

DEVELOPMENT OF ROTOR FOR AXIAL FLOW COMPRESSOR

MOHD IHSAN BIN HUSSIN

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

‘I admit to have read this report and it has followed the scope and quality in Partial
Fulfillment of Requirements for the Degree of Bachelor Mechanical Engineering
(Thermal Fluid)’

Signature :

Supervisor :

Date :

DEVELOPMENT OF ROTOR FOR AXIAL FLOW COMPRESSOR

MOHD IHSAN BIN HUSSIN

This report for Projek Sarjana Muda is submitted in partial fulfillment for Bachelor of
Mechanical Engineering (Thermal Fluid)

Faculty of Mechanical Engineering
Universiti Teknikal Malaysia Melaka

APRIL 2009

“I admit that this report is my own work except for some summaries and information
which I have already stated”

Signature :

Author : MOHD IHSAN BIN HUSSIN

Date : 10th APRIL 2009

This report is dedicated to my lovely mother Mrs. Arseh@Rukinah Sukardi, my father Mr. Hussin Hj. Tengah, and my family.

ACKNOWLEDGEMENT

First of all in the name of Allah, thanks because give me brightness to complete this Project Sarjana Muda (PSM) successfully. There is no regret when go through a thorny road with the guide from The Most Merciful.

In this opportunity I would like to express my sincere gratitude to my supervisor Mr. Mohamad Firdaus Bin Sukri for his invaluable guidance, indispensable help and continuous encouragement throughout the course and the success of this project.

Thank you very much to Faculty of Mechanical Engineering, UTeM for all the cooperation and contribution towards the completion of my PSM. To all my friends, thank you for your encouragement and brilliant idea.

Last but not least, to my family they gave me all the courage, inspiration, motivation, and love that I need in my quest for the success and accomplishment for this project.

ABSTRAK

Mesin turbo merupakan mesin di mana pertukaran tenaga berlaku di antara bendalir yang mengalir dengan bilah kipas yang berputar, hasil daripada tindakan dinamik dan menghasilkan perubahan tekanan dan momentum ke atas bendalir tersebut. Dalam Projek Sarjana Muda ini, kajian terhadap kecondongan sudut bilah dan halaju putaran rotor terhadap kadar alir udara, tekanan, dan kecekapan pemampat dijalankan untuk merekabentuk sebuah rotor pemampat paksi. Beberapa siri eksperimen dijalankan ke atas unit *FM36 Air Flow Compressor Test Rig* yang terdapat di Universiti Teknikal Malaysia Melaka bagi mendapatkan parameter yang optimum bagi bilah bersudut 50°, 60°, 70° dan 80°. Didapati bahawa halaju dan tekanan udara yang dimampat berkadar terus dengan halaju putaran. Sudut bilah yang kurang bertepatan dengan halaju menyebabkan pemampat kehilangan kecekapan disebabkan fenomena ketegunan. Hasil analisis data digunakan dalam penentuan sudut pintalan bilah rotor, di mana ia merupakan faktor penting dalam penghasilan sesebuah rotor pemampat paksi. Kajian ini amatlah penting bagi menambah kefahaman yang mendalam terhadap sesebuah mesin turbo terutamanya pemampat paksi. Hasil daripada kajian ini akan digunakan dalam pembangunan rotor pemampat paksi pada peringkat yang seterusnya.

ABSTRACT

A turbomachine is a device in which energy transfer occurs between a flowing fluid and a rotating element due to dynamic action, and results in a change in pressure and momentum of the fluid. This Projek Sarjana Muda was aim to investigate the effect of blade pitch angle, and rotational speed of rotor to air volume flowrate, net head and efficiency of axial compressor to develop a rotor. Series of experiment will be conduct on FM36 Axial Flow Compressor Test Rig at UTeM's laboratory to obtain optimum parameter for blade with pitch angle 50° , 60° , 70° and 80° . Found that flowrate and net head are directly proportional with rotational speed. Too large or too steep blade pitch angle will made compressor running with low efficiency caused by stall. Analysis from collected data was used to determine amount of twist for rotor blade, which is it was important factor to develop a good and efficient axial compressor. This case study is important to enhance knowledge on turbomachine especially axial compressor. This project will be used for further research in development of rotor for axial flow compressor.

