T.C.
ANKARA YILDIRIM BEYAZIT UNIVERSITY
FACULTY OF ENGINEERING AND NATURAL SCIENCES
MECHANICAL ENGINEERING DEPARTMENT

MCE - 404 MACHINERY LABORATORY - II LABORATORY MANUAL

2018 - 2019 Spring Semester

February 2019, Ankara

PREFACE

Machinery Laboratory course, due to being a practice of the courses taken by engineering faculty students during their undergraduate studies, has a great importance and differs from other courses from this aspect. Therefore, theoretical subjects from other courses can only be deeply understood by giving importance to laboratory courses. Attending all the laboratories and preparing lab reports will contribute to clear understanding of many subjects that is previously investigated by the students theoretically.

The basic starting point of this laboratory manual is to make our students better educated and equipped, also prevent time waste for the students for obtaining laboratory manuals. In addition to this, having an experiment manual would provide a source to our students during their professional lives.

I wish this lab manual will be beneficial for all our students and I sincerely would thank to academic staff of the department who provided the main contribution for this manual to be prepared.

February 2019, Ankara

Prof. Dr. Sadettin ORHAN
Head of the Mechanical Engineering Department

CONTENTS **Page**

1. INTRODUCTION

Machinery Laboratory course, due to being a practice of the courses taken by engineering faculty students during their undergraduate studies, has a great importance and differs from other courses in this aspect. Therefore, theoretical subjects of engineering courses can only be deeply understood through giving importance to laboratory courses. Attending all the laboratories and preparing lab reports will contribute to clear understanding of many subjects that is previously investigated by the students theoretically.

1.1 Scope of the Course

As a practical course, Machinery Laboratory course is oriented to demonstrate the validity of many physical laws which students have learned theoretically during their courses in undergraduate study. Through the experiments within the scope of this course, basic principles of many courses from Engineering Materials course to Thermodynamics course, from Strength of Materials course to Heat Transfer course will be practically examined. From this point of view, Machinery Laboratory course is a summary of undergraduate study and gives an important opportunity to the students to understand all the subjects better.

1.2 Importance and Basis of Experimental Studies

It is obvious that experimental studies are useful to comprehend theoretical subjects. However, in order to reach this target, many regulations have to be provided; for instance, experiments have to be conducted patiently and carefully, the equipment used in experiments have to be calibrated, experiments have to be repeated sufficiently, the measurements have to be done after maintaining steady-state conditions. Even after providing all these regulations, experimental studies include errors. Errors occurring in experimental studies and analysis of errors are explained below.

1.2.1 Experimental Errors and Error Analysis Methods

All experimental studies contain errors due to different reasons. The errors in experimental studies can be classified into three groups. The first one is due to lack of attention and experience of the researcher. Improper selection of measurement equipment and inappropriate design of measurement tools can be considered within this group. The second type of errors is called as constant or systematic errors. These errors are seen generally during repeated measurements and mostly the reasons cannot be determined. The third one is random errors. These are occurring due to personal fluctuations, decrease of attention of people who conducts experiments by the time, random electronic fluctuations, and hysteresis of measurement equipment [1].

In order to determine the validity of experimental results, error analysis has to be conducted. A few methods have been practically developed to determine errors belonging to the parameters calculated by using the data obtained from experiments. The most common ones of these methods are Uncertainty Analysis and Commonsense Basis [1]. Uncertainty method which was found by Kline and McClintock, is more sensitive method since it determines the variable causing the greatest error immediately. Thus, to reduce error, the tool which is used for measurement of the related variable can be considered and investigated deeply. The mentioned

uncertainty analysis method is explained in the following part and practical application of it is explained shortly.

1.2.2 Uncertainty Analysis Method

A more precise method of estimating uncertainty in experimental results has been presented by Kline and McClintock. The method is based on a careful specification of the uncertainties in the various primary experimental measurements. For example, a certain pressure reading might be expressed as

$$p = 100 \text{ kPa } \pm 1 \text{ kPa} \tag{1.1}$$

When the plus or minus notation is used to designate the uncertainty, the person making this designation is stating the degree of accuracy with which he or she believes the measurement has been made. We may note that this specification is in itself uncertain because the experimenter is naturally uncertain about the accuracy of these measurements. If a very careful calibration of an instrument has been performed recently with standards of very high precision, then the experimentalist will be justified in assigning a much lower uncertainty to measurements than if they were performed with a gage or instrument of unknown calibration history.

