DEVELOPMENT OF STRAIN-BASED FATIGUE LIFE CALCULATION SOFTWARE FOR VARIABLE AMPLITUDE LOADING DATA

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I hereby declare that the work in this report is my own except for quotations and summaries which have been duly acknowledged. The report has not been accepted for any degree and is not concurrently submitted for award of other degree.

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ABSTRACT

This thesis presents the development of strain-based fatigue life calculation software for variable amplitude loading data. The main objective of this study is to develop calculation software for fatigue life prediction using MATLAB®. The software allows life predictions to quickly provide fatigue crack initiation using SAESUS data and road loading history on car lower suspension arm. In addition, the fatigue life was predicted using strain life approach subjected to variable amplitude loading. Coffin Manson are the method that provides in the software. Rainflow cycle counting method will be use to extract the cycle from time series data. Then the Palmgren-Rules equation was utilized to calculate cumulative damage. As a result, the GUI will display the result from the method using. From the software development, it can contribute to all user for calculate life prediction especially for variable amplitude loading. Thus the software does not need higher cost and also user friendly.

ABSTRAK

Tesis ini membentangkan satu pembangunan perisian pengiraan hayat lesu bagi data bebanan pelbagai amplitud. Objektif utama adalah untuk membangunkan satu perisian pengiraan untuk analisis hayat lesu menggunakan MATLAB®. Perisian ini membenarkan ramalan hayat untuk permukaan retak dengan menggunakan data SAESUS dan data lengan di bawah ampaian kereta semasa perjalanan. Dalam pada itu, hayat lesu diramal dengan menggunakan pendekatan hayat lesu yang dikenakan untuk pembebanan pelbagai amplitud. Model Coffin Manson merupakan kaedah yang disediakan dalam perisian ini. Kaedah pengiraan aliran hujan dapat digunakan dalam mengembangkan setiap kitaran dari data siri masa. Kemudian, jumlah kerosakan kumulatif dapat ditentukan dengan aturan Palmgren Miner. Keputusannya, satu paparan dapat dipaparkan hasil daripada menggunakan kaedah-kaedah yang disediakan. Perisian ini dapat menyumbang dalam memudahkan pengguna khususnya pelajar bagi mengira sesuatu jangka hayat lesu. Dalam pada itu, perisian ini tidak memerlukan kos yang tinggi dan ianya mesra pengguna.

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LIST OF SYMBOLS

ε_a	Strain amplitude
ε_f	True fracture ductility
ε'_f	Fatigue ductility coefficient
σ	True stress, local stress
$\Delta\sigma$	Stress range
σ_a	Local stress amplitude
σ_m	Local mean stress
σ_{max}	Local maximum stress
σ'_f	Fatigue strength coefficient
E	Modulus of elasticity
N_f	Fatigue life
b	Fatigue strength exponent
c	Fatigue ductility exponent
$2N_f$	Reversals to failure
$\Delta\varepsilon/2$	Total strain amplitude

LIST OF ABBREVIATIONS

ASTM	American Society for Testing and Materials
GUI	Graphical User Interface
SAE	Society of Automotive Engineers
SWT	Smith Watson Topper

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

This is project about Software Development of Strain-Based Fatigue Life Calculation for Variable Amplitude Loading Data using MATLAB® GUI. This project will use a method that need to be taken into consideration to successfully accomplish this project. The methods that are going to use is Coffin Manson.

Fatigue is the most important failure mode to be considered in a mechanical design. Under the action of oscillatory tensile stresses of sufficient magnitude, a small crack will initiate at a point of the stress concentration. Once the crack is initiated, it will tend to grow in a direction orthogonal to the direction of the oscillatory tensile loads. There are several reasons for the dominance of this failure mode and the problems of designing to avoid it: the fatigue process is inherently unpredictable, as evidenced by the statistical scatter in laboratory data; it is often difficult to translate laboratory data of material behavior into field predictions; it is extremely difficult to accurately model the mechanical environments to which the system is exposed over its entire design lifetime; and environmental effects produce complex stress states at fatigue-sensitive hot spots in the system. It can be thought that fatigue can involve a very complicated interaction of several processes and/or influences (Stephens et al. 2001)

A graphical user interface (GUI) is a pictorial interface to a program. A good GUI can make programs easier to use by providing them with a consistent appearance and with intuitive controls like pushbuttons, list boxes, sliders, menus, and so forth. The GUI should behave in an understandable and predictable manner, so that a user knows what to expect when he or she performs an action (Hunt et al. 2001).