LIST OF CONTENT

CHAPTER	TITLE	PAGE
	ADMISSION	ii
	DEDICATION	iii
	ACKNOWLEDGEMENT	iv
	<i>ABTRAK</i>	v
	ABSTRACT	vi
	LIST OF CONTENT	vii
	LIST OF TABLE	xii
	LIST OF FIGURE	xv
	LIST OF SYMBOL	xx
	LIST OF APPENDIX	xxi
CHAPTER I	INTRODUCTION	1
	1.1 Objective	2

CHAPTER	TITLE	PAGE
	1.2 Scope	2
	1.3 Problem statement	2
	1.4 Project methodology	3
CHAPTER II	LITERATURE REVIEW	4
	2.1 Type of turbomachine	6
	2.1.1 Turbines	6
	2.1.2 Fans	7
	2.1.3 Pumps	9
	2.1.4 Compressor	10
	2.2 Axial flow compressor	11
	2.3 Aerodynamic of axial flow compressor	11
	2.3.1 Lift	11
	2.3.2 Stall	12
	2.3.3 Compressor stall	13
	2.4 Blade profile	14
	2.4.1 Angle of attack	15

CHAPTER	TITLE	PAGE
	2.5 Twisting in axial flow compressor	16
	2.5.1 Calculation of twist in compressor blade	18
	2.6 Compressor performance	20
	2.7 Design of an axial flow compressor	22
CHAPTER III	METHODOLOGY	23
	3.1 Experiment	25
	3.1.1 Investigates the effect of various fan speed on pressure, air flow and efficiency	26
	3.2 Analysis of data	29
	3.2.1 Compressor performance	30
	3.3 Findings	30
	3.3.1 Twisting in axial compressor blade	32
	3.4 Rotor design	32
CHAPTER IV	RESULTS	34
	4.1 Experiment by using FM36 axial flow test rig	34
	4.1.1 Analysis of data Experiment 1: Rotor's blade angle 50°	35

CHAPTER	TITLE	PAGE
	4.1.2 Analysis of data Experiment 2: Rotor's blade angle 60°	41
	4.1.3 Analysis of data Experiment 3: Rotor's blade angle 70°	47
	4.1.4 Analysis of data Experiment 4: Rotor's blade angle 80°	53
	4.2 Best efficiency point (BEP)	59
	4.2.1 Sample of calculation for twisting in rotor blade	60
CHAPTER V	DISCUSSION	66
	5.1 Relation between compressor performance, net head and rotational speed	66
	5.2 Relation between angle of attack, pitch angle and compressor performance	68
	5.3 Problems encountered	69
	5.4 Recommendation	70
CHAPTER VI	CONCLUSION	71
	6.1 Conclusion	71

CHAPTER	TITLE	PAGE
	6.2 Summary	71
	6.3 Recommendations	72
	REFERENCES	73
	BIBLIOGRAPHY	76
	APPENDIX	77

LIST OF TABLE

No.	TITLE	PAGE
3.1	Various data of compressor at 1500 rpm, $\theta=50^\circ$	28
3.2	Compressor performance curve at 1500 rpm, $\theta=50^\circ$	30
3.3	Optimum parameter of compressor	31
3.4	Amount of twist for a rotor blade	32
4.1a&b	Compressor performance curve at 750 rpm, $\theta=50^\circ$	35
4.2a&b	Compressor performance curve at 1000 rpm, $\theta=50^\circ$	36
4.3a&b	Compressor performance curve at 1250 rpm, $\theta=50^\circ$	37
4.4a&b	Compressor performance curve at 1500 rpm, $\theta=50^\circ$	38
4.5a&b	Compressor performance curve at 1750 rpm, $\theta=50^\circ$	39
4.6	Best efficiency point at $\theta = 50^\circ$	40
4.7a&b	Compressor performance curve at 750 rpm, $\theta=60^\circ$	41
4.8a&b	Compressor performance curve at 1000 rpm, $\theta=60^\circ$	42

