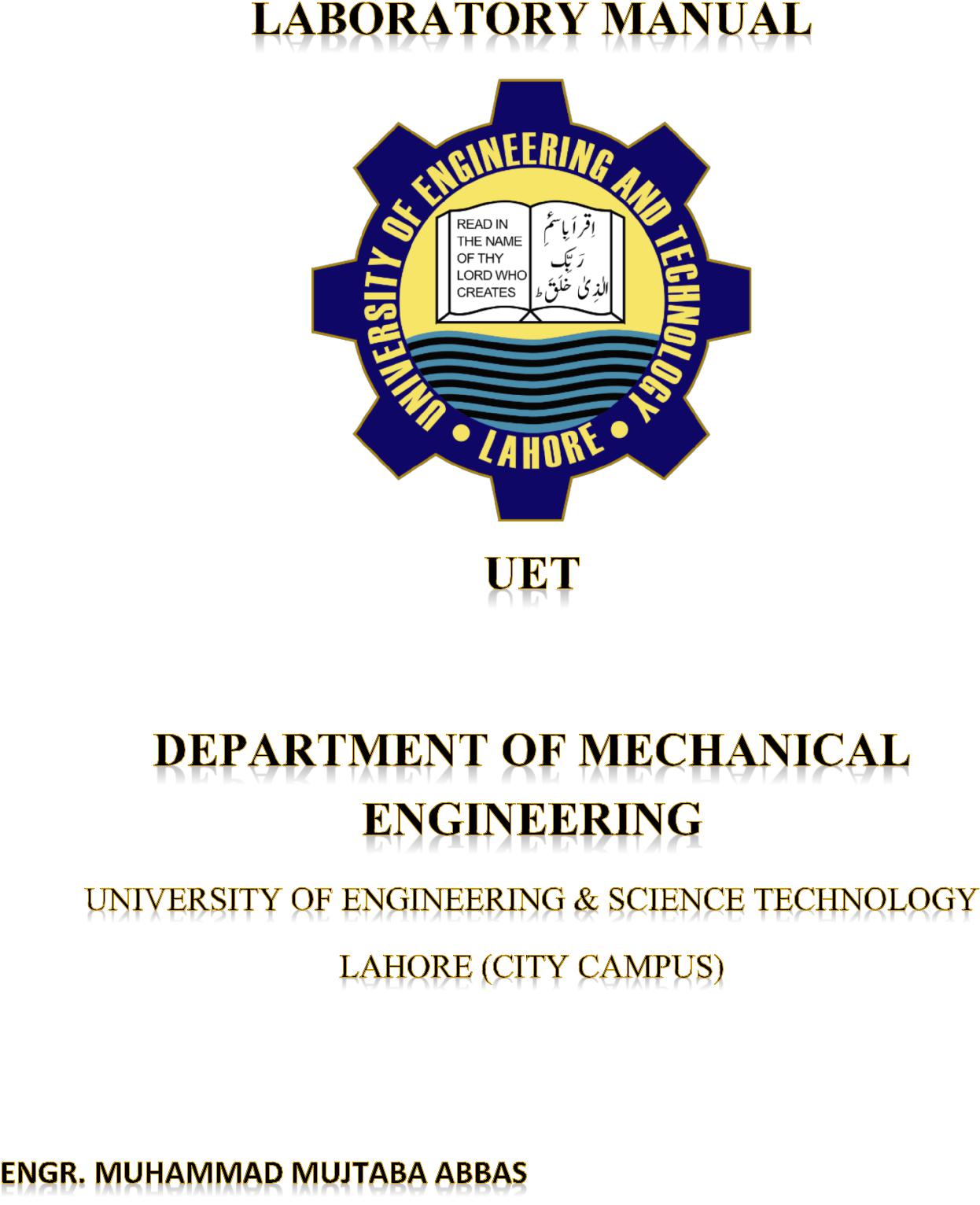
***THERMODYNAMICS II***

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**Submitted by:**

Name =

Registration No =

**Submitted to:**

# 

# Preface

In most of the engineering institutions, the laboratory course forms an integral form of the basic course in Thermodynamics II at undergraduate level. The experiments to be performed in a laboratory should ideally be designed in such a way as to reinforce the understanding of the basic principles as well as help the students to visualize the various phenomenon encountered in different applications.

The objective of this manual is to familiarize the students with practical skills, measurement techniques and interpretation of results. It is intended to make this manual self-contained in all respects, so that it can be used as a laboratory manual. In all the experiments, the relevant theory and general guidelines for the procedure to be followed have been given. Tabular sheets for entering the observations have also been provided in each experiment while graph sheets have been included wherever necessary.

It is suggested that the students should complete the computations, is the laboratory itself. However the students are advised to refer to the relevant text before interpreting the results and writing a permanent discussion. The questions provided at the end of each experiment will reinforce the students understanding of the subject and also help them to prepare for viva-voce exams.

# General Instructions to Students

* The purpose of this laboratory is to reinforce and enhance your understanding of the fundamentals of Fluid mechanics and Hydraulic machines. The experiments here are designed to demonstrate the applications of the basic fluid mechanics principles and to provide a more intuitive and physical understanding of the theory. The main objective is to introduce a variety of classical experimental and diagnostic techniques, and the principles behind these techniques. This laboratory exercise also provides practice in making engineering judgments, estimates and assessing the reliability of your measurements, skills which are very important in all engineering disciplines.
* Read the lab manual and any background material needed before you come to the lab. You must be prepared for your experiments before coming to the lab. In many cases you may have to go back to your fluid mechanics textbooks to review the principles dealt with in the experiment.
* Actively participate in class and don’t hesitate to ask questions. Utilize the teaching assistants. You should be well prepared before coming to the laboratory, unannounced questions may be asked at any time during the lab.
* Carelessness in personal conduct or in handling equipment may result in serious injury to the individual or the equipment. Do not run near moving machinery. Always be on the alert for strange sounds. Guard against entangling clothes in moving parts of machinery.
* Students must follow the proper dress code inside the laboratory. To protect clothing from dirt, wear a lab apron. Long hair should be tied back.
* Calculator, graph sheets and drawing accessories are mandatory.
* In performing the experiments, proceed carefully to minimize any water spills, especially on the electric circuits and wire.
* Make your workplace clean before leaving the laboratory. Maintain silence, order and discipline inside the lab.
* Cell phones are not allowed inside the laboratory.
* Any injury no matter how small must be reported to the instructor immediately.
* Wish you a nice experience in this lab

# 

**Table of contents**

[Preface 3](#_Toc507976352)

[General Instructions to Students 4](#_Toc507976353)

[List of Experiments 9](#_Toc507976354)

[List of Figure 10](#_Toc507976355)

[List of Tables 11](#_Toc507976356)

[1 LAB SESSION 1 12](#_Toc507976357)

[1.1 Learning Objective 12](#_Toc507976358)

[1.2 Apparatus 12](#_Toc507976359)

[1.3 Main Parts of Reciprocating Compressor 12](#_Toc507976360)

[1.4 Related Theory 12](#_Toc507976361)

[1.5 Experimental Procedure 14](#_Toc507976362)

[1.6 Observation and Calculation 15](#_Toc507976363)