MATLAB® is viewed by many users not only as a high-performance language for technical computing but also as a convenient environment for building graphical user interfaces (GUI). Data visualization and GUI design in MATLAB® are based on the Handle Graphics System in which the objects organized in a Graphics Object Hierarchy can be manipulated by various high and low level commands. If using MATLAB®7 the GUI design more flexible and versatile, they also increase the complexity of the Handle Graphics System and require some effort to adapt to.

1.2 PROBLEM STATEMENT

The current software is able to calculate fatigue life for variable amplitude loading data but it's difficult to get the software because of the higher cost. In this development country, the software has been created to display the value that had been calculated. Same for this project, fatigue life calculation software has been developed and will able to display at the MATLAB® program that is GUIDE. The advantages of this GUIDE is it will not only display the value but it will also able to explain the purpose of this program with interesting button and figure and also can guide the users to use this program.

1.3 OBJECTIVES

i. Design MATLAB® GUI for Fatigue Life Calculation

   To create and design GUI using GUIDE in MATLAB® Software package to make an easier for the user to use. The design in GUI must be user-friendly to make sure the user understand to use it.

ii. To Develop Algorithm for Calculating Fatigue Life

Develop the Fatigue Life Prediction Algorithm using method Coffin Manson by implement iteration method to solve the equation. This method will display a fatigue life in MATLAB® GUI.

1.4 HYPOTHESIS

Hypothesis of this project is when the software successfully develops, the data from SAESUS will be used to calculate fatigue life for variable amplitude loading data. This software calculates fatigue life using Coffin Manson method. This software also able to display time domain data and rainflow histogram based on material properties select and loading data used.

1.5 SCOPE OF RESEARCH

The first element need to be considered for scope of this project is development on Strain Life Fatigue Model. This model only focused on one method which is Coffin Manson.

The second element is software that becomes the main part of this project. The software that use in this project is Graphical User Interface Development Environment (GUIDE) in MATLAB® software package. This software is to design and create the GUI layout to make a user-friendly for user. For this GUIDE software is divide into two, first is GUI layout design with a consistent appearance and with intuitive controls like pushbuttons, list boxes, sliders, menus, and so forth. And second is for the program M-File, must design and use the right coding to make sure the design in GUI layout is work properly like what is needed.

CHAPTER 2

LITERATURE REVIEW

2.1 FATIGUE

Fatigue is the process of progressive localized permanent structural change occurring in a material subjected to conditions that produce fluctuating stresses and strains at some point or points and that may culminate in cracks or complete fracture after a sufficient number of fluctuations. If the maximum stress in the specimen does not exceed the elastic limit of the material, the specimen returns to its initial condition when the load is removed. A given loading may be repeated many times, provided that the stresses remain in the elastic range. Such a conclusion is correct for loadings repeated even a few hundred times. However, it is not correct when loadings are repeated thousands or millions of times. In such cases, rupture will occur at a stress much lower than static breaking strength. This phenomenon is known as fatigue (Stephens et al 2001).

To be effective in averting failure, the designer should have a good working knowledge of analytical and empirical techniques of predicting failure so that during the pre-described design, failure may be prevented. That is why; the failure analysis, prediction, and prevention are of critical importance to the designer to achieve a success (Stephens et al 2001).

Fatigue design is one of the observed modes of mechanical failure in practice. For this reason, fatigue becomes an obvious design consideration for many structures, such as aircraft, bridges, railroad cars, automotive suspensions and vehicle frames. For these structures, cyclic loads are identified that could cause fatigue failure if the design is not adequate (Stephens et al. 2001). The basic elements of the fatigue design process are illustrated in Figure 2.1.

