FATIGUE LIFE ESTIMATION OF CYLINDER BLOCK USING STRAIN-LIFE METHOD

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SUPERVISOR'S DECLARATION

I hereby declare that I have checked this thesis and in my opinion this thesis is satisfactory in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering with Automotive Engineering.

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STUDENT'S DECLARATION

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

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ABSTRACT

This project describes the fatigue life estimation of cylinder block using strain-life method. The main objectives of this project are to predict the fatigue life of the cylinder block using strain-life method and to identify the critical locations and to investigate the effect of loading. Aluminum alloys are selected as a cylinder block materials. The fatigue life predicted utilizing the finite element based fatigue analysis code. The structural model of the cylinder block was utilizing the solidworks. The finite element model and analysis were performed utilizing the finite element analysis code. In addition, the fatigue life was predicted using the strain-life approach subjected to variable amplitude loading. TET10 mesh and maximum principal stress were considered in the linear static stress analysis and the critical location was identifying at node (109730). From the fatigue analysis, Smith-Watson-Topper mean stress correction method was conservative life subjected to SAETRN loading. It is observed that the nitrided treatment and polished surface finish produce the longest life. Smith-Watson-Topper (SWT) mean stress correction is conservative method when subjected to SAETRN loading histories and the nitriding with polished combinations have been found the great influences on the fatigue life of cylinder block.

ABSTRAK

Projek ini menggambarkan kehidupan kelelahan anggaran blok silinder menggunakan kaedah ketegangan hayat. Objektif utama projek ini adalah untuk memprediksi hayat lesu blok silinder menggunakan kaedah kehidupan regangan dan mengenalpasti lokasi-lokasi penting dan untuk meneliti kesan daripada muat naik. Paduan Aluminium dipilih sebagai bahan blok silinder. Menjangkakan hayat lesu memanfaatkan elemen hingga berdasarkan analisis kelelahan kod. Model struktur blok silinder dibuat menggunakan SolidWorks. Model elemen hingga dan analisis dilakukan menggunakan analisis elemen hingga kod. Selain itu, kehidupan kelelahan dipercayai menggunakan pendekatan hayat lesu mengalami amplitud pembolehubah bebanan. Unsur TET10 dan maksimum voltan utama yang dipertimbangkan dalam analisis linear stres statik dan lokasi kritikal dianggap di simpul (109730). Dari analisis kelelahan, Smith-Watson-Topper pembetulan voltan rata-rata adalah kaedah konservatif sasaran bebanan SAETRN. Berdasarkan keputusan yang terhad, teramati bahawa penjagaan dan dicelup nitided permukaan terpanjang tamat menghasilkan kehidupan untuk semua kondisi beban. Sebagai kesimpulan, Smith-Watson-Topper (SWT) pembetulan voltan rata-rata adalah kaedah konservatif dan kombinasi nitriding dengan kombinasi dicelup telah dijumpai pengaruh besar dalam kehidupan kelelahan silinder blok.

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LIST OF SYMBOLS

$2Nt$	Transition fatigue life
ε_e	Elastic component of the cyclic strain amplitude
ε'_f	Fatigue ductility coefficient
σ'_f	Fatigue strength coefficient
σ_0	Positive for tensile stress and negative for compressive stress
σ_{max}	Local maximum stress
σ_{UTS}	Tensile strength
σ_{YS}	Yield strength
$\frac{\Delta}{2}$	Strain amplitude
b	Fatigue strength exponent
D	Cumulative damage
E	Modulus of elasticity
KIC	Fracture toughness
n_i	Number of load cycles
n	Strain hardening exponent
N_f	Number of cycles to failure
	Number of fatigue life
$S–N$	Stress verse cycles to failure
	Fatigue strength
	Load cycle with amplitude

LIST OF ABBREVIATIONS

Al	Aluminium
AA	Aluminum Alloy
CAD	Computer-aided design
CAE	Computer-aided engineering
FE	Finite element
FFM	Finite element modeling
LFC	Low fatigue cycle
MBD	Multibody dynamics
MPC	Multi-Point Constraints
SAE	Society of Automotive Engineers
SAETRN	Positive mean loading
SWT	Smith-Watson-Topper
TET	Tetrahedral

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

The fatigue lives of vehicle components play an important role in the design of vehicles to assure the safety and reliability of vehicles. It is of great significance to predict and evaluate the fatigue lives of the components utilizing theories on fatigue life (Li et al., 2009). Fatigue usually involves the initiation and growth of a crack until it reaches a critical size, sometimes causing separation into two or more parts.