[1.7 Specimen Calculations 16](#_Toc507976365)

[1.8 Statistical Analysis 16](#_Toc507976367)

[1.9 Graph 17](#_Toc507976368)

[1.10 Conclusion: 17](#_Toc507976369)

[2 LAB SESSION 2 18](#_Toc507976370)

[2.1 Learning Objective: 18](#_Toc507976371)

[2.2 Apparatus 18](#_Toc507976372)

[2.3 Main Parts of Reciprocating Compressor 18](#_Toc507976373)

[2.4 Experimental Procedure 18](#_Toc507976374)

[2.5 Observations and Calculations 18](#_Toc507976376)

[2.6 Specimen Calculations 19](#_Toc507976377)

[2.7 Statistical Analysis 20](#_Toc507976378)

[2.8 Graphs 20](#_Toc507976379)

[2.9 Conclusion 20](#_Toc507976380)

[3 LAB SESSION 3 21](#_Toc507976381)

[3.1 Learning Objective: 21](#_Toc507976382)

[3.2 Apparatus 21](#_Toc507976383)

[3.3 Main Parts of Reciprocating Compressor 21](#_Toc507976384)

[3.4 Related Theory 21](#_Toc507976385)

[3.5 Experimental Procedure 21](#_Toc507976387)

[3.6 Observations and Calculations 22](#_Toc507976388)

[3.7 Specimen Calculations 22](#_Toc507976389)

[3.8 Statistical Analysis 23](#_Toc507976390)

[3.9 Graph 23](#_Toc507976391)

[3.10 Conclusion 24](#_Toc507976392)

[4 LAB SESSION 4 25](#_Toc507976393)

[4.1 Learning Objective: 25](#_Toc507976394)

[4.2 Apparatus 25](#_Toc507976395)

[4.3 Main Parts of Reciprocating Compressor 25](#_Toc507976397)

[4.4 Experimental Procedure 25](#_Toc507976398)

[4.5 Observations and Calculations 25](#_Toc507976399)

[4.6 Specimen Calculations 26](#_Toc507976400)

[4.7 Statistical Analysis 27](#_Toc507976402)

[4.8 Graph 27](#_Toc507976403)

[4.9 Conclusion 27](#_Toc507976404)

[5 LAB SESSION 5 28](#_Toc507976405)

[5.1 Learning Objective: 28](#_Toc507976406)

[5.2 Apparatus 28](#_Toc507976407)

[5.3 Main Parts of Reciprocating Compressor 28](#_Toc507976408)

[5.4 Theory 28](#_Toc507976409)

[5.5 Experimental Procedure 28](#_Toc507976410)

[5.6 Observations and Calculations 29](#_Toc507976411)

[5.7 Specimen Calculations 29](#_Toc507976412)

[5.8 Statistical Analysis 31](#_Toc507976414)

[5.9 Graphs 31](#_Toc507976415)

[5.10 Conclusion 32](#_Toc507976416)

[6 LAB SESSION 6 33](#_Toc507976417)

[6.1 Learning Objective: 33](#_Toc507976418)

[6.2 Apparatus 33](#_Toc507976419)

[6.3 Main Parts of Reciprocating Compressor 33](#_Toc507976420)

[6.4 Experimental Procedure 33](#_Toc507976421)

[6.5 Observations and Calculations 33](#_Toc507976422)

[6.6 Specimen Calculations 34](#_Toc507976423)

[6.7 Statistical Analysis 36](#_Toc507976425)

[6.8 Graphs 36](#_Toc507976426)

[6.9 Conclusion 36](#_Toc507976427)

[7 LAB SESSION 7 37](#_Toc507976428)

[7.1 Learning Objective: 37](#_Toc507976429)

[7.2 Apparatus 37](#_Toc507976430)

[7.3 Main Parts of Impulse Turbine 37](#_Toc507976431)

[7.4 Theory 37](#_Toc507976432)

[7.5 Experimental Procedure 38](#_Toc507976433)

[7.6 Observations and Calculations 38](#_Toc507976434)

[7.7 Specimen Calculations 39](#_Toc507976435)

[7.8 Statistical Analysis 39](#_Toc507976436)

[7.9 Graphs 39](#_Toc507976437)

[7.10 Conclusion 39](#_Toc507976438)

[8 LAB SESSION 8 40](#_Toc507976439)

[8.1 Learning Objective: 40](#_Toc507976440)

[8.2 Apparatus 40](#_Toc507976441)

[8.3 Main Parts of Impulse Turbine 40](#_Toc507976442)

[8.4 Experimental Procedure 40](#_Toc507976443)

[8.5 Observations & Calculations 41](#_Toc507976444)

[8.6 Specimen Calculations 41](#_Toc507976445)

[8.7Statistical Analysis 42](#_Toc507976446)

[8.8 Graphs 42](#_Toc507976447)

[8.9 Conclusion 42](#_Toc507976448)

[9 LAB SESSION 9 43](#_Toc507976449)

9.1[Learning Objective: 43](#_Toc507976450)

[9.2 Apparatus 43](#_Toc507976451)

[9.3 Main Parts of Reaction Turbine 43](#_Toc507976452)

[9.4 Theory 43](#_Toc507976453)

[9.5 Observations and Calculations 44](#_Toc507976454)

[9.6 Specimen Calculations 44](#_Toc507976455)

[9.7 Statistical Analysis 46](#_Toc507976456)

[9.8 Graphs 46](#_Toc507976457)

[9.9 Conclusion 46](#_Toc507976458)

[10 LAB SESSION 10 47](#_Toc507976459)

[10.1 Learning Objective: 47](#_Toc507976460)

[10.2 Apparatus 47](#_Toc507976461)

[10.3Main Parts of Reaction Turbine 47](#_Toc507976462)

[10.4 Experimental Procedure 47](#_Toc507976463)

[10.5 Observations & Calculations 47](#_Toc507976464)

[10.6 Specimen Calculations 49](#_Toc507976465)

[10.7 Statistical Analysis 49](#_Toc507976466)

[10.8 Graphs 49](#_Toc507976467)

[10.9 Conclusion 50](#_Toc507976468)

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# List of Experiments

|  |  |
| --- | --- |
| **Experiment No.** | **Description** |
| Experiment No. 1 | To investigate the variation of air flow rate with compressor ratio (without intercooling)- (ITU LAB) |
| Experiment No. 2 | To investigate the variation of air flow rate with compressor ratio (with intercooling) - (ITU LAB) |
| Experiment No. 3 | To investigate the variation in the volumetric efficiency with compressor ratio (without intercooling) - (ITU LAB) |
| Experiment No. 4 | To investigate the variation in the volumetric efficiency with compressor ratio (with intercooling) - (ITU LAB) |
| Experiment No. 5 | To determine the variation of isothermal efficiency with compressor ratio (without intercooler) - (ITU LAB) |
| Experiment No. 6 | To examine the variation of isothermal efficiency with compressor ratio (with intercooler) - (ITU LAB) |
| Experiment No. 7 | To examine the torque and power characteristics of a single stage impulse turbine- (ETC LAB) |
| Experiment No. 8 | To determine the isentropic efficiency of a single stage impulse turbine- (ETC LAB) |
| Experiment No. 9 | To investigate the torque and power characteristics of a reaction turbine- (ETC LAB) |
| Experiment No. 10 | To determine the isentropic efficiency of a reaction turbine- (ETC LAB) |

