STRUCTURAL DESIGN AND ANALYSIS OF A MICROTURBINE COMPRESSOR

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Especially dedicated to:

my parents, Sugiharti and Bambang Soegeng;

my sister, Linda Cita Mahars;i

my little niece, Nafesa Shafira Azzahranisa;

my brother in law, Bambang Soedjajono; and my love Ratih Dewi Ayu Ningrum.

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ABSTRACT

A structural design was conducted on a compressor for a microturbine generating 100 kW output power. The scope concerned the conceptual design of gas turbine system, the sizing of the compressor, the computation of loads acting on compressor and the stress analysis for its structural integrity. The dimensions and the physical properties of the compressor impeller were calculated based on the given microturbine output power, using thermodynamic equations on turbomachinery aspects. Thereafter a simplified one-tenth model of the ten-bladed impeller was created in *Fluent*, a Computational Fluid Dynamic (CFD) program, taking into consideration the axisymmetric boundary conditions. The analysis was run at the standard sea level atmospheric conditions (ISA) to obtain the fluid forces acting on the blade surfaces. These forces, together with the rotational inertial loads, were then used as the loading input parameters for the structural integrity analysis done using the Finite Element program *MSC.Nastran*. The resulting stresses and deformations were obtained and contours plotted. Comparisons were done between the curved blade and the straight blade designs. The results showed that the curved blade gave better stress distribution, thus this shape was then tested for various rotational speeds. Analyses were also conducted on different materials for the compressor impeller structure, and steel was subsequently demonstrated to be the one which was to be suitable and safe.

ABSTRAK

Suatu rekabentuk struktur dijalankan ke atas pemampat bagi sebuah mikroturbin yang menghasilkan kuasa keluaran sebesar 100 kW. Skop kerja merangkumi rekabentuk konsep bagi sistem turbin gas, pensaizan pemampat, pengiraan beban yang bertindak ke atas pemempat, dan analisis tegasan bagi memastikan integriti struktur. Dimensi dan ciri fizikal pendesak pemampat dikira berdasarkan kuasa keluaran yang diberikan oleh mikroturbin, menggunakan persamaan-persamaan termodinamik untuk turbomesin. Seterusnya suatu model sepersepuluh yang dipermudahkan dibina dalam perisian dinamik bendalir komputasi (CFD) *Fluent*, mengambil kira keadaan sempadan simetri sepaksi. Analisis dilaksanakan pada keadaan atmosfera aras laut piawai untuk mendapatkan beban-beban bendalir yang bertindak ke atas permukaan bilah. Beban-beban ini, bersama dengan beban inersia putaran, seterusnya digunakan sebagai parameter pembebanan masukan bagi analisis integriti struktur menggunakan perisian unsur terhingga *MSC.Nastran*. Tegasan-tegasan dan perubahan bentuk yang terhasil diperolehi dan konturnya diplotkan. Perbandingan dijalankan ke atas rekabentuk bilah melengkung dan bilah lurus. Keputusan menunjukkan bilah melengkung mempunyai taburan tegasan yang lebih baik, lalu rekabentuk ini diuji pada beberapa kelajuan putaran. Analisis juga dilakukan ke atas bahan struktur pemampat pendesak yang berbeza, dan keluli menunjukkan bahan yang paling sesuai dan selamat.

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LIST OF SYMBOLS

SYMBOL	SUBJECT
2D	Two Dimensional
3D	Three Dimensional
Al 7075	Aluminium Alloy
b	Impeller Outlet Depth
C_1	Compressor Inlet Sound Velocity
C_2	Compressor Outlet Sound Velocity
CFD	Computational Fluid Dynamic
Cp	Gas Constant Pressure
d	Shaft Diameter
d.shaft	Shaft Diameter
d_1	Compressor Inducer Inner Diameter
d_2	Compressor Outer Diameter
DOF	Degree of Freedom
dP/P	Change in Pressure
E	Elastic Modulus
EGT	Exhaust Gas Temperature
ETATH	Gas Turbine System Efficiency
F, G, H	Flux Vector
FEA	Finite Element Analysis
FEM	Finite Element Method
g	Gravitational Acceleration
h	Impeller-to-shaft Attachment Depth
H	Air Enthalpy

Hp	Polytrophic Head
I	Invariant of Stress Tensor
J	Inertial Moment
Kt/Kb	Shock and Fatigue Factor Applied to Torsional Bending Moment
LHV	Lower Heat Value
M_b	Bending Moment due to Centrifugal Force
$M_{D.G}$	Bending Moment due to Differential Growth
MIT	Massachusetts Institute of Technology
Mrot	Impellers Tip Mach number
Mt	Shaft Torsional Moment
MTU	Maschinen Triebwerken Unsere (German Aero Engine Company)
N	Shaft Rotational Speed
n	Polytrophic Constant
p_1	Compressor Inlet Pressure
p_2	Compressor Outlet Pressure
Q	Heat
r	Radial Coordinate
R	Hydraulic Radius
RNG	Renormalization Group
ROM	Reduced Ordered Model
rp	Gas Constant
S	GasConstant Pressure
S.F.	Safety Factor
S_b	Bending Stress
$S_{D.G}$	Bending Test due to Differential Growth
S_m	Mass Added to The Continuous Phase
t	Impeller Hub Depth
T	Traction
T_1	Compressor Inlet Temperature
T_2	Compressor Outlet Temperature
T_C	Thermal Expansion Coefficient
Tet	Tetrahedral Topology
Ti-6Al-4V	Titanium Alloy
TIT	Turbine Inlet Temperature