To add a further specification of the uncertainty of a particular measurement, Kline and McClintock propose that the experimenter specify certain odds for the uncertainty. The above equation for pressure might thus be written

$$p = 100\ kPa\ \pm 1\ kPa\ (20\ to\ 1) \tag{1.2}$$

In other words, the experimenter is willing to bet with 20 to 1 odds that the pressure measurement is within ±1 kPa. It is important to note that the specification of such odds can only be made by the experimenter based on the total laboratory experience.

Suppose that the value R is to be measured by using experimental equipment, and n independent variables which have effects on this value are; $x_1, x_2, x_3,.....,x_n$. In this condition, it can be written as;

$$R = R(\, x_1,\ x_2,\ x_3,.....,x_n\ ) \tag{1.3}$$

If constant error values for each effective variables are $w_1, w_2, w_3,.....,w_n$ and constant error value of R is w_R, then according to uncertainty analysis method;

$$w_R = \pm \left[\left(\frac{\partial R}{\partial x_1} w_1 \right)^2 + \left(\frac{\partial R}{\partial x_2} w_2 \right)^2 + ... + \left(\frac{\partial R}{\partial x_n} w_n \right)^2 \right]^{1/2} \tag{1.4}$$

The formula above is obtained [2]. We should call the student's attention to the requirement that all the uncertainties in Eq. (1.4) should be expressed with the same odds. As a practical matter, the relation is most often used without regard to a specification of the odds of the uncertainties w_n. The experimentalist conducting the experiments is the person best qualified to

estimate such odds, so it not unreasonable to assign responsibility for relaxation of the equal-odds to him or her [2].

1.2.3 An Exemplary Calculation According to Uncertainty Analysis

The uncertainties (constant error values) of measurement tools used in experiments are determined by calibration of these tools. For instance, calibration of measurement tools used in an experiment was done and uncertainties of these tools are given as in Table 1.1. Thus, uncertainties of independent variables are known and by using the Eq. (1.4), uncertainties of dependent variables can be determined.

Table 1.1. Determined Uncertainties of Measurement Tools in an Exemplar Experiment [3]

Measurement Tool	**Calibration Range**	**Uncertainty Values (±*w*)**
Thermometers	0 ~ 80 ºC	± 0.092 ºC
Pressure Gauge (Absolute pressure)	0 ~ 12.5 bar	± 0.980 kPa
Pressure Gauge (Differential pressure)	0 ~ 55 kPa	± 0.123 kPa
Flowmeter (Refrigerant)	0 ~ 2.703 g/s	± 0.019 g/s
Rotameter (Cooling water)	0 ~ 21.2 g/s	± 0.316 g/s
After heater	0 ~ 600 W	± 0.300 W

For example[3], in a counter current parallel flow heat exchanger; logarithmic mean temperature difference (*LMTD*) ΔT_{lm}, is defined as below formula, depending on ΔT_1 and ΔT_2 which are temperature differences between fluids in entrance and exit of heat exchanger:

$$\Delta T_{lm} = \frac{\Delta T_1 - \Delta T_2}{ln\frac{\Delta T_1}{\Delta T_2}} \tag{1.5}$$

In this condition, if uncertainties of the measurements done during entrance and exit of fluids are known, regarding this point, error values related to ΔT_1 and ΔT_2 temperature differences can be found with the aid of the formulas below:

$$w_{\Delta T_1} = \pm \left[\left(w_{T_{1,g}}\right)^2 + \left(w_{T_{2,ç}}\right)^2\right]^{1/2} \tag{1.6}$$

$$w_{\Delta T_2} = \pm \left[\left(w_{T_{1,ç}}\right)^2 + \left(w_{T_{2,g}}\right)^2\right]^{1/2} \tag{1.7}$$

With reference to the mentioned error values, constant error value related to ΔT_{lm} can be found through the Eq. (1.8).

$$w_{\Delta T_{lm}} = \pm \left[\left(\frac{ln\left(\frac{\Delta T_1}{\Delta T_2}\right) - \frac{\Delta T_1 - \Delta T_2}{\Delta T_1}}{\left(ln\left(\frac{\Delta T_1}{\Delta T_2}\right)\right)^2} w_{\Delta T_1} \right)^2 + \left(\frac{-ln\left(\frac{\Delta T_1}{\Delta T_2}\right) + \frac{\Delta T_1 - \Delta T_2}{\Delta T_2}}{\left(ln\left(\frac{\Delta T_1}{\Delta T_2}\right)\right)^2} w_{\Delta T_2} \right)^2 \right]^{1/2} \quad (1.8)$$

1.3 General Regulations about the Course

For the engineering students to reach the beneficial targets of the laboratory course which is a practical application of the undergraduate courses, students should obey the general regulations explained below and should give sufficient importance to preparing experiment (lab) reports. Thus, the below regulations are to be obeyed.

