the remainder is emitted as heat. From Figure 2.3, the elastic strain range in the hysteresis loop is given by [2]

$$\Delta\varepsilon_e = XT + QY = \Delta\sigma/E \tag{2.1}$$

The plastic strain range is equal to TQ or equal to the total strain range minus the elastic strain range. Hence,

$$\Delta\varepsilon_p = \Delta\varepsilon_T - \Delta\sigma/E \tag{2.2}$$

It is important to recognize that fatigue damage will occur only when cyclic plastic strains are generated. Since plastic deformation is not completely reversible, modifications to the structure occur during cyclic straining, which results in the stress-strain response. Depending on the initial state, a metal may undergo cyclic hardening, softening, or remain cyclically stable. All three behaviors may occur in the same material, depending on the initial state of the material and the test conditions. Generally, hysteresis loop stabilizes after about 100 cycles and the material arrives at an equilibrium condition. The cyclically stabilized stress-strain curve may be quite different from the stress-strain curve obtained by monotonic static loading.

The cyclic stress strain curve may be described by a power curve [2]

$$\Delta\sigma = K' (\Delta\varepsilon_p)^{n'} \Delta \qquad (2.3)$$

where n' – cyclic strain hardening component, K' – cyclic strength coefficient.

2.3 Presentation of Fatigue Data

In carrying out routine fatigue investigations using small specimens, the U.T.S of the material is usually first determined and then, making use of this information, a specimen is fatigue tested at an alternating stress level (S_{a1}) estimated to cause failure after a relatively small number of stress cycles (N_{S1}), e.g., between 10,000 and 50,000. Identically prepared specimens may then be tested to failure at lower stress amplitudes until they endure, without breaking up to 10^6 cycles and beyond. To monitor and analyze the fatigue data of the test, various methods are adopted [4], [8]. Some methods for the presentation of fatigue data are given below.

2.3.1 S/N (Wohler) Curve

The relationship between stress (S) and the number of load applications (N) is commonly represented graphically by plotting the stress as ordinate and the cycles to failure on the abscissa. This procedure results in what is known as the S/N curve, the plot of which is shown in Figure 2.4. In order to represent both long and short endurance on one diagram, a logarithmic scale is commonly used for (N). A linear stress scale is most frequently used, although logarithmic scales are usually the alternating stress amplitude (S_a) or range (S_r), but under non-zero mean stress conditions the maximum stress (S_{max}) is sometimes adopted. A common convention is to represent specimens unbroken at the completion of a test by an arrow extending beyond the test point.

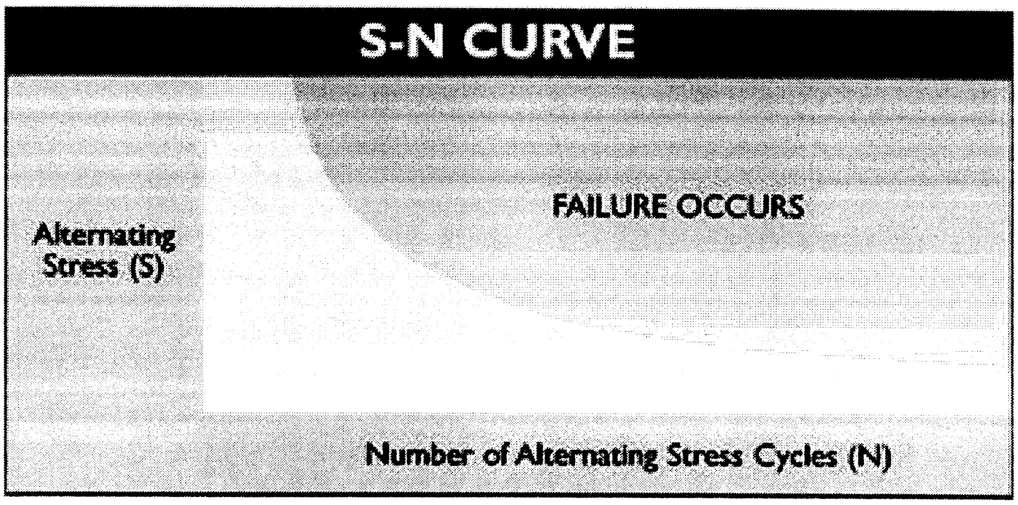


Figure 2.4 S/N (Wohler) curve

At very high loads, yielding or plastic deformation of the material may markedly affect the stress distribution in the specimen and the total deformation will, therefore, be the summation of both elastic and plastic strain components. Under these circumstances, where endurances are relatively short in terms of cycles to failure--i.e., less than about 30,000--it is often more appropriate to consider strain amplitude rather than stress amplitude as the parameter on the ordinate of the S/N diagram. Most determinations of the fatigue properties of materials have been made in completed reverse bending with the zero mean stress ($S_a = 0$) and $R = -1$.

Most non-ferrous materials (aluminum, magnesium, and copper alloys) have an S-N curve without fatigue limit; i.e., the S-N curve slopes gradually downward with increasing number of cycles. In such a case, fatigue properties of the material are given by Fatigue Strength (S_N) at an arbitrary number of cycles--for example, at $N = 10^8$. The S-N curve is sometimes described by the Basquin Equation in the high-cycle region:

$$N\,(S_a)^n = C \tag{2.4}$$

Where S_a – stress amplitude and n, C – empirical constants

The usual procedure for obtaining S-N curve is to test the first specimen at a high stress, where failure is expected in a short number of cycles; e.g., $S = 2/3\ S_U$ (S_U – ultimate static stress). Next, the stress is decreased for each succeeding specimen until one or two specimens do not fail in about 10^7 cycles (for ferrous materials). The highest stress at which the failure does not occur is taken as fatigue limit.

2.3.2 Statistical Nature of Fatigue

Fatigue life and fatigue limit are statistical quantities, and considerable deviation from the S-N curve obtained with only a few specimen is to be expected. Therefore, more specimens and statistical interpretations of experimental data are needed. The data should then lie on a three-dimensional surface [6] representing the relationship between stress, number of cycles to failure, and probability of failure. The two-dimensional representation is given in Figure 2.5 below. At S_1 > 1% of the specimens would be expected to fail at N_1 cycles, 50% at N_2 cycles. The figure also represents decreasing

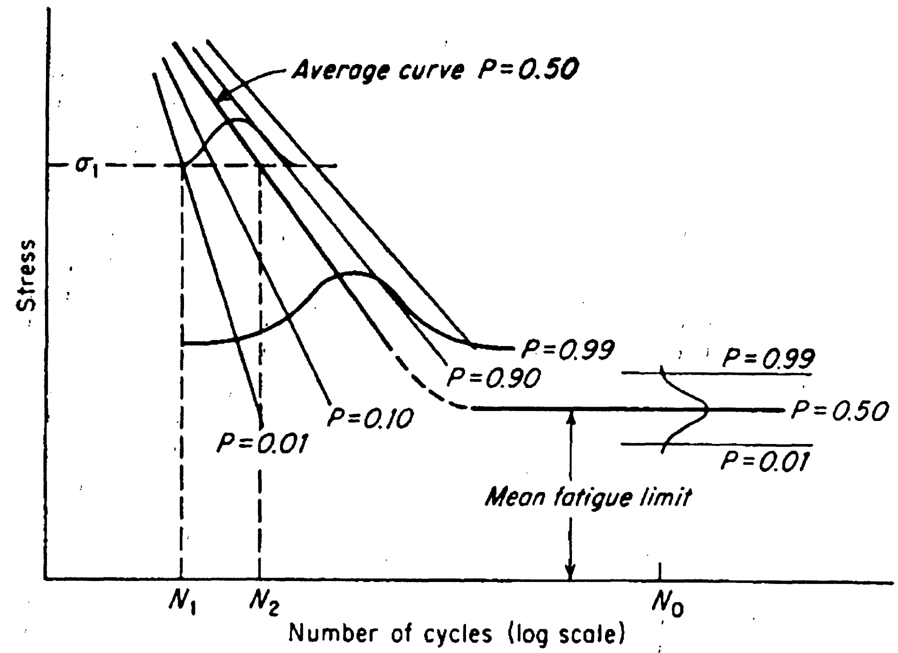


Figure 2. 5 Statistical fatigue data

scatter in fatigue life with increasing stress. For the statistical interpretation of the fatigue limit, we are concerned with the stress distribution at a constant fatigue life.

2.4 Design for Fatigue Prevention

In design for fatigue and damage tolerance, one of two initial assumptions is often made about the state of the material. Both of these are related to the need to invoke continuum mechanics to make the stress/strain/fracture mechanics analysis tractable [6]:

- The material is an ideal homogeneous, continuous, isotropic continuum that is free of defects or flaws.
- The material is an ideal homogeneous, isotropic continuum but contains an ideal crack-like discontinuity that may or may not be considered a defect or flaw, depending on the entire design approach.

The former assumption leads to either the stress-life or strain-life fatigue design approach. These approaches are typically used to design for finite life or “infinite life”. Under both assumptions, the material is considered to be free of defects, except insofar as the sampling procedure used to select material test specimens may “capture” the probable “defects” when the specimen locations are selected for fatigue tests. This often has proved to be an unreliable approach and has led--at least in part--to the damage-tolerant approach.

Another possible difficulty with these assumptions is that inspectability and detectability are not inherent parts of the original design approach. Rather, past and current experience guides field maintenance and inspection procedures, if and when they are considered.

The damage-tolerant approach [5] is used to deal with the possibility that a crack-like discontinuity (or multiple ones) will escape detection in either the initial product release or field inspection practices. Therefore, it couples directly to nondestructive inspection (NDI) and evaluation (NDE). In addition, the potential for initiation of crack propagation must be considered an integral part of the design process and the subcritical crack growth characteristics under monotonic, sustained, and cyclic loads must be incorporated in the design. The final instability parameter, such as plane strain fracture toughness (K_{IC}), also must be incorporated in design. The damage-tolerant approach is based on the ability to track the damage throughout the entire life cycle of the components/system. Material characterization procedures are needed to ensure that valid evaluation of the required material "property" or response characteristic is made.

2.4.1 Strain Life Equation

Cyclically stabilized material properties affect the life of a specimen or engineering component subjected to strain-controlled loading. To accomplish this, it is convenient to begin our analysis by considering the elastic and plastic strain components separately. The elastic term is often described in terms of a relation between the true stress amplitude and number of load reversals [2]:

$$\Delta\varepsilon_e E/2 = \sigma_a = \sigma_f' (2N_f)^b \tag{2.5}$$

where $\Delta\varepsilon_e/2$ = elastic strain amplitude

E = modulus of elasticity

σ_a = stress amplitude

σ_f' = fatigue strength coefficient, defined by the stress intercept at one load reversal ($2N_f = 1$)

N_f = cycles to failure

$2N_f$ = number of load reversals to failure

b = fatigue strength exponent

The above equation is called Basquin's equation and is used for the high-cycle (low strain) regime, where the nominal strains are elastic.

There are a large number of cases when fatigue occurs at high stresses and, therefore, at a low number of cycles, (say at $N < 10^4$ cycles). Low-cycle fatigue failures are created whenever repeated stresses are of thermal origin. Since thermal stresses arise from thermal expansions of materials, fatigue results from fatigue cyclic strain rather than from cyclic stress. For describing the relationship between plastic strain and fatigue life in the low-cycle (high strain) regime, the Coffin-Manson equation is used. The usual way of presenting low-cycle fatigue test results is to plot the plastic strain-range versus N. A straight line is obtained when a log-log scale is used. This relation is called the Coffin-Manson equation, which is given below:

$$\Delta\varepsilon_p/2 = \varepsilon_f^{'} (2N)^c \qquad (2.6)$$

where $\Delta\varepsilon_p/2$ = plastic strain amplitude

$\varepsilon_f^{'}$ = strain intercept (or fatigue ductility coefficient) obtained at 2N = 1.

For most metals, it is equal to the true fraction strain ε_f.

2N = number of strain reversals

c = fatigue ductility exponent (for many metals $-0.5 < c < -0.7$)

2.5 Factors Influencing Fatigue

Many factors which exert little, if any, influence on the static properties of materials and components can cause marked changes in their fatigue characteristics. Irrespective of the type of fatigue loading, their fatigue behavior is particularly sensitive to factors which influence the surface or sub-surface conditions. Some basic factors necessary to cause fatigue failures are

- Large enough fluctuation in the applied stress,
- Maximum tensile stress must be sufficiently high,
- Sufficiently large number of cycles,

- Stress concentration,
- Corrosion,
- Temperature,
- Overload,
- Residual Stress, and
- Metallurgical Factors.

2.5.1 Stress Concentrators

Discontinuities of some form are always present in every machine component and structural assembly. When a component is loaded, discontinuities can result in the development of non-uniform and complex stress fields adjacent to the discontinuity with local peak stresses in such regions much greater than the average or nominal stress across the section. For this reason, such discontinuities are referred to as stress concentrators or stress raisers, and it is usually at such locations that fatigue cracks originate.

2.5.2 Metallurgical Factors

Different manufacturing processes, such as casting, forging, rolling or extrusion, all result in a characteristic metallurgical composition; distribution of inclusions, and porosity are possible within a single piece of material or component. These variations have been shown to affect not only fatigue properties but also other mechanical properties. They should be closely controlled if optimum fatigue properties are to be attained.

2.5.3 Machining and Processing

Only a small percentage of mechanical components are placed in service without the removal of metal in one way or another. Most machining processes impart a characteristic surface finish to the part, but this term refers to the contour or surface profile produced. Profile is, however, only one of the three variables, the other two being residual stresses (which may be favorable or unfavorable) and work hardening.

2.6 Classification of Fatigue Testing Machines

In order to represent the types of fatigue loading to which parts are subjected in service, five main groups of fatigue testing machines [3] have been developed. The principles in each case are shown in Figure 2.6; their classification is related to the basic type of straining action or loading system which is applied to the specimen; i.e.,

- Rotating bending
- Plane bending
- Axial loading (direct tension)
- Torsion
- Combined stress

The machines in each group may be of either the constant load type--e.g., dead weight and centrifugal force, or constant displacement types--e.g., mechanical displacement and constant strain. They may be further classified according to the method of loading--e.g. mechanical, hydraulic, electromagnetic, or pneumatic--and also whether or not they operate under near-resonance conditions.

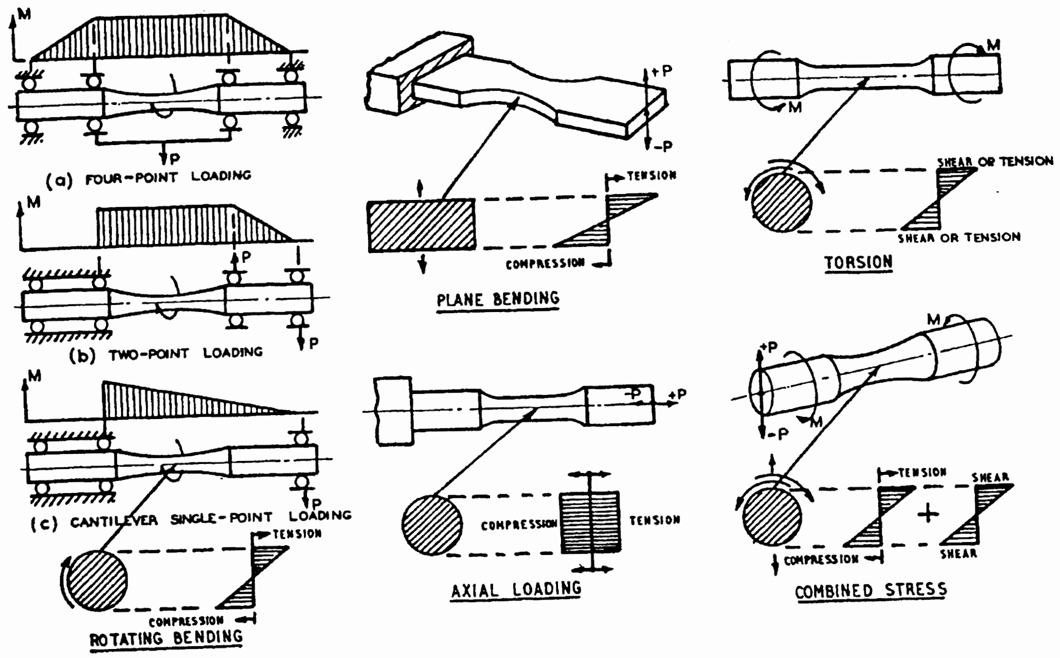


Figure 2.6 Principles of fatigue testing machines [1]

2.6.1 Axial (Direct-Stress) Fatigue Testing Machine

The direct-stress fatigue testing machine subjects a test specimen to a uniform stress or strain throughout its cross section. For the same cross-section, an axial fatigue testing machine must be able to apply a greater force than a static bending machine to achieve the same stress. Axial machines are used to obtain fatigue data for most applications and offer the best method of establishing--by closed-loop control--a controlled strain range in the plastic strain regime (low-cycle fatigue).

Electromechanical Systems

These systems have been developed for axial fatigue studies. Generally they are open-loop systems, but often have partial closed-loop features to continuously correct the mean load. The rotating eccentric mass machine with a direct-stress fixture and the crank and lever machine (Fig 2.7) are typical testing systems using this drive mechanism.

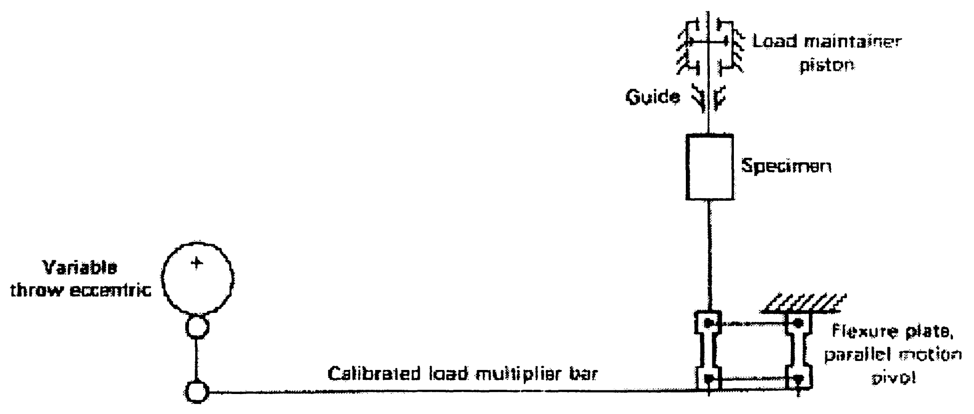

Load maintainer piston
Guide
Specimen
Variable throw eccentric
Flexure plate, parallel motion pivot
Calibrated load multiplier bar

Figure 2.7 Crank and lever testing machine [3]

Servohydraulic closed-loop systems

These systems offer optimum control, monitoring, and versatility in fatigue testing systems. These can be obtained as component systems and can be upgraded as required. A hydraulic actuator typically is used to apply the load in axial fatigue testing. Because of the versatility the servohydraulic system provides in control modes (load, strain, or actuator displacement), the same machine can be used for both high-cycle fatigue and low-cycle (strain-controlled) fatigue testing. A wide variety of grips--particularly self-aligning types--are available for these machines.

Electromagnetic or magnetostrictive excitation is used for axial fatigue testing machine drive systems, particularly when low-load amplitudes and high-cycle fatigue lives are desired in short test duration. The high cyclic frequency of operation of these types of machines enables testing to long fatigue lives ($>10^8$ cycles) within weeks.

2.6.2 Bending Fatigue Machin es

The most common types of fatigue machines are small bending fatigue machines. In general, these simple, inexpensive systems allow laboratories to conduct extensive test programs with a low equipment investment. The common general-purpose fatigue machines are cantilever beam plane bending (repeated flexure) and rotating beam.

Cantilever beam machines

In this the test specimen has a tapered width, thickness, or diameter and results in a portion of the test area having uniform stress with smaller load requirements than required for uniform bending or axial fatigue of the same section size. In bending, the surface stress is highest (maximum outer fibre stress), and this test mode is preferred to study the effect of surface treatments or coatings. The cam or eccentric principles used in the plane-bending machine typically have limited cyclic frequency compared to rotating beam types. Both deflection-controlled and load-controlled types are in common use.

Rotating Beam Machines

The earliest type of fatigue testing machine and the most commonly used is the rotating beam machine, in which a specimen with a round cross section is subjected to a dead-weight load while bearings permit rotation. A given point on the circular test section surface is subjected to a sinusoidal stress amplitude from tension on the top to compression on the bottom with each rotation. Typical rotating beam machine types are shown in the Figure 2.8. The R.R. Moore-type machines can operate up to 10,000 rpm. In all bending-type tests, only the material near the surface is subjected to the maximum stress; therefore, in a small-diameter specimen, only a very small volume of material is under test. Thus, the fatigue properties obtained from small rotating beam fatigue tests typically are higher than those obtained from axial fatigue tests on the same cross-section.

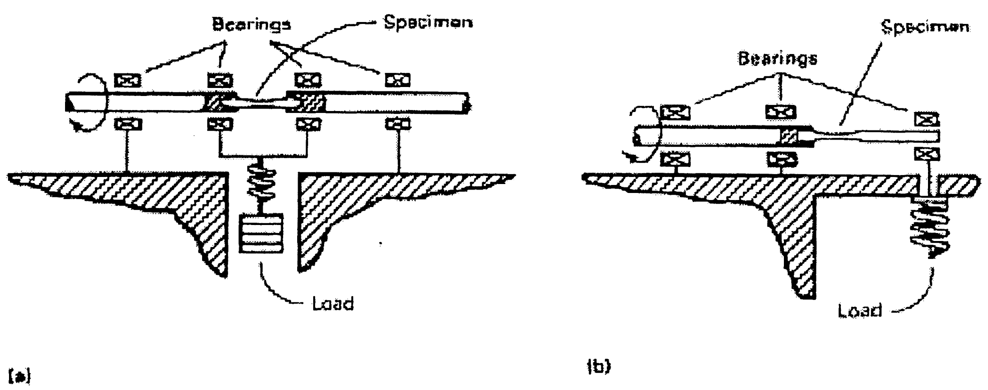


Figure 2. 8 Rotating beam fatigue testing machine [3]

The nominal longitudinal stress amplitude S_a is usually calculated on the basis of elastic bending, but if the elastic range is exceeded, the stress calculated in this way is inaccurate. Under elastic conditions

$$S_a = M_y/I \qquad (2.7)$$

where M = bending at the net test section

I = moment of inertia at the net test section

y = distance from neutral axis to extreme fibre at test section

For a circular section specimen this becomes

$$S_a = 32M/_\pi \, d^3{}_\Delta \qquad (2.8)$$

where d = net diameter of test section.

2.6.3 Torsional Fatigue Testin g Machines

Some engineering applications--e.g., tailshafts of motor vehicles, torque tubes, splined driving shafts, torsion bars, and coil springs--involve repeated torsional loading. Several types of machines have been developed to apply this type of loading in laboratory tests, and most of these have standard fixtures enabling them to be also used for plane bending tests. Zero and non-zero mean stress conditions can be reproduced.

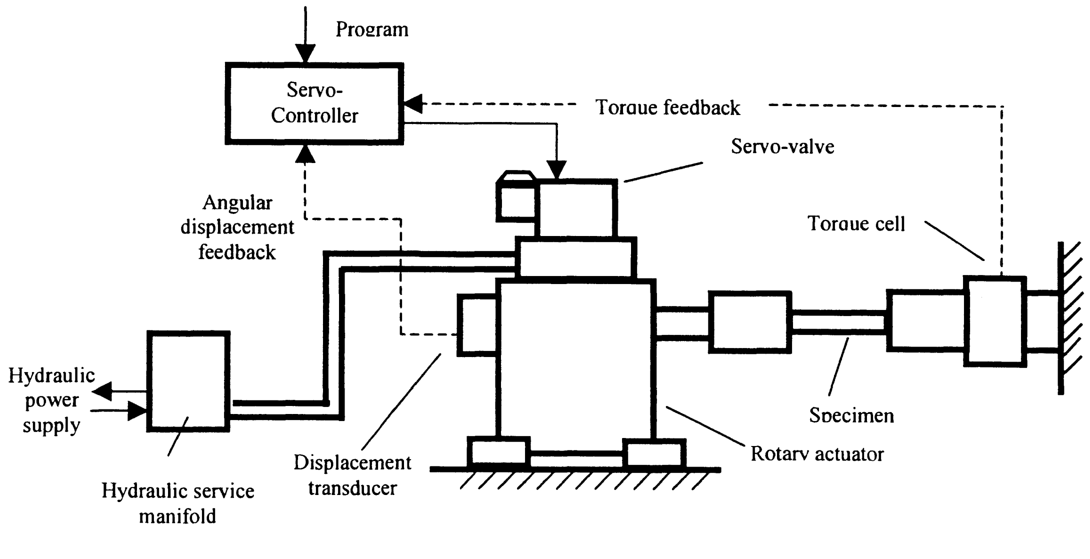


Figure 2.9 Hydraulic torsion fatigue system [3]

Torsional fatigue tests can be performed on axial-type machines using the proper fixtures if the maximum twist required is small. Specially designed torsional fatigue testing machines consist of electromechanical machines, in which linear motion is changed to rotational motion by the use of cranks, and servohydraulic machines, in which rotary actuators are incorporated in closed-loop testing systems (Figure 2.9).

Nominal shear stress at the test section is again calculated on the basis of elastic stress conditions existing throughout the whole section; i.e.,

$$\tau = T\,y/J \tag{2.9}$$

where T = applied torque

y = distance from neutral axis to extreme fibre at test section

J = polar moment of inertia at the net test section.

For a circular section specimen of net test section diameter, d, the stress becomes $\tau = 16T/\pi d^3$. As in the case of flexural loading, the maximum stresses occur at the surface and a stress gradient, decreasing from the surface to the center of the specimen, exists under torsional loading.

2.6.4 Multi-axial Fatigue Testing Machines

Many special fatigue testing machines have been designed to apply two or more modes of loading--in or out of phase--to specimens to determine the properties of metals under biaxial or triaxial stresses. Such tests are of particular significance because most actual service conditions involve complex stress systems, and fatigue failure criteria based on simpler modes must be verified in controlled tests in which multiaxial stress states are imposed.

Bi-axial tension is a common service stress state often requiring evaluation in pressurized systems. A common biaxial fatigue test specimen is a tubular specimen subjected to simultaneous internal pressure and axial loading. In tension-torsion systems, push-pull axial loading and torsional loading are applied simultaneously. Bending-torsion machines are similar. By offsetting the applied load with respect to the specimen centerline, simple machines have been designed to apply simultaneous bending and torsion.

2.6.5 Specialized Fatigue Testing Equipment

To perform fatigue testing of components that are prone to fatigue failure, specialized fatigue testing equipment has been developed for proving tests, research on manufactured components or structural elements, or testing crankshafts, motor vehicles axles, coil and leaf springs, gears, pistons, wheel and tyre assemblies, wire ropes, turbine blades, and aircraft propellers. Frequently these items are too large to be accommodated in conventional fatigue testing machines or involve highly specialized requirements, such as the testing under repeated thermal cycling or testing under acoustic vibration conditions. Equipment for fundamental research is also frequently of a highly specialized nature.

Equipment for the testing of Large Components and Structures – In recent years there has been an increasing tendency to test full-scale structures, components, and assemblies under fatigue loads. Among these are included aircraft structures (wings, pressure cabins, or the complete structure, simultaneously), propeller shafts of ships, welded or riveted steel, and axle assemblies. Thorough inspection of the structures or components at frequent intervals during the test is, thus, usually essential so that failures may be documented and rates of crack propagation determined. For realistic results, the loading spectrum must be representative of service conditions.

Frequently, the loading system is built around the item to be tested. The two most common systems for generating the applied loads in large-scale testing are:

- Resonance or more strictly sub-resonance systems, usually mechanically excited.
- Direct loading systems utilizing hydraulic or mechanical loading.

Resonance System – In the resonance system, the frequency of operation is close to a natural frequency of vibration of the assembly being tested. This forms part of a spring-mass system, and amplitude control may be achieved by a combination of either constant exciting force and variable frequency or constant frequency and variable exciting force. The exciting force can be produced by a rotating out-of-balance mass or oscillator, variable stroke mechanically-driven crank or connecting rod, hydraulic vibrator, or an electromagnetic exciter.

These type of system has two distinct advantages:

- Relatively high cyclic frequencies are usually possible, although because of the mass and flexibility of the specimen these are much less than in the case of small laboratory resonant-type machines.
- Power requirements are considerably less than in direct loading systems as only frictional and damping forces must be overcome.

Direct Loading Systems – These systems consist essentially of a hydraulic jack or jacks connected to a pulsating pressure source with a mechanical system of levers, beams, or cables to transmit the jack force to the loading points of the assembly. This system of loading--although restricted to lower cyclic frequencies--is much more versatile than the resonance system and is also suitable for the simultaneous application of loads in several directions.

To conclude, this chapter has given a brief literature review regarding fatigue mechanisms, factors affecting fatigue behavior of materials, and the various fatigue testing machines available to carry out the tests and present the fatigue data. The next chapter deals with the summary of research and analysis done in terms of testing requirements for fatigue testing, and the comparison of available systems for this purpose, and why we opted to design the Torsion Fatigue Testing System with appropriate system configurations, machine characteristics, and production costs suited for our testing needs.

Chapter: 3 Fatigue Testing System

3.1 Introduction

This chapter presents a summary of research and analysis done in terms of our testing requirements for fatigue testing and a comparison of available systems for this purpose. It explains why the Torsion Fatigue Testing System with appropriate system configurations, machine characteristics, and production costs was designed to meet high and low cycle fatigue testing needs.

Fatigue properties of materials are of utmost importance in the design of mechanical equipment. Many failures in machine parts can be traced to a disregard for this important consideration. In a typical design cycle, however, one does not have the luxury of contemplating the stability of the materials under extended fatigue. There are a very few companies--MTS and INSTRON for instance--which offer machines capable of performing fatigue tests. The typical cost of one of these machines is in the order of a hundred thousand dollars. All of these factors encourage the designer to skip the extended fatigue test and design the system based on static considerations.

Fatigue testing would be a very valuable addition to the designer's toolbox, if a machine capable of performing the test with a sufficient degree of accuracy and a minimum level of investment could be produced. The initial goal of this project was to design a machine and the author's role was to configure the system and design and develop the associated software for conducting various fatigue tests. The system developed has the following specifications:

- Low cost,
- Capable of testing small specimens for material characterization by applying:

  (a) torsion (b) tension (c) any combination of torsion and tension in displacement, torque or velocity modes,
- Capable of regulating the amount of angular/linear displacement or velocity very accurately,
- Capable of maintaining the specified parameters for extended periods of time (days or even weeks) with very little drift in the operating characteristics or perform a single static test, and
- A user-friendly fatigue testing software that can be used to design various tests in a step-by-step manner--defining the function generation and data acquisition requirements for each part of the test--and to control all aspects of the test.

The torsion fatigue testing system has already been developed and the associated software that can carry out high-cycle and low-cycle torsion fatigue testing in torque and displacement modes was developed as part of this research. The long-term goal is to develop this system further, which will be capable of conducting multi-axial fatigue tests, simultaneously, under torsion and tension. The associated software can be further developed to support this feature. The rest of the chapter deals with the configuration of the machine and its characteristics, the associated software, and recommendations regarding future enhancements.

3.2 Test Specifications

The first step in the design was the determination of the maximum forces and torque that would be needed in a test. These specifications were arrived at by considering a steel specimen with a diameter of 5mm under static conditions. The maximum torque that the machine would be expected to produce is 50Nm. Maximum torsional displacement would typically be in the order of a few degrees. The maximum axial force that the machine would need to produce would typically be about 300N. The maximum axial displacement under tension or compression would be in the order of a few millimeters. The table below (Table 3.1) summarizes these figures.

Table 3. 1 Test Specifications

Maximum Force and Torque Specifications	
Torsion	58Nm
Tension	300N
Displacement	10 degrees in torsion, 10mm in tension or compression
Frequency	50Hz

3.3 Survey of Existing Systems

The next step in the design process was a survey of existing machines. The type of machines looked at were systems capable of performing bi-axial testing under a variety of load conditions. During the course of the survey, it was noticed that there were very few companies that offered a good range of test beds. The following is a sampling of the survey. All of these systems are available from MTS corporation.

In Figure 3.1, System 1 is a standard tension hydraulic test bed with a max loading value of 1,000,000 lbf (5MN). System 2 is the hydraulic tabletop version of System 1 with a maximum loading of 5500 lbf (5kN).

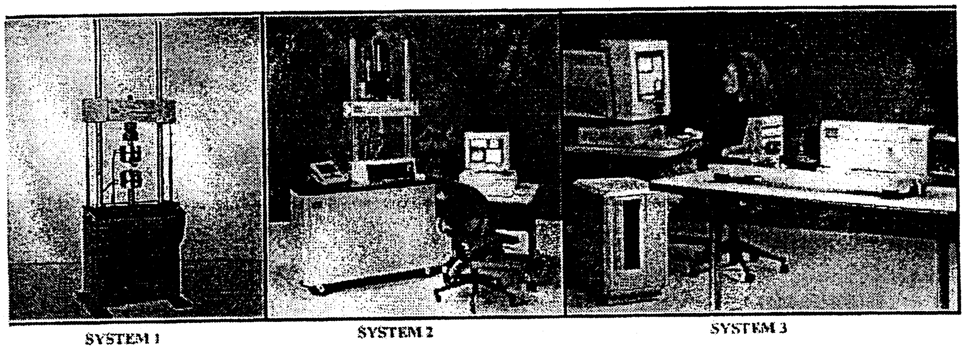


Figure 3.1 A Sampling of the material testing systems from MTS

In 1997 MTS released System 3, a "micro-force" test bed called TITRON for performing tensile tests with a maximum loading 250N linear force and a minimum of 0.002 lbf

(0.01N). This system is run using an electro-servomotor. This system was released two years after our current Torsion Fatigue Testing System, also based on electro-servomotor, was designed and built. In addition to these systems, MTS offers a similar range of hydraulic machines for torsion tests. MTS has recently released a bi-axial hydraulic test bed that is capable of performing both torsion and tension at the same time.

All of these test beds have been designed for extended fatigue testing. There is, however, one obvious drawback. The accuracy of hydraulic systems is not as good as a system driven by an electro-servo motor. Also, cost is in the order of a hundred thousand dollars for each of these machines. The tests that can be done on any of them is limited in scope in the sense that the user of the machine is usually presented with a number of choices about the nature of the test, and any deviations from the norm are not possible. The initial goal of the project was to design around these drawbacks. The machine to be designed must be both low cost and capable of performing a wide variety of tests with very good accuracy for extended periods of time.

3.4 Torsion Fatigue Testing System

3.4.1 Overview

This small-size, low torque, and low-cost computer-controlled torsion fatigue testing system run by electro-servomotor was developed by Dr. H. Pasic and his research team at Ohio Universtiy. It has both static and dynamic loading capabilities and may be run in torque-controlled, angular-velocity controlled, and angular-displacement controlled modes. The fatigue testing software was developed and tested on this machine for high and low-cycle fatigue, and its performance has been tested, analyzed and documented. It also provides a good basis for further development to incorporate bi-axial fatigue testing in the future.