No.	TITLE	PAGE
4.9a&b	Compressor performance curve at 1250 rpm, $\theta=60^\circ$	43
4.10a&b	Compressor performance curve at 1500 rpm, $\theta=60^\circ$	44
4.11a&b	Compressor performance curve at 1750 rpm, $\theta=60^\circ$	45
4.12	Best efficiency point at $\theta = 60^\circ$	46
4.13a&b	Compressor performance curve at 750 rpm, $\theta=70^\circ$	47
4.14a&b	Compressor performance curve at 1000 rpm, $\theta=70^\circ$	48
4.15a&b	Compressor performance curve at 1250 rpm, $\theta=70^\circ$	49
4.15a&b	Compressor performance curve at 1500 rpm, $\theta=70^\circ$	50
4.17a&b	Compressor performance curve at 1750 rpm, $\theta=70^\circ$	51
4.18	Best efficiency point at $\theta = 70^\circ$	52
4.19a&b	Compressor performance curve at 750 rpm, $\theta=80^\circ$	53
4.20a&b	Compressor performance curve at 1000 rpm, $\theta=80^\circ$	54
4.21a&b	Compressor performance curve at 1250 rpm, $\theta=80^\circ$	55
4.22a&b	Compressor performance curve at 1500 rpm, $\theta=80^\circ$	56
4.23a&b	Compressor performance curve at 1750 rpm, $\theta=80^\circ$	57
4.24	Best efficiency point at $\theta = 80^\circ$	58

No.	TITLE	PAGE
4.25	Best Efficiency Point of FM36 axial flow compressor	59
4.26	Best efficiency point (BEP) in different root angle and rotation speed	60
4.27	Calculated values of amount of twist for a rotor blade	65

LIST OF FIGURE

No.	TITLE	PAGE
2.1	Diagrammatic forms of various types of turbomachine (Source: S.L Dixon, (1998))	5
2.1a	Single stage axial flow compressor or pump	5
2.1b	Mixed flow pump	5
2.1c	Centrifugal compressor or pump	5
2.1d	Francis turbine (mixed flow type)	5
2.1e	Kaplan turbine	6
2.1f	Pelton wheel	6
2.2	Pelton wheel	7

(Source: http://en.wikipedia.org/wiki/Pelton_wheel,
retrieved on 19th August 2008)

No.	TITLE	PAGE
2.3	Kaplan Turbine (Source: http://en.wikipedia.org/wiki/Kaplan_turbine , retrieved on 19 th August 2008)	7
2.4	Different types of centrifugal fans (Source: U.S Department of Energy, (2003))	8
2.4a	Forward-Curved blade fan	8
2.4b	Radial-Blade centrifugal fans	8
2.4c	Radial-Tip centrifugal pumps	8
2.4d	Backward-Inclined Fan	8
2.5	Types of fans (Source: U.S Department of Energy, (2003))	9
2.5a	Propeller fan	9
2.5b	Tubeaxial fan	9
2.5c	Vaneaxial fan	9
2.6	The blades of axial flow compressor behave like the wing of an airplane.	12
2.7	Stall phenomenon in aircraft wing	13
2.8	Blade profile (Source: U.S Department of The Army, (1991))	14

No.	TITLE	PAGE
2.9	The angle α is the angle of attack (Source: U.S Department of The Army, (1991))	15
2.10	Rotor blade or propeller blade has twist (Source: Cengel and Cimbala, (2006))	16
2.11	Graphical computation of vector at two different radius (Source: Cengel and Cimbala, (2006))	17
2.12	Velocity vectors at some arbitrary radius r of rotor blade (Source: Cengel and Cimbala, (2006))	19
2.13	Typical pump performance curves (Source: Cengel and Cimbala, (2006))	22
2.14	The operating point (Source: Cengel and Cimbala, (2006))	22
3.1	Flow chart of rotor designing	24
3.2	FM36 air flow compressor test rig	26
3.3	Rotor assembly	27
3.4	DAQ console panel	29
3.5	Butterfly valve	29
3.6	Velocity diagram of axial flow compressor	32
3.7	Rotor drawing by using SolidWorks 2005	33
4.1	Compressor performance curve at 750 rpm, $\alpha = 50^\circ$	35
4.2	Compressor performance curve at 1000 rpm, $\alpha = 50^\circ$	36