1.3.1 General Subjects about the Course

The rules below are given in order to maintain lab sessions in an orderly manner;

1) The related experiment manual should be investigated in detail before coming to the labs.
2) The students without experiment manual will not be accepted to the labs.
3) It is compulsory for every student to attend the lab with his/her own group.
4) The students have to attend at least 80% of the labs and submit all the lab reports which s/he has attended. However, the report grades s/he took will be summed up and the average grade will be calculated by dividing the total grade to total number of labs, even s/he would not attend.
5) The cover page shown in App. 1, must be used in the lab reports.
6) The experiment reports must be prepared in a style that they include all the tables needed for the measurements.
7) Experiment reports must be hand written, not prepared in computers. Both sides of the pages should be used except for the cover page.
8) Lab reports must be submitted at most 1 week later after the experiment date. Late submission of reports is not an accepted choice. Late submitted reports will not be evaluated.
9) Experiment reports will be submitted directly to the related instructor and the answers to the questions asked by the instructor will be strongly effective on your grades.
10) No makeup experiment will be held at the end of the semester.

1.3.2 Preparing Experiment (Lab) Report

1) The cover page shown in App. 1, will be used in the lab reports.

2) The lab reports will include a cover page, the aim of the experiment, a schematic demonstration of the experiment installation, the main equipment of the experiment installation and information about the main equipment.

3) Also the experiment reports will include a table for the measurements done in the related lab, calculations done, a table for results, the graphs to be drawn and a “Comments and Conclusion” part.

1.4 Experiment List and Related Instructors

Name of the experiments and the responsible instructors for the related experiments are given in Table 1.2 below.

Table 1.2. Experiment List, the Related Instructors and Labs

Order	Name of the Experiment	Relevant Instructor	Teaching Assistant	Place
1	Mechanical Measurements Experiment	Assoc. Prof. Dr. Mostafa RANJBAR	R. Assist. Mahmut Cihat YILMAZ	DB 425
2	Cooling System Fault Detection Experiment	Prof. Dr. Erol ARCAKLIOĞLU Assist. Prof. Dr. Hasan ÖZCAN	R. Assist. Aysun GÜVEN	AB 317
3	Fatigue Experiment	Prof. Dr. Adem ÇİÇEK	R. Assist. Necati UÇAK	DB 425
4	Metallography Experiment	Prof. Dr. Veli ÇELİK Assist. Prof. Dr. Yasin SARIKAVAK	R. Assist. Polat KURT	DB 416 DB 417
5	Hydraulic Training Set Experiment	Assist. Prof. Dr. İhsan TOKTAŞ	R. Assist. Halil YILDIRIM	DB 426
6	Air Conditioning Experiment	Assist. Prof. Dr. Kemal BİLEN	R. Assist. Ahmet Yasin SEDEF	AB 317
7	Francis Turbine Experiment	Prof. Dr. Ünal ÇAMDALI	R. Assist. İbrahim TÜRKMEN	AB 317
8	Serial and Parallel Pumps Experiment	Assist. Prof. Dr. Orhan ÖZÇELİK	R. Assist. Gürcan TİRYAKİ	AB 317
9	Three-point Bending Experiment	Prof. Dr. Fahrettin ÖZTÜRK Assist. Prof. Dr. Fatih GÖNCÜ	R. Assist. Oğuzhan MÜLKOĞLU	BB 408
10	Water Level Control Experiment	Prof. Dr. Mehmet SUNAR Assoc. Prof. Dr. Arif ANKARALI	R. Assist. Orçun BİÇER	DB 426

1.5 Experiment Weeks

Experiment weeks are announced (for Fall and Spring Semesters) on the department's website.

