STRESS ANALYSIS AND FATIGUE LIFE PREDICTION OF A WOBBLE-PLATE

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To my beloved mother , father brothers and sister.

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ABSTRACT

A five-stage compressor for compressing natural gas is being designed and evaluated. The compressor operates at 1500 rpm with natural gas pressure of 50 psi. This study examines deformation behavior, stress and strain distribution of the wobble plate component of the compressor. Fatigue loading on the wobble plate is computed from the reaction of compressed gas in each of the five cylinders. The highest pressure in the 5^{th} cylinder is 3000 psi. The calculated stress evolution per revolution of the wobble plate is utilized to predict the fatigue lives of the wobble plate. The fatigue life prediction is performed using Brown-Miller algorithm with Morrow mean stress correction method. Results show that the stress is concentrated in the vicinity of the contact region between the guide plate and the polymer guide ball. The highest stress in the wobble plate and the polymer guide ball is 160.4 MPa and 127.8 MPa respectively. The corresponding predicted fatigue life of the wobble plate is 8×10^8 cycles. A higher stress gradient in the guide ball (max von Mises stress is 3.3 GPa) is predicted when a harder steel ball is employed. This is due to high stiffness of the mating plate/ball surfaces.

ABSTRAK

Pemampat gas natural lima-peringkat telah direka dan dinilai. Pemampat ini beroperasi pada kelajuan 1500 putaran seminit, dengan tekanan gas 50 psi. Kajian ini adalah berkenaan penyelidikan terhadap kelakuan ubah bentuk, dan taburan tegasan dan terikan yang terjadi ke atas komponen tersebut yang diperolehi dan dikira dari tindakbalas gas termampat di dalam setiap lima silinder pemampat tersebut. Tekanan yang tertinggi adalah 3000 psi di dalam silinder kelima. Tegasan setiap putaran *wobble plate* yang dikira digunakan untuk menganggar hayat lesunya. Hayat lesu plat tersebut dikira menggunakan algoritma *Brown-Miller* dengan kaedah *Morrow* bermaksud kaedah pembetulan tegasan purata. Keputusan menunjukan tegasan menumpu terjadi di permukaan sentuhan di antara plat pengawal dan bebola pengawal polimer. Tegasan tertinggi pada *wobble plate* dan bebola pengawal polimer adalah 160.4 MPa dan 127.8 Mpa. Manakala hayat lesu *wobble plate* yang sepadan adalah sebanyak $8x10^8$ kitaran. Dianggarkan kecerunan tegasan yang terjadi pada bebola pengawal akan menjadi lebih tinggi apabila keluli yang lebih kaku (tegasan von Mises maksima adalah 3.3 GPa) digunakan. Perkara ini adalah berdasarkan kewujudan tahap kekakuan yang tinggi pada kedua-dua permukaan plat/bebola.

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σ_1	Maximum principal stress
σ_2	Mean principal stress
σ_3	Minimum principal stress
σ_y	Tensile yield stress
n	Factor of safety
σ_a	Mean stress
$\Delta\varepsilon$	is the applied strain range
$2N_f$	is the endurance in reversals
σ'_f	is the fatigue strength coefficient
ε'_f	is the fatigue ductility coefficient
E	Modulus of Elasticity
ν	Poisson ratio
I	Moment of inertia
P	Force on free end of cantilever
M	Bending Moment
Y	Distance from neutral Axis
UTS	Ultimate tensile stress
σ_{max}	Maximum stress
σ_{min}	Minimum stress
σ_a	Mean stress Range
ε_n	Normal strain
ε_1	Maximum Principal Strain
ε_3	Minimum Principal Strain
γ_{max}	Maximum shear strain
σ_{a0}	stress Range at zero mean stress

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CHAPTER1

INTRODUCTION

1.0 Compressors

A gas compressor is a mechanical device that takes in a gas and increases its pressure by squeezing a volume of it into a smaller volume. Compressor types range from the simple hand pump and the piston-equipped compressor used to inflate tires to machines that use a rotating, bladed element to achieve compression.

The four basic types of compressors are reciprocating, rotary screw, centrifugal, and axial-flow. The most popular type is the reciprocating (or piston-and-cylinder) compressor, which is useful for supplying small amounts of a gas at relatively high pressures. In this type of compressor, a piston is driven within a cylinder; the gas is drawn in through an inlet valve on the suction stroke of the piston and is compressed and driven through another valve on the return stroke.

The rotary-screw compressor uses two meshed rotating helical rotors within a casing to force the gas into a smaller space. The centrifugal compressor consists of a rotating impeller mounted in a casing and revolving at high speed.

This causes a gas that is continuously admitted near the center of rotation to experience an outward flow and a pressure increase due to centrifugal action. In an axial-flow compressor, the gas flows over a set of airfoils spinning on a shaft in a tapered tube. These draw in gas at one end, compress it, and output it at the other end. Axial-flow compressors are used in jet aircraft engines and gas turbines. Air under compression can be stored in closed cylinders to provide a continuous or as-needed supply of pressurized air.

1.1 Project Background

A major step towards preserving a green environment in a cosmopolitan city is through utilization of natural gas as an alternative fuel for automotive combustion engines. This effort is facilitated by the availability of natural gas network supply and compressed gas supply at filling stations. Such natural gas refueling station requires an efficient compressor to compress low line pressure gas supply to high pressure gas storage, piping, metering and disposer system.

The challenge to design, fabricate and evaluate a natural gas compressor is taken by a researcher team at the faculty of mechanical engineering, UNIVERSITI TEKNOLOGI MALAYSIA. A five stage compressor capable of receiving the pressure of natural gas supply up to 3000psi has been designed. This rate of pressure is requiring for proper disposing of the fuel into the gas tank of a car.

The prototype of the compressor is shown in figure1. The design of the compressor employs a pair of wobble plates that synchronize the movement of the five pistons in each cycle through the connecting rods.

Since the wobble plate is subjected to cyclic load due to the reaction forces from each cylinder, fatigue is of great concern. This study examines the stress distribution in the plate material and attempts to predict fatigue lives of the component.

1.2 Objectives of the Project

The objectives of the project are divided into main four points as:

i. To investigate the loading characteristics of the wobble plate component of a natural gas compressor.

ii. To examine the stress distribution in the wobble plate due to proposed loading typical of a five stage compressor.

iii. To estimate the fatigue lifetime of the prototype wobble plate component.

iv. To examine fatigue life of the component for different types of materials.

1.3 Scope of the Study

This study is limited to the design of wobble plate for Natural Gas Compressor; prototype has been conducted by Universiti Teknologi Malaysia researchers. Material used for the wobble plate is Isotropic homogenous aluminum alloy.

The reaction force of the five pistons on the wobble plate is calculated based on the cylinder pressure on the area of the piston, with the neglecting to the effect of the friction on the moving parts.

Commercial FEA package (Abaqus6.5.1) is used for the analysis of the stress and strain occurred on the component under study. For the analysis of fatigue life prediction Fe Safe5.1 package has been used.

1.4 Significance of the Study

This study addresses important issues related to stress analysis and fatigue of a critical engineering component.

i. Stress distribution helps identify the location of the high stress gradient which may require redesign of the component or selection of alternative material.

ii. Numerical modeling using finite element analysis can reduce cost by minimizing the design cycle.

iii. Response of component subjected to complex loading is difficult to observe experimentally, but can be predicted numerically.

iv. Life prediction eliminates fatigue failure early in design stage.