This system may be used in a wide variety of torsion tests for testing various material properties and fatigue studies for advanced material characterization, composite testing, plastics testing, quality of coating testing, biomedical and biomechanical testing, soil and elastomer testing, educational and research purposes, as well as for general purpose fatigue testing of components (electrical switches, connectors, fasteners, springs, automotive parts, appliance parts, tools, sporting equipment, etc.). The system may also be used for the measurement of different material properties, such as shear modulus, creep and viscoelastic properties, fatigue characterization, wear characteristics, quality of coating, response characteristics, etc.

3.4.2 System Configuration

The entire system is designed around a servo control system. There is a brushless servo actuator, a two-axis servo controller, actuator drive, and a host computer. The configuration of the fatigue testing system is shown in Figure 3.2 to Figure 3.5. The

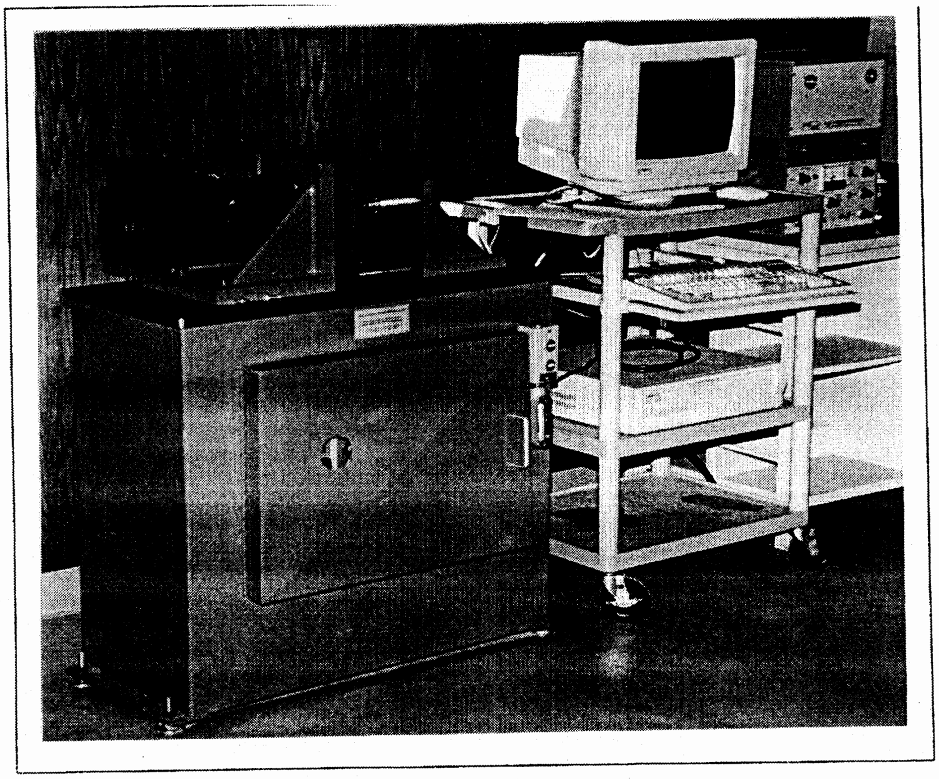


Figure 3.2 Fatigue testing system

specifications of the Apex Series Drive, 6250 Controller, and Apex Motor Specifications are given in Appendices A, B, and C, respectively.

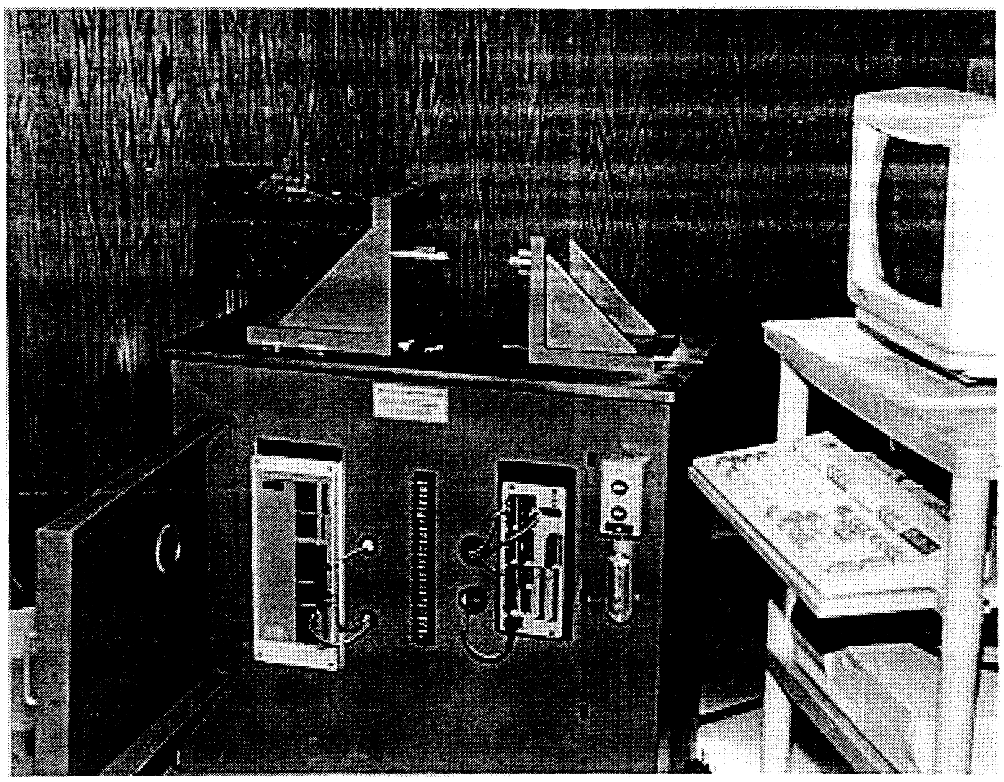


Figure 3.3 Controller and driver of fatigue testing system

Tabletop system - The servomotor is attached to a rigid “L” shaped adjustable mount, as shown in Figure 3.4. A similar mount is used as the fixed-grip holder. Both mounts rest on a rigid, smooth horizontal plate. This solution provides very high stiffness of the system as well as simple specimen’s alignment. The controller and the driver are installed in the case below the plate (see Figure 3.3). With the 4.7kW servomotor, the dimensions of the system are 45”x35”x18”.

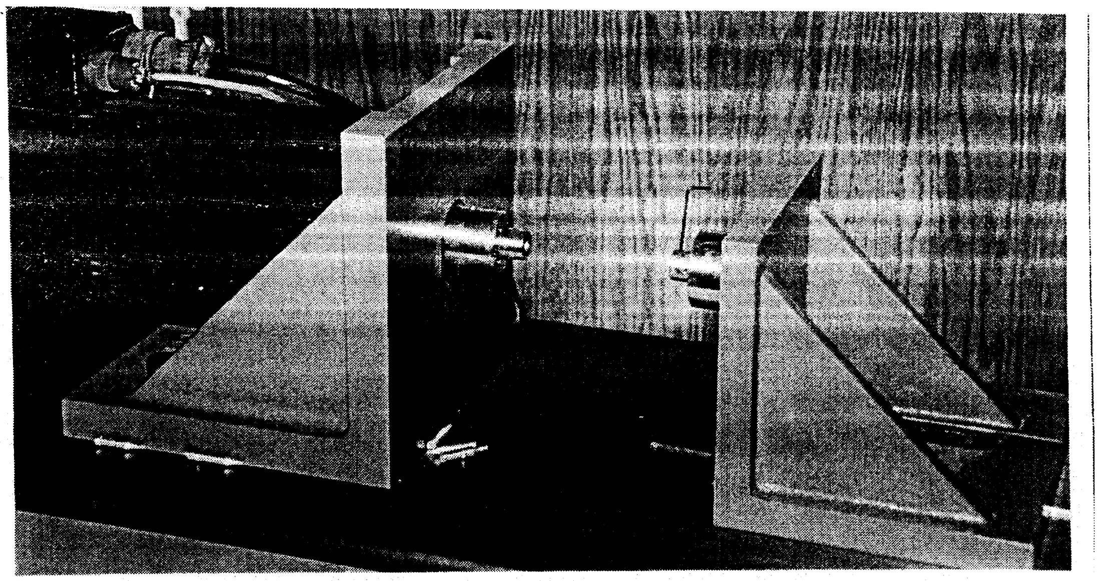


Figure 3. 4 Tabletop system

The system needs no extra cooling under fairly heavy-duty conditions. However, if necessary, both configurations--the driver and servocontroller--may have built-in cooling fans, while cooling the system (up to ½ inch pipe wound around the motor).

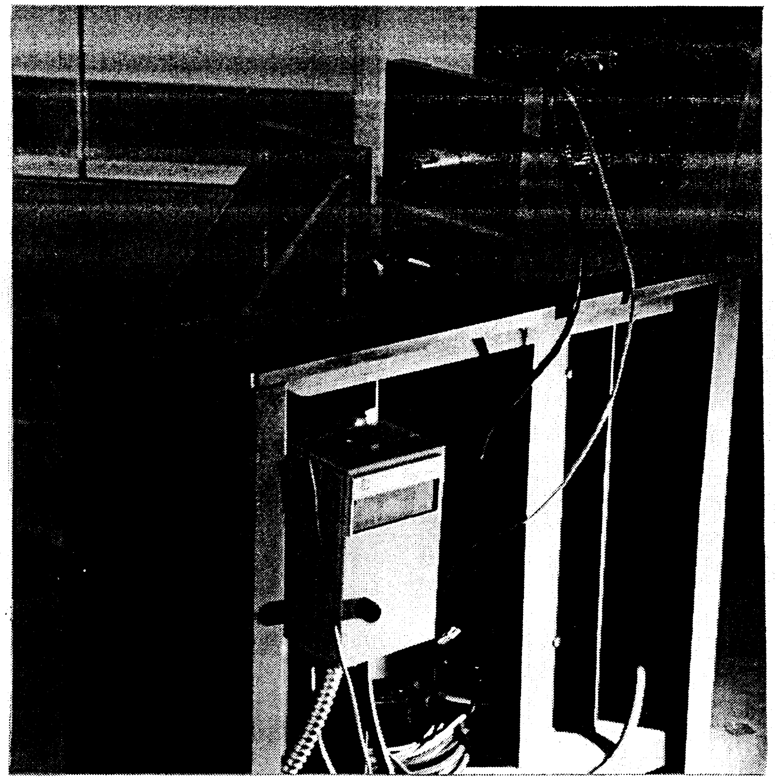


Figure 3. 5 Rear view of the fatigue testing system

Safety screen and environmental chamber (for conducting experiments at elevated or low temperatures, or in vacuum) may also be installed in the working section.

3.4.3 Machine Characteristics

Depending on the power of the servomotor used (ranging from several tens of watts to 8kW), the system can run either monotonic or fatigue tests. The more powerful motors may be used for testing metallic, ASTM standard small-size rounded specimens (typical diameter about 2-6 mm for metals) with permanent torque ranging up to 50Nm and peak intermittent torque of up to 120Nm, depending on the size of the servomotor used. The motor belongs to the class of so-called "brushless motors" in which the rotor (not stator) is the magnet (made from rare-earth materials). This technology makes it possible to overcome the heating problem while retaining large torque and large velocities (more than 20 revolutions per second and also, due to small rotor-inertia, very high accelerations of up to 10,000 rev/sec^2. Therefore, a high enough testing frequency may be achieved; it amounts to about 5Hz (at largest torque and twist angles of up to 120°) and even up to 50Hz at small loads. The twist angle and, therefore, the shear and the stress (as they are mutually proportional) are measured with high resolution of about 10^{-3} of a degree (or even higher) by an encoder (also known as a resolver), which is an integral part of the servocontroller (which controls the motor), such that additional devices for measuring the twist angle are unnecessary.

Since the specimen's alignment in torsion testing is not as important as in uniaxial testing (to avoid buckling), the alignment is simple and inexpensive. Also, in metal testing in torsion the grips may be extremely simple, such as the socket-type with non-circular hole. (The hole is somewhat deeper than the specimen's head, allowing for free axial creep of the specimen).

The servomotor, its controller, the driver, and the PC make a closed-loop system such that the system operation is fully computer-controlled. A digital signal processor is used for high speed control, while a 32-bit microprocessor is used for executing high-level motion programs in all the three modes (load-, velocity- and displacement controlled tests).

The encoder (or resolver) is the integral part of the servomotor's controlling system and is used for twist-angle measurements. Since strains and, therefore, stresses are proportional to the twist-angle; no other instruments apart from the encoder (or resolver) are needed for measuring strains or stresses.

A comprehensive software, which also is an integral part of the system (i.e., of the controller), creates and executes motion-control programs under Microsoft WindowsNT/98 platform. The basis for this software was the Motion Architect command language for running the controller of the machine. Visual Basic 5.0 was used to develop a GUI and incorporate the motion architect commands to run the system without having to run it through the command prompt. The Visual Basic software development tool allows the user to display a graphic user interface. The command language incorporates subroutine definition, conditional programming, unit scaling, programmable I/O, contouring, and mathematical functions. The detailed description of the control system and the associated software is discussed in subsequent chapters.

3.4.4 Production Cost

The total production cost depends on the servomotor used. For the electro-servo motor (4.7kW, continuous torque 28Nm, and intermittent 56Nm), the total retail price of the motor, driver, controller, software twist-angle measuring system, and the PC is $10,000. Therefore, the total production price, including the case and even simple grips (for testing metals) for this--the most expensive--version should not exceed $12,000 to $13,000. The smaller-power systems may certainly be produced for less than $10,000 and the smallest ones with the torque below 1Nm for less than $5,000.

3.4.5 Advantages

Fatigue testing machines of this kind (with electro-servomotor) is not available on the market. A vast majority of these machines are large hydraulic testers, primarily made for axial testing of larger size specimens with only a few exceptions, such as when hydraulic systems are also used for torsion testing (For example, INSTRON and MTS, the world leading producers, have recently started the production of medium-size hydraulic torsion testing machines.).

The MTS system corporation's hydraulic machine (with torque up to 100Nm) costs $100,000. Since the largest specimen's diameter is proportional to the cubic root of the largest torque applied, this means that these machines may run experiments on tough-steel specimens having only about a 30% larger diameter than those tested on the 50Nm machine proposed here (cubic root of 100/50 times 100%). Practically speaking, if the

50Nm machine may run experiments on the tough-steel 6mm specimens, the 100Nm hydraulic machine may test 8mm specimens. This small difference cannot be justified by a price almost ten times higher.

Hydraulic systems must be expensive because their production cost must be high. MTS's cheapest hydraulic power-supply unit alone costs $15,000 and the same cost is hydraulic actuator. For measuring deformations (stresses), expensive transducers and extensometers are used (MTS's typically cost several thousand dollars each), not to mention other disadvantages (space needed for the power-supply unit, numerous moving parts and hydraulic fixtures, alignment devices, large energy consumption devices, etc.). Many of these problems simply do not exist when an electro-servomotor is used.

The system being proposed here is not to be compared with large and expensive systems. It has its own characteristics, and it has been designed for meeting other requirements. Its main properties are:

- Low-torque and small size,
- Low-production price, up to ten times less than the price of a comparable hydraulic machine,
- Additional strain (stress) measuring devices are unnecessary,
- The system has one moving part only (the motor shaft),
- Easy to produce and maintain,
- High precision,

- The system operation is computer controlled and easy to configure and conduct experiments, and
- It meets the current market demands (torsion testing, small size, low cost).

Based on the research conducted, after reviewing the existing systems the torsion fatigue testing system's configuration has been designed to offer a maximum peak torque of 58Nm (continuous torque of 28Nm) with frequency of up to 50Hz. The twist angle measurement resolution is of the order of 10^{-3} degrees (or even higher). The motor is capable of delivering a maximum power of 4.7kW and a rated speed of up to 1,600 rev/sec.

The next chapter deals with the motion control system of the fatigue testing system, which includes the actuator, motor, feedback transducer, and controller. It discusses and accesses the various motion control system configurations available today and analyzes the current system architecture of the Torsion Fatigue System.

Chapter: 4 Motion Control System

4.1 Configuration of Testing System

This chapter explains the architecture, configuration, and design of motion control systems for the fatigue testing system, which includes the actuator, motor, feedback transducer, and controller. It discusses and accesses the various motion control system configurations available today and analyzes each component selected for the current system architecture of the "Torsion Fatigue System".

Many industrial designers are concerned with controlling an entire process. Motion control is one important and influential aspect of complete machine control. Motion control in its widest sense could relate to anything from a welding robot to the hydraulic system in a mobile crane. In the field of electronic motion control, one is primarily concerned with the systems falling within a limited power range typically up to about 10HP (7kW) and requiring precision in one or more aspects. This may involve accurate control of distance or speed--very often both--and sometimes other parameters, such as torque or acceleration rate. In the case of material testing, it may require a precise control of applied torque/force, speed, and distance.

Servo control systems come in many different configurations, but all of them have a common architecture. Figure 4.1 shows the main components of a servo system.

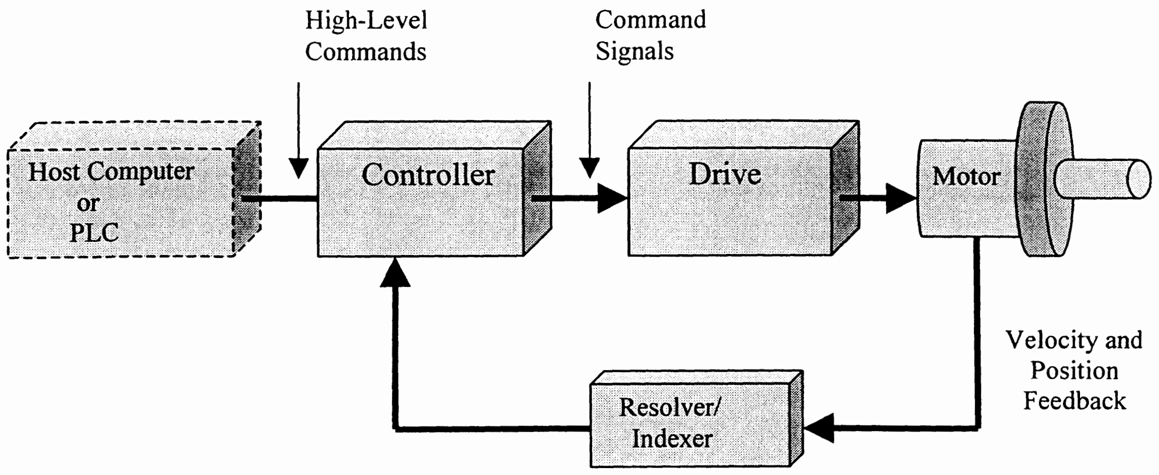


Figure 4. 1 Elements of motion control system

A standard motion control system consists of the following basic elements:

- Host Computer or PLC
- Motor
- Drive
- Indexer/Resolver
- Controller

There are many different machine control architectures that integrate these elements. Each results in varying levels of complexity and integration of both motion and non-motion elements. PLC-based, [15] bus-based, and integrated solutions are all commercially available. The selection of a machine control strategy is based on requirements, performance, total application cost, and technology experience.

4.2 Host Computer or PLC

The host computer, typically a PC, is used to send high-level commands to the controller and to acquire and record data when needed. The PC has the testing software through which the user interacts with the control system. The host computer and the controller are in constant communication via the RS232 link, which is a serial port communication.

4.2.1 Communication Standards

Various standards have been drawn up to define the protocol for the transmission of binary data from within the microcomputer bus structure to external devices, such as display monitors, controllers, and other peripheral equipment. The most commonly accepted standards are those defined by the Institute of Electrical Engineers (IEEE) [12], [16]. The standards fall into the two categories of serial and parallel data communication. The difference between the two relates to the number of bits of information transmitted simultaneously between the devices.

Serial Communication - It is the most common method used for the interconnection of a microcomputer to the relatively slow peripheral hardware or between two computers when transferring a low volume of information. The bits denote the characters of information travelling sequentially along a single path. The (EIA) RS232C or its successors, the RS422 and RS423 [16], is the most widely adopted standard employed, and connection between devices is made via a standard 25-pin connector. This allows communication with one peripheral device only. Twenty-one of the signal lines is defined in the standard, although only five (or even three) are usually required.

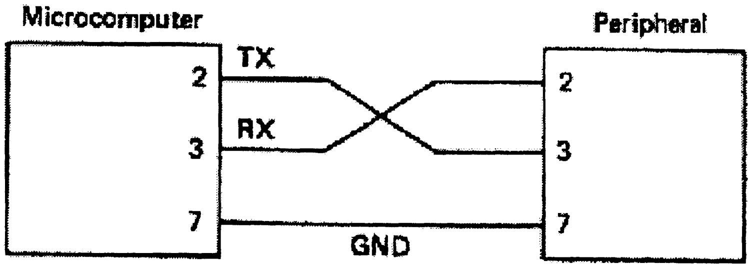


Figure 4. 2 Serial port connections [16]

The three main connections are 'transmitted data' (pin 2), 'received data' (pin 3), and 'signal ground or common return' (pin 7). These would normally be connected, as shown in Figure 4.2. For communication in both directions - i.e., full duplex - the two handshaking control lines--'request to send' (pin4) and 'clear to send' (pin 5)--are also required.

The standard applies to data transmission interchange usually at rates between 110 and 9600 baud. A Logic '1' is represented by a voltage in the range of –3 to –15V and a logic '0' by range of +3 to +15V. This large differentiation between '1' and '0' ensures good immunity against electrical noise. The RS232C is limited to short communication links of about 30m. The voltages and signal connections for the plug are defined in the standard, but the data protocol is not defined. This must be known for the devices, which are to be connected and can be set accordingly by software. The requirements are:

- Baud rate,
- Number of bits in ASCII group defining the character being transmitted,
- Odd, even or no parity,
- Number of stop bits.

Parallel Communication - This communication standard emerged from the need to establish a means of interfacing a variety of instruments for data-logging applications. The most common standard for the integration of automated test systems, developed by Hewlett-Packard, is referred to as the IEEE-488 interface bus, which consists of 24 lines accommodated within standard stacked-type connections. The eight bi-directional data lines carry information as 7-bit ASCII codes between the microcomputer (controller) and an instrument (listener) on the bus. The roles may be reversed when the data are being logged. To process the information on the data bus, up to eight control and status signals are available. The bus is designed to interface with up to 15 instruments within a localized area, involving a total cable length of not more than 20m.

4.3 Motor or Actuator Design

There are essentially three types of electric motors normally used in machine tools--a stepper motor (either rotary or linear or a combination of both), a DC brush motor, or a brushless "servomotor". Servo systems have more or less the same architecture. The term "servomotor" is used to signify that the motor includes an integral feedback device, usually an optical shaft encoder. The motor must be fitted with some kind of feedback device, unless it is a stepper motor.

4.3.1 Stepper Motors

Stepper motors have the benefits of low cost, ruggedness, simplicity in construction, high reliability, no maintenance, wide acceptance, no tweaking to stabilize, no feedback components are needed, and they work in just about any environment and are inherently more fail-safe than some other servo motor types. This is because there is virtually no conceivable failure within the stepper drive module, which could cause the motor to run away. Stepper motors are simple to drive and control in an open-loop configuration. They only require four leads. They provide excellent torque at low speeds--up to 5 times the continuous torque of a brush motor of the same frame size or double the torque of the equivalent brushless motor. This often eliminates the need of a gearbox. A stepper-driven system is inherently stiff with known limits to the dynamic position error. There are three main types of stepper motor:

- Permanent magnet (P.M.) motors – This is widely used for non-industrial applications in fields such as computer peripherals. The motor construction results in relatively large step angles, but its overall simplicity lends itself to economic high-volume production at very low cost. The axial-air gap or disc motor is a variant of the permanent magnet design which achieves higher performance, largely because of its very low rotor inertia. However, this does restrict the applications of the motor to those involving little inertia.
- Variable reluctance motors (V.R.) – There is no permanent magnet in a V.R. motor, so the rotor spins freely without "detent" torque. Torque output for a given frame size is restricted, although the torque-to-inertia ratio is good. This type of motor is frequently used in small sizes for applications such as micro-positioning tables. Variable reluctance motors are seldom used.
- Hybrid motors – The hybrid motor is by far the most widely used stepper motor in industrial applications. The name derives from the fact that it combines the operating principles of other two motor types (P.M and V.R). Most hybrid motors are 2-phase, although 5-phase versions are available. A recent development is the "enhanced hybrid" motor which uses flux-focusing magnets to give a significant improvement in performance, albeit at extra cost.

4.3.2 DC Brush Motors

A basic DC brush motor consists of a permanent magnet servomotor, as shown in Figure 4. 3. These magnets are used to provide a permanently energized magnetic field. They are made of the rare-earth type materials which reduces size and weight in relation to torque produced. The magnet segments are fixed to the steel outer housing by adhesive or bolts. This type of construction provides efficiency and reduces heating. Several different types of DC motor [12] are currently in use, such as

- Iron-cored motor
- Moving coil motor
- Brushless motor

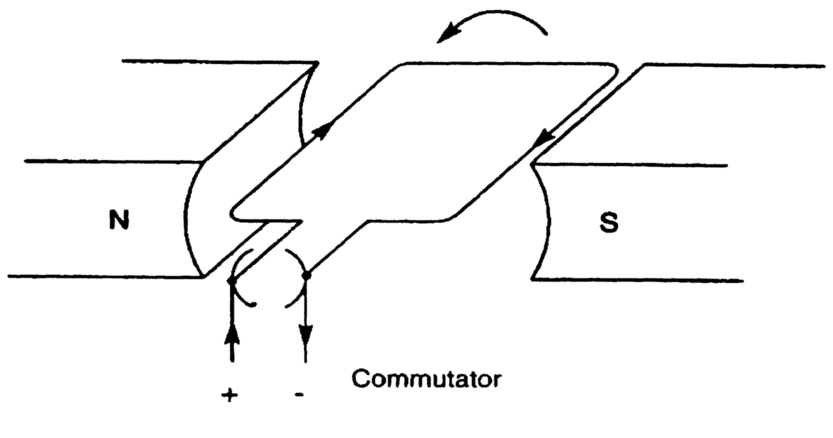


Figure 4. 3 Conventional DC brush motor

4.3.3 Brushless Motors

The term “brushless” has become accepted as referring to a particular variety of servo motor. Clearly a step motor is a brushless device, as is an AC induction motor. (In fact the step motor can form the basis of a brushless servo motor, often called a hybrid servo, which is discussed later.) However, the so-called “brushless” motor has been designed to have a similar performance to the DC brush servo without the limitations imposed by a mechanical commutator.

Within the brushless category are two basic types, referred to as trapezoidal and sinewave motors. In simple terms, the trapezoidal motor is really a brushless DC servo, whereas the sinewave motor bears a close resemblance to the AC synchronous motor. A simple conventional DC brush motor (Figure 4.3) consists of a wound rotor, which can turn within a magnetic field provided by the stator. If the coil connections were to be made through slip rings, this motor would behave like a step motor; reversing the current in the rotor would cause it to flip through 180°. By including the commutator and brushes, the reversal of current is made automatically and the rotor continues to turn in the same direction. By including the commutator and brushes, the reversal of the current is made automatically and the rotor continues to turn in the same direction.

Brushless motor operation - To turn this motor into a brushless design, one must start by eliminating the windings on the rotor. This can be achieved by turning the motor inside out; in other words, make the permanent magnet the rotating part and put the windings on the stator poles. In servo-application, some form of electronic amplifier or drive will be used, so the commutation is done in response to low-level signals from an optical or Hall-effect sensor, (Figure 4.4). This component is referred to as the commutation encoder. So unlike the DC brush motor, the brushless version cannot be driven by simply connecting it to a source of direct current. The current in the external circuit must be reversed at defined rotor positions; as such, the motor is in fact being driven by an alternating current.

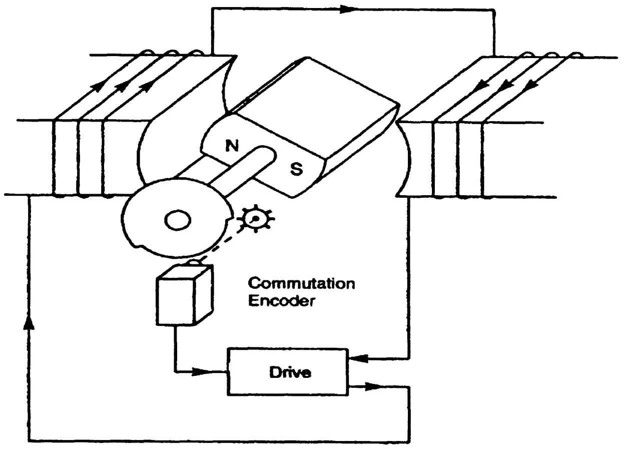


Figure 4.4 Brushless motor [17]

In a conventional brush motor, a rotor consisting of only one coil will exhibit a large torque variation as it rotates. In fact, the characteristic will be sinusoidal, with maximum torque produced when the rotor field is at right angles to the stator field and zero torque at the commutation point (Figure4.5). A practical DC motor has a large number of coils on the rotor with each one connected not only to its own pairs of commutator segments but to the other coils, as well. In this way, the chief contribution to torque is made by a coil operating close to its peak-torque position. There is also an averaging effect produced by current flowing in all the other coils, so the resulting torque ripple is very small.

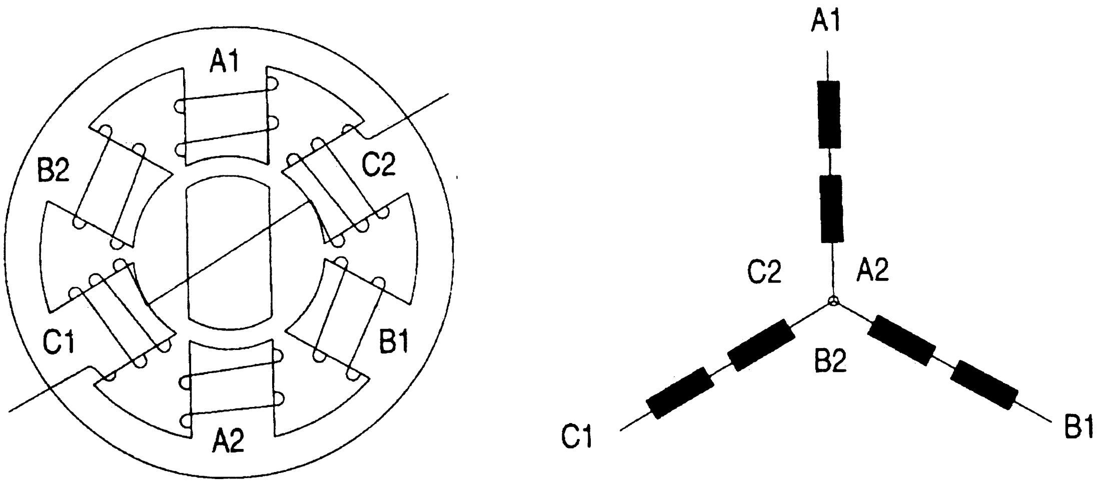


Figure 4.5 3-Phase brushless motor [17]

A similar situation in the brushless motor, however, requires a large number of coils distributed around the stator. This in itself may be feasible, but each coil would then require its own individual drive current. This is clearly prohibitive, so in practice a compromise is made and a typical motor has either two or three sets of coils or “phases”, (Figure 4.5). The motor shown in the diagram is a two-pole, three-phase design. The torque characteristic (Figure 4.6) indicates that maximum torque is produced when the rotor and stator fields are at 90° to each other.

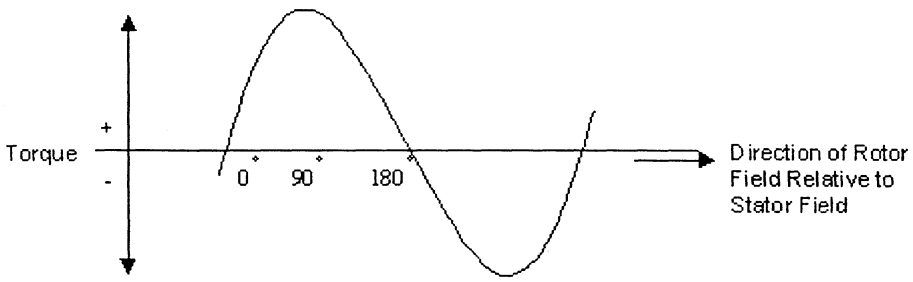


Figure 4.6 Position-torque characteristic

Therefore, to generate constant torque, one needs to be able to keep the stator field at a constant 90° angle to that of rotor. Limiting the number of phases to three means that one can only advance the stator field in increments of 60° of shaft rotation, so one cannot maintain a constant 90° torque angle but can maintain an average of 90° by working between 60° and 120°.

4.4 Motor Drives

A drive can be thought of simply as an amplifier. It takes a command from the controller, amplifies the command, and activates the motor. In practice, however, the drive is more complex. The exact configuration of the drive depends on the type of actuator and is classified as Stepping Motor Drives, DC Brush Motor Drives, and Brushless Motor Drives.

4.4.1 Stepper Motor Drive

The stepper drive delivers electrical power to the motor in response to low-level signals from the control system. The motor is a torque producing device and this torque is generated by the interaction of magnetic fields. The driving force behind the stator field is the magneto-motive force (MMF), which is proportional to the current and to the amp-turns product. Essentially, the drive must act as a source of current. The applied voltage is only significant as a means of controlling the current.

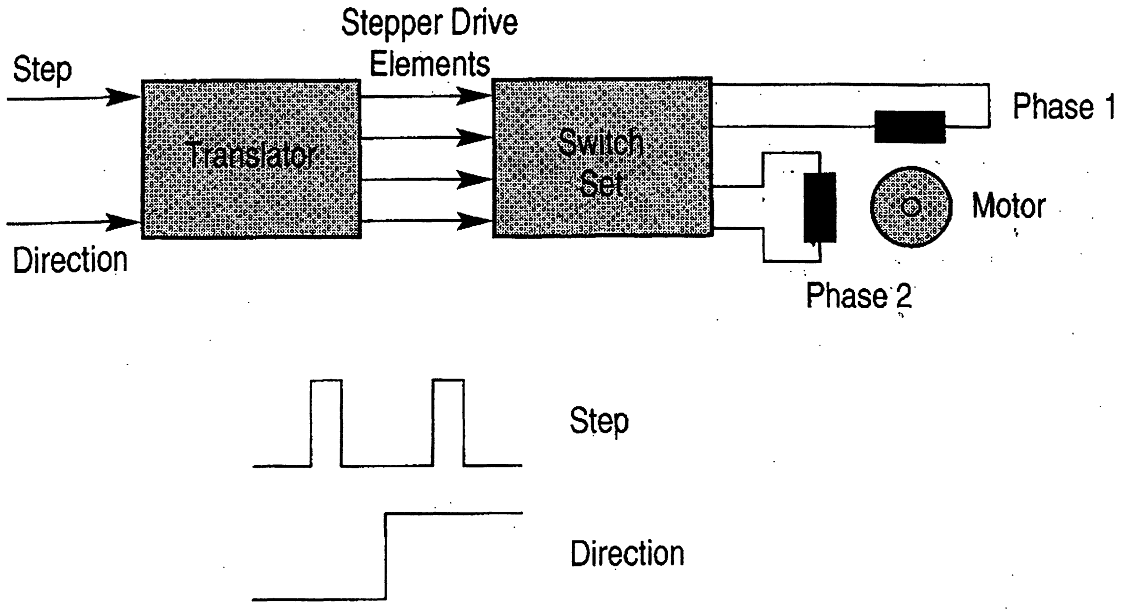


Figure 4.7 Stepper drive elements [17]

Input signals to the stepper drive consist of step pulses and a direction signal. One step pulse is required for every step the motor takes. This is true regardless of the stepping mode. So the drive may require 200 to 101,600 pulses to produce one revolution of the shaft. The most commonly used stepping mode in industrial applications is the half-step pulse frequency of 20kHz.