1.6 Extra Notes about the Semester

1) There will be a midterm exam grade (25%), laboratory reports grade (25%), and a final exam grade (50%) within the scope of the course.
2) To fulfill the course; at least 80% of laboratory attendance and submitting the reports of attended labs are compulsory. Average report grade is calculated over 10 labs.
3) The students who are repeating the course without attendance obligation do not have to attend the experiments, they can attend only exams. In this case, their midterm grade will have an effect of 50%.
4) For other regulations of the course, please see Chapter 1.3 "General Regulations about the Course" in the Laboratory Manual.
5) The updated Laboratory Manual of this semester can be obtained from the department's website.
6) For more information about the experiments, you can contact relevant assistant. For general information about the course, you can also contact Assist. Prof. Dr. Yasin SARIKAVAK.

2. EXPERIMENT MANUALS

2.1. Mechanical Measurements Experiment

2.1.1 Objective

In this manual, we seek to explain some of the terminology used in experimental methods and to show the generalized arrangement of an experimental system. We shall also discuss briefly the standards which are available and the importance of calibration in any experimental measurement.

2.1.2 Introduction

Measurements are one of crucial parts of not only mechanical engineering but all types of engineering fields. Every branch of engineering involves two processes: design, and operations and maintenance. The design may be machine design, building design, circuit design, transportation design, automobile design etc. The operations part involves operation of the machines, automobiles, various plants, circuits etc.

Both, the design, and operations and maintenance involve measurements. For instance, while designing automobile we have to consider dimensions of various parts of the automobiles, the loads they can pick up etc. Similarly, during the operations of the plant, say like industrial refrigeration plant, we have to measure parameters like pressure, temperature, etc. In the power plant we have to measure various quantities of the coal, the quantity of water in the boiler, the amount of steam produced along with its flow rate, temperature and pressure, the amount of power produced, the outlet temperature of the steam from condenser etc. In the large chemical plants large number of such parameters have to be measured.

2.1.3 Theory

2.1.3.1 Definition of Terms

• Readability of an instrument.

This term indicates the closeness with which the scale of the instrument may be read; an instrument with a 12-in scale would have a higher readability than an instrument with a 6-in scale and the same range.

• The least count

is the smallest difference between two indications that can be detected on the instrument scale.

• The sensitivity of an instrument

is the ratio of the linear movement of the pointer on an analog instrument to the change in the measured variable causing this motion. (or the ability of a measuring device to detect small differences in a quantity)

• For example, a 1-mV recorder might have a 25-cm scale length. Its sensitivity would be 25 cm/mV, assuming that the measurement was linear all across the scale.

• Distinction between precision and accuracy,

• Consider the measurement of a known voltage of 100 volts (V) with a certain meter.

• Four readings are taken, and the indicated values are 104, 103, 105, and 105 V.

• Instrument could not be depended on for an accuracy of better than 5 percent (5 V), while a precision of ±1 percent is indicated since the maximum deviation from the mean reading of 104 V is only 1 V.

• It may be noted that the instrument could be calibrated so that it could be used dependably to measure voltages within ±1 V.

• Accuracy can be improved up to but not beyond the precision of the instrument by calibration.

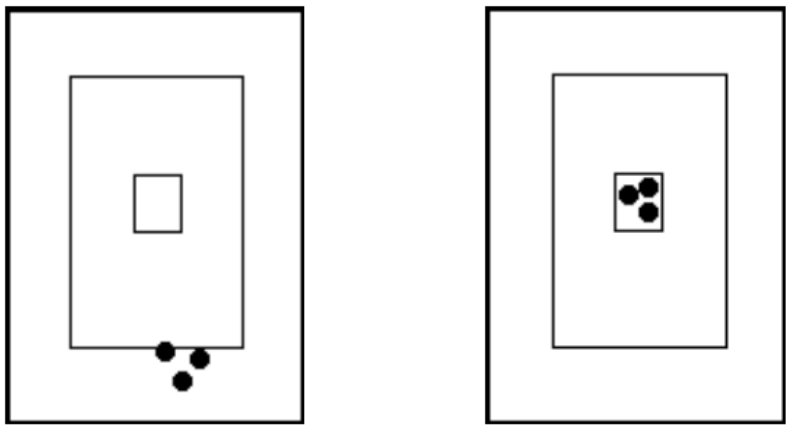


Figure 2.1.1. Accuracy and precision

2.1.3.2 Dimensions and Units

An experimentalist must be familiar with the units which appear on the gages and readout equipment.

The main difficulties arise in mechanical and thermal units (not standardized completely yet) electrical units have been standardized for some time. It is hoped that the SI (Systeme International d'Unites) set of units will eventually prevail.