Internal combustion engine has many complicated parts including the cylinder block where it is one of the most complicated parts if the internal combustion engine. Usually, cylinder block connected with many parts like combustion chamber, intake and exhaust valve ports, valves with valves seat and guides, a fuel injector and a complex of cooling passages. In heat cycling, the cylinder block is related with heat cycling when an engine at stopping, the temperature of an engine is low and when it is running, the temperature is high. (Sasaki and Takahashi, 2006). Using the demand for an aluminum alloy cylinder block has increased and this material to reduce the weight of automobiles and important for environmental protection. It will improve fuel economy. Aluminum and alloys usually are used as cylinder block materials because the material has excellent properties of casting. It has high thermal conductivity, low thermal expansion and high tension or compression strength to be a good thermal. For the reason of light weight required, aluminum alloys are taken by the automotive engineer (Winter et al., 2005).

Nowadays, the design of the components would be optimized for the best performance. Refer to technical and commercial requirements, operation of the internal combustion engines should with higher cylinder pressures (Mendes and Cardoso, 2007). According to Kim and Moon (2007), in designing a cylinder block, it changing the design in a particular region to produce the better, light weight, stronger, increase the safety, and the cost of production is reduce.

1.2 PROBLEM STATEMENT

The failure of the cylinder block for two strokes linear engine is due to fatigue. To solve this problem, it is not limit of any limitation of the CAD and Finite Element Modeling and Analysis, but in how the product knowledge is improved and generated to making the decision and drive innovation (Murphy and Axtman, 2007). There are many practical engineering problems for which we cannot obtain exact solutions to get a better result in daily operation. So, optimization of the component to make the less time to produce the better, stronger, lighter, safer and less cost productions (Rahman et al., 2008). Currently, to optimize the design of the cylinder block, aluminum alloy is suitable material according to their characteristics including lighter, low cost, and acceptable mechanical properties using the simulations for fatigue life analysis. In the end of the result, the component can give the most efficient designs, light-weighting, and have for market success in the automotive and manufacturing industry.

1.3 SCOPE OF STUDY

The scopes of study are as follows:

i. Structural modeling
ii. Finite element method (FEM)
iii. Fatigue analysis under variable amplitude loading
iv. Surface treatment analysis

1.4 OBJECTIVES OF THE PROJECT

The objectives of this project are as follows:

i. To predict the fatigue life of the cylinder block using strain-life method and identify the critical locations.
ii. To investigate the effect of loading on fatigue life.

1.5 OVERVIEW OF THE REPORT

Chapter 1 introduces the background of the project. The problem statement and the scopes of this study also included in this chapter. Chapter 2 presents the literature study about finite element method, strain-life method and variable amplitude loading. Chapter 3 discusses the development of finite element modeling and analysis, fatigue life prediction technique and linear elastic analysis. Chapter 4 presents the results and analysis of the obtained results and discusses it elaborately. Chapter 5 presents the conclusion and recommendation of the future work.

CHAPTER 2

LITERITURE REVIEW

2.1 INTRODUCTION

The purpose of this chapter is to provide a review of the past research related to the fatigue life method, variable amplitude loading and strain-life method.

2.2 FATIGUE LIFE PREDICTION METHOD

Metal fatigue, which results in fatigue cracks, is the process of premature failure or damage of a component subjected to the repeated application of loads which individually would be too small to cause failure. Fatigue cracks usually initiate on the surface of the component on the microscopic scale and they are referred to as crack initiation. During the fatigue life, crack growth usually occurs on the macroscopic scale in the direction normal to the applied tensile stress, and it is referred to as crack propagation.

Takahashi et al. (2008) were studied on creep-fatigue life prediction methods for low-carbon nitrogen-controlled 316 stainless steel (316FR). The authors have been conducting long-term creep and creep-fatigue tests for several products of this steel. Results of these tests and evaluation of life prediction methods based upon them have been partially presented already. Superiority of the ductility exhaustion approach against time fraction approach was made clear. Afterwards, additional tests at lower strain range or longer hold time were started to evaluate the applicability to longer-term region. Some new data have been obtained from these tests and the observations obtained in the early stage were evaluated again. In order to address the concerns about applicability of the life prediction method to multiaxial stress states, biaxial fatigue and creep-fatigue tests using cruciform specimens were additionally performed during this phase of the program.