4.4.2 DC Brush Motor Drives

The amplifiers for both brush and brushless servo motors are either analog or digital. The analog drive has been around for many years, whereas the digital drive is a recent innovation. Both types have their merits.

The Analog Drive - In the traditional analog drive, the desired motor velocity is represented by an analog input voltage usually in the range ±10 volts. Full forward velocity is represented by +10V, and full reverse by –10V. Zero volts represent the stationary condition, and intermediate voltages represent speeds in proportion to the voltage. The various adjustments needed to tune an analog drive are usually made with potentiometers.

The Digital Drive - An alternative to the analog system is the digitally-controlled drive in which tuning is performed by sending data from a terminal or computer. This leads to easy repetition between units and, since such drives are invariably processor-based, facilitates fully-automatic self tuning. The input signal to such a drive may also be an analog voltage but can equally take the form of step and direction signals, like a stepper drive. Digital drives are used more in conjunction with brushless servo motors than with DC brush motors.

A Comparison of Analog and Digital Drives - The analog drive offers the benefit of lower cost and, in the case of a drive using tach feedback, very high performance. The wide bandwidth of the brush tach allows high gains to be used without inducing jitter at standstill, resulting in a very "stiff" system.

The digital drive, while more costly, is comparatively easy to set up and adjustments can quickly be repeated across several units. Automatic self-tuning can be a distinct advantage where the load parameters are unknown or difficult to measure. The digital drive also offers the possibility of dynamic tuning–sometimes vital where the load inertia changes dramatically during machine operation.

Analog DC Drive operation - The elements of an analog velocity amplifier are shown in Figure 4.8. The function of the system is to control motor velocity in response to an analog input voltage.

Motor velocity is measured by a tach generator attached to the motor shaft. This produces a voltage proportional to speed that is compared with the incoming velocity demand signal, and the result of this comparison is a torque demand. If the speed is too low, the drive delivers more current, which in turn creates torque to accelerate the load. Similarly, if the speed is too high or the velocity demand is reduced, current flow in the motor will be reversed to produce a braking torque. This type of amplifier is often referred to as a four-quadrant drive. This means that it can produce both acceleration and braking torque in either direction of rotation. The velocity amplifier in Figure 4.8 has a high gain so that a small velocity difference will produce a large error signal. In this way, the accuracy of speed control can be made very high even when there are large load changes.

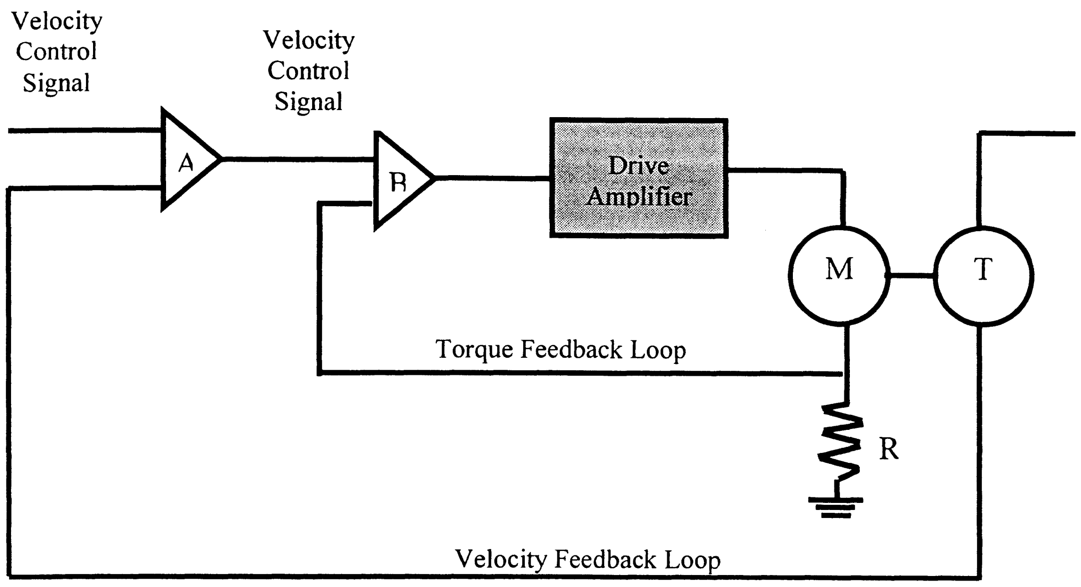


Figure 4.8 Analog servo system

4.4.3 Brushless Motor Drives

This provides a drive technology, which assures specified speed, acceleration, and torque performance. It also provides high torque per motor size and weight, rapid acceleration, and smooth machine operation. A brushless motor drive comes in various configurations and a typical setup for a brushless sinewave drive is shown in Figure 4.9. A sinewave brushless motor can be two or three phase, and the one illustrated in Figure 4.9 is a two-phase version. This uses two H-bridges to control current in the two motor windings, and the power section of this drive closely resembles a pair of DC brush drives. This drive uses a digital processor-based control section, which takes its input in the form of step and direction signals. One needs to generate currents in the two motor windings which follow a sine and cosine pattern as the shaft rotates.

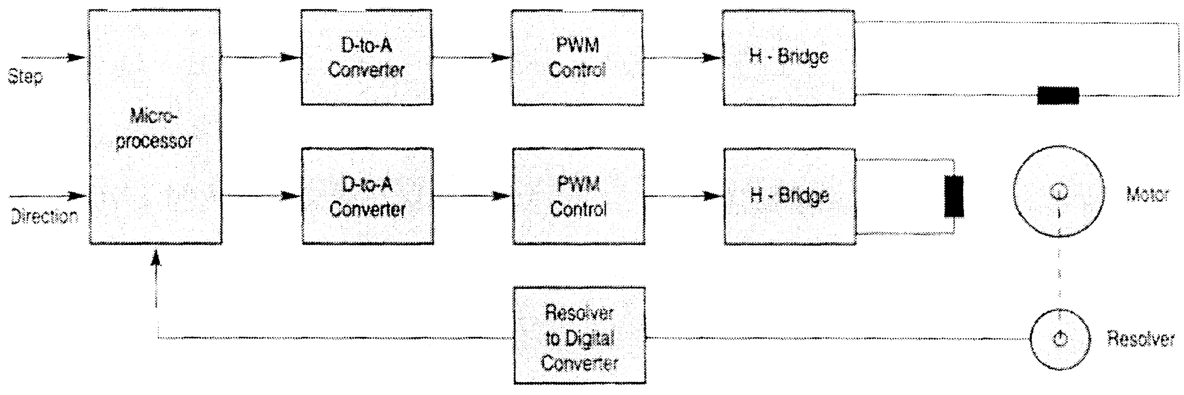


Figure 4.9 Two-phase sinewave brushless drive [17]

The drive shown in the diagram uses a brushless resolver and a resolver-to-digital converter (RDC) to detect the shaft position [14]. From this, one gets a number which can be fed to a look-up table to determine the instantaneous current values for the particular shaft position. The look-up table gives only relative currents in the two windings–the absolute values will depend on the torque demand at the time. So the processor must multiply the sine and cosine values by the torque demand to get the final value of current in each phase. The resulting numbers are fed to D-to-A converts, which produce an analog voltage proportional to demanded current. This is fed to the two PWM chopper amplifiers.

Commutation information for a sinewave drive may also be derived from an absolute or incremental optical encoder. An incremental encoder will be less expensive for the same resolution but requires some form of initialization at power-up in order to establish the required 90° torque angle.

4.4.4 APEX Brushless Servo Drive

The APEX series of brushless servo systems from Compumotor has been selected as a drive for the fatigue testing system as it delivers high performance and reliability. The series can operate a variety of servo motors, in addition to the standard resolver-based motors. Each unit can accept either hall effect or resolver commutation feedback and can be configured for different pole pair motors. The series incorporates sophisticated electronics, which includes a smart power block that interfaces directly to the control board. The APEX 10, 20 and 40 drives are designed for use with servo-controllers in torque or velocity mode to allow control by any standard ±10V analog servo-controller.

The APEX systems use digital signal processor (DSP) technology for a position loop update time of 205μsec and a separate microprocessor to execute high-level motion programs. This advanced design makes the series one of the highest performing single-axis stand-alone systems and, hence, was selected as a servo drive for the actuator (APEX640 brushless motor).

APEX40 Drive – There are two basic modes in which APEX40 drives can operate: torque and velocity. A block diagram of the drive operating in torque mode is shown in Figure 4.10. The gain G_m represents the transfer function of the current regulator and is set up by using the dip switches.

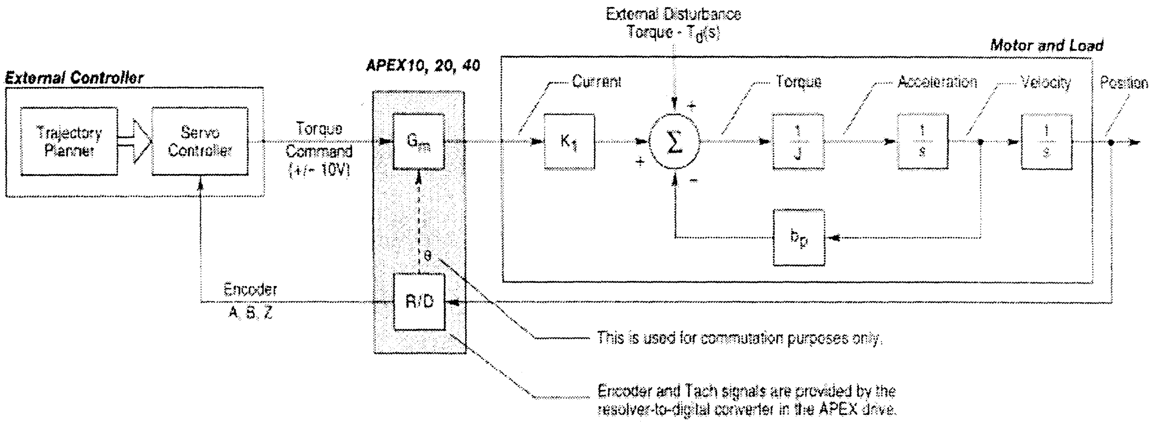


Figure 4.10 Torque mode block diagram [17]

The drive can also be set up in displacement and velocity modes. In case of velocity mode; the ± 10 volt signal represents commanded motor speed. This block diagram is shown in Figure 4.11 below. The gains K_c and K_i are set by the pots labeled "Collective" and "Vel integral" gain, respectively. The gain K_p, is factory set to 1. The gain G_m again represents the transfer function of the current regulator and is set up by dip switches.

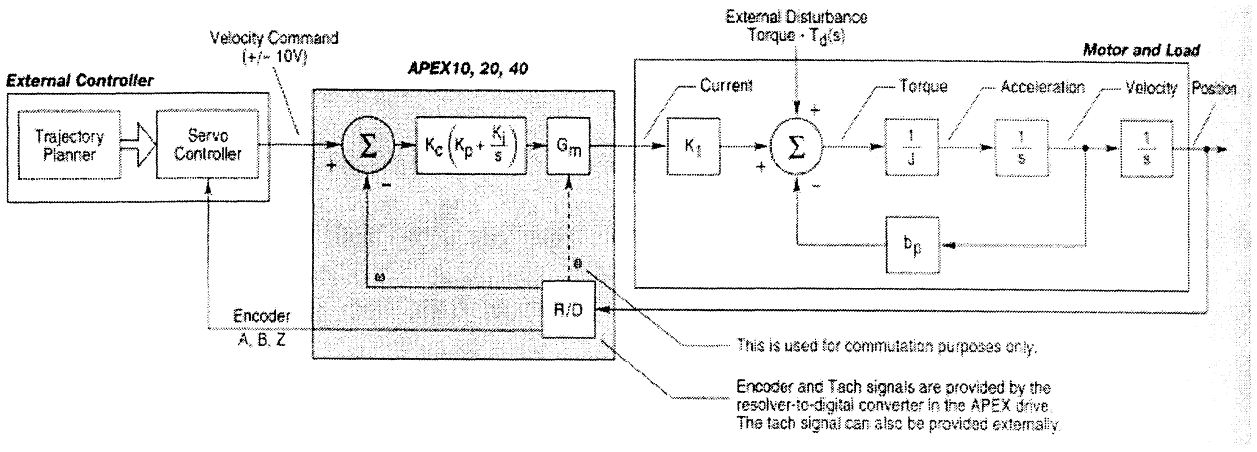

Velocity Command (+/- 10V)
External Controller
Trajectory Planner
Servo Controller
APEX10, 20, 40
$K_c\left(K_p+\frac{K_i}{s}\right)$
G_m
R/D
Encoder A, B, Z
External Disturbance Torque - $T_d(s)$
Motor and Load
Current
Torque
Acceleration
Velocity
Position
K_t
$\frac{1}{J}$
$\frac{1}{s}$
b_p
This is used for commutation purposes only.
Encoder and Tach signals are provided by the resolver-to-digital converter in the APEX drive. The tach signal can also be provided externally.

Figure 4.11 Velocity mode block diagram [17]

4.5 Feedback Transducers

The previous sections in this chapter have covered the principles of operation of a machine control system, the actuators necessary to effect movement, and the methods of control of these actuators. This section examines the elements necessary to provide feedback to the system controller on position, proximity, displacement, velocity and force. There is a wide range of these feedback sensors available like inductive sensors, capacitive sensors, photosensors, pneumatic sensors, resolvers and optical encoders. In order to keep track of the position of the actuator while running the test on a fatigue testing system, one needs a displacement transducer that provides accurate feedback of the displacement, velocity, and torque levels at all times during the test. The displacement transducers may be linear or rotary, analogue or digital, and incremental or absolute. They can also be used to provide direct or indirect feedback. Direct feedback occurs when the transducer is mounted integrally with the elements being monitored. For example, if the movement of a machine-tool table is being measured relative to a fixed bed, then a feedback transducer mounted on the table and/or the bed will provide a direct measurement of displacement. However, if the movement of a torsion fatigue specimen is being measured, then a feedback transducer mounted on the actuator shaft will provide an indirect measurement of displacement of the motor and, hence, the position of the specimen at every instance, because the movement being measured must still be transmitted to the machine-tool table.

4.5.1 Classification of Feedback Transducers

Linear/Rotary Transducers - They are commonly used on machine-tool tables and slideways. They provide reliable and precise direct displacement feedback using optical gratings and encoders. Rotary transducers in the form of optical shaft encoders, potentiometers, and resolvers are popular for mounting integral with servomotor assemblies for indirect displacement feedback.

Analogue/Digital Transducers - They produce a continuously changing signal analogous to the value being measured; potentiometers and resolvers are analogue transducers. Digital transducers produce digital signals; e.g., an optical grating will produce--after signal conditioning--a train of square-wave pulses for input to an electronic counter.

Incremental/Absolute Transducers - They provide signals that must be added as they arrive at the counter to determine the displacement from a known starting, or 'zero', point. However, with an absolute transducer each signal pattern specifies uniquely where the device is located.

4.5.2 Resolver

A resolver is, in principle [14], a rotating transformer with an output proportional to the angle of a rotating element (the rotor) with respect to a fixed element (the stator). If one considers two windings, A and B, (Figure 4.12) and feed winding B with a sinusoidal

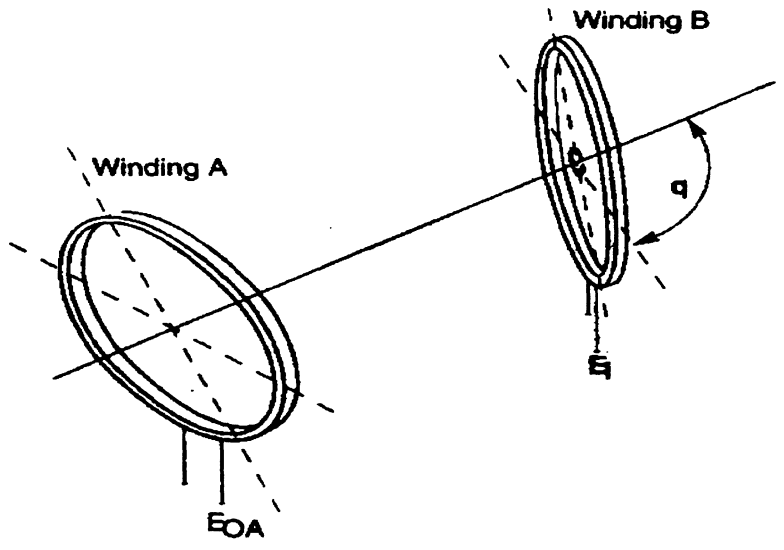


Figure 4.12 Resolver principle [10]

voltage, then a voltage will be induced into winding A. If winding B is rotated, the induced voltage will be at maximum when the planes of A and B are parallel and will be at a minimum when they are at right angles.

Also, the voltage induced into A will vary sinusoidally at frequency of rotation of B so that $E_{OA} = E_I \sin\phi$. If one introduces a third winding (C) positioned at right angles to winding A, then as B is rotated, a voltage will be induced into this winding and this voltage will vary as the cosine of the angle ϕ so that $E_{OC} = E_I \cos\phi$. Referring to Figure 4.13, one can see that if we are able to measure the relative amplitudes of the two windings (A and C) outputs at a particular point in the cycle, these two outputs will be unique to that position.

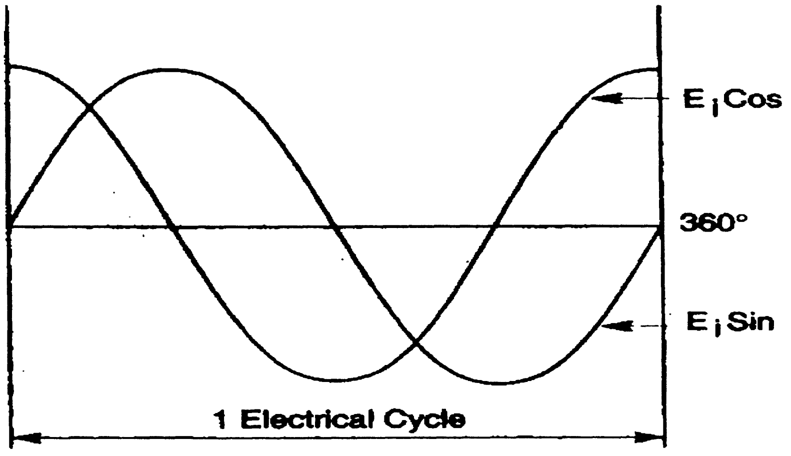


Figure 4.13 Resolver output [10]

The information output from the two phases will usually be converted from analog to digital form for use in a digital positioning system by means of a resolver-to-digital converter. Resolutions up to 65,536 counts per revolution are typical of this type of system. In addition to position information, speed and direction information may also be derived. The resolver is an absolute position feedback device. Within each electrical cycle, Phase A and Phase B maintain a constant (fixed) relationship.

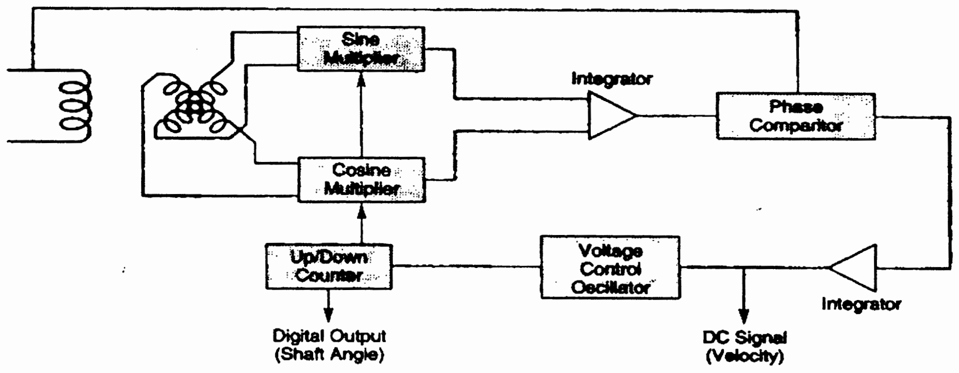


Figure 4.14 Resolver-to-digital converter [16]

The excitation voltage E may be coupled to the rotating windings by slip rings and brushes, though this arrangement is a disadvantage when used with a brushless motor. In such applications, a brushless resolver may be used so that the excitation voltage is inductively coupled to the rotor windings (Figure 4.15).

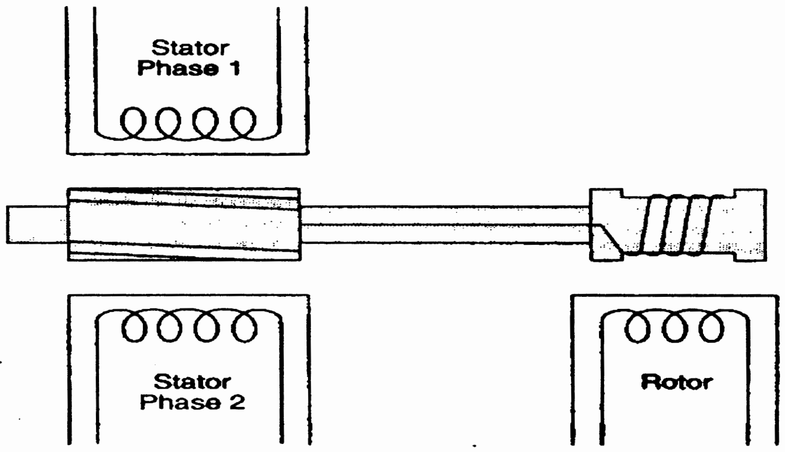


Figure 4.15 Brushless resolver [12]

4.6 Controller

The controller is an essential part of any motion control system. It determines speed, direction, distance, and acceleration rate–in fact, all the parameters associated with the operation that the motor performs. The output from the controller is connected to the drive's input, either in the form of an analog voltage or as step and direction signals. In addition to controlling one or more motors, many controllers have additional inputs and outputs that allow them to monitor other functions on a machine.

Controllers can take a wide variety of forms. Some of the common architectures [15] are Standalone, Bus-based, PLC-based, and X Code-based controllers.

- **Standalone** – This type of controller operates without data or other control signals from external sources. A standalone unit usually incorporates a keypad for data entry as well as display, and frequency includes a main power supply. It will also include some form of nonvolatile memory to allow it to store a sequence of operations. Many controllers that need to be programmed from a terminal or computer can, once programmed, also operate in standalone mode.
- **Bus-based** – A bus-based controller is designed to accept data from a host computer using a standard communications bus. Typical bus systems include STD, VME, and IBM-PC bus. The controller will usually be a plug-in card that conforms to the standards for the corresponding bus system. For example, a

controller operating on the IBM-PC bus resides within the PC, plugging into an expansion slot and functioning as an intelligent peripheral.

4.6.1 2-Axix Servo Controller

Compumotor's 6250 is a stand-alone two-axis servo controller. The 6250 provides sophisticated control for any standard ±10V analog input servo drive system and is perfect for the synchronization of two axes of motion. A Digital Signal Processor (DSP) is used for high-speed servo control. A separate microprocessor is used for executing high-level motion programs. The 6250 controller uses the dual processor approach for precise servo control and motion command execution.

The 6250 controller uses the 6000 command language. This language is powerful enough to implement complex motion control applications. Many useful features are incorporated into the command language, including subroutine definition, conditional programming, unit scaling, programmable I/O, contouring, and mathematical functions. The controller also comes with Motion Architect software, a software package for creating and executing motion control programs under Microsoft Windows.

The 6250 controller is ideal for generating motion control programs for carrying out torsion fatigue testing (both low and high cycle) because of its enormous features and functionality. Some of these are enumerated below:

Motion

- 2 axis of optically isolated servo control (± 10V-12bit analog interface) with incremental encoder feedback
- Control servo drives in velocity or torque mode
- Update rtes for servo loop as fast as 205 micro-sec for one axis
- Digital Signal Processor (DSP) for servo-control (PIV with velocity and acceleration feed-forward)
- 1.2MHz post - quadrature position feedback frequency.

I/O

- Home limit, positive and negative end-of-travel limits
- 48 programmable inputs (24) and outputs (24)
- Auxiliary high-speed programmable inputs and outputs providing position capture or output on position to ± 1 count at maximum encoder frequency
- Drive Enable outputs, Drive Fault inputs
- 3 8-bit analog inputs that can be used for joystick or variable input (temperature, tension, etc.)
- 6250 ANI option offers two ± 10V, 14-bit analog inputs (one per axis) with anti-aliasing filter; it can also be used for position feedback.

Language

- Capability to interrupt program execution on error conditions

- Position-based following
- Linear interpolation
- Variable storage, conditional branching, and math capability
- Program debug tools--trace mode, break points and simulation of I/O
- Scaling of distance, velocity and acceleration
- S curve or trapezoidal motion profiling
- 150,000 bytes of non-volatile memory for storage of programs and paths

Software Provided

- Motion Architect - Microsoft Windows-based application development software
- DOS support software program editor and terminal emulator software
- Dynamic Link Library (DLL) provided for use with Microsoft Windows software development kit

Interface Capability

- Operates stand-alone or interfaces to computers, programmable logic controllers
- Compatible with RP-240 operator interface panel
- Two RS-232C Communications Ports

Physical

- Standalone Package
- 120-240VAC

A partial list of the command language along with the specifications and dimensions of 6250 controller are provided in Appendix B.

The existing motor/drive technologies have been researched, and it was decided that the following configuration will be used for the system which offer a maximum peak torque of 58Nm (continuous torque of 28Nm) with frequency of up to 50Hz and an angular resolution of 10^{-3} degrees (or even higher). Appendices A, B, and C give the specifications for the various parts of the system.

- Drive – Compumotor's APEX 605 Brushless Servo Drive, which is capable of delivering a maximum power of 8kW and accelerations of up to 10,000 rev/sec^2 and frequency of more than 50Hz.
- Controller – Compumotor's 6250 Servo-Controller (32-bit CPU/ 24-bit DSP processor).
- Resolver – Two-phase quadrature incremental encoder with differential or single ended outputs (+5V DC). Max frequency = 1.2 MHz.

The next chapter looks at the material testing software developed for torsion fatigue testing and the testing procedure for the fatigue testing system. It discusses and assesses the various features of the software and establishes a testing procedure to be adopted for carrying out a fatigue test.

Chapter: 5 System Software

5.1 Introduction

This chapter describes the design and development of fatigue testing software and various issues involved. It also discusses the procedure for conducting the high and low cycle fatigue tests in torque and displacement modes using the testing software.

Testing needs may change from week-to-week, month-to-month, or even day-to-day. To meet these changing requirements or to do tests that are not based upon an existing standard, one needs a very flexible program that can carry out the specific tests. Driven by these needs, a flexible software program for high- and low-cycle fatigue testing has been developed along with a Graphic User Interface to execute motion control programs in torque, displacement, and velocity modes for torsional (uniaxial testing). It can also be used to create and run a wide variety of other test programs. Through a series of windows, one can design a test in a step-by-step manner, defining the function generation and data acquisition requirements for the test. The software can be modified easily to incorporate multi-channel control applications, like Bi-Axial Fatigue Testing.

5.2 Graphic User Interface Design Process

A user interface is the part of an application that the user sees and with which he or she interacts. Narrowly defined, this interface comprises the input and output devices and the software that services them. Broadly defined, the interface includes everything that shapes the user's experiences with computers--including documentation, training, and human support.

The user interface is so important to users, designers, and developers of software products because that is what users view and work with. From the user's point of view, the interface is the software. There is a body of knowledge about how people think, learn and work. Intelligent interface design [11] taps into that body of knowledge and applies it to the design of a software interface.

A typical intelligent interface design process consists of analysis, design, and construction, as shown in Figure 5.1.

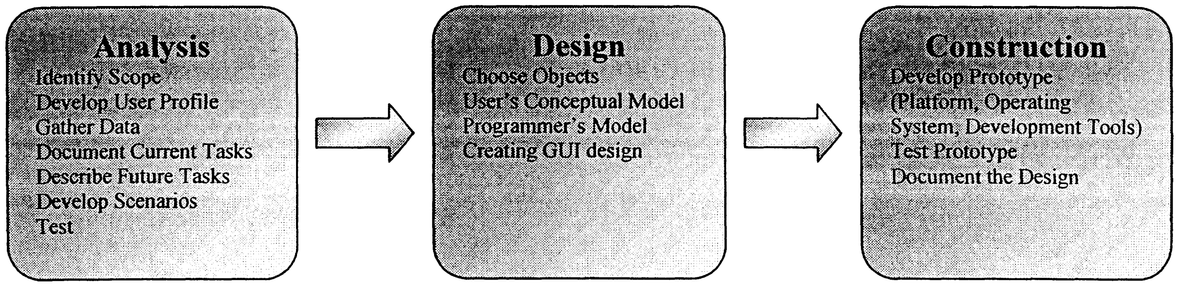


Figure 5.1 Phases of interface design

5.2.1 Analysis

The analysis phase includes both learning about and documenting current testing systems and software and verifying the future tasks. One has to identify all the system hardware, software and project features and requirements that might constrain the interface design. Identify the interface technology that will be employed - for example, GUI. Identify the platform (for example UNIX, DOS, WINDOWS, OS/2; see Ross, Paul [13]) and machines (for example, UNIX workstations, X terminals, PC's). Identify what user interface techniques will be available. Once these issues have been identified, one defines the product usability goals and objectives and develop a user scenarios and tasks.

5.2.2 Design

During this phase, one takes everything that he/she has learned during analysis and creates a solution based on all that he/she knows. The design phase progresses through a number of well-defined steps that should be followed in sequence before one codes the final design.

Once the user's scenarios and tasks have been identified, the next step is the design process of defining interface objects and actions. Next one identifies key object attributes; that is, the information about the objects that the user needs to see when performing tasks, such as the current time and the time when the test run was started. One might also want to display the test parameters that the user has selected for performing the test. Next, one identifies user actions on task objects using information from the task analysis and case scenarios. Once objects have been defined, one determines how to best represent them on the screen and how users will view these objects and the information they contain. When determining object views, one considers the way users will interact with each object and its information. After designing objects and their icons, one determines how users will interact with objects and windows using various types of menus.

5.2.3 Construction

Once the high-level design mockup is tested and revised, one goes about creating a more realistic version of the interface. Prototypes are the tools for constructing the interface. Construction has several purposes:

- Create a hi-fi computer prototype
- Further iterate the design and test the program
- Document the complete, final design for development.

The purpose of a prototyping [11] is to quickly and easily visualize design alternatives and ideas, not to build code that must be used as part of the product. There are many ways to prototype interfaces, starting with pencil-and-paper methods using chalkboards, whiteboards, flipcharts, and storyboards. Prototypes may show visualizations of the interface. There are two ways to approach prototyping–using prototyping tools specifically designed for the task, or using development tools like Visual Basic or Visual C++, that are normally used to write product code.

After the computer prototype is developed, one must implement it in the code. Also the communication and documentation of the entire interface design is done so that while developing the interface one knows how the interface looks and behaves. At this point one will have developed a full interface design--series of screens that match the way the user is going to work with the new system. The interface must be tested and revised several times. This is an interface that will be usable and will not need a lot of changes once it is coded.

5.2.4 Who's Driving the Design – The System or the Interface?

Designing and developing a software product may require integrating many subsystems, programs, and so on. In many cases, the operating system, programming languages, and

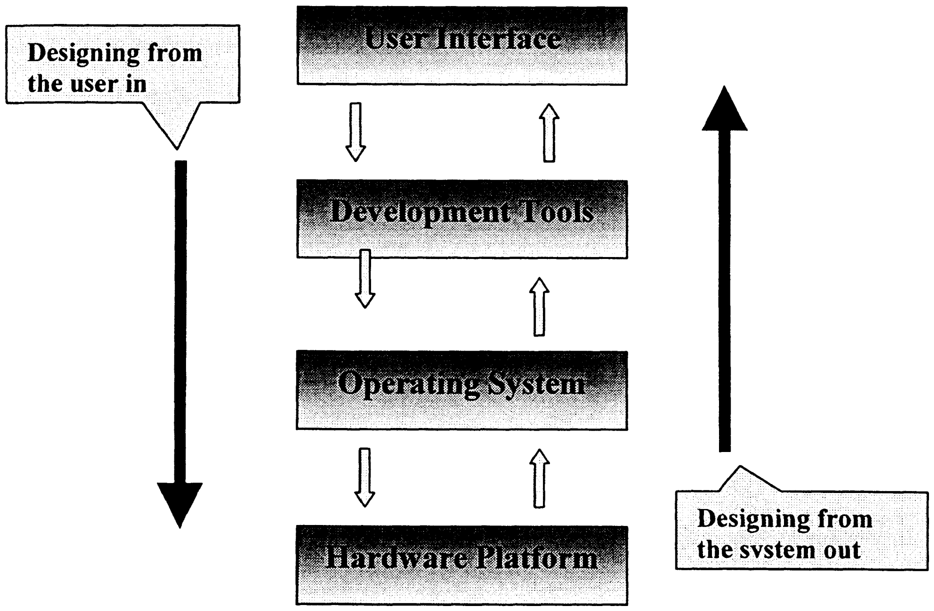


Figure 5. 2 Design from User-In vs. from the System-Out

development tools are already in place or have previously been determined before the user interface is designed. Figure 5. 2 shows two different approaches to interface design. Designing from the system out can predetermine and constrain what type of user interface can be designed and built. The technology itself (the language selected, CASE tool chosen, etc.) often overshadows the paradigm (the frame of reference, way of seeing, process of understanding, and method of mapping).

If you design "from the user in" perspective, you follow the design process outlined here and work with users to build product goals, objectives, and user requirements. You are more likely to design interface metaphors, visual elements, and input/output techniques that match user requirements. Then see if it is possible to build the appropriate user interface using the current development environment. If it cannot be supported, then try implementing it using new widgets and using a different approach.

5.3 Fatigue Testing Software

The Fatigue Testing Software has been developed in Visual Basic 5.0 and runs on a Windows platform (95/98/NT). The beta version of the software has been tested during the senior project rotation. The software, in essence, presents the user with a number of choices regarding the test and parameters of the test and then programs the controller to run the appropriate test. The host computer and the controller are in constant communication [16] during the test via the RS232 link. Data from the controller, such as torque, angular displacement etc., is sent back to the host computer, which then records the data in a file and generates a real-time plot for the process. The source code for this software is included in Appendix D.