Although the SI system is preferred, one must recognize that the English system is still very popular. One must be careful not to confuse the meaning of the term "units" and "dimensions." A dimension is a physical variable used to specify the behavior or nature of a particular system. For example:

• The length of a rod is a dimension of the rod.

• The temperature of a gas may be considered one of the thermodynamic dimensions of the gas.

When we say the rod is so many meters long, or the gas has a temperature of so many degrees Celsius, we have given the units with which we choose to measure the dimension.

2.1.3.3 Calibration

Calibration is the comparison of measurement values which are obtained by a measurement device like a caliper or thermometer with certain calibration standards of known accuracy. In

other words, it is used to establish the reliability of the measuring instrument. For example, a flowmeter might be calibrated by:

• (1) comparing it with a standard flow-measurement facility of the National Institute for Standards (for example TSE),

• (2) comparing it with another flowmeter of known accuracy, or

• (3) directly calibrating with a primary measurement such as weighing a certain amount of water in a tank and recording the time elapsed for this quantity to flow through the meter.

2.1.3.4 Standards

In order to compare the results of experiments on a consistent basis, it is necessary to establish certain standard units of length, weight, time, temperature, and electrical quantities. TSE has the primary responsibility for maintaining these standards in Türkiye. The meter and the kilogram are considered fundamental units. At one time, the standard meter was defined as the length of a platinum-iridium bar maintained at very accurate conditions at the International Bureau of Weights and Measures in Sevres, France.

Figure 2.1.2. Examples of flowmeter

Similarly, the kilogram was defined in terms of a platinum-iridium mass maintained at this same bureau. Standard units of time are established in terms of known frequencies of oscillation of certain devices. The fundamental unit of time, the second(s), has been defined in the past as 1/86400 of a mean solar day. The solar day is measured as the time interval between two successive transits of the sun across a meridian of the earth. The time interval varies with location of the earth and time of year; however, the mean solar day for one year is constant.

The solar year is the time required for the earth to make one revolution around the sun. The mean solar year is 365 days 5 h 48 min 48 s. In October 1967 the Thirteenth General Conference on Weights and Measures adopted a definition of the second as the duration of 9,192,631,770 periods of the radiation corresponding to the transition between the two hyperfine levels of the fundamental state of the atom of cesium-133.

2.1.4 Experiments

This experiment aims to give a brief information about units, measurement and calibration and teach how to use the caliper, micrometer, comparator, bubble level, threading gauge and

protractor to measure the dimensions of the mechanical parts like length, diameter, flatness and angles clearly.

2.1.4.1 Caliper

A caliper is a device that used to measure the distance between two opposite sides of an object. A caliper can be as simple as a compass with inward or outward-facing points. It may also have a depth gauge. In general, the calipers are divided into two according to the measurement system; metric and inches. Furthermore, metric calipers have sensitivity variety like 1/10, 1/20 and 1/50. Caliper may be in mechanic or digital form. Digital calipers must be reset before the measuring. Calipers are also different from each other in the way of measuring range. For example, when a caliper measure a length between 0-300 mm, another caliper may measure between 200-500 mm. It depends on the place of use of the caliper.