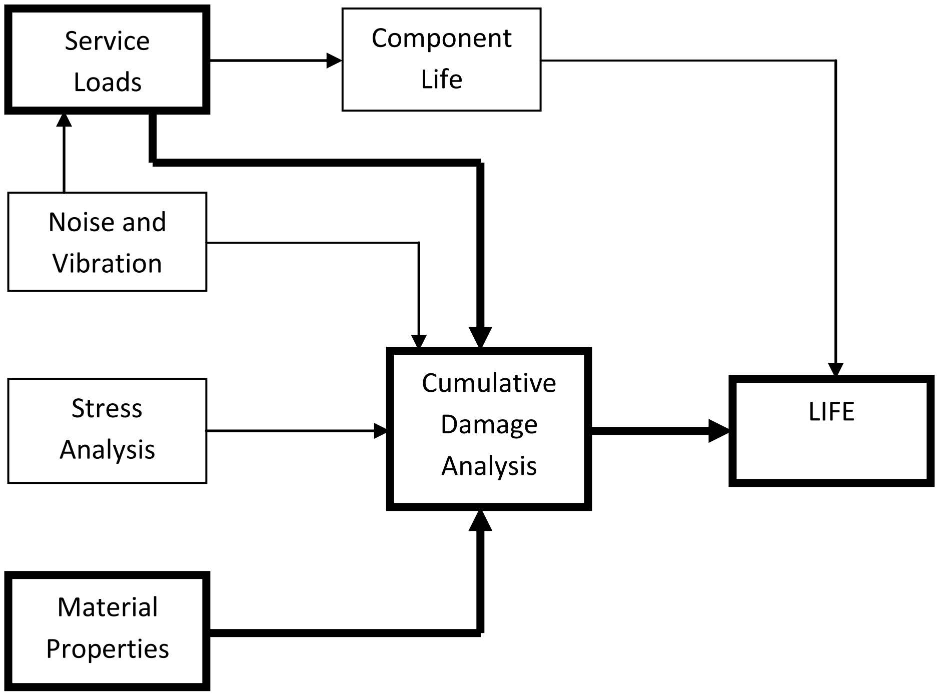

Figure 2.1: The basic elements for the fatigue design process.

Sources: Rise et. al (1988)

Service loads, noise and vibration: Firstly, a description of the service environment is obtained. The goal is to develop an accurate representation of the loads, deflections, strains, noise, vibration etc. that would likely be experienced during the total operating life of the component. Loading sequences are developed from load histories measured and recorded during specific operations. The most useful service load data is recording of the outputs of strain gages which are strategically positioned to directly reflect the input loads experienced by the component or structure. Noise and vibration has also effect on insight in the modes and mechanics of component and structural behaviour. An objective description of the vibration systems can be done in terms of frequency and amplitude information (Rise et. al 1988).

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Stress analysis: The shape of a component or structure and boundary conditions dictates how it will respond to service loads in terms of stresses, strains and deflections. Analytical and experimental methods are available to quantify this behaviour. Finite element techniques can be employed to identify areas of both high stress, where there may be potential fatigue problems, and low stress where there may be potential for reducing weight. Experimental methods can be used in situations where components or structures actually exist. Strain gages strategically located can be used to quantify strains at such critical areas (Rise et. al 1988).

Material properties: A fundamental requirement for any durability assessment is knowledge of the relationship between stress and strain and fatigue life for a material under consideration. Fatigue is a highly localized phenomenon that depends very heavily on the stresses and strains experienced in critical regions of a component or structure. The relationship between uniaxial stress and strain for a given material is unique, consistent and, in most cases, largely independent of location. Therefore, a small specimen tested under simple axial conditions in the laboratory can often be used to adequately reflect the behaviour of an element of the same material at a critical area in a component or a structure. However, the most critical locations are at notches even when loading is uniaxial (Rise et. al 1988).

Cumulative damage analysis: The fatigue life prediction process or cumulative damage analysis for a critical region in a component or structure consists of several closely interrelated steps as can be seen in Figure 2.2 separately. A combination of the load history (Service Loads), stress concentration factors (Stress Analysis) and cyclic stress-strain properties of the materials (Material Properties) can be used to simulate the local uniaxial stress-strain response in critical areas. Through this process it is possible to develop good estimates of local stress amplitudes, mean stresses and elastic and plastic strain components for each excursion in the load history. Rainflow counting can be used to identify local cyclic events in a manner consistent with the basic material behaviour. The damage contribution of these events is calculated by comparison with material fatigue data generated in laboratory tests on small specimens. The damage fractions are summed linearly to give an estimate of the total damage for a particular load.history (Rise et. al 1988).