This material testing software is primarily composed of three modules:

- Test Selection Module
- Data Input Module
- Test Execution Module

5.3.1 Test Selection Module

To run a test using the fatigue testing software, one begins by first switching on the control system of the fatigue testing system and mounting the specimen correctly. After running the executable file of the testing software, the application starts and prompts the user for a login and password, as shown in Figure 5.3. After proper validation, a splash screen comes up displaying information about the software, as shown in Figure 5.4. The welcome screen automatically unloads after a few seconds to display the test selection form where one defines the basic types of test to be run.

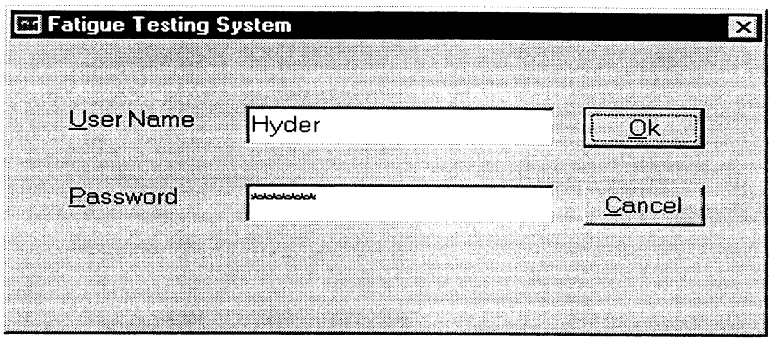
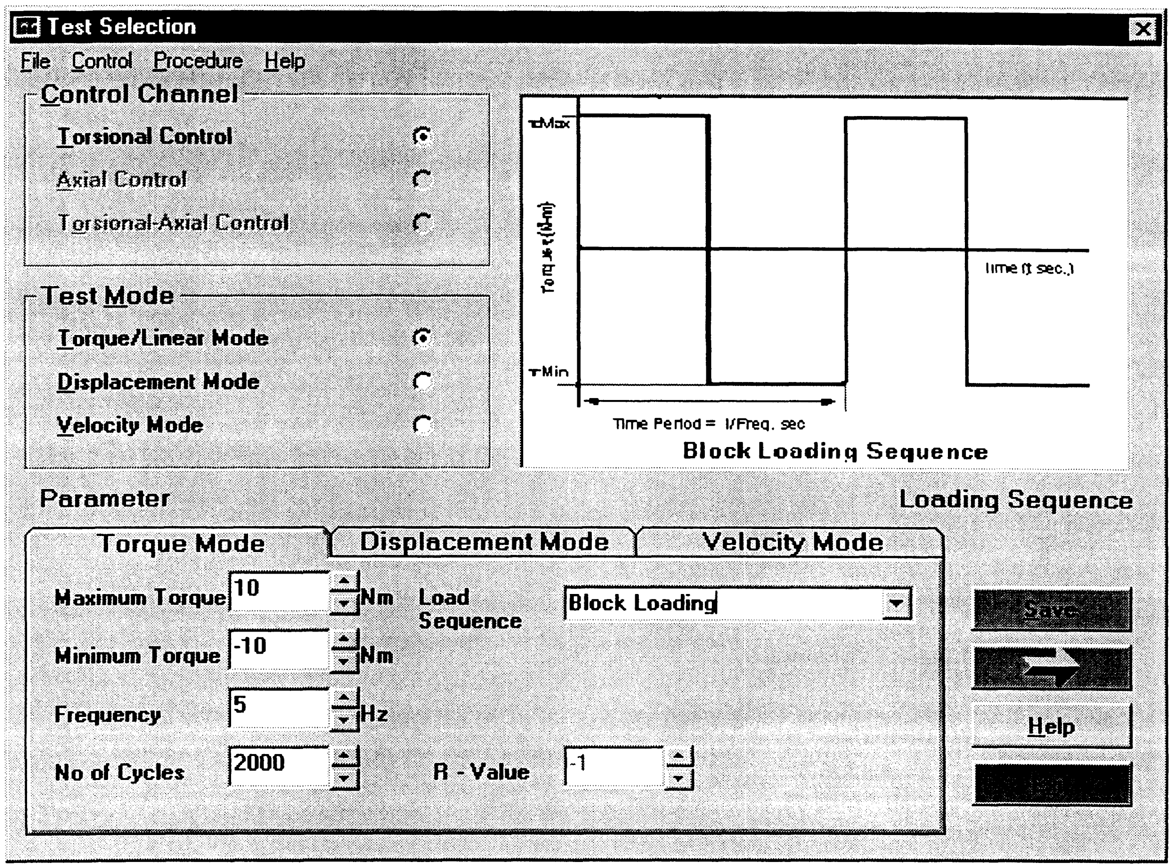


Figure 5.3 Login window

Figure 5.4 Splash screen

5.3.2 Data Input Module

The data input module consists of a test selection form where the user is given a choice of the control channels and various test modes, which he/she can choose, like Torsional Control, Axial Control, and Torsional/Axial Control. The current implementation allows the user to opt for only Torsional Control channel. Once a control channel is selected, then a "Test Mode" has to be selected in order to perform a particular type of test. Three types of test modes are available–Torque/Linear Mode, Displacement Mode, and Velocity Mode.



Control Channel

[✓ Torsional Control]
Axial Control
Torsional-Axial Control

Test Mode

[✓ Torque/Linear Mode]
Displacement Mode
Velocity Mode

Maximum Torque	10 Nm
Minimum Torque	-10 Nm
Frequency	5 Hz
No of Cycles	2000
Load Sequence	Block Loading
R - Value	-1

Figure 5.5 Test selection module

Once a particular test mode is selected, the user is allowed to input certain process parameters. As shown in Figure 5.5, if one selects the "Torque" test mode, then the appropriate tab is displayed in the parameter tab list where he/she can input his/her test conditions. Here, for this particular case, it will allow the user to enter maximum/minimum torque, frequency, number of cycles, type of loading sequence, and the R-value.

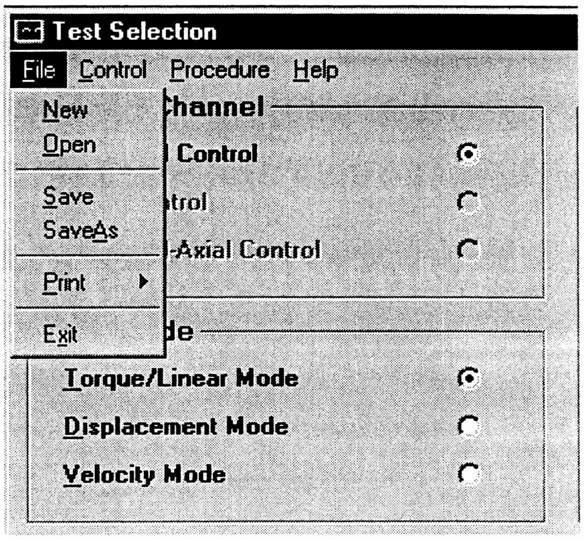


Figure 5.6 File selection menu

In the Test Selection form, the menu bar at the top gives a set of options for opening the test files and printing and saving them, as shown in Figure 5.6. It also gives the option of

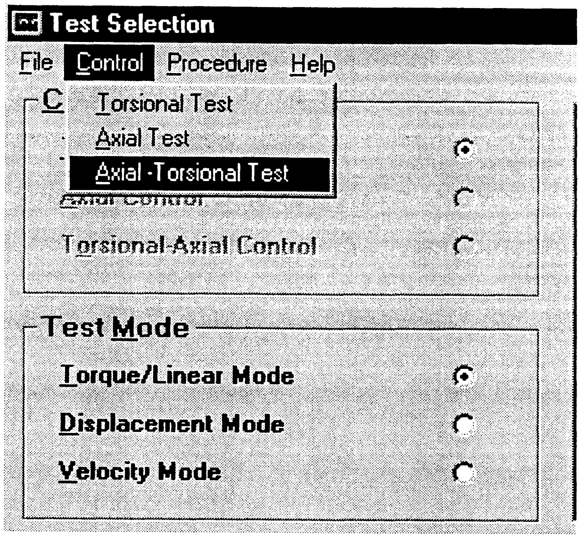


Figure 5.7 Control selection menu

selecting the control channel (Figure 5.7), and an online help about the Motion Architect Software, Compumotor etc., (Figure 5.8).

In the test selection form, an image is displayed on the top right-hand corner, which indicates the type of test selection mode and the loading sequence. This image changes, depending upon the type of loading sequence.

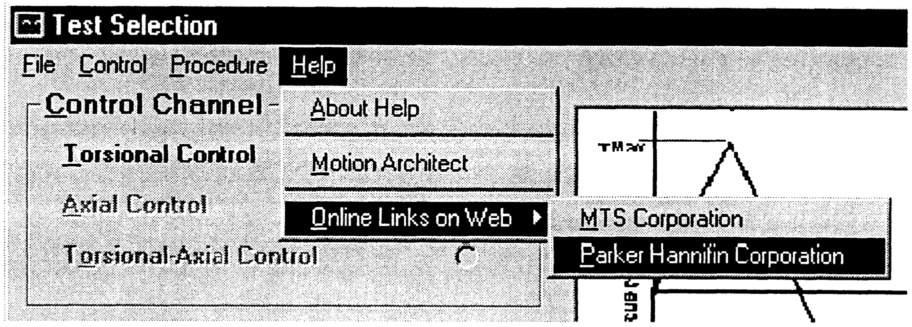
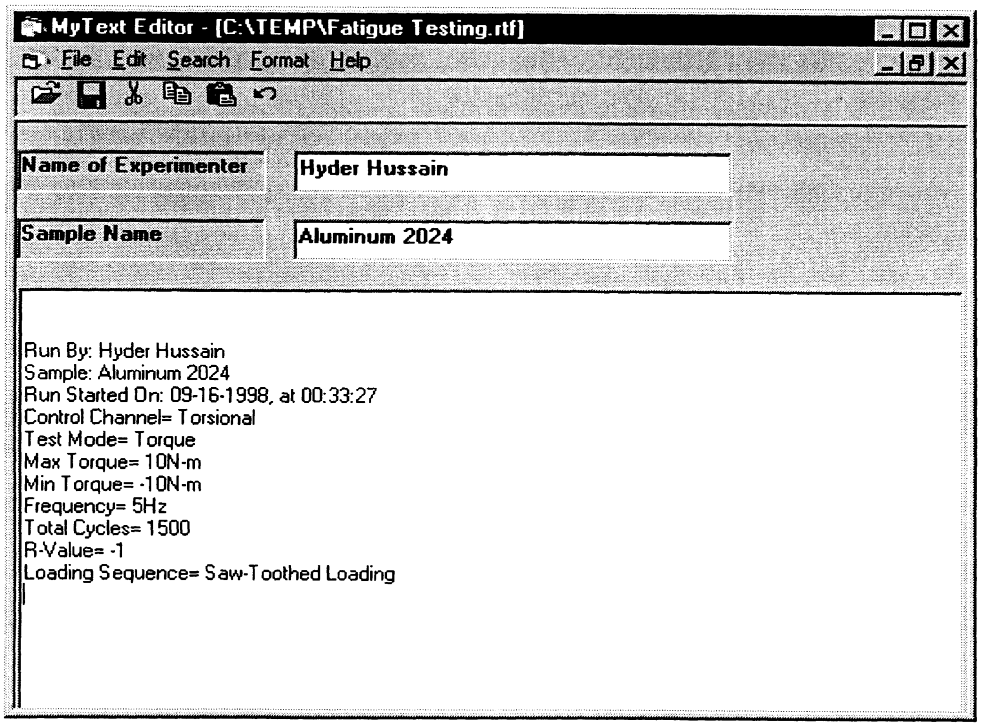


Figure 5.8 Help selection menu

Once the user makes the appropriate test parameters selections and hits the "Save" command button, it will take him to another screen, which is similar to a text editor, where the person can enter his name, sample name, and related information about the test. The test parameters entered in the test selection screen automatically get copied in the editor, and the user can add additional information.


MyText Editor - [C:\TEMP\Fatigue Testing.rtf]
File Edit Search Format Help

Name of Experimenter: Hyder Hussain

Sample Name: Aluminum 2024

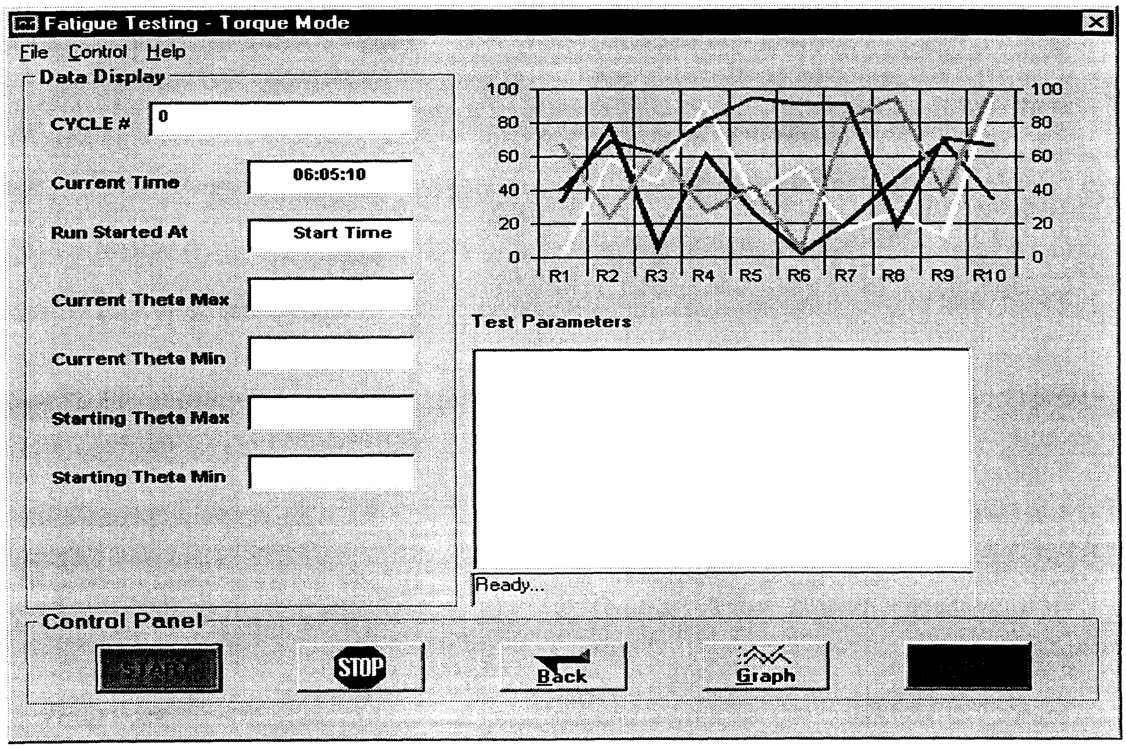
```
Run By: Hyder Hussain
Sample: Aluminum 2024
Run Started On: 09-16-1998, at 00:33:27
Control Channel= Torsional
Test Mode= Torque
Max Torque= 10N-m
Min Torque= -10N-m
Frequency= 5Hz
Total Cycles= 1500
R-Value= -1
Loading Sequence= Saw-Toothed Loading
```

Figure 5.9 Test information editor

After the editor contents are saved, the editor window, (Figure 5.9), is closed and the user is taken back to the Test Selection window. After one is satisfied with the test parameters, one has to hit the command button with the "arrow" icon to go to the appropriate test execution module. Depending upon what test mode the user selects (torque, displacement, or velocity), the corresponding test execution module loads up and the form for executing the test is displayed, as shown in Figure 5.10.

5.3.3 Test Execution Module

Once the user has made all the appropriate test selections and provided the input parameters, the test can be started by hitting the "Start" button in the control panel of the test execution window, as shown in Figure 5.10. The program for running the motor with the given parameters is downloaded to the controllers memory through the RS232 serial port when the test execution window is loaded into the memory and displayed on the screen.



CYCLE # 0

Current Time 06:05:10

Run Started At Start Time

Current Theta Max

Current Theta Min

Starting Theta Max

Starting Theta Min

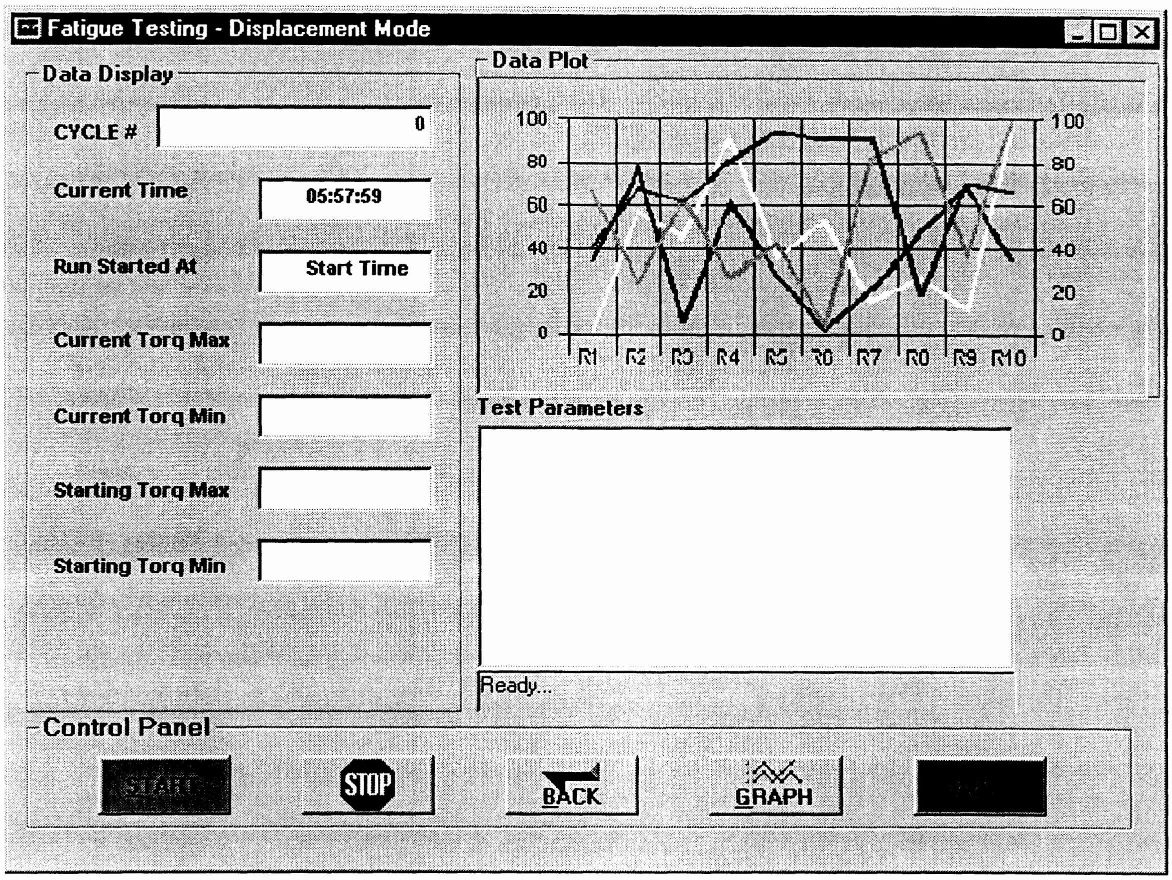
Ready...

Figure 5.10 Torque control mode

Once the command button is clicked, the software sends a signal to the controller to start the test with the appropriate process parameters. The test execution window has four major parts associated with it–Data Display, Data Plot, Test Parameters, and Control Panel. The Data Display frame consists of text boxes and labels which display various parameters, such as number of cycles, current time, run started at, current theta max, current theta min, starting theta max, starting theta min, etc. The test parameter label displays all the values of the process parameters that have been selected for this particular test. The "Control Panel" consists of "Start" button for starting the test, "Stop" button for stopping the system, "Graph" button for displaying the real time plot of the test data, "Back" button for going back to the test selection screen to change the test parameters, "Quit" button to quit the application. A status bar shows the current status of the test.

The test is monitored in real-time by plotting the process parameters in the Data Plot frame through OLE (Object Linking and Embedding) automation. In case of the torque mode, the current maximum/minimum torque is plotted against the number of cycles. The feedback from the encoder is sent back to the controller of the machine from where the data is read through a serial port using a MSComm control. After reading, the data is automatically imported into an Excel spreadsheet in real-time as the test is in progress and a display of the plot is shown in the Data Plot frame, as shown in Figure 5.14. The data in the Excel spreadsheet can be saved for further analysis.

A similar procedure is adopted for carrying out the test in Displacement Mode. Once the appropriate parameters are selected for the fatigue test in displacement mode, a control panel, as shown in Figure 5.11, is loaded to run the test.


Fatigue Testing - Displacement Mode

Data Display

CYCLE # 0

Current Time 05:57:59

Run Started At Start Time

Current Torq Max

Current Torq Min

Starting Torq Max

Starting Torq Min

Test Parameters

Ready...

Figure 5.11 Displacement control mode

In this test, the user can monitor the fluctuations in torque (maximum and minimum values) over a period of time. The test execution window is similar to that in "Torque Mode" and has four major parts associated with it–Data Display, Data Plot, Test Parameters, and Control Panel. The Data Display frame consists of text boxes and labels which display various parameters like number of cycles, current time, run started at, current torque max, current torque min, starting torque max, starting torque min, etc. The test parameter label displays all the values of the process parameters that have been selected for this particular test.

The fatigue system software package is flexible enough to carry out high-low cycle fatigue testing. It can be used to create and run a wide variety of test programs, as described in the previous section, through a series of software windows in a step-by-step manner, defining the function generation and data acquisition requirements for the test. (The source code for the software developed is described in Appendix D).

The next chapter deals with the high- and low-cycle torsion fatigue testing carried out to test the machine performance and analyze the material testing software developed for torsion fatigue testing system. It discusses and accesses the various features of the software and establishes a testing procedure to be adopted to carry out a fatigue test.

Chapter: 6 Fatigue Testing Analysis and Results

6.1 Overview

This chapter reviews the fatigue testing experiments carried out to test the performance of the fatigue testing machine and the software developed. It also discusses and accesses the various features of the software and establishes a testing procedure to be adopted to carry out a fatigue test.

A metal may fail under sufficient cycles of repeated stress, even though the maximum stress applied is considerably less than the strength of the material determined by a static test. Therefore, the control of fracture and fatigue has become a high priority for designers and materials researchers. The following sections describe some of the high- and low-cycle torsion fatigue tests carried out in various modes and under different test parameters to test the specimens and analyze and review the performance of the Fatigue Testing System and its associated software.

6.2 Torsion Fatigue Testing

A broad method for constant amplitude (torque or displacement mode), low-cycle torsion fatigue testing--typically of homogeneous metallic materials--is applied in this case. A requirement of uniform--though not necessarily ambient--temperature, pressure, humidity, etc., is applied to the specimen. Tests have been conducted in constant amplitude stress or strain cycling (without hold times). Such tests are useful in developing data from mechanical design, materials R and D, process and quality control, product performance, and failure analysis. Much valuable information can be obtained regarding the stability of materials under cyclic loading or whether changes occur due to cyclic plastic straining and when cracks begin to form.

The "Torsion Fatigue System" has been used to test the low-cycle fatigue behavior of materials under constant amplitude (stress and displacement) with varying test parameters, such as torque, displacement, frequency, stress ratio, loading cycles, etc.

6.3 Displacement Mode

In this mode, the specimen is subjected to a constant cyclic angular displacement over a period of time and the behavior of the material is studied at different frequencies and different stress ratios (R-value). A low-cycle torsion fatigue test in displacement mode for aluminum 2024 samples were carried out on the "Torsion Fatigue System" and the observations have been analyzed and are presented below.

6.3.1 Test 1 – Specifications and Results

A torsion fatigue test in displacement mode was carried out on an aluminum specimen. The specimen was subjected to a saw-toothed loading sequence with an overall displacement of 10° (± 5°) at a frequency of 10 Hz.

Table 6.1 Displacement Mode Test Parameters (± 5° at 10Hz.)

Test Parameters	
SAMPLE	Aluminum 2024
CONTROL CHANNEL	Torsional
TEST MODE	Displacement
MAX ANGLE	5Deg
MIN ANGLE	-5Deg
FREQUENCY	10Hz
TOTAL CYCLES	1000
R-VALUE	-1
LOADING SEQUENCE	Saw-Toothed Loading

The behavior of the specimen was monitored over time and the characteristic of torque versus number of cycles is plotted in Figure 6.1. As seen in the figure, the amount of torque applied on the specimen is approximately ± 3 N-m that remains constant for 800 cycles. This behavior corresponds to the initial fatigue damage leading to crack nucleation and crack initiation, which includes the early development of fatigue damage (crack initiation) and leads to slip-band crack growth involving the deepening of the initial crack on the planes of high torsional shear stress.

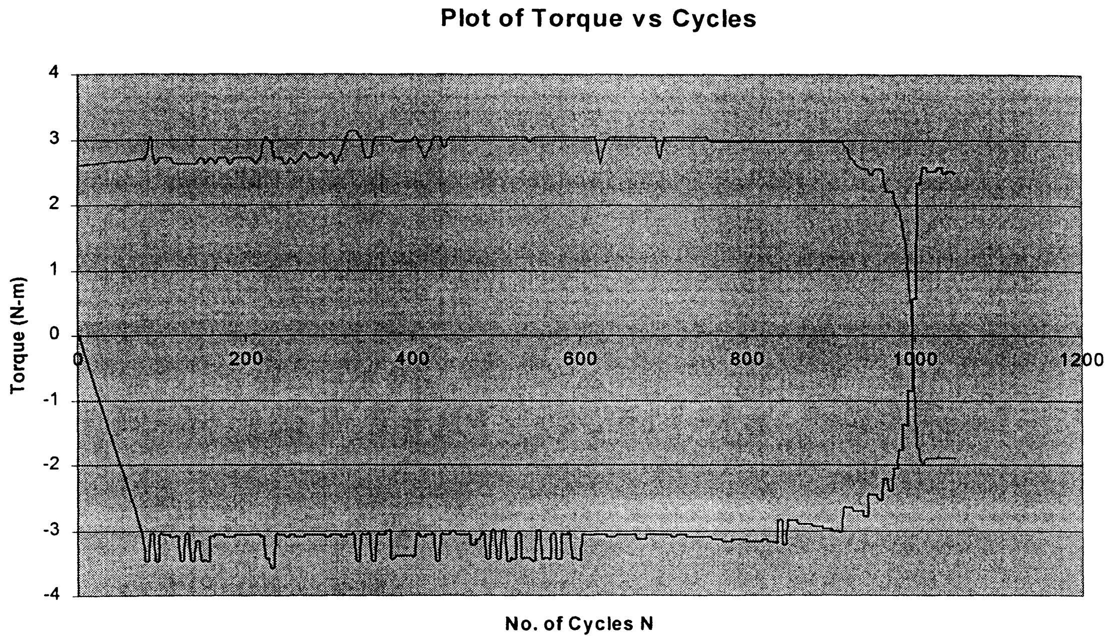


Figure 6.1 Displacement mode characteristics (± 5° at 10Hz.)

As the specimen starts becoming weaker due to the application of constant displacement load on the specimen making it weaker as the number of applied cycles increase, the applied load starts to decrease drastically (due to the crack growth on planes of high tensile stress–Stage II of low-cycle fatigue) as seen in the figure and drops to zero at around 1000 cycles, when the specimen finally breaks due to ultimate ductile failure (Stage III of low-cycle fatigue). This occurs when the crack reaches sufficient length so that the remaining cross-section cannot support the applied load. It can be seen that a larger proportion of the total cycles to failure is spent with the propagation in Stage II in low-cycle fatigue test.

6.3.2 Test 2 – Specifications and Results

This low-cycle torsion fatigue test in displacement was carried out on the same aluminum specimen as in Test 1, with the same set of parameters except for frequency-- which in this case has been increased from 10Hz to 20Hz--and the low cycle behavior of the specimen with change in the frequency of applied displacement has been studied.

Table 6.2 Displacement Mode Test Parameters (± 5° at 20Hz.)

Test Parameters	
SAMPLE	Aluminum 2024
CONTROL CHANNEL	Torsional
TEST MODE	Displacement
MAX ANGLE	5Deg
MIN ANGLE	-5Deg
FREQUENCY	20Hz
TOTAL CYCLES	1100
R-VALUE	-1
LOADING SEQUENCE	Saw-Toothed Loading

The characteristics of torque versus number of cycles have been plotted as in Figure 6.2.

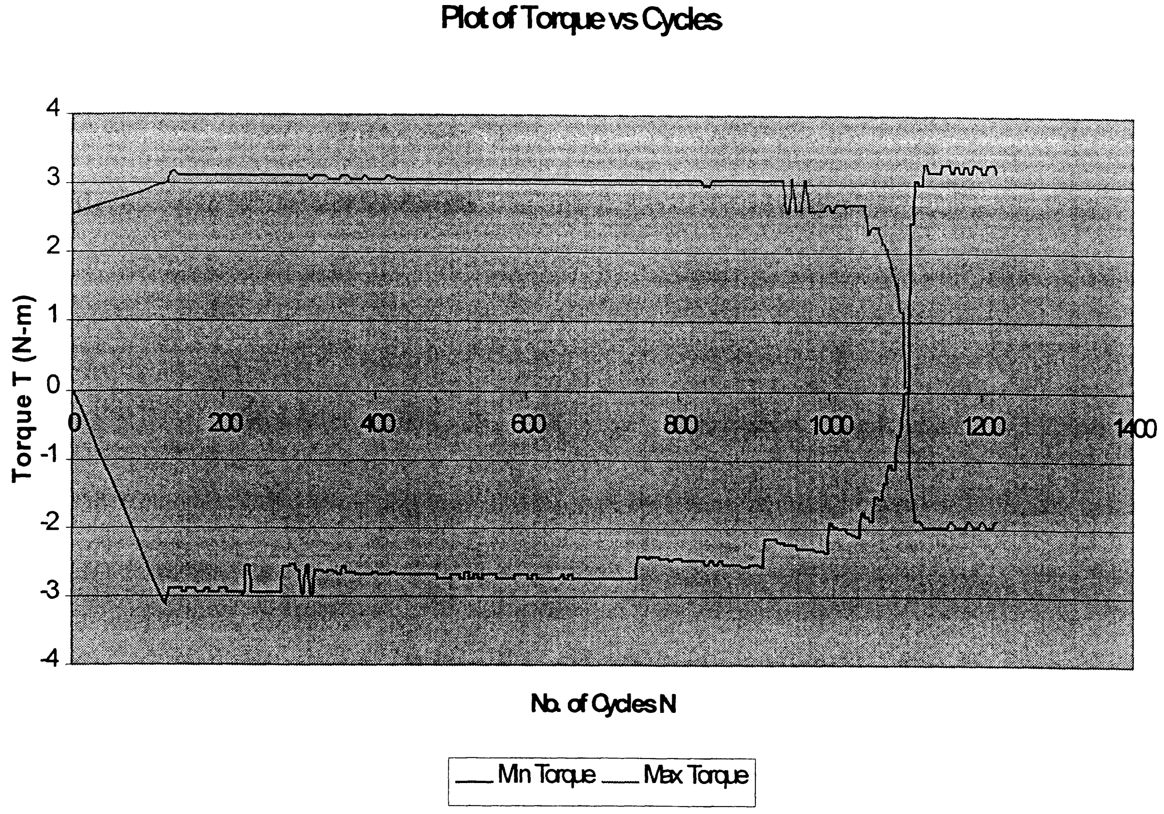


Figure 6.2 Displacement mode characteristics (± 5° at 20Hz.)

As seen from Figure 6.2, there is no drastic change in the behavior of the material when the frequency is increased to 20Hz. The applied load on the specimen is initially ± 3N-m. The torque remains relatively constant for 900 cycles. This behavior corresponds to the initial fatigue damage leading to crack nucleation and crack initiation. The specimen starts becoming weaker due to the application of constant displacement load on the specimen making it weaker as the number of applied cycles increase. The applied load starts to decrease (Stage II of low cycle fatigue), as seen in Figure 6.2, and drops to zero at around 1100 cycles, when the specimen finally breaks due to ultimate ductile failure (Stage III of low-cycle fatigue).

6.3.3 Test 3 – Specifications and Results

This torsion controlled-displacement fatigue test was carried out on the same aluminum specimen as in Test 1 with a different set of test parameters and the low cycle behavior of the specimen with change in the torque with number of cycles has been monitored. The applied displacement is ± 8° at a frequency of 10Hz.

Table 6. 3 Displacement Mode Test Parameters (± 8° at 10Hz.)

Test Parameters	
SAMPLE	Aluminum 2024
CONTROL CHANNEL	Torsional
TEST MODE	Displacement
MAX ANGLE	8Deg
MIN ANGLE	-8Deg
FREQUENCY	10Hz
TOTAL CYCLES	90
R-VALUE	-1
LOADING SEQUENCE	Saw-Toothed Loading

The characteristics of torque versus number of cycles have been plotted, as shown in Figure 6.3.

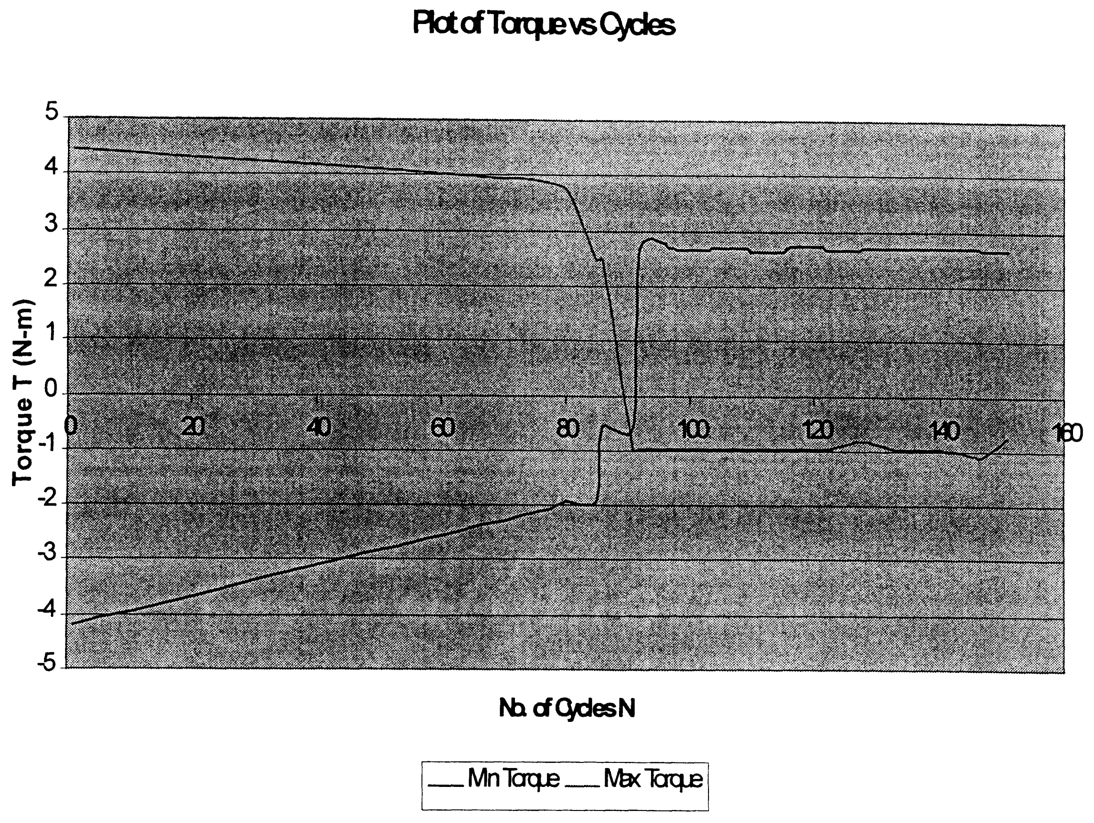


Figure 6.3 Displacement mode characteristics (± 8° at 10Hz.)