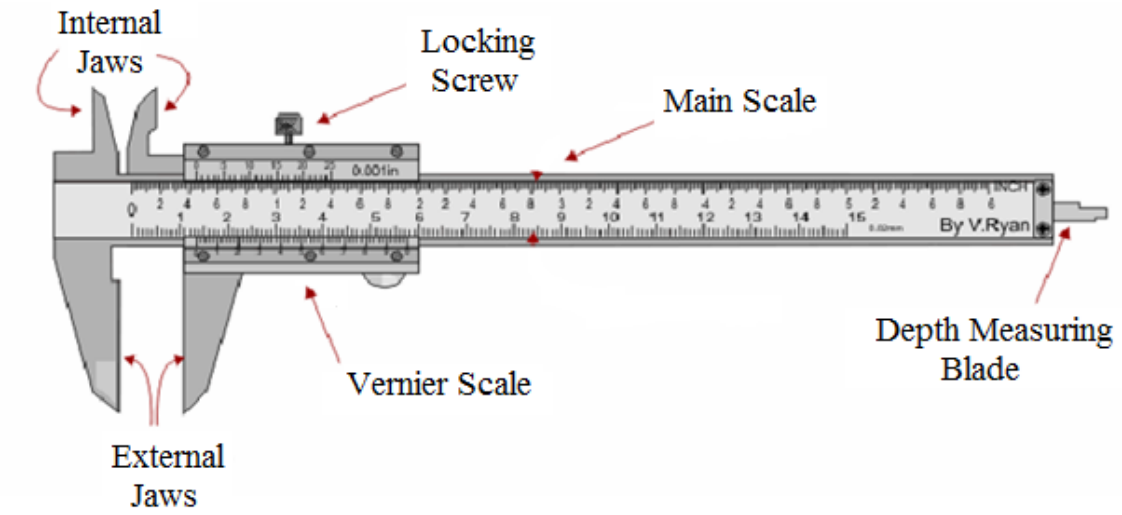


Figure 2.1.3. Vernier Caliper

It is important to clean the object before measuring. The screw must be unlocked and the tips of the caliper are adjusted to fit across the points to be measured. To adjust the caliper, the vernier scale slides when the main scale is fixed. Than the caliper is locked with locking screw and removed to read the measure. The main scale and the vernier scale are read respectively and added together for final result.

The vernier scale is also for sensitivity. Each caliper may have different labels. If the sliding scale doesn't have a label, it can be assumed that the numbered divisions represents 1/10 of the smallest division on the main scale. (1/10 means: if the main scale is 0.1 cm, vernier scale is 0.01 cm)

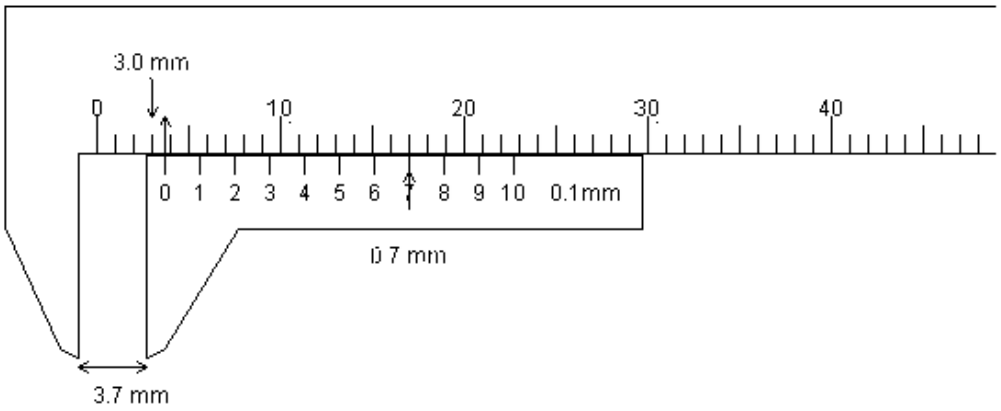


Figure 2.1.4. Measuring example with a schematic view.

2.1.4.1.1 Procedure I

In this experiment, you will measure given sample with vernier caliper and record the data in the given table. Calculate average dimensions and statistical analysis such as mean, standard deviation and uncertainty analysis. Also comment on the results. Then you will use the error propagation formulas to compute the uncertainty in quantities derived from the measurements.

Table 2.1.1.

	Dimension	**Measuring**	**Digital Caliper**
Length(mm)			
Diameter(mm)			

2.1.4.2 Micrometer

A micrometer is a device that used to measure the length and diameter of cylindrical tools more sensitively. The parts of a micrometer can be seen in Figure 2.1.5. To measure a diameter, thimble is turned until the spindle compress the part and then it is locked to fixed micrometer.

At the end, the dimension is read from sleeve. The ratchet is for protect the part from over compress, so that the original dimension of the part stays stable.

There are some kind of micrometers that can measure the inertial diameters and depth. They may be in both mechanical and digital form.