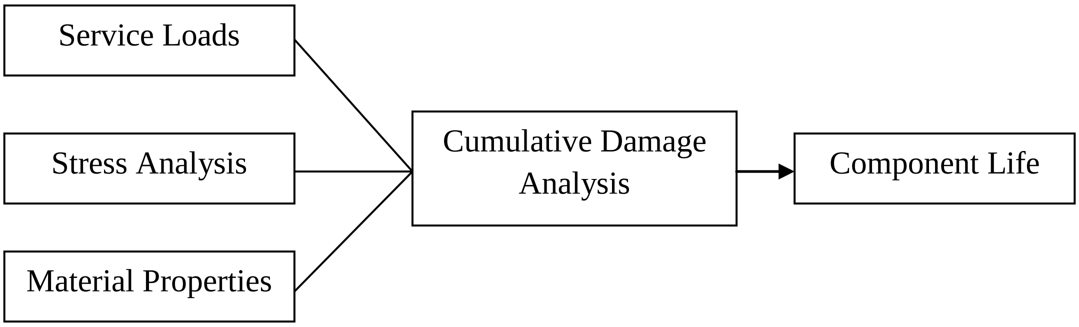

Figure 2.2: The cumulative damage analysis process

Sources: Ariduru (2004)

Component test: It must be carried out at some stage in a development of a product to gain confidence in its ultimate service performance. Component testing is particularly in today's highly competitive industries where the desire to reduce weight and production costs must be balanced with the necessity to avoid expensive service failures (Ariduru 2004).

Fatigue life estimates are often needed in engineering design, specifically in analyzing trial designs to ensure resistance to cracking. A similar need exists in the troubleshooting of cracking problems that appear in prototypes or service models of machines, vehicles, and structures. That is the reason that the predictive techniques are employed for applications ranging from initial sizing through prototype development and product verification. The functional diagram in Figure 2.3 shows the role of life prediction in both preliminary design and in subsequent evaluation-redesign cycles, then in component laboratory tests, and finally in field proving the tests of assemblies or composite vehicles and a conventional stress analysis might lead to a assumption of safety that does not exist (Ariduru 2004).

2.2 STRESS-LIFE BASED APPROACH (S-N METHOD)

For the fatigue design and components, several methods are available. All require similar types of information. These are the identification of candidate locations for fatigue failure, the load spectrum for the structure or component, the stresses or strains at the candidate locations resulting from the loads, the temperature, the corrosive environment, the material behaviour, and a methodology that combines all these effects to give a life prediction. Prediction procedures are provided for estimating life using stress life (Stress vs. Number of cycle's curves), hot-spot stresses, strain life, and fracture mechanics. With the exception of hot-spot stress method, Figure 2.3 shows all these procedures have been used for the design of aluminium structures.