As seen from Figure 6.3, there is a drastic change in the behavior of the material when the applied displacement is increased from ±5° to ±8°. The applied load on the specimen is initially ± 4N-m. The applied torque drops rapidly as the number of cycles increase. This behavior corresponds to the initial fatigue damage leading to crack nucleation and crack initiation. The specimen starts becoming weaker due to the application of constant displacement load on the specimen making it weaker as the number of applied cycles increase. The applied load starts to decrease drastically (Stage II of low cycle fatigue) and drops to zero at around 90 cycles, when the specimen finally breaks due to *ultimate ductile failure* (Stage III of low cycle fatigue).

6.3.4 Test 4 – Specifications and Results

This high-cycle torsion fatigue test in displacement mode was carried out on the same aluminum specimen (Aluminum 2024) with a different set of test parameters and the high-cycle behavior of the specimen with change in the torque with number of cycles has been monitored. The applied displacement in this case is ± 3° at a frequency of 20Hz.

Table 6. 4 Displacement Mode Test Parameters (± 3° at 20Hz.)

Test Parameters	
SAMPLE	Aluminum 2024
CONTROL CHANNEL	Torsional
TEST MODE	Displacement
MAX ANGLE	3Deg
MIN ANGLE	-3Deg
FREQUENCY	20Hz
TOTAL CYCLES	14500
R-VALUE	-1
LOADING SEQUENCE	Saw-Toothed Loading

The characteristics of torque versus number of cycles have been plotted, as shown in Figure 6.4.

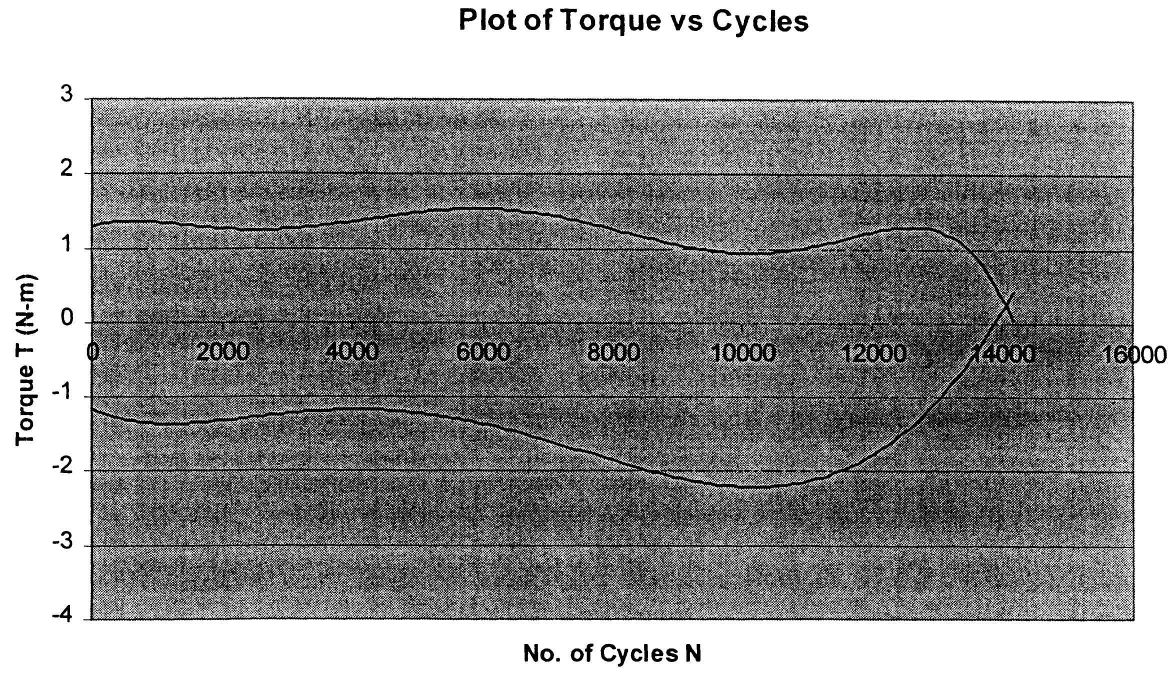


Figure 6. 4 Displacement mode characteristics (± 3° at 20Hz.)

As seen from Figure 6.4, there is a drastic change in the behavior of the material when the applied displacement is decreased to ±3°. The applied load on the specimen is initially ± 1.2N-m. The applied torque remains steady as the number of cycles increases. This behavior corresponds to the initial fatigue damage leading to crack nucleation and crack initiation. This sort of behavior is observed for approximately 8000 cycles before there is any significant change in the applied torque as the number of cycles increases. The specimen starts becoming weaker due to the application of constant displacement load on the specimen making it weaker as the number of applied cycles increase. The applied load starts to decrease drastically (Stage II of low cycle fatigue) and drops to zero at around 14,000 cycles, when the specimen finally breaks due to ultimate ductile failure (Stage III of low cycle fatigue).

It is also observed that any tests carried out on the aluminum 2024 specimen in displacement mode with $< \pm 3°$ results in a significant increase in the number of cycles to failure (>30,000 cycles), at which point the test enters the high-cycle fatigue region and approaches the limit of infinite number of cycles before failure occurs (also known as the fatigue limit).

6.4 Torque Mode

In this mode, the specimen is subjected to a constant cyclic torque over a period of time and the behavior of the material is studied at different frequencies and different stress ratios (R-value). A low-cycle torsion fatigue test in torque mode for aluminum 2024 samples were carried out on the "Torsion Fatigue System", and the observations have been analyzed and are presented below.

6.4.1 Test 1 – Specifications and Results

A torsion fatigue test in torque mode was carried out on an aluminum specimen. The specimen was subjected to a saw-toothed loading sequence with an overall torque of 4Nm (± 2Nm) at a frequency of 20 Hz.

Table 6. 5 Torque Mode Test Parameters (± 2Nm at 20Hz.)

Test Parameters	
SAMPLE	Aluminum 2024
CONTROL CHANNEL	Torsional
TEST MODE	Torque
MAX TORQUE	2N-m
MIN TORQUE	-2N-m
FREQUENCY	20Hz
TOTAL CYCLES	9800
R-VALUE	-1
LOADING SEQUENCE	Saw-Toothed Loading

The behavior of the specimen was monitored over time, and the characteristics of angular displacement versus number of cycles is plotted in Figure 6.5.

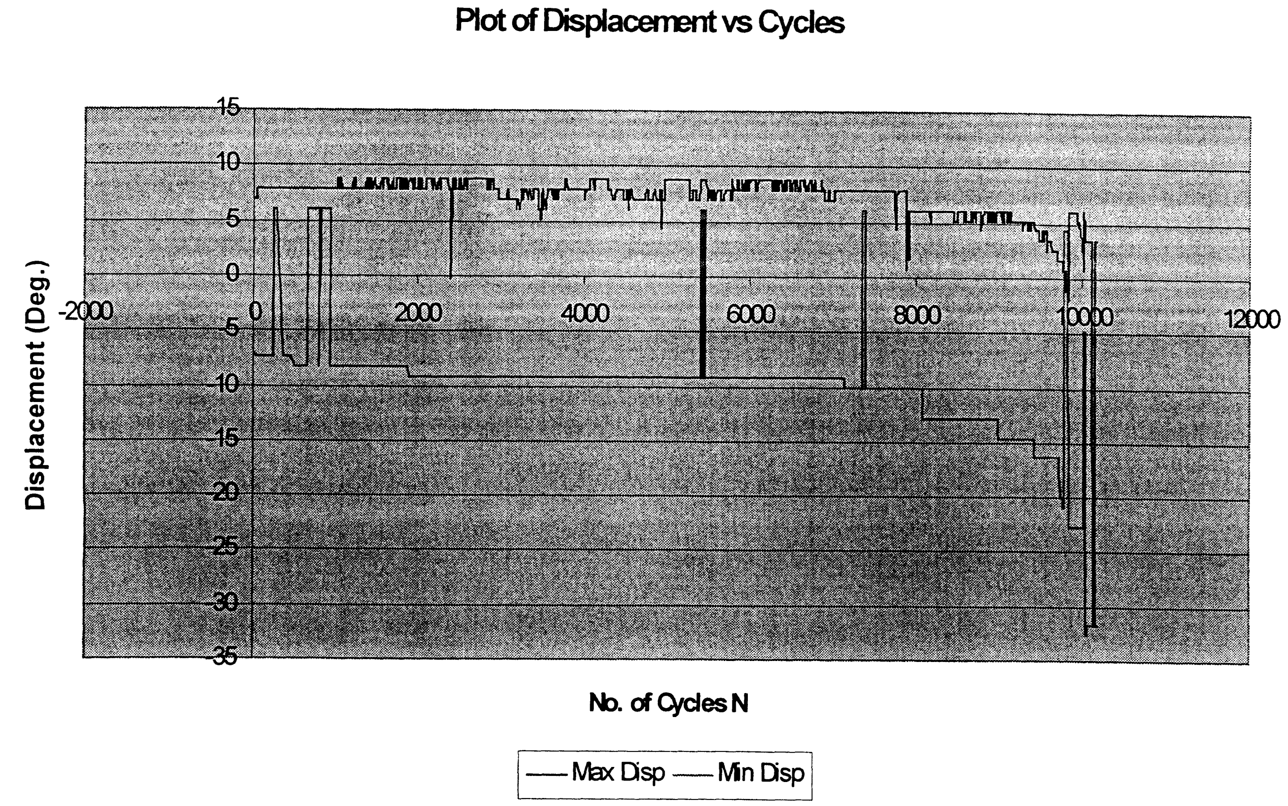


Figure 6.5 Torque mode test parameters (± 2Nm at 20Hz)

As seen in the figure, the amount of initial angular displacement shown by the specimen is approximately ± 0.8°, which remains constant for 8500 cycles. This behavior corresponds to the initial fatigue damage leading to crack nucleation and crack initiation, which includes the early development of fatigue damage (crack initiation) and leads to slip-band crack growth involving the deepening of the initial crack on the planes of high torsional shear stress. The specimen starts becoming weaker due to the application of constant torque load and increase in the number of applied cycles. For the same applied torque, the applied displacement starts to increase drastically (due to the crack growth on planes of high tensile stress–Stage II of low cycle fatigue), as seen in the figure, and grows to infinity at around 98000 cycles, when the specimen finally breaks due to ultimate ductile failure (Stage III of low cycle fatigue). This occurs when the crack reaches sufficient length so that the remaining cross section cannot support the applied load. It can be seen that a larger proportion of the total cycles to failure is spent with the propagation in Stage II in low-cycle fatigue test.

6.4.2 Test 2 – Specifications and Results

A torsion fatigue test in torque mode was carried out on an aluminum specimen. The specimen was subjected to a saw-toothed loading sequence with an overall torque of 6Nm (± 4Nm & -2Nm) at a frequency of 20 Hz.

Table 6. 6 Torque Mode Test Parameters (+4Nm & -2Nm at 20Hz.)

Test Parameters	
SAMPLE	Aluminum 2024
CONTROL CHANNEL	Torsional
TEST MODE	Torque
MAX TORQUE	4N-m
MIN TORQUE	-2N-m
FREQUENCY	20Hz
TOTAL CYCLES	4800
R-VALUE	-2
LOADING SEQUENCE	Saw-Toothed Loading

The behavior of the specimen was monitored over time and the characteristics of angular displacement versus number of cycles is plotted in Figure 6.6.

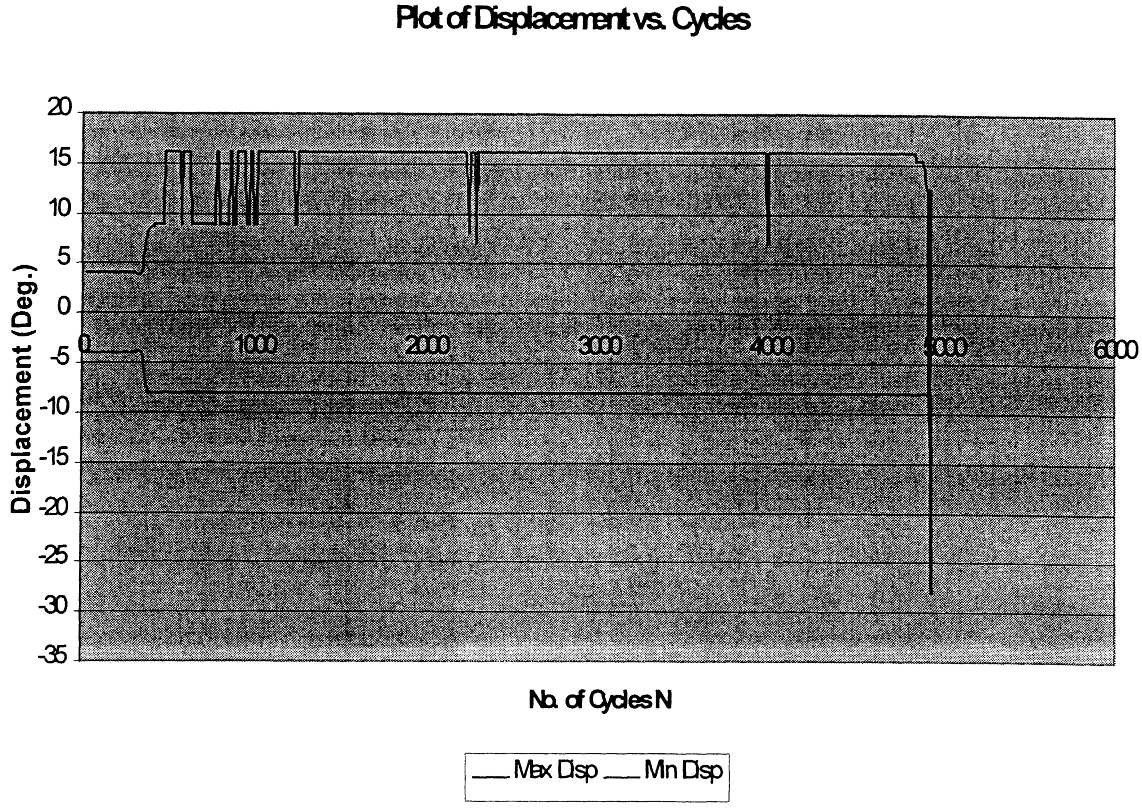


Figure 6.6 Torque mode test parameters (+4Nm & -2Nm at 20Hz)

As seen from Figure 6.6, there is a significant change in the behavior of the material when the applied torque is changed to a maximum torque of +4Nm and a minimum torque of -2Nm at a frequency of 20Hz. The initial angular displacement of the specimen is initially +1.6° and –0.8°. The overall displacement remains relatively constant for 4800 cycles. This behavior corresponds to the initial fatigue damage leading to crack nucleation and crack initiation. The specimen starts becoming weaker due to the application of constant torque load and increase in the number of applied cycles. The angular displacement of the specimen increases drastically, as seen in Figure 6.6, and drops to zero at around 4900 cycles, when the specimen finally breaks due to ultimate ductile failure (Stage III of low cycle fatigue).

6.4.3 Test 3 – Specifications and Results

This torsion fatigue test in displacement was carried out on the same aluminum specimen as in Test 1 with a different set of test parameters and the low-cycle behavior of the specimen with change in the torque with number of cycles has been monitored. The applied displacement is ± 8° at a frequency of 10Hz.

Table 6.7 Torque Mode Test Parameters (± 2.5Nm at 20Hz.)

Test Parameters	
SAMPLE	Aluminum 2024
CONTROL CHANNEL	Torsional
TEST MODE	Torque
MAX TORQUE	2.5N-m
MIN TORQUE	-2.5N-m
FREQUENCY	20Hz
TOTAL CYCLES	670
R-VALUE	-1
LOADING SEQUENCE	Saw-Toothed Loading

The behavior of the specimen was monitored over time and the characteristics of angular displacement versus number of cycles is plotted in Figure 6.7.

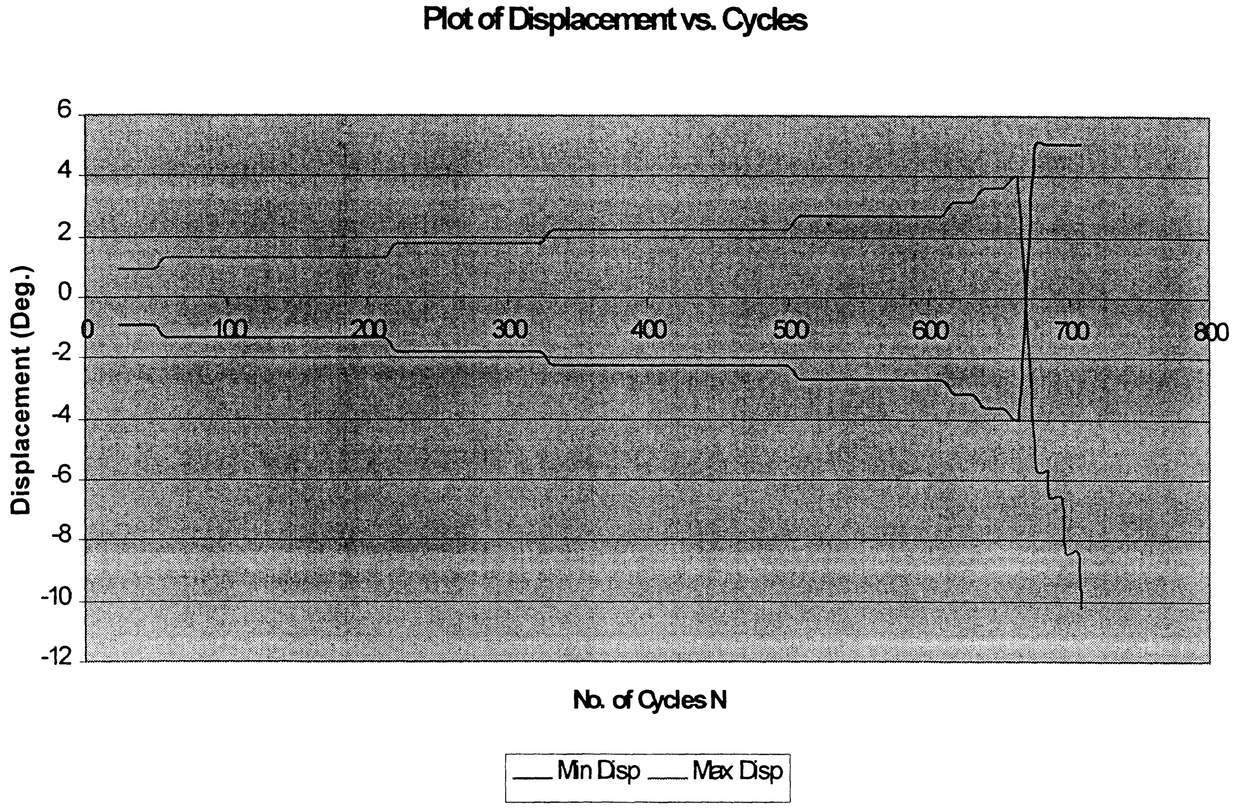


Figure 6.7 Torque mode test parameters (± 2.5Nm at 20Hz)

As seen from Figure 6.7, there is a drastic change in the behavior of the material when the applied torque is increased to ±2.5Nm. The displacement on the specimen is initially ± 1°. The angular displacement of the specimen increases rapidly as the number of cycles increases. This behavior corresponds to the initial fatigue damage leading to crack nucleation and crack initiation. The specimen starts becoming weaker due to the application of constant torque load and increase in the number of applied cycles. The angular displacement starts to increase drastically (Stage II of low cycle fatigue) and shoots to infinity at around 680 cycles, when the specimen finally breaks due to ultimate ductile failure (Stage III of low cycle fatigue).

6.4.4 Test 4 – Specifications and Results

This low-cycle torsion fatigue test in torque mode was carried out on the same aluminum specimen (Aluminum 2024) with a different set of test parameters. The fatigue behavior of the specimen was monitored with change in the angular displacement with number of cycles. The applied torque in this case is ± 3Nm at a frequency of 20Hz.

Table 6. 8 Torque Mode Test Parameters (± 3Nm at 20Hz.)

Test Parameters	
SAMPLE	Aluminum 2024
CONTROL CHANNEL	Torsional
TEST MODE	Torque
MAX TORQUE	3N-m
MIN TORQUE	-3N-m
FREQUENCY	20Hz
TOTAL CYCLES	475
R-VALUE	-1
LOADING SEQUENCE	Saw-Toothed Loading

The behavior of the specimen was monitored over time and the characteristics of angular displacement versus number of cycles is plotted in Figure 6.8.

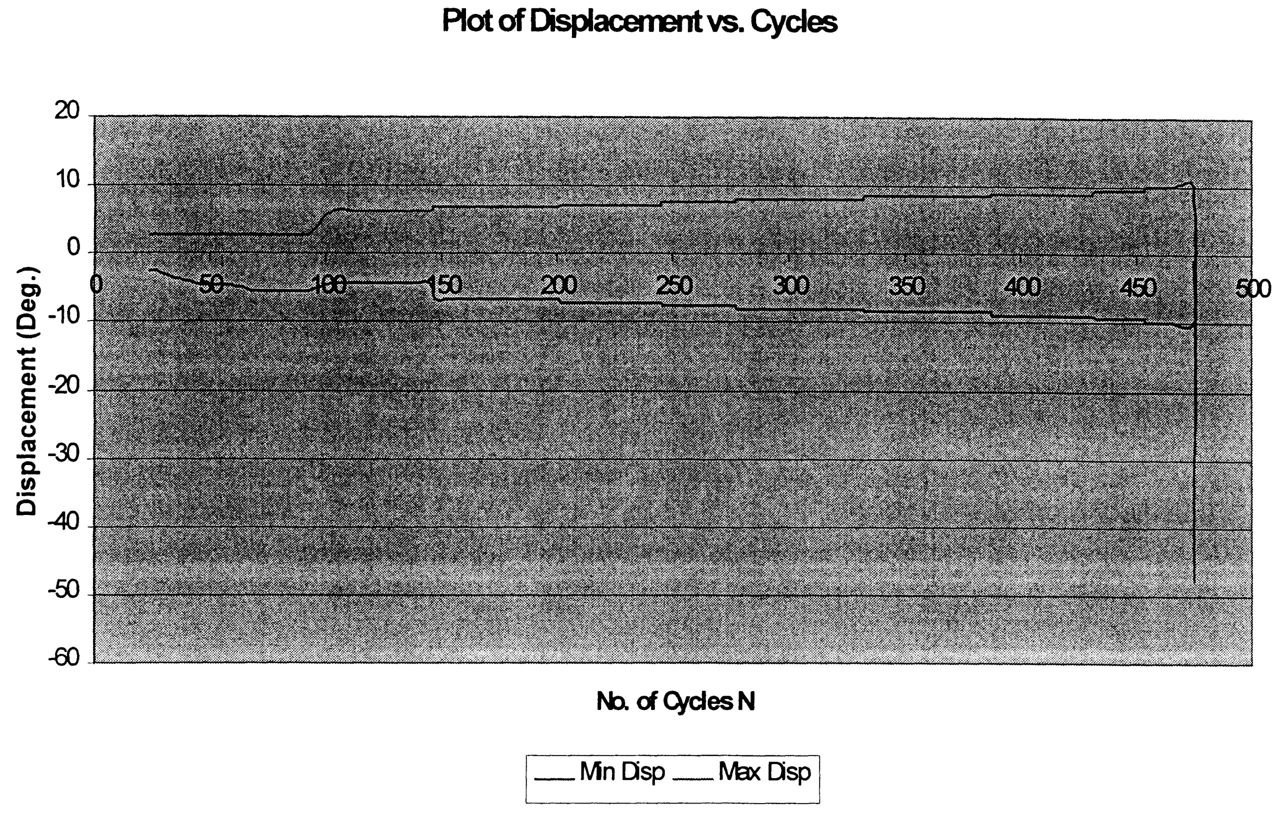


Figure 6.8 Torque mode test parameters (± 3Nm at 20Hz)

As seen from Figure 6.7, there is a considerable change in the behavior of the material when the applied torque is increased to ±3Nm. The initial displacement on the specimen is initially ± 2°. The angular displacement gradually increases as the number of cycles increases. This behavior corresponds to the initial fatigue damage leading to crack nucleation and crack initiation. This sort of behavior is observed for approximately 450 cycles before there is any significant change in the angular displacement as the number of cycles increase. The specimen starts becoming weaker due to the application of constant torque load and increase in the number of applied cycles. The angular displacement increases drastically at around 480 cycles, and shoots to infinity when the specimen finally breaks due to ultimate ductile failure (Stage III of low-cycle fatigue).

It is also observed that any tests carried out on the aluminum 2024 specimen in torque mode with > ± 3Nm results in a significant decrease in the number of cycles to failure (<50 cycles). When the applied torque is reduced to less than 1.5Nm, the number of cycles to failure increases significantly (>15,000 cycles), at which point the test enters the high-cycle fatigue region and approaches the limit of infinite number of cycles before failure occurs (also known as the fatigue limit).

6.5 Testing Results

Torsion fatigue tests carried out in torque mode and displacement mode on the aluminum specimens using the fatigue testing machine and the associated software have shown remarkably impressive results, as shown above. Tests have been conducted in various modes and under varying test parameters. The data obtained from these tests is on a real-time basis and is automatically recorded and plotted using the testing software developed for the user to see and analyze the behavior of the test specimen.

In many applications, materials are subjected to vibrating or oscillating forces. The behavior of materials in such applications requires the application of cyclic loading in a laboratory test to determine how a material will behave under repeated cycles of loading and unloading. Because the material is subjected to repeated load cycles in actual use, designers are faced with predicting material life, which is defined as total number of cycles to failure under specified loading conditions. This is plotted on a stress versus number of cycles (or S-N) curve. The frequency of loading, type of loading sequence, applied torque and applied displacement, and R-value and are some of the parameters that effect the material behavior, as shown in the above conducted experiments in displacement mode and torque mode. The dynamic behavior of the materials can be accurately determined using the Torsion Fatigue System with a great deal of accuracy. This fatigue testing gives much data to predict in-service life of materials.

Chapter: 7 Conclusion and Future Work

7.1 Conclusion

Considering the fact that many structures and vital machine components are subjected to fluctuating loads, the need to develop new fatigue testing machines has gained a high importance. The torsion fatigue testing system has been developed at Ohio University against this backdrop to resolve many questions across a wide spectrum of materials applications. The main objective of this thesis was to configure the existing fatigue testing system and to design a graphic user interface (GUI) based testing software to carryout high and low cycle fatigue tests.

There is a wide combination of tests possible on this system using the testing software developed. The Fatigue Testing Software is developed for this machine on a Windows platform using Visual Basic 5.0. It is robust enough to perform high- and low-cycle torsion fatigue tests in both torque-controlled mode and displacement-controlled mode by providing a user the convenience of choosing test parameters, such as frequency, angular displacement, torque, R-value, loading sequence, and number of cycles. The flexibility is virtually unlimited, and almost any combination of tests with complex stress functions can be programmed into the system. The operator interface is kept to a bare minimum, and this can be further enhanced in the future. To the best of the author's knowledge, there is no other similar system currently available on the market.

7.2 Future Work

Knowledge of fatigue and fracture resistance of materials requires extensive analysis and testing. Because of the increasing demands for material testing requirements and the need for a more precise and accurate study of fatigue behavior of materials in various loading modes, there is a need for further development of the existing system in the future. The machine can be developed to incorporate additional functionality for carrying out a bi-axial fatigue testing (simultaneous torsion and tension).

There is also a growing need to study the fatigue behavior of materials at high temperatures. An environmental chamber can be built to encase the specimen that could be subjected to elevated temperatures during fatigue testing. The system software can also be enhanced to incorporate subroutine definitions, contouring, mathematical functions, etc.

Finally, additional functionality, such as simulating service loading sequences, user defined tests, and multi-channel control, can be developed in the future to enhance the performance of the existing fatigue testing system.

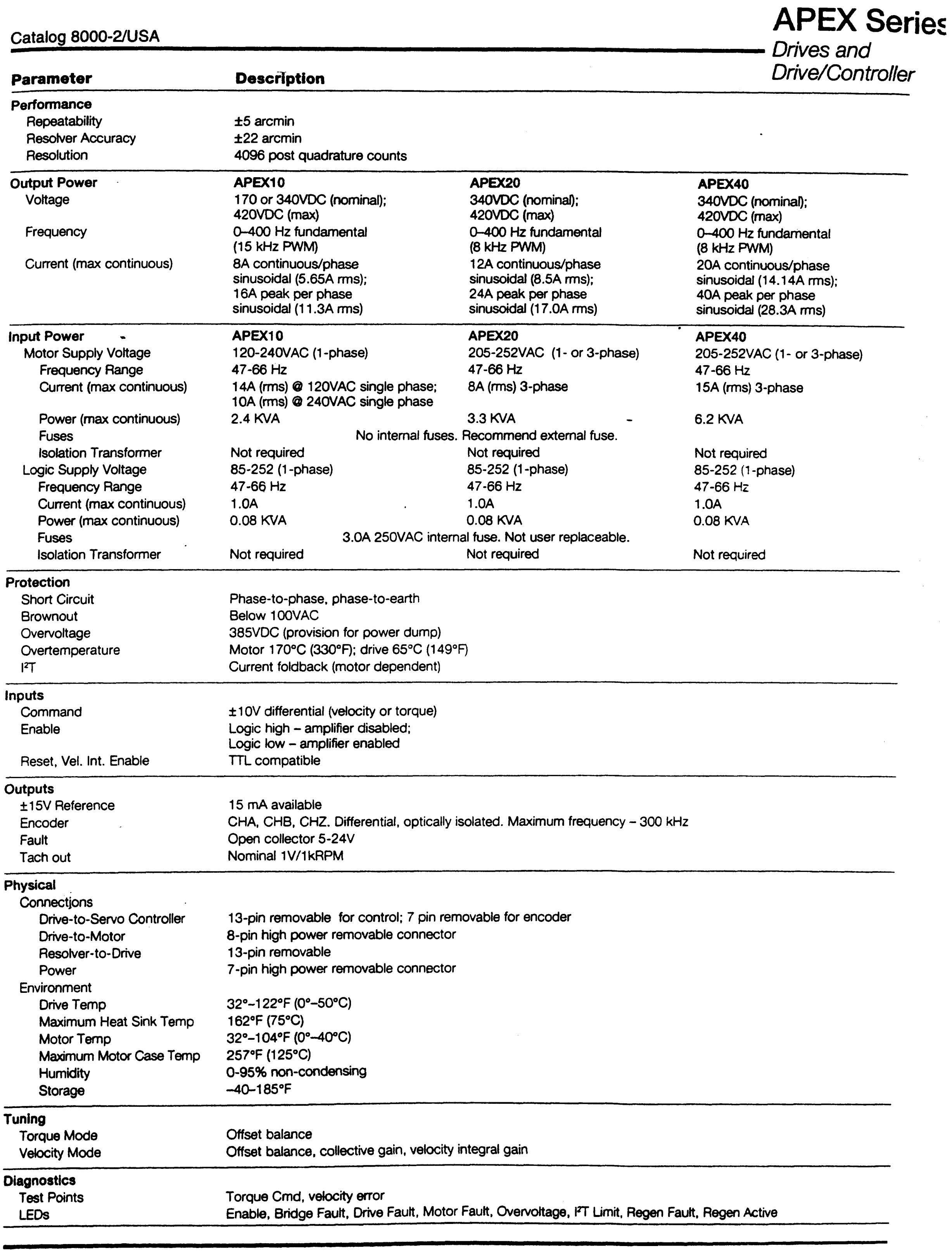
Bibliography

1. Mann, J. Y., Fatigue of Materials, Melbourne University Press, London, 1967.
2. Hertzberg, Richard W., Deformation Fracture Mechanics of Engineering Materials, John Wiley & Sons, Inc., 1989.
3. ASM International, Handbook Vol. 8: Mechanical Testing, The Materials Information Society, 1996.
4. ASM International, ASM Handbook Vol. 19: Fatigue and Fracture, The Materials Information Society, 1996.
5. Heywood, R. B., Designing Against Fatigue, Champman and Wall, London, 1996.
6. Dieter, George E., Mechanical Metallurgy, McGraw Hill, U.K, 1988.
7. Popov, E. P., Engineering Mechanics of Solids, Prentice Hall, Englewood Cliffs, NJ, 1990.
8. Weibull, W., Fatigue Testing and Analysis of Results, Pergamon Press, London, 1961.
9. Zahavi, E.; Torbilo, Fatigue Design, CRC Press, New York, V 1996.
10. Spong, M. W.; Vidyasagar, Robot Dynamics and Control, John Wiley and Sons, New York, M 1989.
11. Yoe, Sarah C., Intelligent Interface Design, McGraw Hill, New York, 1992.
12. Kohsal, D., Manufacturing Engineer's Reference Book, Butterworth-Heinemann, Boston, 1993
13. Ross, Paul W., The Handbook of Software for Engineers and Scientists, CRC Press, Boca Raton, FL, 1996
14. Olsson, Gustaf; Piani, Gianguido, Computer Systems for Automation and Control, Prentice Hall, New York, 1992.
15. Parr, E. A., Programmable Controllers, Industrial Press, New York, N.Y, 1987.

16. Putmann, Byron W., RS-232 Simplified, Englewood Cliffs, NJ: Prentice-Hall, 1987.

17. Compumotor, Step Motor and Servo Motor Systems and Controls, Parker Automation, Rohnert Park, CA, 1999.

Appendix A: APEX Series Drives – Specifications for the APEX drives used in the fatigue testing system [17].