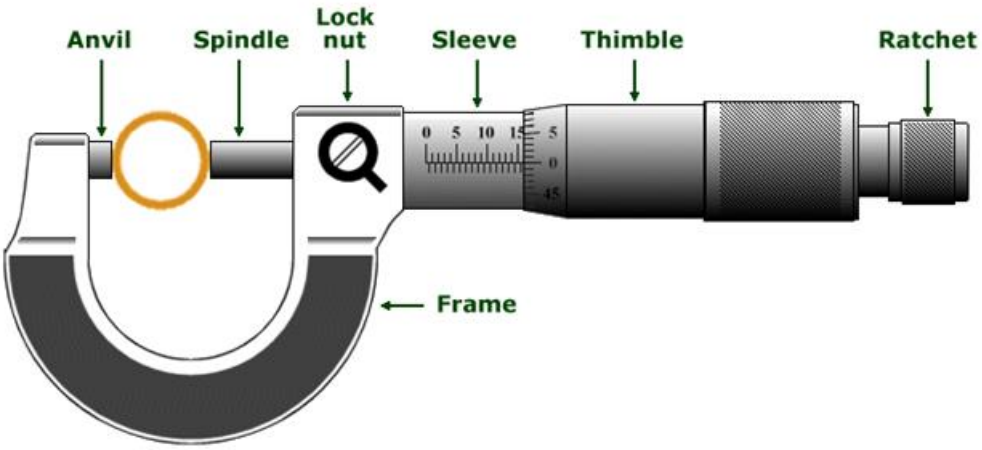


Figure 2.1.5. Micrometer

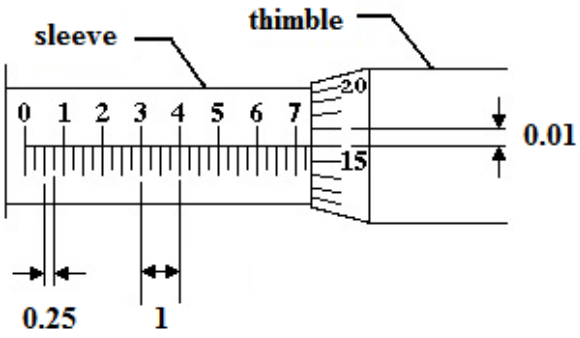


Figure 2.1.6. Schematic view of a micrometer

2.1.4.2.1 Procedure II

In this experiment, you will measure given sample with a micrometer and record the data in the given table. Calculate average dimensions and statistical analysis such as mean, standard deviation and uncertainty analysis. Also comment on the results. Then you will use the error propagation formulas to compute the uncertainty in quantities derived from the measurements.

Table 2.1.2.

	Dimension	**Measuring**
Length(mm)		
Diameter(mm)		

2.1.4.3 Comparator

A comparator is a device that used to measure the height and depth of the parts or to compare the height of two tools or to measure the flatness of a plate.

Figure 2.1.7. Comparator

When the touching part of the comparator moves, the aiguille (indicator) rotates. Each rotation of the aiguille corresponds to 1 mm dimension and it is counted in index mobile part. Most of the comparators have 0.01 mm sensitivity. Comparators have measuring limits like 10 mm. If it is used to control the flatness, the end point is put on the surface and it is reset. After that the measuring body is moved and the difference can be read.

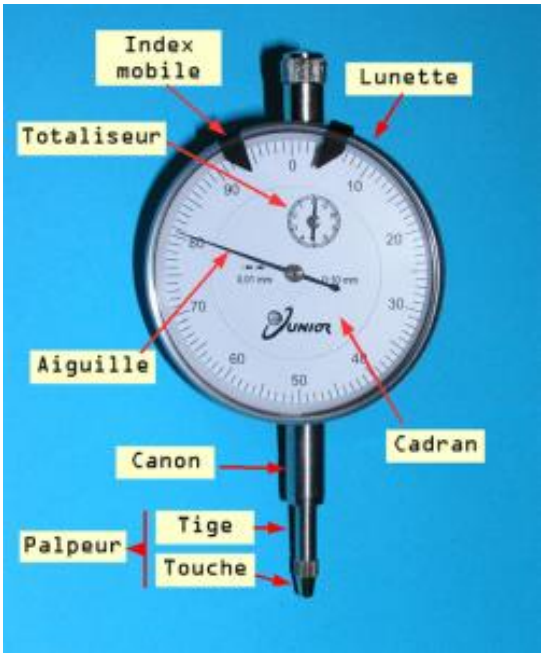


Figure 2.1.8. Schematic view of a comparator

2.1.4.3.1 Procedure III

In this experiment, you will measure the flatness of the given samples with comparator and record the data in the given table.

Table 2.1.3.

	Difference
Sample 1	
Sample 2	

2.1.4.4 Threading Gauge

A threading gauge is a control device that produced according to screw standards and aims to understand which screw pitch does a screw have. A 0.25 – 6.00 mm measuring threading gauge can be seen in Figure 2.1.9.