No.	TITLE	PAGE
4.3	Compressor performance curve at 1250 rpm, = 50°	37
4.4	Compressor performance curve at 1500 rpm, = 50°	38
4.5	Compressor performance curve at 1750 rpm, = 50°	39
4.6	Compressor performance curve at 750 rpm, = 60°	41
4.7	Compressor performance curve at 1000 rpm, = 60°	42
4.8	Compressor performance curve at 1250 rpm, = 60°	43
4.9	Compressor performance curve at 1500 rpm, = 60°	44
4.10	Compressor performance curve at 1750 rpm, = 60°	45
4.11	Compressor performance curve at 750 rpm, = 70°	47
4.12	Compressor performance curve at 1000 rpm, = 70°	48
4.13	Compressor performance curve at 1250 rpm, = 70°	49
4.14	Compressor performance curve at 1500 rpm, = 70°	50
4.15	Compressor performance curve at 1750 rpm, = 70°	51
4.16	Compressor performance curve at 750 rpm, = 80°	53
4.17	Compressor performance curve at 1000 rpm, = 80°	54
4.18	Compressor performance curve at 1250 rpm, = 80°	55
4.19	Compressor performance curve at 1500 rpm, = 80°	56

No.	TITLE	PAGE
4.20	Compressor performance curve at 1750 rpm, $\beta = 80^\circ$	57
4.21	Velocity diagram of axial compressor	60
4.22	Velocity vectors at some arbitrary radius r of rotor blade (Source: Cengel and Cimbala, (2006))	61
4.23	Difference pitch angle along the rotor blade	64
5.1	Graph of net head against rotational speed of compressor	67
5.2	Graph of efficiency against blade pitch angle	68

LIST OF SYMBOL

α	=	Angle of attack ($^{\circ}$)
D	=	Diameter (m)
g	=	Gravity ($9.81m/s$)
H	=	Net head ($mmWg$)
\dot{m}	=	mass flow rate (kg/s)
N	=	speed (rpm)
r	=	radius (m)
T	=	Torque ($N.m$)
U	=	Blade speed, ωr
	=	Tangential blade speed in a radius r (m/s)
V	=	Absolute velocity (m/s)
V_{in}	=	Inlet velocity (m/s)
ω	=	Rotation speed, rad/s
W	=	Relative velocity
Q	=	volume flow rate, m^3/s

LIST OF APPENDIX

No.	TITLE	PAGE
1.	Dixson FM36 axial flow compressor test rig layout	77
2.	Dixson FM36 axial flow compressor DAQ Console display	78
3.	Rotor with pitch angle $\theta = 50^\circ$	79
4.	Rotor with pitch angle $\theta = 60^\circ$	80
5.	Rotor with pitch angle $\theta = 70^\circ$	81
6.	Rotor with pitch angle $\theta = 80^\circ$	82

CHAPTER I

INTRODUCTION

A turbomachine is a device in which energy transfer occurs between a flowing fluid and a rotating element due to dynamic action, and results in a change in pressure and momentum of the fluid. Mechanical energy transfer occurs inside or outside of the turbomachine, usually in a steady-flow process. Turbomachines include all those machines that produce power, such as turbines, as well as those types that produce a head or pressure, such as centrifugal pumps and compressors. The turbomachine extracts energy from or imparts energy to a continuously moving stream of fluid.

The turbomachine as described above covers a wide range of machines, such as gas turbines, steam turbines, centrifugal pumps, centrifugal and axial flow compressors, windmills, water wheels, and hydraulic turbines. Pressure, force values of fluid flow on blades are very important for design.

In turbomachine problems, pressure, force values of fluid flow on blades are very important for design. Designers need to know how their compressor works before design a model of rotor blade, especially the moment and propulsive force values supplied by fluid in environment. More, they also need to know the behavior of these rotor blades for