ŧ	Shaft Torsional Stress
U	Internal Energy
U.T.S	Ultimate Tensile Strength
u_1	Compressor Inner Diameter Speed
u_2	Compressor Outer Diameter Speed
V	Volume
v	Specific Volume of Air
vr_1	Inlet Tangential Air Velocity
vr_2	Outlet Tangential Air Velocity
wp	Polytrophic Shaft Power
x	Axial Coordinate
z	Compressibility Factor
$\beta = \alpha$	Degree of Curvature
η_p	Compressor Polytrophic Efficiency
π	Phi
σ	Stress Tensor
σ_{VM}	Von Mises Stress
Ψ	Characteristic of Pressure Number
$\dot{m}$	Mass Flow
τ	Impeller-to-shaft Applied Torsional Stress
γ	Air Constant
ρ	Specific Mass
$\rho\vec{g}$	Gravitational Body Force
$\vec{F}$	External Body Force
μ	Air Molecular Viscosity
$\vec{v}$	Absolute Velocity
$\vec{\Omega}$	Angular Velocity Vector
$k - \varepsilon$	Turbulence Transport Model
δ	Deflection to Differential Growth

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CHAPTER 1

INTRODUCTION

1.1 Background

Nowadays, the need of energy production to be used for either industrial or several transportations is in great demand. The type of power generation has become the major concern because of its widespread need. For the concern of recent time needs, the suitable power generation type is one which achieves a relatively better efficiency, low in cost, and satisfied the demanding criteria.

For those needs the gas turbine system is the answer. Gas turbines are internal combustion engines that they use a rotating shaft or rotor instead of "reciprocating" in cylinders. It has the advantages of small dimensions, light weight, easy to be serviced (resulting to low maintenance cost), and most of all it can produce more power (relative to the power produced-to-weight ratio) and faster speed spin. They became practical sixty years ago; today gas turbines are one of the keystone technologies of the civilization [1].

Because of its critical role, it is understandable that innovation to a step further is needed. In a field where the major role needed and development costs both are the major concerns, it was thought to build the smallest possible gas turbine, and to explore whether the device could be made into smaller size. The microturbine is actually the scale-down of the large ordinary gas turbine system.

This is what gave birth to this project – since the advantages of gas turbines are already known compare to the others, this project deal with designing of microturbine compressor and the corresponding overall integrity analysis of the designated compressor.

1.2 Objective of Study

The objective of this study is to design a compressor shape for 100 kW microturbine output, and conduct stress analysis based on static loading condition to ascertain its structural integrity of shape under the loads experienced in its normal operation.

1.3 Scope of Study

The project also includes the dimensional design of the compressor (impeller and its shaft). The design, then, investigated by obtaining the load under various operation conditions, and then the analysis of the structure's integrity using finite element method is conducted. It is expected that the project will provide the recommendation that can help to improve the performance of compressor design base on the previous analysis.

The scope of study consists of two major parts. The first is to design the dimension of the compressor based on the given output power. The design is expected to be the most optimal dimension to that proposed output.

The second part is the analysis of the designated dimension of the compressor. This part is investigating the load acting on the compressor using computational fluid dynamic program and conducting analysis of the structural integrity using the finite element analysis program.

1.4 Outline of Report

This project is divided into six chapters. Chapter 1 presents the background of the study, which gave birth to this project. It also covers the objective of study, the scope of study and this project's outline.

Chapter 2 describes the literature review of the project. It explains the general review of the gas turbine concept. Several reference and cites' are quotes in this chapter to be the base knowledge of the design. The specific microturbine part review is described to support the specific need of the assumptions on the project.

Chapter 3 describes the step methodology to determine the properties of the design compressor to be used to the analysis. Here the flow diagrams are provided into every part design such as the shaft material design, impeller material design, compressor properties and compressor blade design, all to describe the step to obtain the data needed.

Chapter 4 discussed the dimensioning of the compressor that can be optimally suited to the designated output power. The calculations are conducted in this chapter. Assumptions on various conditions are given here together with the important base reference quotes. Then both of them will be calculated with the appropriate equations to obtain the compressor dimension and initial data's needed for further analysis.

Chapter 5 examines the data provided by previous chapter to be used on the Computational Fluid Dynamic (CFD) program, which is here will be the *Fluent* program chosen. The result data will be regarded as the loads of certain operational condition acting on the designated compressor dimension.

On chapter 6 will be introduced the using of Finite Element Analysis (FEA) program, continue by modeled design approaches provided to be examined. The data produced by the CFD program then applied to the structure analysis by using the FEA program, which uses the *Nastran* program.

On chapter 7 will asses the analysis results both by fluid dynamic aspect and finite element aspect. The safety criteria will also be provided in concern of safety for the material used. Comparison result may also be provided in order to get the optimum result of analysis. At the end the determination of material used is expected to be established.

At the end of the project, which is will be on chapter 8, will provide the highlighted conclusions and expected to have recommendation, could be provided to help to improve the performance of compressor design base on the previous analysis. This is by combining analysis from the initial design, loads acting on compressor until the structure integrity. So by this way, it is expected to have a sufficient conclusion on overall performance of the design that could be realized by making the microturbine compressor into real.