# 

# List of Figure

**Figure 1.1: Two stage reciprocating compressor ………………………………………..12**

**Figure 7.1: Impulse Turbine Unit…………………………………………………………38**

**Figure 9.1: Reaction Turbine Unit…………………………………………………...........45**

# List of Tables

[**Table 1.1: Calculation Compressor**](#page15) **Ratio** **without intercooling** [**15**](#page15)

**Table 1.2: Results 16**

[**Table 2.1: Calculation Compressor**](#page15) **Ratio** **with intercooling 1**[**9**](#page15)

**Table 2.2: Results 20**

[**Table 3.1: Calculation Compressor**](#page15) **Ratio** **without intercooling 22**

**Table 3.2: Results 23**

[**Table 4.1: Calculation Compressor**](#page15) **Ratio** **with intercooling 27**

**Table 4.2: Results 28**

[**Table 5.1: Calculation Compressor**](#page15) **Ratio** **without intercooling 30**

**Table 5.2: Results 32**

[**Table 6.1: Calculation Compressor**](#page15) **Ratio** **with intercooling 35**

**Table 6.2: Results 36**

[**Table 7.1: Calculations of shaft power of Impulse Turbine**](#page15) **39**

**Table 8.1: Calculations of isentropic efficiency of Impulse Turbine 43**

[**Table 7.1: Calculations of shaft power of Reaction Turbine**](#page15) **46**

**Table 8.1: Calculations of isentropic efficiency of Reaction Turbine 49**

# 1 LAB SESSION 1

Investigation of variation of air flow rate with compressor ratio (without intercooling)

## 1.1 Learning Objective

At the end of this study, the student will be able to

* Understand the relationship between air flow rate and compressor ratio.

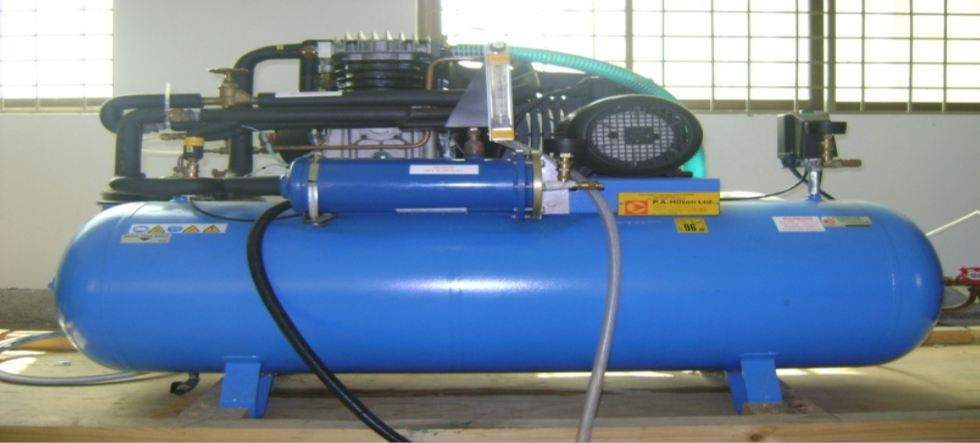
## 1.2 Apparatus

Two stage reciprocating compressor

## 1.3 Main Parts of Reciprocating Compressor

1. 1st stage compressor
2. 2nd stage compressor
3. Intercooler
4. Pressure gauges
5. Water purge valve
6. Rota-meter

## 1.4 Related Theory

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**Figure 1.1 Two stage Compressor**

**Air Compressor**

A machine suck low pressure, low temperature air from atmosphere and compresses it to high pressure and high temperature by reciprocating motion of compressor is called a compressor.

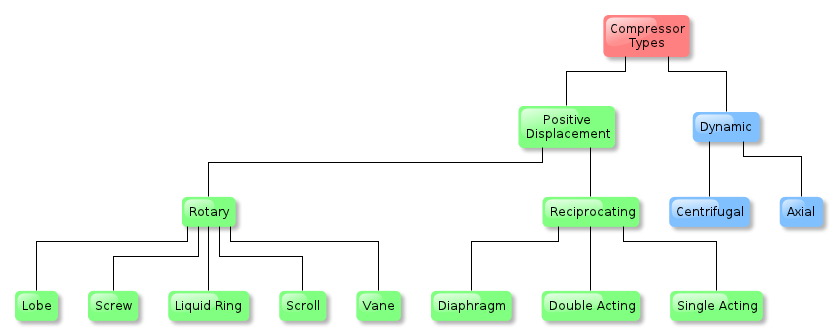
**Working Principal**

Work must be done upon the gas by an external agency. An air compressor takes in air at atmospheric pressure, compresses it at the cost of the work supplied, and delivers the high pressure air to a storage vessel called receiver from which it may be conveyed by the pipe line to a place where the supply of compressed air is required.

**Following advantages of compresses air are as follow**:

* Compressed air produces smooth translation with more uniform force
* Air does not possess the potential shock hazard of electricity or the potential fire hazard of oils.
* It is a utility that is generated in-house, so owners have more control over it than any other utility.
* It can be used to push a piston, as in a jackhammer.
* Compressed air provides torque and rotation power for pneumatic tools, such as drills, brushes, nut runners, riveting guns, and screwdrivers.
* Common applications are to cool large buildings.
* To operate lift, reams and pump.
* In paint spraying and in air conveying, the dynamic pressure of the air imparts motion.

**Types of Compressor**

****

**Positive Displacement Compressor**

In positive displacement type compressors, compression is achieved by trapping air into an enclosed space and then reducing its volume. Since a fixed amount of air is trapped each time, its pressure rises as its volume is reduced. When the pressure rises to the required level, then it is expelled from the enclosed space and a fresh charge of low-pressure air is drawn in and the cycle continues. Since the flow of air to the compressor is not steady, the positive displacement type compressor is a pulsating flow device. However, since the operating speeds are normally very high the flow appears to be almost steady on macroscopic time scale. Depending upon the construction, positive displacement type compressors can be classified into:

* Reciprocating type
* Rotary type with sliding vanes (rolling piston type or multiple vane type)
* Rotary screw type (single screw or twin-screw type)

**Reciprocating Compressors**

Reciprocating air compressors compresses air in a cylinder by reciprocating motion of piston and supplies high pressure air with intermittent discharge. Rotary compressors have compressed air at low pressure but with continuous and high discharge. Reciprocating air compressors may be single acting or double acting.

Reciprocating compressors consist of a piston moving back and forth in a cylinder, with suction and discharge valves to achieve suction and compression of air. Its construction and working are somewhat similar to a two-stroke engine, as suction and compression of air are completed in one revolution of the crank. Reciprocating air compressors are positive displacement machines, meaning that they increase the pressure of the air by reducing its volume. This means they are taking in successive volumes of air which is confined within a closed space and elevating this air to a higher pressure. The reciprocating air compressor accomplishes this by a piston within a cylinder as the compressing and displacing element.