Catalog 8000-2/USA

APEX Serie
Drives and Drive/Controller

Parameter	**Description**		
Performance			
Repeatability	±5 arcmin		
Resolver Accuracy	±22 arcmin		
Resolution	4096 post quadrature counts		
Output Power	**APEX10**	**APEX20**	**APEX40**
Voltage	170 or 340VDC (nominal); 420VDC (max)	340VDC (nominal); 420VDC (max)	340VDC (nominal); 420VDC (max)
Frequency	0–400 Hz fundamental (15 kHz PWM)	0–400 Hz fundamental (8 kHz PWM)	0–400 Hz fundamental (8 kHz PWM)
Current (max continuous)	8A continuous/phase sinusoidal (5.65A rms); 16A peak per phase sinusoidal (11.3A rms)	12A continuous/phase sinusoidal (8.5A rms); 24A peak per phase sinusoidal (17.0A rms)	20A continuous/phase sinusoidal (14.14A rms); 40A peak per phase sinusoidal (28.3A rms)
Input Power	**APEX10**	**APEX20**	**APEX40**
Motor Supply Voltage	120-240VAC (1-phase)	205-252VAC (1- or 3-phase)	205-252VAC (1- or 3-phase)
Frequency Range	47-66 Hz	47-66 Hz	47-66 Hz
Current (max continuous)	14A (rms) @ 120VAC single phase; 10A (rms) @ 240VAC single phase	8A (rms) 3-phase	15A (rms) 3-phase
Power (max continuous)	2.4 KVA	3.3 KVA	6.2 KVA
Fuses	No internal fuses. Recommend external fuse.		
Isolation Transformer	Not required	Not required	Not required
Logic Supply Voltage	85-252 (1-phase)	85-252 (1-phase)	85-252 (1-phase)
Frequency Range	47-66 Hz	47-66 Hz	47-66 Hz
Current (max continuous)	1.0A	1.0A	1.0A
Power (max continuous)	0.08 KVA	0.08 KVA	0.08 KVA
Fuses	3.0A 250VAC internal fuse. Not user replaceable.		
Isolation Transformer	Not required	Not required	Not required
Protection			
Short Circuit	Phase-to-phase, phase-to-earth		
Brownout	Below 100VAC		
Overvoltage	385VDC (provision for power dump)		
Overtemperature	Motor 170°C (330°F); drive 65°C (149°F)		
I^2T	Current foldback (motor dependent)		
Inputs			
Command	±10V differential (velocity or torque)		
Enable	Logic high – amplifier disabled; Logic low – amplifier enabled		
Reset, Vel. Int. Enable	TTL compatible		
Outputs			
±15V Reference	15 mA available		
Encoder	CHA, CHB, CHZ. Differential, optically isolated. Maximum frequency – 300 kHz		
Fault	Open collector 5-24V		
Tach out	Nominal 1V/1kRPM		
Physical			
Connections			
Drive-to-Servo Controller	13-pin removable for control; 7 pin removable for encoder		
Drive-to-Motor	8-pin high power removable connector		
Resolver-to-Drive	13-pin removable		
Power	7-pin high power removable connector		
Environment			
Drive Temp	32°–122°F (0°–50°C)		
Maximum Heat Sink Temp	162°F (75°C)		
Motor Temp	32°–104°F (0°–40°C)		
Maximum Motor Case Temp	257°F (125°C)		
Humidity	0-95% non-condensing		
Storage	–40–185°F		
Tuning			
Torque Mode	Offset balance		
Velocity Mode	Offset balance, collective gain, velocity integral gain		
Diagnostics			
Test Points	Torque Cmd, velocity error		
LEDs	Enable, Bridge Fault, Drive Fault, Motor Fault, Overvoltage, I^2T Limit, Regen Fault, Regen Active		

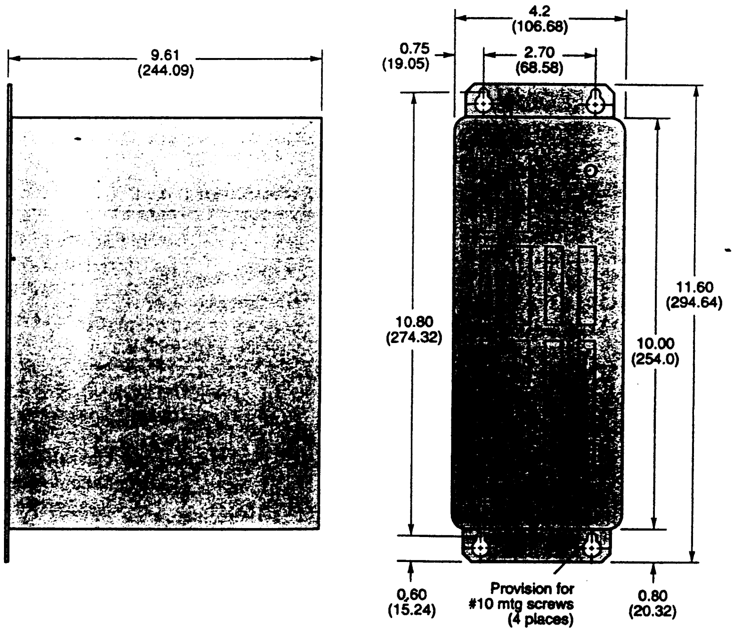
Appendix B: 6250 Servo Controller – Specifications [17]

Specifications

Parameter	Value
Power	
Input	100-120/200-240VAC, 50-60 Hz, or 110-340VDC
Servo Performance	
Processor	32-bit CPU/24 bit DSP
Servo update	As fast as 205 µsec per axis, user selectable
Encoder	Two phase quadrature incremental encoders with differential (recommended) or single ended outputs (+5VDC TTL compatible). Max frequency = 1.2 MHz, post-quadrature. Minimum time between transitions = 833 ns. Optically isolated
Position	±2,147,483,648 encoder counts
Velocity	1 to 1,200,000 encoder counts/sec.
Acceleration	1 to 50,000,000 encoder counts/sec^2
Inputs	
24 Programmable	Plug compatible with OPTO-22™ signal conditioning equipment (50 pin DIN header). TTL compatible, voltage range 0-24VDC.
2 Interrupt	TTL compatible, voltage range 0-24VDC.
3 Analog	Voltage range 0-2.5VDC, 8-bit A/D converter.
Enable	Hardware analog command output enable. TTL compatible, voltage range 0-24VDC.
Home; Pos and Neg Limits; Drive Fault; Trigger; Release; Axis Select, & Velocity Select	TTL compatible, voltage range 0-24VDC.
Outputs	
24 Programmable	Plug compatible with OPTO-22™ signal conditioning equipment (50 pin DIN header). Open collector output will sink up to 30 mA, and allow up to 24VDC.
2 Auxiliary	Open collector output will sink up to 30 mA, and allow up to 24VDC.
Command signal	±10V Analog output. 12 bit resolution DAC.
Enable drive	Relay output will sink up to 30 mA and allow up to 24VDC. (Normally open and normally closed available)

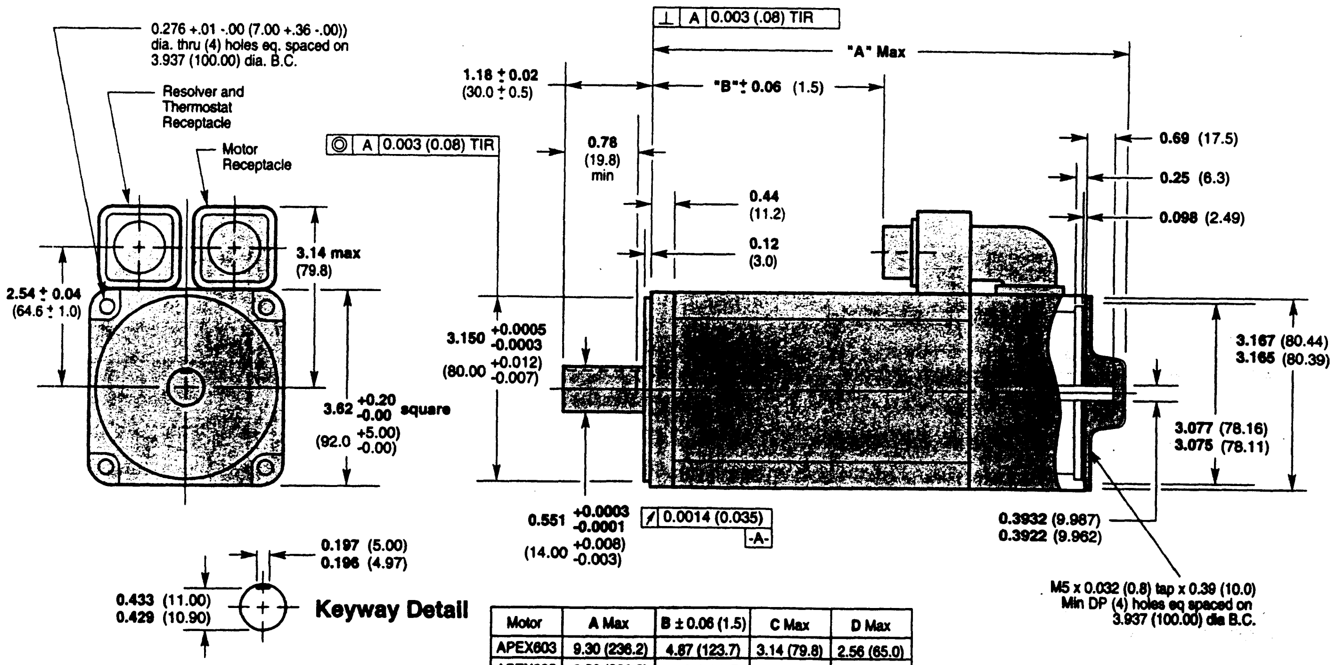
Dimensions

(–) denotes millimeters



Appendix C: APEX Motor – Specifications [17]

APEX603, 605, 606, 610



Motor	A Max	B ± 0.06 (1.5)	C Max	D Max
APEX603	9.30 (236.2)	4.87 (123.7)	3.14 (79.8)	2.56 (65.0)
APEX605	9.30 (236.2)	4.87 (123.7)	3.14 (79.8)	2.56 (65.0)
APEX606	10.86 (275.8)	6.42 (163.1)	3.14 (79.8)	2.56 (65.0)
APEX610	12.42 (315.4)	7.23 (183.6)	3.42 (86.8)	2.62 (66.5)

APEX Motor Only Technical Data

		APEX602	APEX603	APEX604	APEX605	APEX606
Continuous Stall Torque @ 40° ambient	lb-in	13.9	21.6	20	22	40
	oz-in	222	346	315	346	634
	Nm	1.57	2.44	2.22	2.44	4.48
Peak Torque	lb-in	39.4	65.4	56	68	122
	oz-in	630	1,046	899	1,085	1,957
	Nm	4.45	7.38	6.35	7.66	13.82
Rated Power	hp	1.5	1.3	2.0	2.0	2.1
	k Watts	1.12	1.0	1.5	1.5	1.6
Rated Speed	rpm	7,500	3,800	7,500	6,200	3,600
	rps	125	63	125	103	60
Rated Current	A (rms)	4.2	3.0	6.0	5	5.3
Peak Current	A (rms)	12.6	9.6	18.0	16.6	17.2
Rotor Inertia	oz-in^2 (mass)	2.52	4.02	4.18	5.43	9.44
	oz-in-sec^2	0.006	0.01	0.01	0.01	0.02
	kg m^2 x 10^{-6}	46.1	99.6	76.5	99.6	172.9
Motor Weight	lbs	7.0	9.0	8.5	10.0	13.4
	kg	3.2	4.1	3.9	4.5	6.1
Recommended APEX Drive		APEX10 or APEX6151		APEX20 or APEX6152		

Appendix D: Fatigue Testing Software – Source Code

‘ Form Name: FormLoginMenu – validates the user login and password

```
Option Explicit

Private Sub cmdCancel_Click()
   txtUsername = ""
   txtPassword = ""
   'frmLoginMenu.Hide
End Sub

Private Sub cmdOK_Click()
      frmLoginMenu.Hide
End Sub

Public Sub GetUserInfo(sUsername As String, sPassword As String)
   frmLoginMenu.Show vbModal
   sUsername = txtUsername
   sPassword = txtPassword
   Unload frmLoginMenu
End Sub
```

‘ Form Name: frmWelcome – splash screen which welcomes the user into the system

```
Option Explicit

Private Sub Timer1_Timer()
frmWelcome.Hide
frmTestSelection.Show
Timer1.Enabled = False
End Sub
```

‘ Form Name: frmTestSelection – Test selection window which gives the user the option of selecting different test parameters.

```
Option Explicit

Private Sub Form_Load()
optTorsional.Value = True
optTorque.Value = True

If Right$(App.Path, 1) = "\" Then
   Image1.Picture = LoadPicture(App.Path & "Graphics\TorqSawtooth.bmp")
Else
   Image1.Picture = LoadPicture(App.Path & "\Graphics\TorqSawtooth.bmp")
End If
```

```
txtTorqRval.Text = "-1"
txtDispRval.Text = "-1"
txtVelRval.Text = "-1"

With cmbTorqLoadSeq
        .AddItem "Saw-Toothed Loading"    ' Add each item to list.
        .AddItem "Block Loading"
        .AddItem "Ramp Loading"
        .AddItem "Sinusoidal Loading"
        .AddItem "Multi-Rate Ramp & Hold"
        .AddItem "Multi-Axial Loading"
        .Text = cmbTorqLoadSeq.List(0)    ' Display first item.
End With

With cmbDispLoadSeq
        .AddItem "Saw-Toothed Loading"    ' Add each item to list.
        .AddItem "Block Loading"
        .AddItem "Ramp Loading"
        .AddItem "Sinusoidal Loading"
        .AddItem "Multi-Rate Ramp & Hold"
        .AddItem "Multi-Axial Loading"
        .Text = cmbDispLoadSeq.List(0)    ' Display first item.
End With

With cmbVelLoadSeq
        .AddItem "Saw-Toothed Loading"    ' Add each item to list.
        .AddItem "Block Loading"
        .AddItem "Ramp Loading"
        .AddItem "Sinusoidal Loading"
        .AddItem "Multi-Rate Ramp & Hold"
        .AddItem "Multi-Axial Loading"
        .Text = cmbVelLoadSeq.List(0)    ' Display first item.
End With

End Sub


Public Sub displayParam(Optional temp As RichTextBox, Optional Index As Integer)

  Dim Motion1$
  Dim Motion2$
  Dim Motion3$
  Dim Motion4$
  Dim Motion5$
  Dim Motion6$
  Dim Motion7$
  Dim Motion8$
  Dim Motion9$
  Dim Motion10$
  Dim Motion11$
  Motion10$ = "Run By: " + frmTextBox.txtExpName.Text
  Motion11$ = "Sample: " + frmTextBox.txtSampleName.Text
```

```
If SSTab1.Tab = 0 Then


Motion1$ = "Control Channel= " + "Torsional"
Motion2$ = "Test Mode= " + "Torque"
Motion3$ = "Max Torque= " + txtMaxTorq.Text + "N-m"
Motion4$ = "Min Torque= " + txtMinTorq.Text + "N-m"
Motion5$ = "Frequency= " + txtTorqFreq.Text + "Hz"
Motion6$ = "Total Cycles= " + txtTorqCycles.Text
Motion7$ = "R-Value= " + txtTorqRval.Text
Motion8$ = "Loading Sequence= " + cmbTorqLoadSeq.Text
Motion9$ = "Run Started On: " + Date$ + ", at " + Time$


Motion1$ = Motion10$ & vbCrLf & Motion11$ & vbCrLf & Motion9$ & vbCrLf &
        Motion1$ & vbCrLf & Motion2$ & vbCrLf & Motion3$ & vbCrLf & Motion4$
        & vbCrLf & Motion5$ & vbCrLf & Motion6$ & vbCrLf & Motion7$ & vbCrLf
        & Motion8$

temp.Text = temp.Text + vbCrLf + Motion1$

ElseIf SSTab1.Tab = 1 Then

Motion1$ = "CONTROL CHANNEL= " + "Torsional"
Motion2$ = "TEST MODE= " + "Displacement"
Motion3$ = "MAX ANGLE= " + txtMaxAng.Text + "Deg"
Motion4$ = "MIN ANGLE= " + txtMinAng.Text + "Deg"
Motion5$ = "FREQUENCY= " + txtDispFreq.Text + "Hz"
Motion6$ = "TOTAL CYCLES= " + txtDispCycles.Text
Motion7$ = "R-Value= " + txtDispRval.Text
Motion8$ = "Loading Sequence= " + cmbDispLoadSeq.Text
Motion9$ = "Run Started On: " + Date$ + ", at " + Time$

Motion1$ = Motion10$ & vbCrLf & Motion11$ & vbCrLf & Motion9$ & vbCrLf &
        Motion1$ & vbCrLf & Motion2$ & vbCrLf & Motion3$ & vbCrLf & Motion4$
        & vbCrLf & Motion5$ & vbCrLf & Motion6$ & vbCrLf & Motion7$ & vbCrLf & Motion8$

temp.Text = temp.Text + vbCrLf + Motion1$

ElseIf SSTab1.Tab = 2 Then

Motion1$ = "CONTROL CHANNEL= " + "Torsional"
Motion2$ = "TEST MODE= " + "Velocity"
Motion3$ = "MAX VELOCITY= " + txtMaxVel.Text + "Deg"
Motion4$ = "MIN VELOCITY= " + txtMinVel.Text + "Deg"
Motion5$ = "FREQUENCY= " + txtVelFreq.Text + "Hz"
Motion6$ = "TOTAL CYCLES= " + txtVelCycles.Text
Motion7$ = "R-Value= " + txtVelRval.Text
Motion8$ = "Loading Sequence= " + cmbVelLoadSeq.Text
Motion9$ = "Run Started On: " + Date$ + ", at " + Time$

Motion1$ = Motion10$ & vbCrLf & Motion11$ & vbCrLf & Motion9$ & vbCrLf &
```

```
            Motion1$ & vbCrLf & Motion2$ & vbCrLf & Motion3$ & vbCrLf & Motion4$
            & vbCrLf & Motion5$ & vbCrLf & Motion6$ & vbCrLf & Motion7$ & vbCrLf
            & Motion8$

   temp.Text = temp.Text + vbCrLf + Motion1$


   End If

 ' parameter to be passed to the rich text box for display in the test running forms
   par = temp.Text

End Sub


Sub cmdContinue_Click()

If SSTab1.Tab = 0 Then
   TabIndex = Val(SSTab1.Tab)
   Load frmMainTorque
'  Call displayParam(frmMainTorque.rtfText, 1)
   frmMainTorque.Show
   frmTestSelection.Hide


ElseIf SSTab1.Tab = 1 Then
   TabIndex = Val(SSTab1.Tab)
   Load frmMainDisplacement
'  Call displayParam(frmMainDisplacement.rtfText, 1)
   frmMainDisplacement.Show
   frmTestSelection.Hide


ElseIf SSTab1.Tab = 2 Then
   TabIndex = Val(SSTab1.Tab)
   Load frmMainVelocity
'  Call displayParam(frmMainVelocity.rtfText, 1)
   frmMainVelocity.Show
   frmTestSelection.Hide


End If

End Sub

Private Sub cmdExit_Click()
End
End Sub

Private Sub cmdHelp_Click()
Load frmHelp
frmHelp.Show
End Sub
```

```
Private Sub cmdSave_Click()
Call textpad
End Sub


Private Sub mnuAbout_Click(Index As Integer)
Load frmAbout
frmAbout.Show
End Sub

Private Sub mnuMotionArc_Click(Index As Integer)
Dim RetVal
RetVal = Shell("C:\Ma6000\Ma6000.EXE", 1)   ' Run Motion Architect
End Sub

Private Sub mnuMTS_Click(Index As Integer)
Dim RetVal
RetVal = Shell("C:\Program Files\Netscape\Navigator\Program\NETSCAPE.EXE -h
http://www.mts.com", 1)   ' Run Netscape.
End Sub

Private Sub mnuParker_Click(Index As Integer)
Dim RetVal
RetVal = Shell("C:\Program Files\Netscape\Communicator\Program\NETSCAPE.EXE -h
http://www.parker.com", 1)   ' Run Netscape.
End Sub

Private Sub mnuSave_Click(Index As Integer)
Load frmInfo
frmInfo.Show
End Sub

Private Sub mnuTorsion_Click(Index As Integer)
optTorsional.Value = True
End Sub

Private Sub optTorque_Click()
SSTab1.Tab = 0
Image1.Picture = LoadPicture(App.Path & "\Graphics\TorqSawtooth.bmp")
txtTorqRval.Text = "-1"
End Sub

Private Sub optDisplacement_Click()
SSTab1.Tab = 1
Image1.Picture = LoadPicture(App.Path & "\Graphics\DispSawtooth.bmp")
txtDispRval.Text = "-1"
End Sub


Private Sub optVelocity_Click()
SSTab1.Tab = 2
Image1.Picture = LoadPicture(App.Path & "\Graphics\VelSawtooth.bmp")
```

```
txtVelRval.Text = "-1"
End Sub


Private Sub udDispCycles_DownClick()
txtDispCycles.Text = str$(Val(txtDispCycles.Text) - 100)
   If Val(txtDispCycles.Text) < 0 Then
      txtDispCycles.Text = 0
      MsgBox "No Of Cycles Cannot Be Less Than 0", vbInformation
   End If
 txtDispCycles.Refresh
End Sub

Private Sub udDispCycles_UpClick()
txtDispCycles.Text = str$(Val(txtDispCycles.Text) + 100)
    'If Val(txtTorqCycles.Text) > 50 Then
      'txtTorqCycles.Text = 50
   'End If
   If Val(txtDispCycles.Text) < 0 Then
      txtDispCycles.Text = 0
      MsgBox "No Of Cycles Cannot Be Less Than 0", vbInformation
   End If
 txtDispCycles.Refresh
End Sub

Private Sub udDispFreq_DownClick()
txtDispFreq.Text = str$(Val(txtDispFreq.Text) - 0.5)
   If Val(txtDispFreq.Text) < 0 Then
      txtDispFreq.Text = 0
      MsgBox "Frequency Cant Be Less Than 0", vbInformation
   End If
 txtDispFreq.Refresh
End Sub

Private Sub udDispFreq_UpClick()
txtDispFreq.Text = str$(Val(txtDispFreq.Text) + 0.5)
   If Val(txtDispFreq.Text) >= 50 Then
      txtDispFreq.Text = 50
   End If
   If Val(txtDispFreq.Text) < 0 Then
      txtDispFreq.Text = 0
      MsgBox "Frequency Cant Be Less Than 0", vbInformation
   End If
 txtDispFreq.Refresh
End Sub

Private Sub udDispRval_DownClick()
txtDispRval.Text = str$(Val(txtDispRval.Text) - 0.1)

 txtDispRval.Refresh
End Sub

Private Sub udDispRval_UpClick()
```

```
txtDispRval.Text = str$(Val(txtDispRval.Text) + 0.1)

 txtDispRval.Refresh
End Sub

Private Sub udMaxAng_DownClick()
txtMaxAng.Text = str$(Val(txtMaxAng.Text) - 0.5)
   If Val(txtMaxAng.Text) <= -360 Then
      txtMaxAng.Text = 0
   End If
 txtMaxAng.Refresh
End Sub

Private Sub udMaxAng_UpClick()
txtMaxAng.Text = str$(Val(txtMaxAng.Text) + 0.5)
   If Val(txtMaxTorq.Text) >= 360 Then
      txtMaxTorq.Text = 0
   End If
 txtMaxAng.Refresh
End Sub

Private Sub udMaxTorq_DownClick()
txtMaxTorq.Text = str$(Val(txtMaxTorq.Text) - 0.5)
   If Val(txtMaxTorq.Text) < -40 Then
      txtMaxTorq.Text = -40
   End If
 txtMaxTorq.Refresh
End Sub

Private Sub udMaxTorq_UpClick()
txtMaxTorq.Text = str$(Val(txtMaxTorq.Text) + 0.5)
   If Val(txtMaxTorq.Text) > 40 Then
      txtMaxTorq.Text = 40
   End If
 txtMaxTorq.Refresh
End Sub

Private Sub udMaxVel_DownClick()
txtMaxVel.Text = str$(Val(txtMaxVel.Text) - 0.1)
   If Val(txtMaxVel.Text) < -40 Then
      txtMaxVel.Text = -40
   End If
 txtMaxVel.Refresh
End Sub

Private Sub udMaxVel_UpClick()
txtMaxVel.Text = str$(Val(txtMaxVel.Text) + 0.1)
   If Val(txtMaxVel.Text) >= 40 Then
      txtMaxVel.Text = 40
   End If
 txtMaxVel.Refresh
End Sub
```

```
Private Sub udMinAng_DownClick()
txtMinAng.Text = str$(Val(txtMinAng.Text) - 0.5)
   If Val(txtMinAng.Text) <= -360 Then
      txtMinAng.Text = 0
   End If
 txtMinAng.Refresh
End Sub

Private Sub udMinAng_UpClick()
txtMinAng.Text = str$(Val(txtMinAng.Text) + 0.5)
   If Val(txtMinAng.Text) >= 360 Then
      txtMinAng.Text = 360
   End If
 txtMinAng.Refresh
End Sub

Private Sub udMinTorq_DownClick()
txtMinTorq.Text = str$(Val(txtMinTorq.Text) - 0.5)
   If Val(txtMinTorq.Text) < -40 Then
      txtMinTorq.Text = -40
   End If
 txtMinTorq.Refresh
End Sub

Private Sub udMinTorq_UpClick()
txtMinTorq.Text = str$(Val(txtMinTorq.Text) + 0.5)
   If Val(txtMinTorq.Text) > 40 Then
      txtMinTorq.Text = 40
   End If
 txtMinTorq.Refresh

End Sub


Private Sub udMinVel_DownClick()
txtMinVel.Text = str$(Val(txtMinVel.Text) - 0.1)
   If Val(txtMinVel.Text) < -40 Then
      txtMinVel.Text = -40
   End If
 txtMinVel.Refresh
End Sub

Private Sub udMinVel_UpClick()
txtMinVel.Text = str$(Val(txtMinVel.Text) + 0.1)
   If Val(txtMinVel.Text) >= 40 Then
      txtMinVel.Text = 40
   End If
 txtMinVel.Refresh
End Sub

Private Sub udTorqCycles_DownClick()
txtTorqCycles.Text = str$(Val(txtTorqCycles.Text) - 100)
   If Val(txtTorqCycles.Text) < 0 Then
```

```
        txtTorqCycles.Text = 0
        MsgBox "No Of Cycles Cannot Be Less Than 0", vbInformation
    End If
 txtTorqCycles.Refresh
End Sub

Private Sub udTorqCycles_UpClick()
txtTorqCycles.Text = str$(Val(txtTorqCycles.Text) + 100)
     'If Val(txtTorqCycles.Text) > 50 Then
        'txtTorqCycles.Text = 50
    'End If
    If Val(txtTorqCycles.Text) < 0 Then
        txtTorqCycles.Text = 0
        MsgBox "No Of Cycles Cannot Be Less Than 0", vbInformation
    End If
 txtTorqCycles.Refresh
 End Sub

 Private Sub udTorqFreq_DownClick()
txtTorqFreq.Text = str$(Val(txtTorqFreq.Text) - 0.5)

    If Val(txtTorqFreq.Text) < 0 Then
        txtTorqFreq.Text = 0
        MsgBox "Frequency Should be greater Than 0", vbInformation
    End If
 txtTorqFreq.Refresh
End Sub

Private Sub udTorqFreq_UpClick()
txtTorqFreq.Text = str$(Val(txtTorqFreq.Text) + 0.5)
    If Val(txtMinTorq.Text) > 50 Then
        txtMinTorq.Text = 50
    End If
    If Val(txtTorqFreq.Text) < 0 Then
        txtTorqFreq.Text = 0
        MsgBox "Frequency Should be greater Than 0", vbInformation
    End If
 txtTorqFreq.Refresh
End Sub

Private Sub udVelCycles_DownClick()
txtVelCycles.Text = str$(Val(txtVelCycles.Text) - 100)
    If Val(txtVelFreq.Text) < 0 Then
        txtVelFreq.Text = 0
        MsgBox "No Of Cycles Should Be Greater Than 0", vbInformation
    End If
 txtVelCycles.Refresh
End Sub

Private Sub udVelCycles_UpClick()
txtVelCycles.Text = str$(Val(txtVelCycles.Text) + 100)

    If Val(txtVelFreq.Text) < 0 Then
```

```
      txtVelFreq.Text = 0
      MsgBox "No Of Cycles Should Be Greater Than 0", vbInformation
   End If

 txtVelCycles.Refresh
End Sub

Private Sub udVelFreq_DownClick()
txtVelFreq.Text = str$(Val(txtVelFreq.Text) - 0.5)
   If Val(txtVelFreq.Text) < 0 Then
      txtVelFreq.Text = 0
      MsgBox "Frequency Cannot Be Less Than 0", vbInformation
   End If
 txtVelFreq.Refresh
End Sub

Private Sub udVelFreq_UpClick()
txtVelFreq.Text = str$(Val(txtVelFreq.Text) + 0.5)
   If Val(txtVelFreq.Text) >= 50 Then
      txtVelFreq.Text = 50
   End If
   If Val(txtVelFreq.Text) < 0 Then
      txtVelFreq.Text = 0
      MsgBox "Frequency Cannot Be Less Than 0", vbInformation
   End If
 txtVelFreq.Refresh
End Sub



Private Sub udVelRval_DownClick()
txtVelRval.Text = str$(Val(txtVelRval.Text) - 0.1)

 txtVelRval.Refresh
End Sub

Private Sub udVelRval_UpClick()
txtVelRval.Text = str$(Val(txtVelRval.Text) + 0.1)

 txtVelRval.Refresh
End Sub

Private Sub cmbTorqLoadSeq_Click()
If txtMaxTorq = "" Or txtMinTorq = "" Or txtTorqFreq = "" Or txtTorqCycles = "" Then
Call LoadSeq_Change
Exit Sub
Else
Call LoadSeq_Change
txtTorqRval.Text = str$(Val(txtMaxTorq) / Val(txtMinTorq))
txtTorqRval.Refresh
End If
End Sub
```

```
Private Sub cmbDispLoadSeq_Click()
If txtMaxAng = "" Or txtMinAng = "" Or txtDispFreq = "" Or txtDispCycles = "" Then
Call LoadSeq_Change
Exit Sub
Else
Call LoadSeq_Change
txtDispRval.Text = str$(Val(txtMaxAng) / Val(txtMinAng))
txtDispRval.Refresh
End If
End Sub


Private Sub cmbVelLoadSeq_Click()
If txtMaxVel = "" Or txtMinVel = "" Or txtVelFreq = "" Or txtVelCycles = "" Then
Call LoadSeq_Change
Exit Sub
Else
Call LoadSeq_Change
txtVelRval.Text = str$(Val(txtMaxVel) / Val(txtMinVel))
txtVelRval.Refresh
End If
End Sub

Private Sub LoadSeq_Change()

Dim stab
stab = SSTab1.Tab

On Error GoTo ErrHandler
Select Case stab

Case 0
   If cmbTorqLoadSeq.ListIndex = 0 Then
   Image1.Picture = LoadPicture(App.Path & "\Graphics\TorqSawtooth.bmp")
   ElseIf cmbTorqLoadSeq.ListIndex = 1 Then
   Image1.Picture = LoadPicture(App.Path & "\Graphics\TorqBlock.bmp")
   ElseIf cmbTorqLoadSeq.ListIndex = 2 Then
   Image1.Picture = LoadPicture(App.Path & "\Graphics\TorqRamp.bmp")
   ElseIf cmbTorqLoadSeq.ListIndex = 3 Then
   Image1.Picture = LoadPicture(App.Path & "\Graphics\TorqSine.bmp")
   ElseIf cmbTorqLoadSeq.ListIndex = 4 Then
   Image1.Picture = LoadPicture(App.Path & "\Graphics\Multi-RateRampHold.bmp")
   ElseIf cmbTorqLoadSeq.ListIndex = 5 Then
   Image1.Picture = LoadPicture(App.Path & "\Graphics\Multi-Axial.bmp")
   End If

Case 1
   If cmbDispLoadSeq.ListIndex = 0 Then
   Image1.Picture = LoadPicture(App.Path & "\Graphics\DispSawtooth.bmp")
   ElseIf cmbDispLoadSeq.ListIndex = 1 Then
   Image1.Picture = LoadPicture(App.Path & "\Graphics\DispBlock.bmp")
   ElseIf cmbDispLoadSeq.ListIndex = 2 Then
   Image1.Picture = LoadPicture(App.Path & "\Graphics\DispRamp.bmp")
   ElseIf cmbDispLoadSeq.ListIndex = 3 Then
   Image1.Picture = LoadPicture(App.Path & "\Graphics\DispSine.bmp")
   ElseIf cmbDispLoadSeq.ListIndex = 4 Then
   Image1.Picture = LoadPicture(App.Path & "\Graphics\Multi-RateRampHold.bmp")
   ElseIf cmbDispLoadSeq.ListIndex = 5 Then
   Image1.Picture = LoadPicture(App.Path & "\Graphics\Multi-Axial.bmp")
   End If

Case 2
   If cmbVelLoadSeq.ListIndex = 0 Then
   Image1.Picture = LoadPicture(App.Path & "\Graphics\VelSawtooth.bmp")
   ElseIf cmbVelLoadSeq.ListIndex = 1 Then
   Image1.Picture = LoadPicture(App.Path & "\Graphics\VelBlock.bmp")
   ElseIf cmbVelLoadSeq.ListIndex = 2 Then
   Image1.Picture = LoadPicture(App.Path & "\Graphics\VelRamp.bmp")
   ElseIf cmbVelLoadSeq.ListIndex = 3 Then
   Image1.Picture = LoadPicture(App.Path & "\Graphics\VelSine.bmp")
   ElseIf cmbVelLoadSeq.ListIndex = 4 Then
   Image1.Picture = LoadPicture(App.Path & "\Graphics\Multi-RateRampHold.bmp")
   ElseIf cmbVelLoadSeq.ListIndex = 5 Then
   Image1.Picture = LoadPicture(App.Path & "\Graphics\Multi-Axial.bmp")
   End If

End Select
Exit Sub

ErrHandler:
Select Case Err.Number      'Analyze error code and load messge

    Case 53
      MsgBox "This Loading Sequence is not available." & Chr$(10) & Chr$(13) &
        "Please Make Another Selection", vbExclamation + vbOKOnly, "Loading
        Sequence"

    Case Else
      MsgBox "This Loading Sequence is not available." & Chr$(10) & Chr$(13) &
        "Please Make Another Selection", vbExclamation + vbOKOnly, "Loading
        Sequence"

End Select

End Sub
```