Adib and Pluvinage (2003) were proposed the theoretical and numerical aspects of the volumetric approach for fatigue life prediction in notched components. This paper discussed the complete investigation in theoretical base, intrinsic features, assumptions and its applicability for various notched components. The effective stress, effective plastic zone and relative stress gradient are determined by means of elastic–plastic finite element analysis.

Ås et al. (2008) were studied surface roughness characterization for fatigue life predictions using finite element analysis. The authors aimed are to establish a method to improve the fatigue life prediction of components with rough surfaces. Methods for determining residual stresses and microstructure are well established, whereas surface roughness cannot readily be characterized in terms of fatigue life. Common methods employing reduction factors and roughness parameters are notoriously inaccurate, leading to large safety factors and overly conservative designs. A new method is proposed, in which microscopic surface measurements are used to create finite element models of surface topography. The influence of surface roughness on fatigue life can then be based on stress solutions instead of empirically derived reduction factors.

Chu (1997) was studied multiaxial fatigue life prediction method in the ground vehicle industry. Author was reviewed the features of multiaxial fatigue method through application to the analysis of three types of input history. These are load or strain controlled constant amplitude test results, a local strain history recorded by rosette strain gages installed at a critical location and an external load history of a real structural component.

Shim and Kim (2008) was studied the cause of failure and optimization of a V-belt pulley considering fatigue life uncertainty in automotive applications. Authors also analyzed a critical part by using plastic processing methods and investigated the cause of failure. The applied stress distribution of the pulley under high-tension and torque was obtained by using FEA. Based on these results, the fatigue life of the pulley considering the variation in the fatigue strength was estimated with a durability analysis simulator. A study on the shape of the optimal design was performed to increase the fatigue life of the pulley, while minimizing the weight of the V-belt pulley in the compressor system of a vehicle.

2.3 VARIABLE AMPLITUDE LOADING

Constant amplitude fatigue loading is defined as fatigue under cyclic loading with constant amplitude and a constant mean load. However, engineering components are usually subjected to variable amplitude loading which can be defined by complex loading histories of varying cyclic stress amplitudes, mean stresses and loading frequencies.

When components are subjected to variable amplitude service loads, additional uncertainties arise, whether the loading in laboratory tests related to the loads that could be expected to appear. Traditionally this problem is solved by using the simplifying assumption of damage accumulation, and constant amplitude tests in laboratory are transformed to variable amplitude severity by the Palmgren-Miner rule which says that a load cycle with amplitude adds to the cumulative damage (*D)*, a quantity (*1/*). Here, denotes the fatigue life under constant amplitude loading with amplitude and n_i is the number of load cycles at this amplitude.

$$D = \quad - \tag{2.1}$$

The lack of validity of this accumulation rule has been demonstrated in many applications and in consequence its usage will introduce uncertainties which must be compensated for by safety factors.

One possible way to diminish the deviations from the damage accumulation rule is to perform the laboratory experiments closer to the service behaviour with respect to the loads. A method for establishing a Wohler curve based on variable amplitude loads has recently been developed and is presented in a parallel paper

Johannesson et al. (2005). The use of this method should be customized to each specific application by performing laboratory tests with load spectra covering different service requirements. One idea is that service measurements are used to establish a few reference load spectra for use in laboratory tests. Based on the resulting variable amplitude Wohler curve, fatigue life can be predicted for load spectra similar to the reference types.

Sonsino (2006) was studied about fatigue testing under variable amplitude loading. Author was aimed at presenting how spectra and test conditions should be clearly described and how statistics can be applied when variable amplitude test results. The major reason for carrying out variable amplitude loading (VAL) tests is the fact that a prediction of fatigue life under this complex loading is not possible by any cumulative damage hypothesis. Therefore, for the purpose of fatigue lifting, experiences must be gained by such tests which allow to derive real damage sums by comparing Woehler- and Gassner-lines. Variable amplitude loading (VAL) tests are principally carried out like constant amplitude loading tests (CAL) on different load levels. As long as the frequency does not affect the fatigue life, or particular attention of the frequency content is not required, the frequency can be increased for shortening the testing time. However, depending on the interaction between the testing machine and the stiffness of the specimen, the overall testing frequency can be limited. In such cases, especially low load amplitudes can be accelerated by an amplitude and frequency adaptive control.