## 1.5 Experimental Procedure

Procedure starts by entering fresh air from any source at the inlet of first compressor and conditions like temperature pressure are noted at that condition compressor increases the pressure of air. Output of first stage compressor is then enter to intercooler which has some cooling medium like water to reduce the temperature of compressed air, temperature at the exit of intercooler is nearly equal to the initial temperature. After this output air is used as input of second compressor second compressor increases pressure mire to a higher value than first one. Note temperature and pressure readings at this condition.

## 1.6 Observation and Calculation

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## Table 1.1: Calculation of compressor ratio without intercooling

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| No. of obs | Inlet Temperature  T1  oC | Air exit 1st stage T2  oC | Air inlet of 2nd stage  T3  oC | Air exist of 2nd stage  T4  oC | 1st stag pressure P1  kNm-2 | 2nd stage pressure P2  kNm-2 | Manometric height  H | Compressor  Speed  Nc  Rpm | Compressor  Current |
|  |  |  |  |  |  |  |  |  |  |
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## 

## 1.7 Specimen Calculations

T1 = \_\_\_\_\_0C, T2 = \_\_\_\_\_0C, T3 = \_\_\_\_\_\_0C, T4 = \_\_\_\_0C

1st stage pressure = P1= \_\_\_\_\_ KNm-2

2nd stage pressure = P2=\_\_\_\_\_ KNm-2

Manometric height=h= \_\_\_\_\_\_m

Air flow measurement= qv = 4.71384×10-5 = \_\_\_\_\_\_\_ m3/s

Where qv = air flow volume, h= orifice plate manometer pressure mmWg

Inlet abs =Pia = Pi + Patm = 0 + 101.325 = 101.325 KNm-2

1st stage abs= P1a = P1 + Patm = \_\_\_\_\_\_ + 101.325 = \_\_\_\_\_\_\_ KNm-2

2nd stage abs = P2a =P2 + Patm= \_\_\_\_\_\_ + 101.325 = \_\_\_\_\_\_\_ KNm-2

1st stage pressure ratio = = \_\_\_\_\_\_

2nd stage pressure ratio = = \_\_\_\_\_\_

Overall pressure ratio =\_\_\_\_\_\_

## Table 1.2: Results

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Sr.# | qv | 1st stage pressure ratio | 2nd stage pressure ratio | Overall pressure ratio |
| 01 |  |  |  |  |
| 02 |  |  |  |  |
| 03 |  |  |  |  |
| 04 |  |  |  |  |
| 05 |  |  |  |  |
| 06 |  |  |  |  |
| 07 |  |  |  |  |

## 

## 1.8 Statistical Analysis

## 1.9 Graph

Graph between Q, 1st stage P/R, 2nd stage P/R and Overall P/R

## 1.10 Conclusion:

# 2 LAB SESSION 2

Investigation of variation of air flow rate with compressor ratio (with intercooling)

## 2.1 Learning Objective:

At the end of this study, the student will be able to

* Understand the relationship between air flow rate and compressor ratio.

## 2.2 Apparatus

Two stage reciprocating compressor

## 2.3 Main Parts of Reciprocating Compressor

1. 1st stage compressor
2. 2nd stage compressor
3. Intercooler
4. Pressure gauges
5. Water purge valve
6. Rota-meter

## 2.4 Experimental Procedure

## Procedure starts by entering fresh air from any source at the inlet of first compressor and conditions like temperature pressure are noted at that condition compressor increase the pressure of air. Output of first stage compressor is then enter to intercooler which has some cooling medium like water to reduce the temperature of compressed air, temperature at the exit of intercooler is nearly equal to the initial temperature. After this output air is used as input of second compressor second compressor increases pressure mire to a higher value than first one. Note temperature and pressure readings at this condition.

## 2.5 Observations and Calculations



**Table 2.1: Calculation of compressor ratio with intercooling**

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| No. of obs | Inlet Temperature  T1  oC | Air exit of 1st stage T2  oC | Air inlet of 2nd stage  T3  oC | Air exist of 2nd stage  T4  oC | Water inlet  T5  oC | Water outlet  T6  oC | 1st stag pressure P1  kNm-2 | 2nd stage pressure P2  kNm-2 | Manometric height  h | Cooling water flow  mw  g/s |
|  |  |  |  |  |  |  |  |  |  |  |
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## 2.6 Specimen Calculations

T1 = \_\_\_0C, T2 = \_\_0C, T3 = \_\_\_0C, T4 = \_\_\_0C, T5= \_\_\_0C, T6= \_\_\_0C

1st stage pressure = P1= \_\_\_\_\_ KNm-2

2nd stage pressure = P2=\_\_\_\_\_ KNm-2

Manometric height=h= \_\_\_\_\_\_m

Air flow measurement= qv = 4.71384×10-5 = \_\_\_\_\_\_\_ m3/s

Where qv = air flow volume, h= orifice plate manometer pressure mmWg

Inlet abs =Pia = Pi + Patm = 0 + 101.325 = 101.325 KNm-2

1st stage abs= P1a = P1 + Patm = \_\_\_\_\_\_ + 101.325 = \_\_\_\_\_\_\_ KNm-2

2nd stage abs = P2a =P2 + Patm= \_\_\_\_\_\_ + 101.325 = \_\_\_\_\_\_\_ KNm-2

1st stage pressure ratio = = \_\_\_\_\_\_

2nd stage pressure ratio = = \_\_\_\_\_\_

Overall pressure ratio =\_\_\_\_\_\_\_

**Table 2.1: Results**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Sr.# | qv | 1st stage pressure ratio | 2nd stage pressure ratio | Overall pressure ratio |
| 01 |  |  |  |  |
| 02 |  |  |  |  |
| 03 |  |  |  |  |
| 04 |  |  |  |  |
| 05 |  |  |  |  |
| 06 |  |  |  |  |
| 07 |  |  |  |  |

## 

## 2.7 Statistical Analysis

## 2.8 Graphs

Graph between Q, 1st stage P/R, 2nd stage P/R and Overall P/R

## 2.9 Conclusion

# 3 LAB SESSION 3

To investigate the variation in the volumetric efficiency with compressor ratio (without intercooling)

## 3.1 Learning Objective:

At the end of this study, student will be able to

* Explain the relationship of volumetric efficiency with compressor ratio.

## 3.2 Apparatus

Two stage reciprocating compressor

## 3.3 Main Parts of Reciprocating Compressor

1. 1st stage compressor
2. 2nd stage compressor
3. Intercooler
4. Pressure gauges
5. Water purge valve
6. Rota-meter

## **3.4 Related Theory**

Volumetric Efficiency

Volumetric efficiency is the ratio of the actual volume of gas drawn into the cylinder to the piston displacement. The volumetric efficiency directly affects the capacity because the capacity depends directly on the cylinder’s piston displacement.

## **3.5 Experimental Procedure**

Procedure starts by entering fresh air from any source at the inlet of first compressor and conditions like temperature pressure are noted at that condition compressor increase the pressure of air, after this output of this air is used as input of second compressor second compressor increases pressure mire to a higher value than first one. Note temperature and pressure readings at this condition.