‘ Form Name: frmMainTorque – Test execution window for running the test in torque mode.

```
Option Explicit
Dim RowNo As Integer
'Dim Index As Integer
Dim bLog As Boolean
```

```
Private Sub Form_Load()

   'startdonemax = False
   'startdonemin = False
   fileopen = True
   startbutton = True

   Set Excel1 = New Excel.Application
   Excel1.Workbooks.Add
   Call LogTorqData
   oleChart.Visible = True

   ' Calling the Main Torsion Program from Torsion Module
   Call Torsion_Program

   rtfText.Text = par

   lblStatus.Caption = "Ready..."

   Call TimerTorque_Timer


End Sub

Private Sub cmdTorqBack_Click()
If MSComm1.PortOpen = True Then
   MSComm1.Output = "k" + Chr$(13)
   MSComm1.Output = "!reset" + Chr$(13)
   Do
   Loop Until MSComm1.OutBufferCount = 0
End If
fileopen = False
sdmax = 0
sdmin = 0
startbutton = False
Close

frmMainTorque.Hide
'Load frmTestSelection
frmTestSelection.Show

End Sub

Private Sub cmdTorqGraph_Click()
Dim msg
If frmTestSelection.cmdSave.Value = False Then
   msg = "Sorry! you have not opted to record the experiment" + Chr$(13)
   msg = msg & "A display of the graph is not possible" + Chr$(13)
   msg = msg & "Please save the data."
   MsgBox msg, vbOKCancel + vbInformation, "Save Data"
   Exit Sub
```

```
End If

If MSComm1.PortOpen = True Then
  MSComm1.Output = "!k" + Chr$(13)
  MSComm1.Output = "reset" + Chr$(13)
  Do
  Loop Until MSComm1.OutBufferCount = 0
End If
fileopen = False
Close
Load frmInfo

End Sub

Private Sub cmdTorqQuit_Click()
If MSComm1.PortOpen = True Then
   MSComm1.Output = "!k" + Chr$(13)
   MSComm1.Output = "!reset" + Chr$(13)
   Do
   Loop Until MSComm1.OutBufferCount = 0
   MSComm1.PortOpen = False

Else
   fileopen = False
   startbutton = False
   Close
End If

   Excel1.Quit
   Set Excel1 = Nothing

End

End Sub

Private Sub cmdTorqStart_Click()
If MSComm1.PortOpen <> True Then
  MSComm1.PortOpen = True
  startbutton = True
  MSComm1.Output = "MTORQ2" + Chr$(13)
  frmMainTorque.txtStartTime.Text = Time$
  startbutton = True
Else
  startbutton = True
  MSComm1.Output = "MTORQ2" + Chr$(13)
  frmMainTorque.txtStartTime.Text = Time$

End If

' Call LogDispData
lblStatus.Caption = "Running the Test in Displacement Mode...."

End Sub
```

```
Private Sub cmdTorqStop_Click()
MSComm1.Output = "!k" + Chr$(13)
MSComm1.Output = "reset" + Chr$(13)
Do
Loop Until MSComm1.OutBufferCount = 0
Close
fileopen = False
startbutton = False
lblStatus.Caption = "The Test has been Stopped!"
End Sub

Private Sub mnuAboutHelp_Click(Index As Integer)
Load frmAbout
frmAbout.Show
End Sub

Private Sub mnuexit_Click(Index As Integer)
If MSComm1.PortOpen = True Then
   MSComm1.Output = "!k" + Chr$(13)
   MSComm1.Output = "!reset" + Chr$(13)
   Do
   Loop Until MSComm1.OutBufferCount = 0
   MSComm1.PortOpen = False

Else
   fileopen = False
   startbutton = False
   Close
End If

   Excel1.Quit
   Set Excel1 = Nothing
End
End Sub

Private Sub mnuMotionArc_Click(Index As Integer)
Dim RetVal
RetVal = Shell("C:\Ma6000\Ma6000.EXE", 1)   ' Run Motion Architect
End Sub

Private Sub mnuMTS_Click(Index As Integer)
Dim RetVal
RetVal = Shell("C:\Program Files\Netscape\Communicator\Program\NETSCAPE.EXE -h
http://www.mts.com", 1)   ' Run Netscape.
End Sub

Private Sub mnuParker_Click(Index As Integer)
Dim RetVal
RetVal = Shell("C:\Program Files\Netscape\Communicator\Program\NETSCAPE.EXE -h
http://www.parker.com", 1)   ' Run Netscape.
End Sub
```

```
Private Sub mnuStart_Click(Index As Integer)
If MSComm1.PortOpen <> True Then
  MSComm1.PortOpen = True
  startbutton = True
  MSComm1.Output = "MTORQ2" + Chr$(13)
  frmMainTorque.txtStartTime.Text = Time$
  startbutton = True
Else
  startbutton = True
  MSComm1.Output = "MTORQ2" + Chr$(13)
  frmMainTorque.txtStartTime.Text = Time$

End If

' Call LogDispData
lblStatus.Caption = "Running the Test in Displacement Mode...."

End Sub

Private Sub mnuStop_Click(Index As Integer)
MSComm1.Output = "!k" + Chr$(13)
MSComm1.Output = "reset" + Chr$(13)
Close
fileopen = False
startbutton = False
End Sub

Private Sub mnuTestSelection_Click(Index As Integer)
If MSComm1.PortOpen = True Then
   MSComm1.Output = "k" + Chr$(13)
   MSComm1.Output = "!reset" + Chr$(13)
   Do
   Loop Until MSComm1.OutBufferCount = 0
End If
fileopen = False
sdmax = 0
sdmin = 0
startbutton = False
Close

frmMainTorque.Hide
Load frmTestSelection
frmTestSelection.Show
End Sub

Private Sub MSComm1_OnComm()

Dim dat As String

Select Case MSComm1.CommEvent
   Case 1008
      dat = MSComm1.Input
      Call TORQ_ShowData(dat$)
   Case 2
      dat = MSComm1.Input
      Call TORQ_ShowData(dat$)
End Select
frmMainTorque.txtCurrTime.Text = Time$

End Sub


Sub MesgDisplay()
Dim msg, Title, Response, datafile$, infofile$
Title = "Torsion Test-Torque Mode"
msg = "The Machine has been programmed with the parameters you selected" + Chr$(13)

If frmInfo.cmdSave.Value = True Then
   datafile$ = Left$(frmInfo.txtExpName.Text, 4) + ".dat"
   infofile$ = Left$(frmInfo.txtExpName.Text, 4) + ".inf"
   msg = msg & "You have opted to save the values of Theta vs Time in a file" + Chr$(13)
   msg = msg & "The name of the file will be" + datafile$ + Chr$(13)
   msg = msg & "The information you entered will be in the file: " + infofile$ + Chr$(13)
msg = "The Machine has been programmed with the parameters you selected" + Chr$(13)
End If
Response = MsgBox(msg, vbInformation, Title)

End Sub



Private Sub TimerTorque_Timer()
frmMainTorque.txtCurrTime.Text = Time$
frmMainTorque.txtCurrTime.Refresh
End Sub
```

‘ Form Name: frmMainDisplacement – Test execution window for running the test in displacement mode.

```
Option Explicit

Dim RowNo As Integer
Dim Index As Integer
Dim bLog As Boolean
'Public Excel As Object

Private Sub Form_Load()
   'startdonemax = False
   'startdonemin = False
   fileopen = True
   startbutton = False

   Set Excel1 = New Excel.Application
   Excel1.Workbooks.Add
```

```
    Call LogDispData
    oleChart.Visible = True


' Calling the Main Torsion Program from Torsion Module
    Call Torsion_Program

    rtfText.Text = par

    lblStatus.Caption = "Ready..."

    Call TimerDisp_Timer

End Sub


Private Sub mnuAboutHelp_Click(Index As Integer)
Load frmAbout
frmAbout.Show
End Sub

Private Sub mnuexit_Click(Index As Integer)
If MSComm1.PortOpen = True Then
   MSComm1.Output = "!k" + Chr$(13)
   MSComm1.Output = "!RESET" + Chr$(13)
   Do
   Loop Until MSComm1.OutBufferCount = 0
   MSComm1.PortOpen = False

Else
    fileopen = False
    startbutton = False
    Close
End If

    Excel1.Quit
    Set Excel1 = Nothing
End
End Sub

Private Sub mnuMotionArchitect_Click(Index As Integer)
Dim RetVal
RetVal = Shell("C:\Ma6000\Ma6000.EXE", 1)   ' Run Motion Architect
End Sub

Private Sub mnuMTS_Click(Index As Integer)
Dim RetVal
RetVal    =    Shell("C:\Program    Files\Netscape\Communicator\Program\NETSCAPE.EXE    -h
http://www.mts.com", 1)  ' Run Netscape.
End Sub

Private Sub mnuParker_Click(Index As Integer)
Dim RetVal
```

```
RetVal = Shell("C:\Program Files\Netscape\Communicator\Program\NETSCAPE.EXE -h
http://www.parker.com", 1)  ' Run Netscape.
End Sub

Private Sub mnuStart_Click(Index As Integer)
If MSComm1.PortOpen <> True Then
   MSComm1.PortOpen = True
   startbutton = True
   MSComm1.Output = "MDISP1" + Chr$(13)
   frmMainDisplacement.txtStartTime.Text = Time$

Else
   startbutton = True
   MSComm1.Output = "MDISP1" + Chr$(13)
   frmMainDisplacement.txtStartTime.Text = Time$

End If

' Call LogDispData
lblStatus.Caption = "Running the Test in Displacement Mode...."

End Sub

Private Sub mnuStop_Click(Index As Integer)
MSComm1.Output = "!k" + Chr$(13)
MSComm1.Output = "RESET" + Chr$(13)
Do
Loop Until MSComm1.OutBufferCount = 0

Close
fileopen = False
startbutton = False
End Sub

Private Sub mnuTestSelection_Click(Index As Integer)
If MSComm1.PortOpen = True Then
  MSComm1.Output = "!k" + Chr$(13)
  MSComm1.Output = "RESET" + Chr$(13)
  Do
  Loop Until MSComm1.OutBufferCount = 0
End If

fileopen = False

sdmax = 0
sdmin = 0

startbutton = False
Close
frmMainDisplacement.Hide
Load frmTestSelection
frmTestSelection.Show
End Sub
```

```
Private Sub MSComm1_OnComm()
Dim dat As String

Select Case MSComm1.CommEvent
   Case 1008
      dat = MSComm1.Input
      Call DISP_ShowData(dat$)
   Case 2
      dat = MSComm1.Input
      If startbutton = True Then
         Call DISP_ShowData(dat$)
      End If

End Select

End Sub

Private Sub cmdDispStart_Click()
If MSComm1.PortOpen <> True Then
   MSComm1.PortOpen = True
   startbutton = True
   MSComm1.Output = "MDISP1" + Chr$(13)
   frmMainDisplacement.txtStartTime.Text = Time$

Else
   startbutton = True
   MSComm1.Output = "MDISP1" + Chr$(13)
   frmMainDisplacement.txtStartTime.Text = Time$

End If

' Call LogDispData
lblStatus.Caption = "Running the Test in Displacement Mode...."

End Sub

Private Sub cmdDispStop_Click()
MSComm1.Output = "!k" + Chr$(13)
MSComm1.Output = "RESET" + Chr$(13)
Do
Loop Until MSComm1.OutBufferCount = 0

Close
fileopen = False
startbutton = False
lblStatus.Caption = "The Test has been Stopped!"
End Sub

Private Sub cmdDispBack_Click()

If MSComm1.PortOpen = True Then
   MSComm1.Output = "!k" + Chr$(13)
```

```
  MSComm1.Output = "RESET" + Chr$(13)
  Do
  Loop Until MSComm1.OutBufferCount = 0
End If

fileopen = False

sdmax = 0
sdmin = 0

startbutton = False
Close

frmMainDisplacement.Hide
'Load frmTestSelection
frmTestSelection.Show
End Sub


Private Sub cmdDispQuit_Click()
If MSComm1.PortOpen = True Then
  MSComm1.Output = "!k" + Chr$(13)
  MSComm1.Output = "!RESET" + Chr$(13)
  Do
  Loop Until MSComm1.OutBufferCount = 0
  MSComm1.PortOpen = False

Else
   fileopen = False
   startbutton = False
   Close
End If

   Excel1.Quit
   Set Excel1 = Nothing

End

End Sub


Private Sub TimerDisp_Timer()
frmMainDisplacement.txtCurrTime.Text = Time$
frmMainDisplacement.txtCurrTime.Refresh
End Sub
```

‘ Form Name: frmAbout – Window that displays information about the testing software and its copy rights.

```
Option Explicit
```

```
' Reg Key Security Options...
Const READ_CONTROL = &H20000
Const KEY_QUERY_VALUE = &H1
Const KEY_SET_VALUE = &H2
Const KEY_CREATE_SUB_KEY = &H4
Const KEY_ENUMERATE_SUB_KEYS = &H8
Const KEY_NOTIFY = &H10
Const KEY_CREATE_LINK = &H20
Const KEY_ALL_ACCESS = KEY_QUERY_VALUE + KEY_SET_VALUE + _
            KEY_CREATE_SUB_KEY + KEY_ENUMERATE_SUB_KEYS + _
            KEY_NOTIFY + KEY_CREATE_LINK + READ_CONTROL

' Reg Key ROOT Types...
Const HKEY_LOCAL_MACHINE = &H80000002
Const ERROR_SUCCESS = 0
Const REG_SZ = 1                    ' Unicode nul terminated string
Const REG_DWORD = 4                    ' 32-bit number

Const gREGKEYSYSINFOLOC = "SOFTWARE\Microsoft\Shared Tools Location"
Const gREGVALSYSINFOLOC = "MSINFO"
Const gREGKEYSYSINFO = "SOFTWARE\Microsoft\Shared Tools\MSINFO"
Const gREGVALSYSINFO = "PATH"

Private Declare Function RegOpenKeyEx Lib "advapi32" Alias "RegOpenKeyExA" (ByVal hKey As
Long, ByVal lpSubKey As String, ByVal ulOptions As Long, ByVal samDesired As Long, ByRef
phkResult As Long) As Long
Private Declare Function RegQueryValueEx Lib "advapi32" Alias "RegQueryValueExA" (ByVal hKey As
Long, ByVal lpValueName As String, ByVal lpReserved As Long, ByRef lpType As Long, ByVal lpData
As String, ByRef lpcbData As Long) As Long
Private Declare Function RegCloseKey Lib "advapi32" (ByVal hKey As Long) As Long


Private Sub cmdSysInfo_Click()
 Call StartSysInfo
End Sub

Private Sub cmdOK_Click()
 Unload Me
End Sub

Private Sub Form_Load()
  Me.Caption = "About " & App.Title
  lblVersion.Caption = "Version " & App.Major & "." & App.Minor & "." & App.Revision
  lblTitle.Caption = App.Title
End Sub

Public Sub StartSysInfo()
  On Error GoTo SysInfoErr

  Dim rc As Long
  Dim SysInfoPath As String

  ' Try To Get System Info Program Path\Name From Registry...
```

```
    If GetKeyValue(HKEY_LOCAL_MACHINE, gREGKEYSYSINFO, gREGVALSYSINFO,
SysInfoPath) Then
    ' Try To Get System Info Program Path Only From Registry...
    ElseIf GetKeyValue(HKEY_LOCAL_MACHINE, gREGKEYSYSINFOLOC,
gREGVALSYSINFOLOC, SysInfoPath) Then
        ' Validate Existance Of Known 32 Bit File Version
        If (Dir(SysInfoPath & "\MSINFO32.EXE") <> "") Then
            SysInfoPath = SysInfoPath & "\MSINFO32.EXE"

        ' Error - File Can Not Be Found...
        Else
            GoTo SysInfoErr
        End If
    ' Error - Registry Entry Can Not Be Found...
    Else
        GoTo SysInfoErr
    End If

    Call Shell(SysInfoPath, vbNormalFocus)

    Exit Sub
SysInfoErr:
    MsgBox "System Information Is Unavailable At This Time", vbOKOnly
End Sub

Public Function GetKeyValue(KeyRoot As Long, KeyName As String, SubKeyRef As String, ByRef
KeyVal As String) As Boolean
    Dim i As Long                        ' Loop Counter
    Dim rc As Long                        ' Return Code
    Dim hKey As Long                        ' Handle To An Open Registry Key
    Dim hDepth As Long                        '
    Dim KeyValType As Long                        ' Data Type Of A Registry Key
    Dim tmpVal As String                        ' Tempory Storage For A Registry Key Value
    Dim KeyValSize As Long                        ' Size Of Registry Key Variable
    '------------------------------------------------------------
    ' Open RegKey Under KeyRoot {HKEY_LOCAL_MACHINE...}
    '------------------------------------------------------------
    rc = RegOpenKeyEx(KeyRoot, KeyName, 0, KEY_ALL_ACCESS, hKey) ' Open Registry Key

    If (rc <> ERROR_SUCCESS) Then GoTo GetKeyError        ' Handle Error...

    tmpVal = String$(1024, 0)                        ' Allocate Variable Space
    KeyValSize = 1024                        ' Mark Variable Size

    '------------------------------------------------------------
    ' Retrieve Registry Key Value...
    '------------------------------------------------------------
    rc = RegQueryValueEx(hKey, SubKeyRef, 0, _
                KeyValType, tmpVal, KeyValSize)    ' Get/Create Key Value

    If (rc <> ERROR_SUCCESS) Then GoTo GetKeyError        ' Handle Errors

    If (Asc(Mid(tmpVal, KeyValSize, 1)) = 0) Then        ' Win95 Adds Null Terminated String...
    tmpVal = Left(tmpVal, KeyValSize - 1)           ' Null Found, Extract From String
  Else                          ' WinNT Does NOT Null Terminate String...
    tmpVal = Left(tmpVal, KeyValSize)              ' Null Not Found, Extract String Only
  End If
  '-----------------------------------------------------------
  ' Determine Key Value Type For Conversion...
  '-----------------------------------------------------------
  Select Case KeyValType                        ' Search Data Types...
  Case REG_SZ                                ' String Registry Key Data Type
    KeyVal = tmpVal                          ' Copy String Value
  Case REG_DWORD                              ' Double Word Registry Key Data Type
    For i = Len(tmpVal) To 1 Step -1             ' Convert Each Bit
      KeyVal = KeyVal + Hex(Asc(Mid(tmpVal, i, 1)))  ' Build Value Char. By Char.
    Next
    KeyVal = Format$("&h" + KeyVal)              ' Convert Double Word To String
  End Select

  GetKeyValue = True                           ' Return Success
  rc = RegCloseKey(hKey)                         ' Close Registry Key
  Exit Function                             ' Exit

GetKeyError:     ' Cleanup After An Error Has Occured...
  KeyVal = ""                               ' Set Return Val To Empty String
  GetKeyValue = False                          ' Return Failure
  rc = RegCloseKey(hKey)                         ' Close Registry Key
End Function
```

' Form Name: frmHelp – Window that displays help information regarding the testing software.

```
Option Explicit

Private Sub cmdClose_Click()
Unload frmHelp
End Sub

Private Sub Form_Load()
Dim helptext

helptext = vbCrLf & "                    TYPES OF FATIGUE TESTS    " & vbCrLf
helptext = helptext &
"_____________________________________________________________________________"
helptext = helptext & vbCrLf & vbCrLf
helptext = helptext & "Torque Mode" & vbCrLf
helptext = helptext & "___________" & vbCrLf & vbCrLf
helptext = helptext & "The specimen will be placed in torsion. When this test is performed," & vbCrLf
helptext = helptext & "the motor will supply a constant torque (specified) in a cyclic fashion" & vbCrLf
helptext = helptext & "i.e in the positive and negative sense. The maximum torque(= -min torque)" &
vbCrLf
helptext = helptext & "will be applied to the speciment at a specified frequency." & vbCrLf & vbCrLf
helptext = helptext & "Displacement Mode" & vbCrLf
helptext = helptext & "________________" & vbCrLf & vbCrLf
helptext = helptext & "The specimen will be subjected to a positive and negative displacement" & vbCrLf
helptext = helptext & "in a cyclic fashion with a specified frequency. In this mode the motor" & vbCrLf
helptext = helptext & "is essentially executing a sinusoidal path in terms of its shaft angle" & vbCrLf


rtfHelp.Text = helptext


End Sub
```

‘ Form Name: frmTextEdit – Window that gives the user the option of including the experimenter name and the test specifications which are saved to a file.

```
Option Explicit

Private Sub imgproc_Click(Index As Integer)
Select Case Index
  Case 0
    Call mFileProc(frmTextBox.dlgText, frmTextBox.rtfText, 1) 'open
  Case 1
    Call mFileProc(frmTextBox.dlgText, frmTextBox.rtfText, 2) 'save
  Case 2
    Call mEditProc(frmTextBox.dlgText, frmTextBox.rtfText, 2) 'cut
  Case 3
    Call mEditProc(frmTextBox.dlgText, frmTextBox.rtfText, 3) 'copy
  Case 4
    Call mEditProc(frmTextBox.dlgText, frmTextBox.rtfText, 4) 'paste
  Case 5
    Call mEditProc(frmTextBox.dlgText, frmTextBox.rtfText, 0) 'undo
End Select
End Sub

Private Sub mnuexit_Click()
End
End Sub
```

‘ Form Name: frmTextBox

```
Option Explicit

Private Sub Form_Load()
frmtexted.imgproc(5).Enabled = False    'undo image
mnuedit(0).Enabled = False              'undo menu
```

```
End Sub

Private Sub Form_Resize()
Call mRsizeTextBox
End Sub

Private Sub mnualign_Click(Index As Integer)
Call mAlignProc(dlgText, rtfText, Index)
End Sub

Private Sub mnuedit_Click(Index As Integer)
Call mEditProc(dlgText, rtfText, Index)
Select Case Index
   Case 0
      frmtexted.imgproc(5).Enabled = False
      mnuedit(0).Enabled = False
   Case 5
      frmtexted.imgproc(5).Enabled = True
      mnuedit(0).Enabled = True
End Select
End Sub



Private Sub mnueditmain_Click()
If Clipboard.GetText <> "" Then
   frmtexted.imgproc(4).Enabled = True
   mnuedit(4).Enabled = True
Else
   frmtexted.imgproc(4).Enabled = False
   mnuedit(4).Enabled = False
End If

If rtfText.SelText = "" Then
   frmtexted.imgproc(2).Enabled = False 'cut image is disabled
   frmtexted.imgproc(3).Enabled = False 'copy image is disabled

   mnuedit(2).Enabled = False 'cut menu item is disabled
   mnuedit(3).Enabled = False 'copy menu item is disabled
   mnuedit(5).Enabled = False 'del menu item is disabled

Else
   frmtexted.imgproc(2).Enabled = True 'cut image is disabled
   frmtexted.imgproc(3).Enabled = True 'copy image is disabled
   mnuedit(2).Enabled = True
   mnuedit(3).Enabled = True
   mnuedit(5).Enabled = True
End If
End Sub

Private Sub mnufile_Click(Index As Integer)
Call mFileProc(dlgText, rtfText, Index)
End Sub
```

```
Private Sub mnuhelp_Click(Index As Integer)
Call mHelpProc(dlgText, rtfText, Index)
End Sub

Private Sub mnusearch_Click(Index As Integer)
Call mSearchProc(dlgText, rtfText, Index)
End Sub

Private Sub rtfText_Change()
rtfText.Tag = "1"
End Sub

Private Sub rtfText_KeyPress(KeyAscii As Integer)
If txtExpName.Text = "" Or txtSampleName.Text = "" Then
  KeyAscii = 0
End If
End Sub

Private Sub txtExpName_KeyPress(KeyAscii As Integer)
Select Case KeyAscii
Case 9
  If txtExpName.Text <> "" And txtSampleName.Text <> "" Then
    rtfText.Text = rtfText.Text + vbCrLf
    Call frmTestSelection.displayParam(rtfText)
  End If

Case 13
  If txtExpName.Text <> "" And txtSampleName.Text <> "" Then
    rtfText.Text = rtfText.Text + vbCrLf
    Call frmTestSelection.displayParam(rtfText, 1)
  End If
End Select
End Sub

Private Sub txtSampleName_KeyPress(KeyAscii As Integer)
Select Case KeyAscii

  Case 9
    If txtExpName.Text <> "" And txtSampleName.Text <> "" Then
    rtfText.Text = rtfText.Text + vbCrLf
    Call frmTestSelection.displayParam(rtfText)
    End If

  Case 13
  If txtExpName.Text <> "" And txtSampleName.Text <> "" Then
    rtfText.Text = rtfText.Text + vbCrLf
    Call frmTestSelection.displayParam(rtfText)
  End If

End Select
End Sub
```

‘ Module Name: Module1

```
'------ Variable Declarations

DefInt A-Z
Global TabIndex As Integer
Global port
Global sdmax
Global sdmin
Global fileopen
Global oldmax$
Global oldmin$
Global startbutton
Global Echo         ' Echo on/off flag
Global CancelSend   ' Flag to stop sending a text file
Global par As String 'parameters to be passed to the richtext box in the main forms

'------ MSComm Event Constants

Global Const mscomm_ev_send = 1
Global Const mscomm_ev_recieve = 2
Global Const mscomm_ev_cts = 3
Global Const mscomm_ev_dsr = 4
Global Const mscomm_ev_cd = 5
Global Const mscomm_ev_ring = 6
Global Const msscomm_ev_eof = 7

'------ MSComm Error Code Constants

Global Const mscomm_er_break = 1001
Global Const mscomm_er_ctsto = 1002
Global Const mscomm_er_dsrto = 1003
Global Const mscomm_er_frame = 1004
Global Const mscomm_er_overrun = 1006
Global Const mscomm_er_cdto = 1007
Global Const mscomm_er_txover = 1008
Global Const mscomm_er_rxparity = 1009
Global Const mscomm_er_txfull = 1010

'------ Common Dialog Constants

Global Const CDERR_CANCEL = 32755
Global Const CF_SCREENFONTS = &H1&



Sub Main()

   Dim sUsername As String
   Dim sPassword As String
```

```
  frmLoginMenu.GetUserInfo sUsername, sPassword

  If sUsername = "fatigue" And sPassword = "fatigue" Then
    Unload frmLoginMenu
    Load frmWelcome
    frmWelcome.Show
  Else
    MsgBox "The user cancelled or failed to log in", vbInformation, "Login Aborted"
  End If

End Sub
```