Kang et al. (2007) were studied a thermo-mechanical fatigue damage model for variable temperature and loading amplitude conditions. The approach in this study required a few steps to predict fatigue life of the exhaust systems subjected to thermo-mechanical loading. The first step was to obtain strain history at variable load amplitudes and temperatures. Then, it was necessary to identify a closed loading cycle. The closed loading cycle contained strain range, cycle time, mean stress, and equivalent temperature. This information was used to calculate mechanical fatigue damage and oxidation damage for the cycle. The next step was to calculate mechanical fatigue damage using the Smith–Watson–Topper equation with fatigue properties at room temperature. The last step for this approach was to determine the oxidation damages due to high temperature effect. The total damage was the summation of the mechanical fatigue damage and the oxidation damage. A case study with automotive exhaust systems was conducted to validate this approach and showed that the approach correlated well with experimental results under variable amplitude thermo-mechanical loading.

Nolting et al. (2007) were investigated the variable amplitude fatigue of bonded aluminum joints. The purpose of this paper is to examine the effect of overload cycles and variable amplitude loading on the fatigue behavior of bare and clad adhesively bonded double strap joints. Four sets of fatigue tests were conducted. The first set was constant amplitude tests that compared the fatigue behavior of bare and clad joints. The next series of tests subjected the specimens to periodic overload spectra to determine the effect of overload cycles on fatigue life and failure mode. The third test series was effective stress range vs. fatigue life tests. These were periodic overload tests that are designed to estimate the upper bound of the damage caused by the small cycles in the loading spectrum. The effective stress range vs. failure life curve was used in conjunction with a linear cumulative damage summation to calculate the fatigue lives of specimens subjected to variable amplitude loading spectra. In the fourth series of tests, specimens were subjected to those variable amplitude loading spectra and the test results compared to the calculated fatigue lives.

Bayley et al. (2000) were studied fatigue crack initiation and growth in A517 submerged arc welds under variable amplitude loading. Authors were presented a comparison between fatigue crack initiation and growth predictions for a submerged arc welded butt joint in ASTM A517 steel and the corresponding laboratory results. The fatigue tests of the butt-welded joint involved a variable amplitude spectrum consisting of three storm sequences per year. Fatigue crack initiation, coalescence and growth were monitored using a localized potential drop system. Multiple fatigue crack initiation sites were found along the weld toe of the specimen, and this was followed by fatigue crack coalescence. Fatigue life, crack initiation and growth predictions were carried out using *S–N*, local notch strain and fatigue crack propagation approaches respectively. A comparison between the predicted and experimental fatigue lives indicated that the *S–N* and fatigue crack propagation approaches were conservative while the strain life predictions were un-conservative.

2.4 STRAIN-LIFE METHOD

The local strain–life approach for fatigue life prediction has been widely accepted by the automotive industry since 1977. The local strain–life method can be used for pro-active design stages for a number of trial geometry and fabrication alternatives because, provided that the material data are given, life estimates may be made prior to the existence of any actual components. Design cycle reduction, via this method, is beneficial regarding both time and cost.

Williams et al. (2003) were studied a practical method for statistical analysis of strain–life fatigue data. Author intends to provide useful guidelines for the deterministic and probabilistic analyses of strain–life data which will result in true representation of the cyclic stress–strain and strain–life fatigue parameters. Discussion of the notch analysis methods and the mean stress correction formulas is beyond the scope of this study. Compared to the ASTM standard practice for statistical analysis of strain–life fatigue data, this paper has the following unique features:

1. A linear regression model is restricted to the linear range of the data, e.g. either the low cycle fatigue (LCF) data or the high cycle fatigue (HCF) data.

2. A threshold of plastic strain amplitude of 0.0005 is suggested, below which the data points can be neglected to avoid measurement errors.

3. A method based on a modification of the Owen tolerance interval is incorporated to quantify the statistical variation of fatigue data.