## 3.6 Observations and Calculations

Compressor swept volume per revolution = 0.3544×10-3 m3



**Table 3.1: Calculation of compressor ratio without intercooling**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| No. of obs | Inlet Temperature  T1  oC | Air exit of 1st stage T2  oC | Air inlet of 2nd stage  T3  oC | Air exist of 2nd stage  T4  oC | 1st stag pressure P1  kNm-2 | 2nd stage pressure P2  kNm-2 | Manometric height  H | Compressor speed  Nc  Rpm | Compressor  Current  I  Amp |
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## 3.7 Specimen Calculations

T1 = \_\_\_0C,T 2 = \_\_0C, T3 = \_\_\_0C, T4 = \_\_\_0C,

1st stage pressure = P1= \_\_\_\_\_ kNm-2

2nd stage pressure = P2=\_\_\_\_\_ kNm-2

Manometric height=h= \_\_\_\_\_\_m

Air flow measurement= qv = 4.71384×10-5= \_\_\_\_\_\_\_ m3/s

Where qv = air flow volume, h= orifice plate manometer pressure mmWg

Inlet abs =Pia = Pi + Patm = 0 + 101.325 = 101.325 KNm-2

1st stage abs= P1a = P1 + Patm = \_\_\_\_\_\_ + 101.325 = \_\_\_\_\_\_\_ KNm-2

2nd stage abs = P2a =P2 + Patm= \_\_\_\_\_\_ + 101.325 = \_\_\_\_\_\_\_ KNm-2

1st stage pressure ratio = = \_\_\_\_\_\_

2nd stage pressure ratio = = \_\_\_\_\_\_

Overall pressure ratio =\_\_\_\_\_\_\_

Va= (compressor swept volume per revolution × Nc) / 60 = \_\_\_\_\_\_ m3/ second

ηv= × 100 = \_\_\_\_\_ %

**Table 3.2: Results**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Sr.# | qv | Va | ɳv | Overall P/R |  |
| 01 |  |  |  |  |
| 02 |  |  |  |  |
| 03 |  |  |  |  |
| 04 |  |  |  |  |
| 05 |  |  |  |  |
| 06 |  |  |  |  |
| 07 |  |  |  |  |

## 3.8 Statistical Analysis

## 3.9 Graph

Graph between overall pressure ratio and volumetric efficiency.

**3.10 Conclusion**

# 4 LAB SESSION 4

To investigate the variation in the volumetric efficiency with compressor ratio (with intercooling)

## 4.1 Learning Objective:

At the end of this study, student will be able to

* Explain the relationship of volumetric efficiency with compressor ratio.

## 4.2 Apparatus

## Two stage reciprocating compressor

## 4.3 Main Parts of Reciprocating Compressor

1. 1st stage compressor
2. 2nd stage compressor
3. Intercooler
4. Pressure gauges
5. Water purge valve
6. Rota-meter

## 4.4 Experimental Procedure

Procedure starts by entering fresh air from any source at the inlet of first compressor and conditions like temperature pressure are noted at that condition compressor increase the pressure of air. Output of first stage compressor is then enter to intercooler which has some cooling medium like water to reduce the temperature of compressed air, temperature at the exit of intercooler is nearly equal to the initial temperature. After this output of the air is used input of second compressor second compressor increases pressure mire to a higher value than first one. Note temperature and pressure readings at this condition

## 4.5 Observations and Calculations

Compressor swept volume per revolution = 0.3544×10-3 m3



**Table 4.1: Calculation of Compressor Ratio with intercooling**

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| No. of obs | Inlet Temperature  T1  oC | Air exit of 1st stage T2  oC | Air inlet of 2nd stage  T3  oC | Air exist of 2nd stage  T4  oC | Water inlet  T5  oC | Water outlet  T6  oC | 1st stag pressure P1  kNm-2 | 2nd stage pressure P2  kNm-2 | Manometric height  H | Cooling water flow  mw  g/s |
|  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |
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|  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |

## 4.6 Specimen Calculations

T1 = \_\_\_0C, T2 = \_\_0C, T3 = \_\_\_0C, T4 = \_\_\_0C, T5= \_\_\_0C, T6= \_\_\_0C

1st stage pressure = P1= \_\_\_\_\_ KNm-2

2nd stage pressure = P2=\_\_\_\_\_ KNm-2

Manometric height=h= \_\_\_\_\_\_m

Air flow measurement= qv = 4.71384×10-5 = \_\_\_\_\_\_\_ m3/s

Where qv = air flow volume, h= orifice plate manometer pressure mmWg

Inlet abs =Pia = Pi + Patm = 0 + 101.325 = 101.325 KNm-2

1st stage abs= P1a = P1 + Patm = \_\_\_\_\_\_ + 101.325 = \_\_\_\_\_\_\_ KNm-2

2nd stage abs = P2a =P2 + Patm= \_\_\_\_\_\_ + 101.325 = \_\_\_\_\_\_\_ KNm-2

1st stage pressure ratio = = \_\_\_\_\_\_

2nd stage pressure ratio = = \_\_\_\_\_\_

Overall pressure ratio =\_\_\_\_\_\_\_

Va = (compressor swept volume per revolution × Nc) / 60 = \_\_\_\_\_\_ m3/ s

ηv= × 100 = \_\_\_\_\_ %

## Table 4.2: Results

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Sr.#** | **qv** | **Vs** | **ɳv** | **Overall P/R** |  |
| 01 |  |  |  |  |
| 02 |  |  |  |  |
| 03 |  |  |  |  |
| 04 |  |  |  |  |
| 05 |  |  |  |  |
| 06 |  |  |  |  |
| 07 |  |  |  |  |

## 4.7 Statistical Analysis

## 4.8 Graph

Graph between overall pressure ratio and volumetric efficiency

## 4.9 Conclusion

# 

# 5 LAB SESSION 5

To investigate the variation of isothermal efficiency with compressor ratio (without intercooler)

## 5.1 Learning Objective:

At the end of this study, student will be able to

* Explain the relationship of isothermal efficiency with compressor ratio.

## 5.2 Apparatus

Two stage compressor

## 5.3 Main Parts of Reciprocating Compressor

1. 1st stage compressor
2. 2nd stage compressor
3. Intercooler
4. Pressure gauges
5. Water purge valve
6. Rota-meter

## 5.4 Theory

**Isothermal Efficiency**

The isothermal efficiency is defined as the ratio of the work input to the isothermal process, to the work input to the actual process between the same inlet and exit pressures.

ηC = Reversible isothermal compressor work/Actual compressor work.

## 5.5 Experimental Procedure

Procedure starts by entering fresh air from any source at the inlet of first stage of compressor and conditions like temperature pressure are noted at that condition compressor increase the pressure of air, after this output of the air is used as input of second stage of compressor. It increases pressure mire to a higher value than first one. Note temperature and pressure readings at this condition.