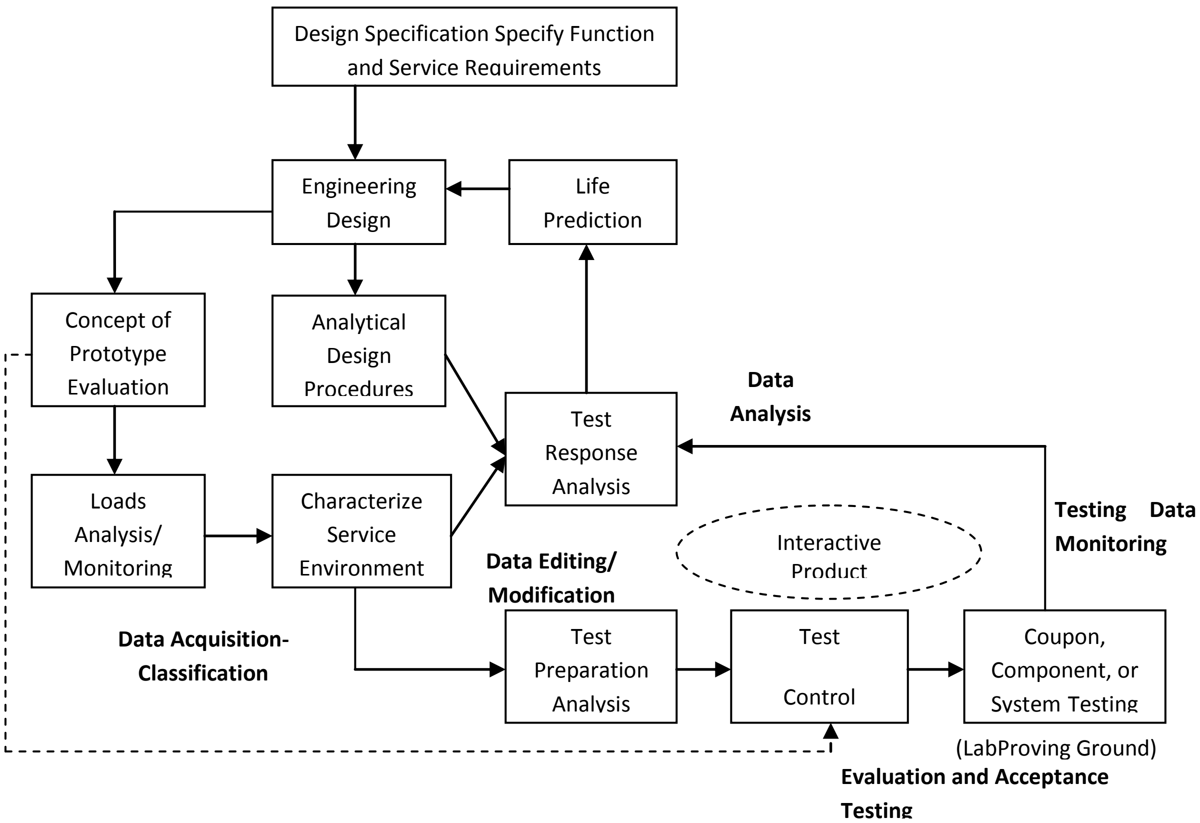

Figure 2.3: Functional diagram of engineering design and analysis

Sources: Rise et al. (1988)

Since the well-known work of Wöhler in Germany starting in the 1850's, engineers have employed curves of stress versus cycles to fatigue failure, which are often called S-N curves (stress-number of cycles) or Wöhler's curve (Lalanne et al.1999). Since the well-known work of Wöhler in Germany starting in the 1850's,engineers have employed curves of stress versus cycles to fatigue failure, which are often called S-N curves (stress-number of cycles) or Wöhler's curve.

The basis of the stress-life method is the Wöhler S-N curve, that is a plot of alternating stress, S, versus cycles to failure, N. The data which results from these tests can be plotted on a curve of stress versus number of cycles to failure. This curve shows the scatter of the data taken for this simplest of fatigue tests. A typical S-N material data can be seen in Figure 2.4. The arrows imply that the specimen had not failed in 10^7 cycles (Lalanne et al. 1999)

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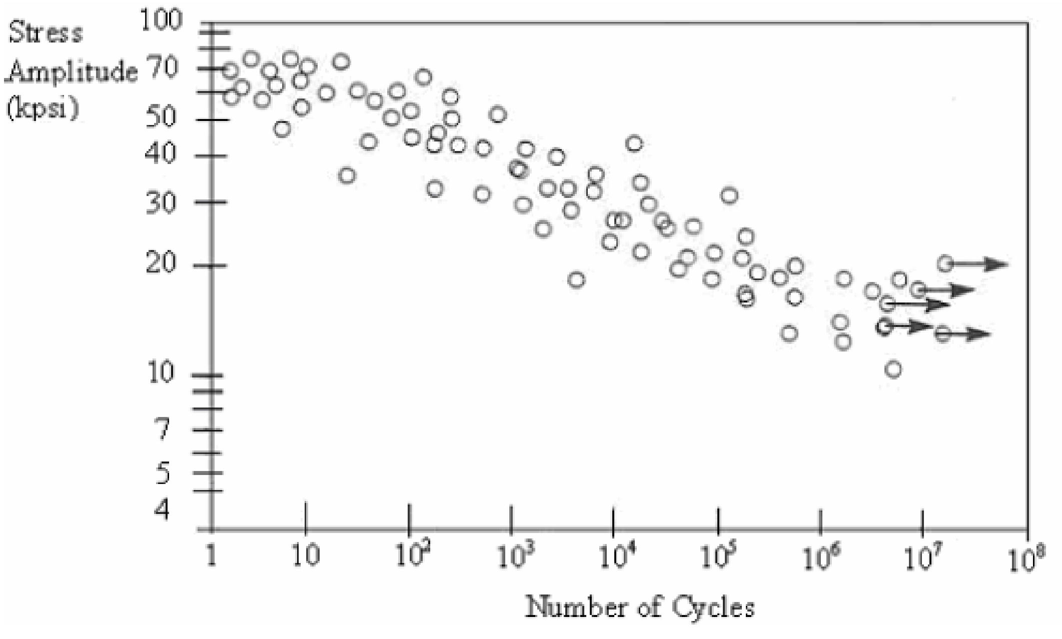

Figure 2.4: A typical S-N material data

Sources: Ariduru (2004)