‘ Module Name: Torsion Module

```
Option Explicit


Dim RowNo As Integer
Dim Index As Integer
Dim bLog As Boolean
Dim datafile As String
Global Excel1 As Object


' Main program for Torsion Testing

Public Sub Torsion_Program()

  On Error GoTo CommunicationError

  ' Dim sTestSelection
  ' Dim sLoadingSeq

Select Case TabIndex

  '---------- Torque Mode
  Case 0
    ' Open the MSComm1
    Call OpenPort

    ' Download Torque Program to the Controller
    Call TORQ_ProgramDown

    ' Display the graph of Displacement vs time
    Call TORQ_GraphParam

    ' Open the file to save Displacement vs time data
    'Call OpenFile

  '---------- Displacement Mode
  Case 1
    ' Open the MSComm1
```

```
        Call OpenPort

        ' Download Displacement Program to the Controller
        Call DISP_ProgramDown

        ' Display the graph of Torque vs time
        Call DISP_GraphParam

        ' Open the file to save Torque vs time data
        'Call OpenFile


    '---------- Velocity Mode
    Case 2
        ' Open the MSComm1
        Call OpenPort

        ' Download Velocity Program to the Controller
        Call VEL_ProgramDown

        ' Display the graph of Velocity vs time
        Call VEL_GraphParam

        ' Open the file to save Velocity vs time data
       'Call OpenFile



End Select

Exit Sub

CommunicationError:

 End Sub

Public Sub OpenPort()

Select Case TabIndex

    '---------- Torque Mode
    Case 0
    With frmMainTorque.MSComm1
                    .CommPort = 1
                    .Settings = "9600,N,8,1"
                    .InputLen = 0
                    .InBufferCount = 0
                    .OutBufferCount = 0
                    .OutBufferSize = 1024
                    .InBufferSize = 4096
                    .Handshaking = XonXoff
                    .RThreshold = 20
                    .NullDiscard = True
                    .PortOpen = True
   End With


   '---------- Displacement Mode
   Case 1
   frmMainDisplacement.MSComm1.CommPort = 1
   frmMainDisplacement.MSComm1.Settings = "9600,N,8,1"
   frmMainDisplacement.MSComm1.InputLen = 0
   frmMainDisplacement.MSComm1.InBufferCount = 0
   frmMainDisplacement.MSComm1.OutBufferCount = 0
   frmMainDisplacement.MSComm1.OutBufferSize = 1024
   frmMainDisplacement.MSComm1.InBufferSize = 4096
   frmMainDisplacement.MSComm1.Handshaking = XonXoff
   frmMainDisplacement.MSComm1.RThreshold = 20
   frmMainDisplacement.MSComm1.NullDiscard = True
   frmMainDisplacement.MSComm1.PortOpen = True

   '---------- Velocity Mode
   Case 2
   With frmMainVelocity.MSComm1
                    .CommPort = 1
                    .Settings = "9600,N,8,1"
                    .InputLen = 0
                    .InBufferCount = 0
                    .OutBufferCount = 0
                    .OutBufferSize = 1024
                    .InBufferSize = 4096
                    .Handshaking = XonXoff
                    .RThreshold = 20
                    .NullDiscard = True
                    .PortOpen = True
   End With


End Select

End Sub

' New Torque Program ---- MTORQ2

Public Sub TORQ_ProgramDown()
 Dim TORQFREQ As Double
 Dim TMAX As Double

 Dim TMIN As Double
 Dim CYCLES As Integer
 Dim loadIndex As Integer   ' List Index for the items in the combo boxes for loading seq

 TORQFREQ = Val(frmTestSelection.txtTorqFreq)
 TMAX = Val(frmTestSelection.txtMaxTorq)
 TMIN = Val(frmTestSelection.txtMinTorq)
 CYCLES = Val(frmTestSelection.txtTorqCycles)
```

```
loadIndex = frmTestSelection.cmbTorqLoadSeq.ListIndex

' Main Torque Program for MTORQ2

frmMainTorque.MSComm1.Output = "" + Chr$(13) + Chr$(13) + Chr$(13)
'frmMainTorque.MSComm1.Output = "ECHO0" + Chr$(13)
frmMainTorque.MSComm1.Output = "DEL MTORQ2" + Chr$(13)
frmMainTorque.MSComm1.Output = "DEF MTORQ2" + Chr$(13)
frmMainTorque.MSComm1.Output = "GOSUB STORQ2" + Chr$(13)
frmMainTorque.MSComm1.Output = "GOSUB MOTTOR2" + Chr$(13)
frmMainTorque.MSComm1.Output = "END" + Chr$(13)

' Setup Program for MTORQ2 for torque mode
frmMainTorque.MSComm1.Output = "DEL STORQ2" + Chr$(13)
frmMainTorque.MSComm1.Output = "DEF STORQ2" + Chr$(13)
frmMainTorque.MSComm1.Output = "INDAX1" + Chr$(13)
frmMainTorque.MSComm1.Output = "SGP0" + Chr$(13)
frmMainTorque.MSComm1.Output = "SGI0" + Chr$(13)
frmMainTorque.MSComm1.Output = "SGV0" + Chr$(13)
frmMainTorque.MSComm1.Output = "ERES4000" + Chr$(13)
frmMainTorque.MSComm1.Output = "DRIVE1" + Chr$(13)
frmMainTorque.MSComm1.Output = "PSET0" + Chr$(13)
frmMainTorque.MSComm1.Output = "SMPER500" + Chr$(13)
frmMainTorque.MSComm1.Output = "END" + Chr$(13)

' MOTTOR2 program for motion in torque mode

frmMainTorque.MSComm1.Output = "DEL MOTTOR2" + Chr$(13)
frmMainTorque.MSComm1.Output = "DEF MOTTOR2" + Chr$(13)
frmMainTorque.MSComm1.Output = "VAR1=" + CStr(TMAX) + Chr$(13)
frmMainTorque.MSComm1.Output = "VAR2=" + CStr(TMIN) + Chr$(13)
frmMainTorque.MSComm1.Output = "VAR3=" + CStr(TORQFREQ) + Chr$(13)
frmMainTorque.MSComm1.Output = "VAR10=VAR1*(1/8.24)" + Chr$(13)
frmMainTorque.MSComm1.Output = "VAR20=VAR2*(1/8.24)" + Chr$(13)
frmMainTorque.MSComm1.Output = "VAR30=1/(VAR3*2)" + Chr$(13)
frmMainTorque.MSComm1.Output = "VAR6=" + CStr(CYCLES) + Chr$(13)
frmMainTorque.MSComm1.Output = "VARS1=" + Chr$(34) + "THMAX" + Chr$(34) + Chr$(13)
frmMainTorque.MSComm1.Output = "VARS2=" + Chr$(34) + "THMIN" + Chr$(34) + Chr$(13)
frmMainTorque.MSComm1.Output = "VARS3=" + Chr$(34) + "C" + Chr$(34) + Chr$(13)
frmMainTorque.MSComm1.Output = "VARS4=" + Chr$(34) + "E" + Chr$(34) + Chr$(13)
frmMainTorque.MSComm1.Output = "VAR9=0" + Chr$(13)

Select Case loadIndex

  ' Motion Architect Program for Saw-Toothed Loading Sequence in Torque Mode
  Case 0

  frmMainTorque.MSComm1.Output = "L" + Chr$(13)
  frmMainTorque.MSComm1.Output = "WRVARS3" + Chr$(13)
  frmMainTorque.MSComm1.Output = "SOFFS(VAR10)" + Chr$(13)
  frmMainTorque.MSComm1.Output = "VAR4=PE" + Chr$(13)
  frmMainTorque.MSComm1.Output = "WRVARS1" + Chr$(13)
frmMainTorque.MSComm1.Output = "WRVAR4" + Chr$(13)
'frmMainTorque.MSComm1.Output = "TDAC" + Chr$(13)
frmMainTorque.MSComm1.Output = "T(VAR30)" + Chr$(13)
frmMainTorque.MSComm1.Output = "SOFFS0" + Chr$(13)
frmMainTorque.MSComm1.Output = "T0.02" + Chr$(13)
frmMainTorque.MSComm1.Output = "SOFFS(VAR20)" + Chr$(13)
frmMainTorque.MSComm1.Output = "T(VAR30)" + Chr$(13)
frmMainTorque.MSComm1.Output = "VAR5=PE" + Chr$(13)
frmMainTorque.MSComm1.Output = "WRVARS2" + Chr$(13)
frmMainTorque.MSComm1.Output = "WRVAR5" + Chr$(13)
'frmMainTorque.MSComm1.Output = "TDAC" + Chr$(13)
'frmMainTorque.MSComm1.Output = "WRVAR9" + Chr$(13)
'frmMainTorque.MSComm1.Output = "TPE" + Chr$(13)
frmMainTorque.MSComm1.Output = "SOFFS0" + Chr$(13)
frmMainTorque.MSComm1.Output = "T0.02" + Chr$(13)

frmMainTorque.MSComm1.Output = "IF(PE>500 OR PE<-500)" + Chr$(13)
frmMainTorque.MSComm1.Output = "WRVARS4" + Chr$(13)
frmMainTorque.MSComm1.Output = "T10" + Chr$(13)
frmMainTorque.MSComm1.Output = "DRIVE0" + Chr$(13)
frmMainTorque.MSComm1.Output = "NIF" + Chr$(13)

frmMainTorque.MSComm1.Output = "L10" + Chr$(13)
frmMainTorque.MSComm1.Output = "WRVARS3" + Chr$(13)
frmMainTorque.MSComm1.Output = "SOFFS(VAR10)" + Chr$(13)
frmMainTorque.MSComm1.Output = "T(VAR30)" + Chr$(13)
frmMainTorque.MSComm1.Output = "SOFFS0" + Chr$(13)
frmMainTorque.MSComm1.Output = "T0.02" + Chr$(13)
frmMainTorque.MSComm1.Output = "SOFFS(VAR20)" + Chr$(13)
frmMainTorque.MSComm1.Output = "T(VAR30)" + Chr$(13)
frmMainTorque.MSComm1.Output = "SOFFS0" + Chr$(13)
frmMainTorque.MSComm1.Output = "T0.02" + Chr$(13)

frmMainTorque.MSComm1.Output = "IF(PE>500 OR PE<-500)" + Chr$(13)
frmMainTorque.MSComm1.Output = "WRVARS4" + Chr$(13)
frmMainTorque.MSComm1.Output = "T10" + Chr$(13)
frmMainTorque.MSComm1.Output = "DRIVE0" + Chr$(13)
frmMainTorque.MSComm1.Output = "NIF" + Chr$(13)

frmMainTorque.MSComm1.Output = "VAR9=VAR9+1" + Chr$(13)
frmMainTorque.MSComm1.Output = "IF(VAR9>VAR6)" + Chr$(13)
frmMainTorque.MSComm1.Output = "GOTO FINISH" + Chr$(13)
frmMainTorque.MSComm1.Output = "NIF" + Chr$(13)
frmMainTorque.MSComm1.Output = "LN" + Chr$(13)

frmMainTorque.MSComm1.Output = "VAR9=VAR9+1" + Chr$(13)
frmMainTorque.MSComm1.Output = "IF(VAR9>VAR6)" + Chr$(13)
frmMainTorque.MSComm1.Output = "GOTO FINISH" + Chr$(13)
frmMainTorque.MSComm1.Output = "NIF" + Chr$(13)
frmMainTorque.MSComm1.Output = "LN" + Chr$(13)
frmMainTorque.MSComm1.Output = "END" + Chr$(13)

    'Motion Architect Program in Torque Mode for Block Loading Sequence
```

```
  Case 1

  ' Motion Architect Program in Torque Mode for Ramp Loading Sequence
  Case 2

   ' Motion Architect Program in Torque Mode for Sinusoidal Loading Sequence
  Case 3

  ' Motion Architect Program in Torque Mode for Multi-Rate Ramp & Hold Loading Sequence
  Case 4

  ' Motion Architect Program in Torque Mode for Multi-Axial Loading Loading Sequence
  Case 5


 End Select

End Sub

' New Torque Program ---- MTORQ2

Public Sub DISP_ProgramDown()
 Dim DISPFREQ As Double
 Dim TMAX As Double
 Dim TMIN As Double
 Dim CYCLES As Integer
 Dim loadIndex As Integer   ' List Index for the items in the combo boxes for loading seq

 DISPFREQ = Val(frmTestSelection.txtDispFreq)
 TMAX = Val(frmTestSelection.txtMaxAng)
 TMIN = Val(frmTestSelection.txtMinAng)
 CYCLES = Val(frmTestSelection.txtDispCycles)

 loadIndex = frmTestSelection.cmbDispLoadSeq.ListIndex

 ' Main Displaement Program for MDISP1

 frmMainDisplacement.MSComm1.Output = "" + Chr$(13) + Chr$(13) + Chr$(13)
 frmMainDisplacement.MSComm1.Output = "ECHO0" + Chr$(13)
 frmMainDisplacement.MSComm1.Output = "DEL MDISP1" + Chr$(13)
 frmMainDisplacement.MSComm1.Output = "DEF MDISP1" + Chr$(13)
 frmMainDisplacement.MSComm1.Output = "GOSUB SDISP1" + Chr$(13)
 frmMainDisplacement.MSComm1.Output = "GOSUB MOTDIS1" + Chr$(13)
 frmMainDisplacement.MSComm1.Output = "END" + Chr$(13)

 ' Setup Program for MDISP1 in displacement mode

 frmMainDisplacement.MSComm1.Output = "DEL SDISP1" + Chr$(13)
 frmMainDisplacement.MSComm1.Output = "DEF SDISP1" + Chr$(13)
 frmMainDisplacement.MSComm1.Output = "INDAX1" + Chr$(13)
 frmMainDisplacement.MSComm1.Output = "SGP18" + Chr$(13)
 frmMainDisplacement.MSComm1.Output = "SGI0" + Chr$(13)
 frmMainDisplacement.MSComm1.Output = "SGV5" + Chr$(13)
frmMainDisplacement.MSComm1.Output = "ERES4000" + Chr$(13)
frmMainDisplacement.MSComm1.Output = "SMPER0" + Chr$(13)
frmMainDisplacement.MSComm1.Output = "SCALE1" + Chr$(13)
frmMainDisplacement.MSComm1.Output = "SCLD1" + Chr$(13)
frmMainDisplacement.MSComm1.Output = "SCLV4000" + Chr$(13)
frmMainDisplacement.MSComm1.Output = "SCLA4000" + Chr$(13)
frmMainDisplacement.MSComm1.Output = "MA1" + Chr$(13)
frmMainDisplacement.MSComm1.Output = "LH0" + Chr$(13)
frmMainDisplacement.MSComm1.Output = "LS0" + Chr$(13)
frmMainDisplacement.MSComm1.Output = "DRFLVL1" + Chr$(13)
frmMainDisplacement.MSComm1.Output = "DRIVE1" + Chr$(13)
frmMainDisplacement.MSComm1.Output = "PSET0" + Chr$(13)
frmMainDisplacement.MSComm1.Output = "END" + Chr$(13)

' MOTDIS1 program for motion in displacement mode

frmMainDisplacement.MSComm1.Output = "DEL MOTDIS1" + Chr$(13)
frmMainDisplacement.MSComm1.Output = "DEF MOTDIS1" + Chr$(13)
frmMainDisplacement.MSComm1.Output = "VAR1=" + CStr(TMAX) + Chr$(13)
frmMainDisplacement.MSComm1.Output = "VAR2=" + CStr(TMIN) + Chr$(13)
frmMainDisplacement.MSComm1.Output = "VAR3=" + CStr(DISPFREQ) + Chr$(13)
frmMainDisplacement.MSComm1.Output = "VAR10=VAR1*(4000/360)" + Chr$(13)
frmMainDisplacement.MSComm1.Output = "VAR20=VAR2*(4000/360)" + Chr$(13)
frmMainDisplacement.MSComm1.Output = "VAR30=1/(VAR3*2)" + Chr$(13)
frmMainDisplacement.MSComm1.Output = "VAR5=" + CStr(CYCLES) + Chr$(13)
frmMainDisplacement.MSComm1.Output = "VARS1=" + Chr$(34) + "THMIN" + Chr$(34) + Chr$(13)
frmMainDisplacement.MSComm1.Output = "VARS2=" + Chr$(34) + "THMAX" + Chr$(34) + Chr$(13)
frmMainDisplacement.MSComm1.Output = "VARS3=" + Chr$(34) + "L" + Chr$(34) + Chr$(13)
frmMainDisplacement.MSComm1.Output = "VARS4=" + Chr$(34) + "VAR6" + Chr$(34) + Chr$(13)
frmMainDisplacement.MSComm1.Output = "VAR9=0" + Chr$(13)

Select Case loadIndex

 ' Motion Architect Program for Saw-Toothed Loading Sequence
 Case 0

    'frmMainDisplacement.MSComm1.Output = "DEL SAWT" + Chr$(13)
    'frmMainDisplacement.MSComm1.Output = "DEF SAWT" + Chr$(13)
    frmMainDisplacement.MSComm1.Output = "IF (VAR20<0)" + Chr$(13)
    frmMainDisplacement.MSComm1.Output = "VAR8=(2*VAR10-2*VAR20)*VAR3" + Chr$(13)
    frmMainDisplacement.MSComm1.Output = "ELSE" + Chr$(13)
    frmMainDisplacement.MSComm1.Output = "VAR8=(2*VAR10+2*VAR20)*VAR3" + Chr$(13)
    frmMainDisplacement.MSComm1.Output = "NIF" + Chr$(13)
    frmMainDisplacement.MSComm1.Output = "V, (VAR8)" + Chr$(13)
    'frmMainDisplacement.MSComm1.Output = "V50" + Chr$(13)
    frmMainDisplacement.MSComm1.Output = "VAR7=(1/10)*VAR10*(1/40)*VAR3" + Chr$(13)
    frmMainDisplacement.MSComm1.Output = "A, (VAR7)" + Chr$(13)
    frmMainDisplacement.MSComm1.Output = "L" + Chr$(13)
    frmMainDisplacement.MSComm1.Output = "WRVARS3" + Chr$(13)
    frmMainDisplacement.MSComm1.Output = "D(VAR10)" + Chr$(13)
    frmMainDisplacement.MSComm1.Output = "GO" + Chr$(13)
    frmMainDisplacement.MSComm1.Output = "WAIT(MOV=B0)" + Chr$(13)
    frmMainDisplacement.MSComm1.Output = "WRVARS1" + Chr$(13)
    frmMainDisplacement.MSComm1.Output = "TDAC" + Chr$(13)
    frmMainDisplacement.MSComm1.Output = "t(VAR30)" + Chr$(13)

    frmMainDisplacement.MSComm1.Output = "D(VAR20)" + Chr$(13)
    frmMainDisplacement.MSComm1.Output = "GO" + Chr$(13)
    frmMainDisplacement.MSComm1.Output = "WAIT(MOV=B0)" + Chr$(13)
    frmMainDisplacement.MSComm1.Output = "WRVARS2" + Chr$(13)
    frmMainDisplacement.MSComm1.Output = "TDAC" + Chr$(13)
    frmMainDisplacement.MSComm1.Output = "t(VAR30)" + Chr$(13)
    frmMainDisplacement.MSComm1.Output = "L5" + Chr$(13)
    frmMainDisplacement.MSComm1.Output = "WRVARS3" + Chr$(13)
    frmMainDisplacement.MSComm1.Output = "D(VAR10)" + Chr$(13)
    frmMainDisplacement.MSComm1.Output = "GO" + Chr$(13)
    frmMainDisplacement.MSComm1.Output = "WAIT(MOV=B0)" + Chr$(13)
    frmMainDisplacement.MSComm1.Output = "t(VAR30)" + Chr$(13)
    frmMainDisplacement.MSComm1.Output = "D(VAR20)" + Chr$(13)
    frmMainDisplacement.MSComm1.Output = "GO" + Chr$(13)
    frmMainDisplacement.MSComm1.Output = "WAIT(MOV=B0)" + Chr$(13)
    frmMainDisplacement.MSComm1.Output = "t(VAR30)" + Chr$(13)
    frmMainDisplacement.MSComm1.Output = "VAR9=VAR9+1" + Chr$(13)
    frmMainDisplacement.MSComm1.Output = "IF (VAR9>=VAR5)" + Chr$(13)
    frmMainDisplacement.MSComm1.Output = "GOTO FINISH" + Chr$(13)
    frmMainDisplacement.MSComm1.Output = "NIF" + Chr$(13)
    frmMainDisplacement.MSComm1.Output = "LN" + Chr$(13)
    frmMainDisplacement.MSComm1.Output = "VAR9=VAR9+1" + Chr$(13)
    frmMainDisplacement.MSComm1.Output = "IF (VAR9>=VAR5)" + Chr$(13)
    frmMainDisplacement.MSComm1.Output = "GOTO FINISH" + Chr$(13)
    frmMainDisplacement.MSComm1.Output = "NIF" + Chr$(13)
    frmMainDisplacement.MSComm1.Output = "LN" + Chr$(13)
    frmMainDisplacement.MSComm1.Output = "END" + Chr$(13)

    frmMainDisplacement.MSComm1.Output = "DEL FINISH" + Chr$(13)
    frmMainDisplacement.MSComm1.Output = "DEF FINISH" + Chr$(13)
    frmMainDisplacement.MSComm1.Output = "S" + Chr$(13)
    frmMainDisplacement.MSComm1.Output = "TDAC" + Chr$(13)
    frmMainDisplacement.MSComm1.Output = "END" + Chr$(13)



'Motion Architect Program for Block Loading Sequence

Case 1
    frmMainDisplacement.MSComm1.Output = "VAR7=2*100*(VAR10-VAR20)*VAR3" + Chr$(13)
    frmMainDisplacement.MSComm1.Output = "V, (VAR7)" + Chr$(13)
    frmMainDisplacement.MSComm1.Output = "A, (VAR7)" + Chr$(13)
    frmMainDisplacement.MSComm1.Output = "AD, (VAR7)" + Chr$(13)
    frmMainDisplacement.MSComm1.Output = "PSET0" + Chr$(13)
    frmMainDisplacement.MSComm1.Output = "L" + Chr$(13)
    frmMainDisplacement.MSComm1.Output = "WRVARS3" + Chr$(13)
    frmMainDisplacement.MSComm1.Output = "D(VAR10)" + Chr$(13)
    frmMainDisplacement.MSComm1.Output = "GO" + Chr$(13)
    frmMainDisplacement.MSComm1.Output = "WAIT(MOV=B0)" + Chr$(13)
```

```
            frmMainDisplacement.MSComm1.Output = "WRVARS1" + Chr$(13)
            frmMainDisplacement.MSComm1.Output = "TDAC" + Chr$(13)
            frmMainDisplacement.MSComm1.Output = "D(VAR20)" + Chr$(13)
            frmMainDisplacement.MSComm1.Output = "GO" + Chr$(13)
            frmMainDisplacement.MSComm1.Output = "WAIT(MOV=B0)" + Chr$(13)
            frmMainDisplacement.MSComm1.Output = "WRVARS2" + Chr$(13)
            frmMainDisplacement.MSComm1.Output = "TDAC" + Chr$(13)
            frmMainDisplacement.MSComm1.Output = "T(VAR30)" + Chr$(13)
            frmMainDisplacement.MSComm1.Output = "L5" + Chr$(13)
            frmMainDisplacement.MSComm1.Output = "WRVARS3" + Chr$(13)
            frmMainDisplacement.MSComm1.Output = "D(VAR10)" + Chr$(13)
            frmMainDisplacement.MSComm1.Output = "GO" + Chr$(13)
            frmMainDisplacement.MSComm1.Output = "WAIT(MOV=B0)" + Chr$(13)
            frmMainDisplacement.MSComm1.Output = "TDAC" + Chr$(13)
            frmMainDisplacement.MSComm1.Output = "T(VAR30)" + Chr$(13)
            frmMainDisplacement.MSComm1.Output = "VAR9=VAR9+1" + Chr$(13)
            frmMainDisplacement.MSComm1.Output = "IF (VAR9>=VAR5)" + Chr$(13)
            frmMainDisplacement.MSComm1.Output = "GOTO FINISH" + Chr$(13)
            frmMainDisplacement.MSComm1.Output = "NIF" + Chr$(13)
            frmMainDisplacement.MSComm1.Output = "LN" + Chr$(13)
            frmMainDisplacement.MSComm1.Output = "END" + Chr$(13)

            frmMainDisplacement.MSComm1.Output = "DEL FINISH" + Chr$(13)
            frmMainDisplacement.MSComm1.Output = "DEF FINISH" + Chr$(13)
            frmMainDisplacement.MSComm1.Output = "S" + Chr$(13)
            frmMainDisplacement.MSComm1.Output = "TDAC" + Chr$(13)
            frmMainDisplacement.MSComm1.Output = "END" + Chr$(13)




    ' Motion Architect Program for Ramp Loading Sequence
    Case 2

     ' Motion Architect Program for Sinusoidal Loading Sequence
    Case 3

    ' Motion Architect Program for Multi-Rate Ramp & Hold Loading Sequence
    Case 4

    ' Motion Architect Program for Multi-Axial Loading Loading Sequence
    Case 5

 End Select

End Sub

Sub VEL_ProgramDown()

End Sub
```

```
Sub TORQ_GraphParam()

End Sub

Sub DISP_GraphParam()

End Sub

Sub VEL_GraphParam()

End Sub
Sub TORQ_ShowData(dat$)
Dim cycle, angle$, sign$
Dim i As Integer
Dim j As Integer
Dim k As Integer
Dim n As Integer
sdmax = 0
sdmin = 0

If startbutton = False Then Exit Sub

i = 0

i = InStr(UCase$(dat$), "E")

   'If i Then
    '  Call salute
     ' Exit Sub
  ' End If

i = 0
j = 0

Do
   i = InStr(i + 1, dat$, "T")
   j = InStr(i + 1, dat$, Chr$(13))
   k = InStr(j + 1, dat$, Chr$(13))

   If i And j Then
      sign$ = Mid$(dat$, i, 5)
      angle$ = Mid$(dat$, (j + 1), 3)
   End If

If sign$ = "THMAX" Then
   frmMainTorque.txtCurrThetaMax.Text = Val(Format(Val(angle$) * 360 / 400, "0.00"))
End If

If sign$ = "THMIN" Then
   frmMainTorque.txtCurrThetaMin.Text = Val(Format(Val(angle$) * 360 / 400, "0.00"))
End If
```

```
Loop While i

If sdmax <= 5 And Val(frmMainTorque.txtCurrThetaMax.Text) <> 0 Then
   frmMainTorque.txtStrThetaMax.Text = frmMainTorque.txtCurrThetaMax.Text
   frmMainTorque.txtStrThetaMax.Refresh
   sdmax = sdmax + 1
End If

If sdmin <= 5 And Val(frmMainTorque.txtStrThetaMin.Text) <> 0 Then
   frmMainTorque.txtStrThetaMin.Text = frmMainTorque.txtCurrThetaMin.Text
   frmMainTorque.txtStrThetaMin.Refresh
   sdmin = sdmin + 1
End If

frmMainTorque.txtCurrThetaMax.Refresh
frmMainTorque.txtCurrThetaMin.Refresh

i = 0
j = 0

Do
i = InStr(i + 1, dat$, "C")
If i Then
   frmMainTorque.txtCycles.Text = Val(frmMainTorque.txtCycles.Text) + 1
   frmMainTorque.txtCycles.Refresh
End If
Loop While i

   RowNo = RowNo + 1
   Excel1.Visible = True
   Excel1.WindowState = xlMinimized

   If RowNo > 1 And RowNo <= 400 Then

      Excel1.ActiveWorkbook.ActiveSheet.Range("A" & RowNo).Value =
Val(frmMainTorque.txtCycles.Text)
      Excel1.ActiveWorkbook.ActiveSheet.Range("B" & RowNo).Value =
Val(frmMainTorque.txtCurrThetaMax.Text)
      Excel1.ActiveWorkbook.ActiveSheet.Range("C" & RowNo).Value =
Val(frmMainTorque.txtCurrThetaMin.Text)

      n = RowNo Mod 20
      If n = 0 And RowNo > 20 Then
         Call TorqDataPlotMacro
         frmMainTorque.oleChart.Paste
      End If

      ' Excel.ActiveWorkbook.ActiveSheet.Range("D" & RowNo).Value

   Else
      ' call  Macro for clearing the Cells in the excel
      Call Clear_Cell
```

```
        RowNo = 1
    End If

'If fileopen = True Then
 '  If Val(frmMainTorque.txtCycles.Text) <> 0 And Val(frmMainTorque.txtCurrThetaMax.Text) <> 0 And
 Val(frmMainTorque.txtCurrThetaMin.Text) <> 0 Then
  '     If (frmMainTorque.txtCurrThetaMax.Text) <> oldmax$ Or (frmMainTorque.txtCurrThetaMin.Text)
<> oldmin$ Then
   '        Print #1, Val(frmMainTorque.txtCycles.Text); " "; frmMainTorque.txtCurrThetaMax.Text; " ";
frmMainTorque.txtCurrThetaMin.Text
    '       oldmax$ = frmMainTorque.txtCurrThetaMax.Text
    '       oldmin$ = frmMainTorque.txtCurrThetaMin.Text
     ' End If
    'End If
'End If

End Sub
Sub salute()


    Dim dgdef, msg, Response, Title     'declare variables

    msg = "A signal has been recieved from the machine indicating "
    msg = msg & "the conclusion of the test. If you perceive that there is no "
    msg = msg & "crack visible please hit the 'CANCEL' button to go back and "
    msg = msg & "start the test. All the values collected so far will be preserved "
    msg = msg & "and the test will continue as before. "
    msg = msg & "Hit the OK button to conlude the test"
    Title = "Torsion Fatigue Testing"
    dgdef = 49
    Response = MsgBox(msg, dgdef, Title)
    If Response = 1 Then Exit Sub
    If Response = 2 Then Exit Sub

End Sub

Sub DISP_ShowData(dat$)
Dim cycle, torque$, sign$
Dim i As Integer
Dim j As Integer
Dim k As Integer
Dim n As Integer

i = 0
Do
    i = InStr(i + 1, dat$, "TH")
    j = InStr(i + 1, dat$, Chr$(13))
    k = InStr(j + 1, dat$, "*TDAC")
    If i Then
        sign$ = Mid$(dat$, i, 5)
        torque$ = Mid$(dat$, (j + 6), 6)
    End If
  If sign$ = "THMAX" Then
     frmMainDisplacement.txtCurrTorqMax.Text = Val(Format(Val(torque$) * 8.24!, "0.0000"))
  End If

  If sign$ = "THMIN" Then
  '   frmMainDisplacement.txtCurrTorqMin.Text = (Val(torque$)) * 8.24!
   frmMainDisplacement.txtCurrTorqMin.Text = Val(Format(Val(torque$) * 8.24!, "0.0000"))
  End If


  If sdmax <= 5 And Val(frmMainDisplacement.txtCurrTorqMax.Text) <> 0 Then
     frmMainDisplacement.txtStrTorqMax.Text = frmMainDisplacement.txtCurrTorqMax.Text
     frmMainDisplacement.txtStrTorqMax.Refresh
     sdmax = sdmax + 1
  End If

  If sdmin <= 5 And Val(frmMainDisplacement.txtCurrTorqMin.Text) <> 0 Then
     frmMainDisplacement.txtStrTorqMin.Text = frmMainDisplacement.txtCurrTorqMin.Text
     frmMainDisplacement.txtStrTorqMin.Refresh
     sdmin = sdmin + 1
  End If

  Loop While i

     frmMainDisplacement.txtCurrTorqMax.Refresh
     frmMainDisplacement.txtCurrTorqMin.Refresh



  i = 0
  j = 0

  Do
  i = InStr(i + 1, dat$, "L")
     If i Then
        frmMainDisplacement.txtCycles.Text = Val(frmMainDisplacement.txtCycles.Text) + 1
        frmMainDisplacement.txtCycles.Refresh
     End If
  Loop While i



  RowNo = RowNo + 1
  Excel1.Visible = True
  Excel1.WindowState = xlMinimized

  If RowNo > 1 And RowNo <= 400 Then

     Excel1.ActiveWorkbook.ActiveSheet.Range("A" & RowNo).Value =
Val(frmMainDisplacement.txtCycles.Text)
     Excel1.ActiveWorkbook.ActiveSheet.Range("B" & RowNo).Value =
Val(frmMainDisplacement.txtCurrTorqMax.Text)
```

```
    Excel1.ActiveWorkbook.ActiveSheet.Range("C" & RowNo).Value =
Val(frmMainDisplacement.txtCurrTorqMin.Text)

    n = RowNo Mod 20
    If n = 0 Or RowNo > 20 Then
      Call DataPlotMacro
      frmMainDisplacement.oleChart.Paste
    End If

    ' Excel.ActiveWorkbook.ActiveSheet.Range("D" & RowNo).Value

  Else
    ' call  Macro for clearing the Cells in the excel
    Call Clear_Cell
    RowNo = 1
  End If

End Sub

Sub VEL_ShowData(dat$)

End Sub

Sub OpenFile()

  Dim str As String, i As Integer, j As Integer

  j = Len(strFileName)

  For i = j - 4 To 1 Step -1
  If Mid$(strFileName, i, 1) = "\" Then
  Exit For
  End If
  str = Mid$(strFileName, i, 1) + str
  Next i

  datafile$ = str + "_data.txt"

  Open datafile$ For Output As #1

End Sub


Public Sub DataPlotMacro()
'
' DataPlotMacro Macro
' Macro recorded 9/28/98 by Hyder Hussain
'
On Error GoTo ErrHandler

With Excel1.ActiveWorkbook.ActiveSheet
  .Range("A2:C400").Select
End With
```

```
With Excel1.ActiveWorkbook
        .Charts.Add
        .ActiveChart.chartType = xlXYScatterSmoothNoMarkers
        .ActiveChart.SetSourceData Source:=Sheets("Sheet1").Range("A2:C10"), PlotBy _
            :=xlColumns
        .ActiveChart.Location Where:=xlLocationAsObject, Name:="Sheet1"
End With

With Excel1.ActiveWorkbook.ActiveChart
        .HasTitle = True
        .ChartTitle.Characters.Text = "Plot of Torque vs Cycles"
        .Axes(xlCategory, xlPrimary).HasTitle = True
        .Axes(xlCategory, xlPrimary).AxisTitle.Characters.Text = "No. of Cycles N"
        .Axes(xlValue, xlPrimary).HasTitle = True
        .Axes(xlValue, xlPrimary).AxisTitle.Characters.Text = "Torque T (N-m)"
End With

With Excel1.ActiveWorkbook.ActiveChart.Axes(xlCategory)
        .HasMajorGridlines = True
        .HasMinorGridlines = True
End With

With Excel1.ActiveWorkbook.ActiveChart.Axes(xlValue)
        .HasMajorGridlines = True
        .HasMinorGridlines = True
End With
With Excel1.ActiveWorkbook
        .ActiveChart.HasLegend = True
        .ActiveChart.ChartArea.Copy
End With

Exit Sub

ErrHandler:
Select Case Err.Number
    Case 1004       ' Don't want to save the file
        On Error Resume Next
    Case Else
        MsgBox "An error has occured in Plotting the Data!"
    End
End Select

End Sub



Public Sub LogDispData()
    RowNo = 1
    'Excel1.Workbooks.Add
    'Excel.Visible = false

    'Excel.WindowState = xlMinimized
    With Excel1.ActiveWorkbook.ActiveSheet
```

```
        .Columns("A:A").ColumnWidth = 13.11
        .Columns("B:B").ColumnWidth = 22.01
        .Columns("C:C").ColumnWidth = 22.01
        .Columns("D:D").ColumnWidth = 22.01
  End With
    Excel1.ActiveWorkbook.ActiveSheet.Range("A" & 1).Value = "CYCLES"
    Excel1.ActiveWorkbook.ActiveSheet.Range("B" & 1).Value = "Max Torque(N-m)"
    Excel1.ActiveWorkbook.ActiveSheet.Range("C" & 1).Value = "Min Torque (N-m)"
    Excel1.ActiveWorkbook.ActiveSheet.Range("D" & 1).Value = "Mean Torque (N-m)"

  'Call DataPlotMacro
  'frmMainDisplacement.oleChart.Paste

End Sub
Sub Clear_Cell()
'
' Macro  Clear_Cell
' Macro recorded 10/1/98 by Hyder Hussain
'

With Excel.ActiveWorkbook.ActiveSheet
  .Range("A2:C400").Select
  .Selection.ClearContents
  .Range("A2").Select
End With

End Sub


Public Sub TorqDataPlotMacro()
'
' TorqDataPlotMacro Macro
' Macro recorded 10/7/98 by Hyder Hussain
'

  Range("D2").Select
  ActiveCell.FormulaR1C1 = "=AVERAGE(RC[-2]:RC[-1])"
  Range("D2").Select
  Selection.AutoFill Destination:=Range("D2:D11"), Type:=xlFillDefault
  Range("D2:D400").Select
  Range("A2:D400").Select
  Charts.Add
  ActiveChart.chartType = xlXYScatterSmoothNoMarkers
  ActiveChart.SetSourceData Source:=Sheets("Sheet2").Range("A2:D400"), PlotBy _
    :=xlColumns
  ActiveChart.Location Where:=xlLocationAsObject, Name:="Sheet2"
  With ActiveChart
    .HasTitle = True
    .ChartTitle.Characters.Text = "Plot of Displacement vs Cycles"
    .Axes(xlCategory, xlPrimary).HasTitle = True
    .Axes(xlCategory, xlPrimary).AxisTitle.Characters.Text = "No. of Cycles N"
    .Axes(xlValue, xlPrimary).HasTitle = True
    .Axes(xlValue, xlPrimary).AxisTitle.Characters.Text = "Displacement (deg)"
```

```
   End With
   ActiveChart.HasLegend = True
   ActiveChart.Legend.Select
   Selection.Position = xlBottom
   ActiveChart.ApplyDataLabels Type:=xlDataLabelsShowNone, LegendKey:=False
   ActiveChart.ChartArea.Copy

End Sub

Public Sub LogTorqData()
   RowNo = 1
   'Excel1.Workbooks.Add


   With Excel1.ActiveWorkbook.ActiveSheet
         .Columns("A:A").ColumnWidth = 13.11
         .Columns("B:B").ColumnWidth = 22.01
         .Columns("C:C").ColumnWidth = 22.01
         .Columns("D:D").ColumnWidth = 22.01
   End With
      Excel1.ActiveWorkbook.ActiveSheet.Range("A" & 1).Value = "CYCLES"
      Excel1.ActiveWorkbook.ActiveSheet.Range("B" & 1).Value = "Max Disp (deg)"
      Excel1.ActiveWorkbook.ActiveSheet.Range("C" & 1).Value = "Min Disp (deg)"
      Excel1.ActiveWorkbook.ActiveSheet.Range("D" & 1).Value = "Mean Disp (deg)"

End Sub
```

‘ Module Name: mTextPad

```
Option Explicit
Global strUndo As String
Global intstart As Integer
Global strFileName As String




Public Sub textpad()
Dim PauseTime, Start, Finish, TotalTime
Call mRsizeTextBox
Load frmtexted
frmtexted.Show
Load frmTextBox
frmTextBox.Caption = "Untitled - Textpad"
frmTextBox.rtfText.Tag = 0
frmTextBox.dlgText.Filter = "All Files (*.*)|*.*|rtf files (*.rtf)|*.rtf"
frmTextBox.dlgText.FilterIndex = 2

End Sub

Public Sub mRsizeTextBox()
```

```
frmTextBox.rtfText.Top = 1440 'frmTextBox.ScaleTop
frmTextBox.rtfText.Left = frmTextBox.ScaleLeft
frmTextBox.rtfText.Width = frmTextBox.ScaleWidth
frmTextBox.rtfText.Height = frmTextBox.ScaleHeight


End Sub

Public Sub mFileProc(dlg As CommonDialog, rtf As RichTextBox, Index As Integer)
Dim frmNew As New frmTextBox
Dim choice As Integer
Dim askedtoclose As Boolean
Select Case Index
  Case 0 'new
    If rtf.Tag = "1" Then
      If dlg.filename <> "" Then
        Call mFileProc(dlg, rtf, 2)
      Else
        Call mFileProc(dlg, rtf, 3)
      End If
    End If
    rtf.Text = ""
    rtf.Tag = "0"
    frmTextBox.Caption = "Untitled - TextPad"
  Case 1 'open
    If rtf.Tag = "1" Then
      If dlg.filename <> "" Then
        Call mFileProc(dlg, rtf, 2)
      Else
        Call mFileProc(dlg, rtf, 3)
      End If
    End If

    dlg.ShowOpen
    If dlg.filename <> "" Then
      rtf.Text = ""
      rtf.LoadFile dlg.filename, rtfRTF
      frmTextBox.Caption = dlg.filename
      rtf.Tag = "0"
    End If
  Case 2 'save
    If dlg.filename <> "" Then
      choice = MsgBox("Do you wanted to save the changes made", vbYesNo, "Save File..")
      If choice = vbYes Then
        rtf.SaveFile dlg.filename, rtfRTF
      End If
      rtf.Tag = "0"
    Else
      Call mFileProc(dlg, rtf, 3)
    End If
  Case 3 'save as
    dlg.ShowSave
    If dlg.filename <> "" Then
```

```
            rtf.Tag = "0"
            rtf.SaveFile dlg.filename
            frmTextBox.Caption = dlg.filename
        End If
    Case 4 'ignore
    Case 5 'pagesetup
        dlg.Flags = cdlPDPrintSetup
        dlg.ShowPrinter
    Case 6 'print
        dlg.Flags = cdlPDReturnDefault
        dlg.Flags = cdlPDAllPages
        dlg.ShowPrinter
        Printer.Print rtf.Text
        Printer.EndDoc
    Case 7 'ignore
    Case 8 'Close
        If rtf.Tag = "1" Then
            If dlg.filename <> "" Then
                rtf.SaveFile dlg.filename

     'strFileName = dlg.filename
                rtf.Tag = "0"
            Else
                dlg.ShowSave
            End If
        End If
        askedtoclose = True
        'Unload frmTextBox
        'Unload frmtexted

End Select
If askedtoclose = True Then
strFileName = dlg.filename
Unload frmTextBox
Unload frmtexted
End If
End Sub

Public Sub mEditProc(dlg As CommonDialog, rtf As RichTextBox, Index As Integer)
Static counter As Integer
Static counterwrap As Integer
Select Case Index
    Case 0 'undo
        If counter = 1 Then
            rtf.SelStart = intstart
            rtf.SelText = strUndo
            counter = 0
            frmTextBox.mnuedit(0).Enabled = False
        End If

    Case 1 'ignore

    Case 2 'Cut
```

```
        Clipboard.Clear
        Clipboard.SetText rtf.SelText
        rtf.SelText = ""
    Case 3 'copy
        Clipboard.Clear
        Clipboard.SetText rtf.SelText
    Case 4 'paste
        rtf.SelText = Clipboard.GetText
    Case 5 'del
        strUndo = rtf.SelText
        intstart = rtf.SelStart
        counter = 1
        rtf.SelText = ""
        frmTextBox.mnuedit(0).Enabled = True

    Case 6 'ignore
    Case 7 'select all
        rtf.SelStart = 0
        rtf.SelLength = Len(rtf.Text)

    Case 8 'time date
        rtf.SelText = Now
    Case 9 'ignore
    Case 10 'word wrap
        If counterwrap = 0 Then
            rtf.ScrollBars = rtfVertical
            counterwrap = 1
        Else
            rtf.ScrollBars = rtfBoth
            counterwrap = 0
        End If
End Select
End Sub

Public Sub mSearchProc(dlg As CommonDialog, rtf As RichTextBox, Index As Integer)
Static strFind As String
Static strReplace As String
Static intPos As Integer
Select Case Index
    Case 0 'find
        strFind = InputBox("Find ...", "Find String", strFind)
        intPos = rtf.Find(strFind, 0, Len(rtf), 2)
        rtf.SelStart = intPos

    Case 1 'find next
        intPos = rtf.Find(strFind, rtf.SelStart + 1, Len(rtf), 2)
        If intPos > -1 Then
            rtf.SelStart = intPos
        End If
    Case 2
        Call mSearchProc(dlg, rtf, 0)
        strReplace = InputBox("Replace with ..", "Find and Replace", "")
        rtf.SelStart = intPos
    rtf.SelLength = Len(strReplace)
    rtf.SelText = ""
    rtf.SelText = strReplace
End Select
End Sub

Public Sub mHelpProc(dlg As CommonDialog, rtf As RichTextBox, Index As Integer)
Select Case Index
  Case 0
    dlg.HelpFile = "notepad.HLP"
    dlg.HelpCommand = cdlHelpContents
    dlg.ShowHelp  ' Display Visual Basic Help contents topic.

  Case 1 'ignore

  Case 2
    Load frmAbout
    frmAbout.Show

End Select
End Sub

Public Sub mAlignProc(dlg As CommonDialog, rtf As RichTextBox, Index As Integer)
Select Case Index
  Case 0 ' left alignment
    rtf.SelAlignment = 0
  Case 1 ' alignment
    rtf.SelAlignment = 1
  Case 2 'center alignment
    rtf.SelAlignment = 2
End Select
End Sub
```

*****