## 5.6 Observations and Calculations

****

**Table 5.1: Calculation of compressor ratio without intercooling**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| No. of obs | Inlet Temperature  T1  oC | Air exit of 1st stage T2  oC | Air inlet of 2nd stage  T3  oC | Air exist of 2nd stage  T4  oC | 1st stag pressure P1  kNm-2 | 2nd stage pressure P2  kNm-2 | Manometric height  H | Compressor  Speed  Nc  Rpm | Compressor  Current  I  Amp |
|  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |
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|  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |

## 5.7 Specimen Calculations

T1 = \_\_\_0C, T2 = \_\_0C, T3 = \_\_\_0C, T4 = \_\_\_0C

1st stage pressure = P1= \_\_\_\_\_ KNm-2

2nd stage pressure = P2=\_\_\_\_\_ KNm-2

Manometric height=h= \_\_\_\_\_\_m

Air flow measurement= qv = 4.71384×10-5 = \_\_\_\_\_\_\_ m3/s

Where qv = air flow volume, h= orifice plate manometer pressure mmWg

Inlet abs =Pia = Pi + Patm = 0 + 101.325 = 101.325 KNm-2

1st stage abs= P1a = P1 + Patm = \_\_\_\_\_\_ + 101.325 = \_\_\_\_\_\_\_ KNm-2

2nd stage abs = P2a =P2 + Patm= \_\_\_\_\_\_ + 101.325 = \_\_\_\_\_\_\_ KNm-2

1st stage pressure ratio = = \_\_\_\_\_\_

2nd stage pressure ratio = = \_\_\_\_\_\_

Overall pressure ratio =\_\_\_\_\_\_\_

ρ Air=Pi / RTi = \_\_\_\_\_\_ kg/ litre

Mass flow of air = = qv × ρ Air= \_\_\_\_\_\_ kg/s

For adiabatic compression

To= Ti or

For the 1st stage compression T2= T1 = \_\_\_\_\_\_K= \_\_\_\_\_\_\_0C

Adiabatic work required for compression

WAdiabatic

= = \_\_\_\_\_\_\_ watts

Heat is observed by the cooling water and the heat lost can be determined from

Qwater= mwater Cpwater (T6 - T5)= \_\_\_\_\_ watts

For the 2nd stage compression T4= T3 = \_\_\_\_\_\_\_\_K =\_\_\_\_\_\_\_\_ 0C

Adiabatic work required for compression

WAdiabatic

= \_\_\_\_\_\_\_ watts

WTotal = \_\_\_\_\_\_ watts

Wiso = mRt1ln( P1/ Pa) for first stage = \_\_\_\_\_\_ watts

Wiso = mRt3ln( P2/ P1) for second stage =\_\_\_\_\_\_ watts

Wiso(total)= = mRt1ln( P1/ Pa) + mRt3ln( P2/ P1) = \_\_\_\_\_\_ watts

ɳiso= Isothermal work / Actual work = \_\_\_\_\_\_ %

## Table 5.2: Results

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| No.of obs. | T2 | T4 | Wiso | Wactual | Isothermal efficiency |
| 1 |  |  |  |  |  |
| 2 |  |  |  |  |  |
| 3 |  |  |  |  |  |
| 4 |  |  |  |  |  |
| 5 |  |  |  |  |  |

## 

## 5.8 Statistical Analysis

## 5.9 Graphs

* Isothermal efficiency vs 1st stage P/R
* Isothermal efficiency vs 2nd stage P/R
* Isothermal efficiency vs overall P/R

## 5.10 Conclusion

# 6 LAB SESSION 6

To investigate the variation of isothermal efficiency with compressor ratio (with intercooler)

## 6.1 Learning Objective:

At the end of this study, student will be able to

* Explain the relationship of isothermal efficiency with compressor ratio.

## 6.2 Apparatus

Two stage compressor

## 6.3 Main Parts of Reciprocating Compressor

1. 1st stage compressor
2. 2nd stage compressor
3. Intercooler
4. Pressure gauges
5. Water purge valve
6. Rota-meter

## 6.4 Experimental Procedure

Procedure starts by entering fresh air from any source at the inlet of first stage of compressor and conditions like temperature pressure are noted at that condition compressor increase the pressure of air, after this output of the air is used as input of second stage of compressor. It increases pressure mire to a higher value than first one. Note temperature and pressure readings at this condition.

## 6.5 Observations and Calculations

****

**Table 6.1: Calculation of compressor ratio with intercooling**

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| No. of obs | Inlet Temperature  T1  oC | Air exit of 1st stage T2  oC | Air inlet of 2nd stage  T3  oC | Air exist of 2nd stage  T4  oC | Water inlet  T5  oC | Water outlet  T6  oC | 1st stag pressure P1  kNm-2 | 2nd stage pressure P2  kNm-2 | Manometric height  H | Cooling water flow  mw  g/s |
|  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |
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|  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |

## 

## 6.6 Specimen Calculations

T1 = \_\_\_0C, T2 = \_\_0C, T3 = \_\_\_0C, T4 = \_\_\_0C

1st stage pressure = P1= \_\_\_\_\_ KNm-2

2nd stage pressure = P2=\_\_\_\_\_ KNm-2

Manometric height=h= \_\_\_\_\_\_m

Air flow measurement= qv = 4.71384×10-5 = \_\_\_\_\_\_\_ m3/s

Where qv = air flow volume, h= orifice plate manometer pressure mmWg

Inlet abs =Pia = Pi + Patm = 0 + 101.325 = 101.325 KNm-2

1st stage abs= P1a = P1 + Patm = \_\_\_\_\_\_ + 101.325 = \_\_\_\_\_\_\_ KNm-2

2nd stage abs = P2a =P2 + Patm= \_\_\_\_\_\_ + 101.325 = \_\_\_\_\_\_\_ KNm-2

1st stage pressure ratio = = \_\_\_\_\_\_

2nd stage pressure ratio = = \_\_\_\_\_\_

Overall pressure ratio =\_\_\_\_\_\_\_

**ρ Air** =Pi / RTi = \_\_\_\_\_\_ kg/ litre

Mass flow of air = = qv × **ρ Air** = \_\_\_\_\_\_ kg/s

For adiabatic compression

To= Ti or

For the 1st stage compression T2= T1 = \_\_\_\_\_\_K= \_\_\_\_\_\_\_0C

Adiabatic work required for compression

WAdiabatic

= = \_\_\_\_\_\_\_ watts

Heat is observed by the cooling water and the heat lost can be determined from

Qwater= mwater Cpwater (T6 - T5)= \_\_\_\_\_ watts

For the 2nd stage compression T4= T3 = \_\_\_\_\_\_\_\_K =\_\_\_\_\_\_\_\_ 0C

Adiabatic work required for compression

WAdiabatic  = \_\_\_\_\_\_\_ watts

WTotal = \_\_\_\_\_\_ watts

Wiso = mRt1ln( P1/ Pa) for first stage = \_\_\_\_\_\_ watts

Wiso = mRt3ln( P2/ P1) for second stage =\_\_\_\_\_\_ watts

Wiso(total)= = mRt1ln( P1/ Pa) + mRt3ln( P2/ P1) = \_\_\_\_\_\_ watts

ɳiso= Isothermal work / Actual work = \_\_\_\_\_\_ %

## Table 6.2: Results

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| No.of obs. | T2 | T4 | Wiso | Wactual | Isothermal efficiency |
| 1 |  |  |  |  |  |
| 2 |  |  |  |  |  |
| 3 |  |  |  |  |  |
| 4 |  |  |  |  |  |
| 5 |  |  |  |  |  |

## 6.7 Statistical Analysis

## 6.8 Graphs

* Isothermal efficiency vs 1st stage P/R
* Isothermal efficiency vs 2nd stage P/R
* Isothermal efficiency vs overall P/R

## 6.9 Conclusion

# 7 LAB SESSION 7

To investigate the Torque and Power characteristics of a single stage impulse turbine.

