AERODYNAMIC INVESTIGATIONS INTO THE INFLUENCE OF STATIONARY COMPONENTS ON THE CENTRIFUGAL COMPRESSOR PERFORMANCE

by

BASHARAT SALIM

A THESIS SUBMITTED
IN FULFILMENT OF THE REQUIREMENTS FOR
THE DEGREE OF

DOCTOR OF PHILOSOPHY

DEPARTMENT OF APPLIED MECHANICS
INDIAN INSTITUTE OF TECHNOLOGY, DELHI
INDIA

AUGUST, 1989

CERTIFICATE

This is to certify that the thesis entitled **AERODYNAMIC INVESTIGATIONS INTO THE INFLUENCE OF STATIONARY COMPONENTS ON THE CENTRIFUGAL COMPRESSOR PERFORMANCE** being submitted by **MR. BASHARAT SALIM** to the INDIAN INSTITUTE OF TECHNOLOGY, DELHI for the award of the degree of **DOCTOR OF PHILOSOPHY** in Department of Applied Mechanics is a record of bonafied research work carried out by him. He has worked under our guidance and supervison and has fulfilled the requirement for the submission of this thesis which, to our knowledge, has reached the requisite standard.

The results contained in this thesis have not been submitted in part or in full to any other University or Institute for the award of any degree or diploma.

DR. D.P. Agrawal
Assistant Professor
Mechanical Engg. Department
Indian Instt. of Tech. Delhi
New Delhi-110016

DR. R.C. MALHOTRA
Professor
Dept. of Applied Mech.
Indian Instt. of Tech.
New Delhi-110016.

ACKNOWLEDGEMENTS

It is with a sense of reverence gratitude and appreciation, that I thank Prof. R.C. Malhotra and Dr. D.P. Agrawal, thesis supervisors. Their general scholarly and methodological perespeclivision has mainly contributed to the formulation of this thesis.

I record my gratefulness to Dr. S.N. Singh for his invaluable contributions at all the stages of this endeavour.

I record my sincere thanks and special appreciation to Mr. Mohammad Iqbal Khan and Mr. Mukhtar Ahmad for their generous help and sparing time for proof reading the manuscript. I am beholden to them from the deeps of my heart. Thanks are also to Dr. A.K. Raghav and Prof. P.K. Sen for their help.

I extend my sincere thanks to the staff of Gas Dynamic Laboratory of Applied Mechnics Department for their skillful work during fabrications and experimentation. Thanks are also due to the staff of other laboratories of the Applied Mechanics Department.

The patience, understanding, moral support and encouragement rendered by my wife Mrs. Shafiqa salim and daughter "Suha" can not be expressed in words. In this situations silence rather than the eloquence is more appropriate response. I also thank my parents for the encouragement, without which, this work would not have been possible.

I also wish to express my special appreciation to Mr. Saraswat, Mr. Arora and Mr. M.K. Gaur for their services by the way of drafting figures and typing the manuscript.

BASHARAT SALIM

ABSTRACT

Centrifugal compressors are work absorbing machines in which the moving blades of the impeller suck in air in an axial direction and exhaust it into a vaneless diffuser at higher pressure, temperature and velocity. The flow at the exit of the impeller is highly non uniform formed by the complex interaction of numerous aerodynamic effect within and outside it. In moderate and high pressure compressors the vaneless diffuser is of very short length and is followed by vaned diffuser. The diffuser converts the available kinetic energy at the exit of impeller into pressure energy and exhausts into exit system for down stream usage. Performance and aerodynamics wise impeller and diffusers are interdependent. In small compressors the volute casing follows the diffuser. The presence of volute casing creats circumfential pressure distortion within both the vaneless diffuser and the impeller. The poor quality of flow at the inlet of an impeller generated by spatial restrictious on the machine, causes performance degredation of the centrifugal compressor. In a centrifugal compressor the aerodynamics within its elements and their performance is greatly effected by the interaction between the rotating impeller and its various stationary elements. The present study attempted to explore few of these interactions. Emphasis has been however given to the interval aerodynamic

of vaneless and vaned diffusers and the influence of these on the flow at the exit of the impeller.

For achieving these objectives, a centrifugal compressor rig was fabricated. Its compressor has a nineteen bladed radial tipped impeller with a matching inducer and a shroud casing. The impeller eye diameter is 300 mm exit diameter is 508mm and the blade thickness at its tip is 34mm. It is powered by 15 KW AC induction motor by means of a V belt and pulley. It rotates at 3000rpm. The impeller sucks in air at the inlet and feeds to a 38mm wide parallel walled diffuser. The diameter ratio of diffuser is 2.0. Both vaneless and vaned diffuser have been used in the present study. The vaned diffuser consisted of 18 composite profiled fibre glass vanes with initial part being logarthemic spiral and the later part beyond the throat being straight. The diffuser fed the air into an asymetric volute casing for being exhausted to the atmosphere through a delivery pipe which housed an orific meter and a cup and disc valve for flow metery and flow control respectively. In all nine configurations were tested by changing the inlet duct (3 geometries) with vaneless and vaned diffusers and four diffuser vane inlet angles (12^{o}, 16^{o}, 20^{o}, 24^{o}) in the vaned diffuser. The impeller and the volute casing was not altered in the present study.

The experimental programme was concerned with data collection in terms of velocity flow angle total and static pressure distributions from hub to shroud plane by traversing a 3 hole probe with the help of a traversing mechanism. The turbulence level has been measured with the help of DISA 55 D 01 constant temperature hot wire system using a DISA 44 P 11 probe. Static pressures on the hub shroud, shroud casing and diffuser vane surface were measured with the help of wall static taps. From this data pressure recovery and stagnation pressure loss both along the radius and with the flow rate has been calculated. The results have been mostly presented in a graphical form.

Results depict that the shape of both the impeller and stage characteristics depends upon inlet volume and diffuser vane inlet angle. Stage static pressure rise depends upon the matching of diffuser vane inlet angle with the flow angle at the exit of the impeller. Stable operating range increases with decrease in inlet volume and decreases with increase in diffuser vane inlet angle. With Vaned diffusers the flow range is dependent on the inlet volume. Vaned diffusers showed improvement of the pressure rise not only in the diffuser but more significantly in the impeller also. Configurations with vaneless diffuser showed tendency of the back flow from impeller exit to impeller inlet which manifested as a pressure rise at the tip of the impeller inlet. These configurations also depicted separation within the impeller channels. Impeller exit flow showed non uinformity in all the configurations tested. The non-uniformity depended upon both the inlet volume and the diffuser vane inlet angle. Both vaneless and vaned diffuser showed existance of reverse flow zones at the impeller exit and in the diffuser.

The reverse flow at the exit of diffuser was observed only in VLI configuration. The maximum pressure recovery in the diffuser was achieved in the confugration VD V. The mismatching was found to exist between the diffuser and other coomponents of the compressor configuration VD V which decreases its overall performance upto the exit of the configuration where VD 11 was observed to yield maximum stage static pressure coefficient $\Psi_{6s} = 1.43$.

CONTENTS

TABLES

PLATES