## 7.1 Learning Objective:

At the end of this study, student will be able to

* Explain the torque and power relationship of impulse turbine.

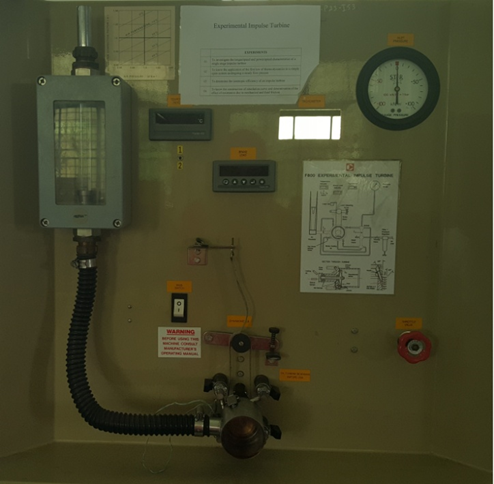
## 7.2 Apparatus

Impulse turbine unit, two stage compressor

## 7.3 Main Parts of Impulse Turbine

1. Pressure gauge
2. Rota-meter
3. Temperature sensors
4. Brake band for applying friction
5. Flow control valve

## 7.4 Theory



**Figure 7.1: Impulse Turbine Unit**

**Impulse turbine**

In an impulse turbine, the fluid is sent through a nozzle so that most of its mechanical energy is converted into kinetic energy. The high speed jet then impinges on bucket-shaped vanes that transfer energy to the turbine shaft.

The modern and most efficient type of impulse turbine was invented by Lester A.Pelton in 1878. And the rotating wheel is now called a **Pelton wheel** in his honor. The buckets of the Pelton wheel are designed so as to split the flow in half and turn the flow nearly 180 degrees.

A portion of the outermost part of each bucket is cut out so that the majority of the jet can pass through the bucket that is not aligned with the jet to reach the most aligned bucket. In this way, the maximum amount of momentum from the jet is utilized.

## 7.5 Experimental Procedure

1. Prepare the turbine for experiment performance by attaching compressor with it.
2. Adjust the throttle valve until the inlet air pressure is the desired value – say 60kN m-2 gauge (this pressure must then be constant throughout the test).
3. Unscrew the brake adjusting screw until the turbine runs close to its maximum speed but not exceeding 40,000 rpm.
4. When conditions are stable, note the speed, spring balance reading and air flow rate.
5. Rotate the brake adjusting screw until the turbine runs at about 85% of the initial speed and when stable repeat observation.
6. Repeat in similar decrements of speed until the turbine finally the stalls.
7. The test may now be repeated at other constant turbine inlet pressures.

## 7.6 Observations and Calculations

Inlet pressure = 60 kNm-2

Effective radius= 0.0145 m



**Table 7.1: Calculation of shaft power of impulse turbine**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| No. | Inlet pressure  P1  kN/m2 | Inlet Temperature  T1 | Exit  Temperature  T2 | Rotational  Speed  N  × 103 | Brake  Band  Force  F  N | Air flow rate  g/s | Torque  M  Nm  × 10-3 | Shaft  Power  Ps  Watts |
| 1. |  |  |  |  |  |  |  |  |
| 2. |  |  |  |  |  |  |  |  |
| 3. |  |  |  |  |  |  |  |  |
| 4. |  |  |  |  |  |  |  |  |
| 5. |  |  |  |  |  |  |  |  |
| 6. |  |  |  |  |  |  |  |  |
| 7. |  |  |  |  |  |  |  |  |
| 8. |  |  |  |  |  |  |  |  |

## 

## 7.7 Specimen Calculations

Torque=M = brake band force × radius = \_\_\_\_\_\_Nm

Shaft power = torque × angular speed= M× (2∏ N)/ 60= \_\_\_\_\_\_\_\_ kW

## 7.8 Statistical Analysis

## 7.9 Graphs

* Torque vs speed
* Power vs speed

## 7.10 Conclusion

# 8 LAB SESSION 8

To determine the isentropic efficiency of a single stage impulse turbine.

## 8.1 Learning Objective:

At the end of this study, student will be able to

* Explain the relationship of pressure and isentropic efficiency of impulse turbine.

## 8.2 Apparatus

Impulse turbine unit, two stage compressor

## 8.3 Main Parts of Impulse Turbine

1. Pressure gauge
2. Rota-meter
3. Temperature sensors
4. Brake band for applying friction
5. Flow control valve

## 8.4 Experimental Procedure

1. Prepare the turbine for experiment performance by attaching compressor with it.
2. Adjust the throttle valve until the inlet air pressure is the desired value – say 60kN m-2 gauge (this pressure must then be constant throughout the test).
3. Unscrew the brake adjusting screw until the turbine runs close to its maximum speed but not exceeding 40,000 rpm.
4. When conditions are stable, note the speed, spring balance reading and air flow rate.
5. Rotate the brake adjusting screw until the turbine runs at about 85% of the initial speed and when stable repeat observation.
6. Repeat in similar decrements of speed until the turbine finally the stalls.
7. The test may now be repeated at other constant turbine inlet pressures.

## 

## 8.5 Observations & Calculations

Inlet pressure = 60 kNm-2

Effective radius= 0.0145 m



**Table 8.1: Calculation of isentropic efficiency of impulse turbine**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| No. | Inlet pressure  P | Inlet Temperature  T1 | Exit  Temperature  T2 | Rotational  Speed  N  ×10^3 | Brake  Band  Force  F  N | Air flow rate  g/s | Torque  M  Nm  ×10^-3 | Shaft  Power  Ps  Watts |
| 1. |  |  |  |  |  |  |  |  |
| 2. |  |  |  |  |  |  |  |  |
| 3. |  |  |  |  |  |  |  |  |
| 4. |  |  |  |  |  |  |  |  |
| 5. |  |  |  |  |  |  |  |  |
| 6. |  |  |  |  |  |  |  |  |
| 7. |  |  |  |  |  |  |  |  |
| 8. |  |  |  |  |  |  |  |  |

## 8.6 Specimen Calculations

Torque=M = brake band force × radius = \_\_\_\_\_\_Nm

Shaft power =P= torque × angular speed= M× (2∏ N)/ 60

Absolute temperature at inlet T1= \_\_\_\_ oC = \_\_\_\_+273= \_\_\_\_\_ K

Atmospheric pressure = \_\_\_\_\_ kNm-2

Absolute pressure at inlet = P1 = patm+P= \_\_\_\_\_\_ kNm-2

Absolute pressure at exist =P2= patm= \_\_\_\_\_\_ kNm-2

Turbine pressure ratio rp = P1/ P2 = \_\_\_\_\_

Turbine Exist temperature =T2= T1 = \_\_\_\_\_\_ K

Isentropic Power= m Cp (T1-T2)= \_\_\_\_\_\_\_ watts

Efficiency= (Actual Power/Isentropic Power) ×100= \_\_\_\_\_\_ %

## 8.7Statistical Analysis

## **8.8 Graphs**

* Inlet pressure vs Isentropic efficiency
* Inlet pressure vs power

## 8.9 Conclusion

# 

# 9 LAB SESSION 9

To investigate the Torque and Power characteristics of a single stage reaction turbine.

## Learning Objective:

At the end of this study, student will be able to

* Explain the torque and power relationship of reaction turbine.

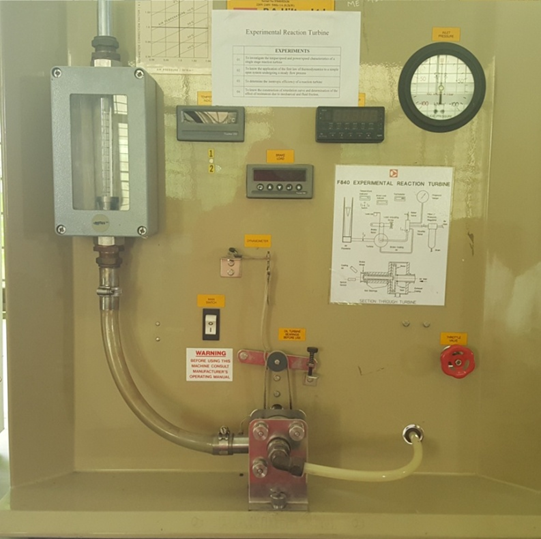
## 9.2 Apparatus

Reaction turbine unit, two stage compressor

## 9.3 Main Parts of Reaction Turbine

1. Pressure gauge
2. Rota-meter
3. Temperature sensors
4. Brake band for applying friction
5. Flow control valve

## 9.4 Theory



**Figure 9.1: Reaction Turbine Unit**

**Reaction turbine**

In reaction turbines the rotation is mainly achievedby the reaction forces created by the acceleration of the water in the runner. The basic principle is the same as a rotating lawn sprinkler in which water enters the arms of the sprinkler at low velocity and leave through the jets at high velocity. The exact manner in which this acceleration is achieved in turbine depends upon the whether the runner is of the propeller, Kaplin, Francis or Deriaz type.

The great variety possible in the geometry of the runner makes Reaction Turbines suitable for a wide range of applications. In all types it is normal for a fraction of the hydraulic pressure to be converted into velocity as it passes through the inlet structure which consists of a spiral casing and a gate apparatus leading to the runner. The power from the water (Pressure and Velocity) is then converted into mechanical power in the runner. It is usual for the exit pressure from the runner to be below atmospheric. This is achieved by using a **draft tube.**

## 9.5 Observations and Calculations

Inlet pressure = 60 kNm-2

Effective radius= 0.0145 m



**Table 9.1: Calculations of shaft power of reaction turbine**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| No. | Inlet pressure  P1 | Inlet Temperature  T1 | Exit  Temperature  T2 | Rotational  Speed  N  \*10^3 | Brake  Band  Force  F  N | Air flow rate  g/s | Torque  M  Nm  \*10^-3 | Shaft  Power  Ps  Watts |
| 1. |  |  |  |  |  |  |  |  |
| 2. |  |  |  |  |  |  |  |  |
| 3. |  |  |  |  |  |  |  |  |
| 4. |  |  |  |  |  |  |  |  |
| 5. |  |  |  |  |  |  |  |  |
| 6. |  |  |  |  |  |  |  |  |
| 7. |  |  |  |  |  |  |  |  |
| 8. |  |  |  |  |  |  |  |  |

## 

## 9.6 Specimen Calculations

Torque=M = brake band force × radius = \_\_\_\_\_\_Nm

Shaft power = torque × angular speed= M× (2∏ N)/ 60= \_\_\_\_\_\_

## 

## 9.7 Statistical Analysis

## 9.8 Graphs

* Torque vs speed
* Power vs speed

## 9.9 Conclusion

# 

# 10 LAB SESSION 10

To determine the isentropic efficiency of a single stage reaction turbine

## 10.1 Learning Objective:

At the end of this study, student will be able to

* Explain the relationship of inlet pressure and isentropic efficiency of reaction turbine.

## 10.2 Apparatus

Impulse turbine unit, two stage compressor

## 10.3Main Parts of Reaction Turbine

1. Pressure gauge
2. Rota-meter
3. Temperature sensors
4. Brake band for applying friction
5. Flow control valve

## 10.4 Experimental Procedure

1. Prepare the turbine for experiment performance by attaching compressor with it.
2. Adjust the throttle valve until the inlet air pressure is the desired value – say 60 kN m-2 gauge (this pressure must then be constant throughout the test).
3. Unscrew the brake adjusting screw until the turbine runs close to its maximum speed but not exceeding 40,000 rpm.
4. When conditions are stable, note the speed, spring balance reading and air flow rate.
5. Rotate the brake adjusting screw until the turbine runs at about 85% of the initial speed and when stable repeat observation.
6. Repeat in similar decrements of speed until the turbine finally the stalls.
7. The test may now be repeated at other constant turbine inlet pressures.

## 10.5 Observations & Calculations

Inlet pressure = 60 kNm-2

Effective radius= 0.0145 m



**Table 10.1: Calculations of isentropic efficiency of reaction turbine**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| No. | Inlet pressure  P | Inlet Temperature  T1 | Exit  Temperature  T2 | Rotational  Speed  N  \*10^3 | Brake  Band  Force  F  N | Air flow rate  g/s | Torque  M  Nm  \*10^-3 | Shaft  Power  Ps  Watts |
| 1. |  |  |  |  |  |  |  |  |
| 2. |  |  |  |  |  |  |  |  |
| 3. |  |  |  |  |  |  |  |  |
| 4. |  |  |  |  |  |  |  |  |
| 5. |  |  |  |  |  |  |  |  |
| 6. |  |  |  |  |  |  |  |  |
| 7. |  |  |  |  |  |  |  |  |
| 8. |  |  |  |  |  |  |  |  |

## 

## 10.6 Specimen Calculations

Torque=M = brake band force × radius = \_\_\_\_\_\_Nm

Shaft power =P= torque × angular speed= M× (2∏ N)/ 60 = \_\_\_\_\_\_\_\_= \_\_\_\_\_\_\_\_\_kW

Absolute temperature at inlet T1= \_\_\_\_ oC = \_\_\_\_+273= \_\_\_\_\_ K

Atmospheric pressure = \_\_\_\_\_ kNm-2

Absolute pressure at inlet = P1 = patm+P= \_\_\_\_\_\_ kNm-2

Absolute pressure at exist =P2= patm= \_\_\_\_\_\_ kNm-2

Turbine pressure ratio rp = P1/ P2 = \_\_\_\_\_

Turbine Exist temperature =T2= T1 = \_\_\_\_\_\_ K

Isentropic Power= m Cp (T1-T2)= \_\_\_\_\_\_\_ watts

Efficiency= (Actual Power/Isentropic Power) ×100= \_\_\_\_\_\_ %

## 10.7 Statistical Analysis

## 10.8 Graphs

* Inlet pressure vs Isentropic efficiency
* Inlet pressure vs power

## 10.9 Conclusion