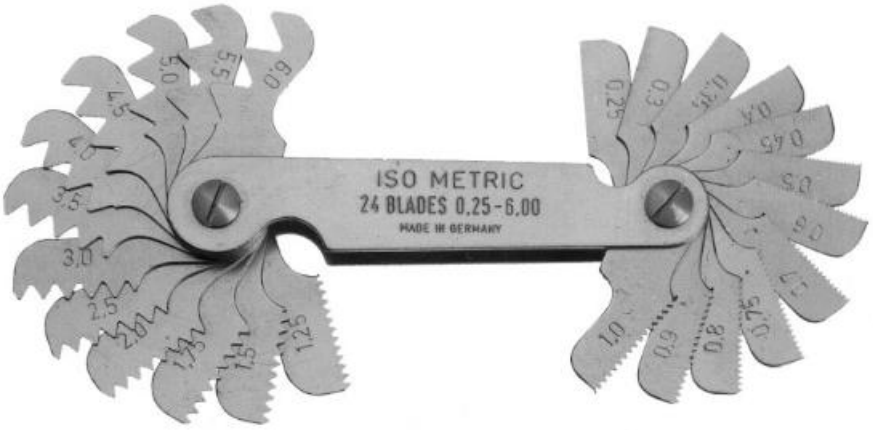


Figure 2.1.9. Threading gauge

2.1.4.4.1 Procedure IV

In this experiment, you will determine the screw pitches of the given samples with threading gauge and record the data in the given table.

Table 2.1.4.

	Dimension	**Measuring**
Sample 1		
Sample 2		
Sample 3		

2.1.4.5 Spirit Level

A spirit (bubble) level is a device that used to measure the flatness of a surface, in other words it is used to understand if a surface is horizontal or vertical. It has a colored alcohol inside a glass cover. Basically, it uses the gravity.

Figure 2.1.10. Spirit level

2.1.4.5.1 Procedure V

In this experiment, you will control the flatness of given samples with bubble level.

Table 2.1.5.

	Control
Sample 1	
Sample 2	

2.1.4.6 Protractor

A protractor is a device that measures the angles. While one type of the proctors measures the angles in degrees, other measures in radians. It can be divided in to 180º or 360º. Generally, protractors are made of transparent plastics in order to see the measuring body through it. It can also used to control the flatness of the surfaces.

Figure 2.1.11. Protractor

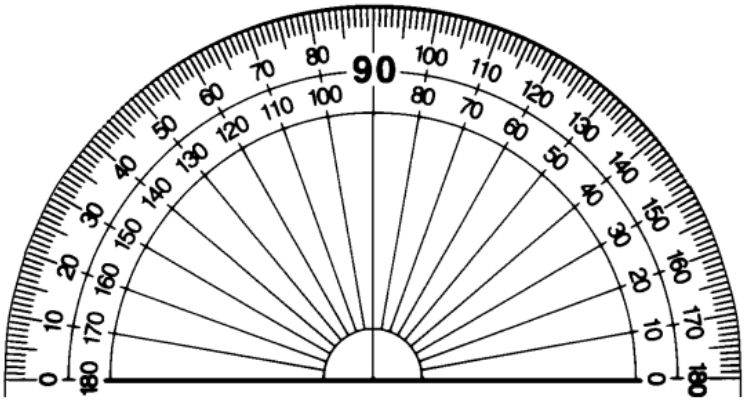


Figure 2.1.12. Schematic view of a protractor

2.1.4.6.1 Procedure VI

In this experiment, you will measure the angles of given samples with protractor and record the data in the given table.

Table 2.1.6.

	Dimension	**Measuring**
Sample 1		
Sample 2		

2.1.5 Report

In your laboratory, reports must have the followings;

a) Cover page.
b) A short introduction.
c) All the necessary tables of the recorded measurements.

Discussion of your results and a conclusion.

2.2 Cooling System Fault Detection Experiment

2.2.1 Objective

In this experiment, two artificial faults will be used to demonstrate the implementation of diagnosis so we can easily observe the difference between normal and faulty conditions on the p-h diagrams. The refrigeration troubleshooting experimental setup (Bulgurcu, 2010) consists of a hermetic reciprocating compressor, a finned type air cooled condenser, an automatic expansion valve and a unit type evaporator, as shown in Figure 2.2.2.

2.2.2 Introduction

It is well known that performance degradation resulting from the development of faults within vapor compression systems can result in significant increase in energy consumption. Since cooling and refrigeration comprise over a third of the electrical energy consumption in residential and commercial buildings, the development of diagnostic modules that can effectively detect incipient faults could result in significant cost and energy savings that would have a dramatic economic and environmental impact. The image of basic refrigeration experimental setup is shown in Figure 2.2.1.

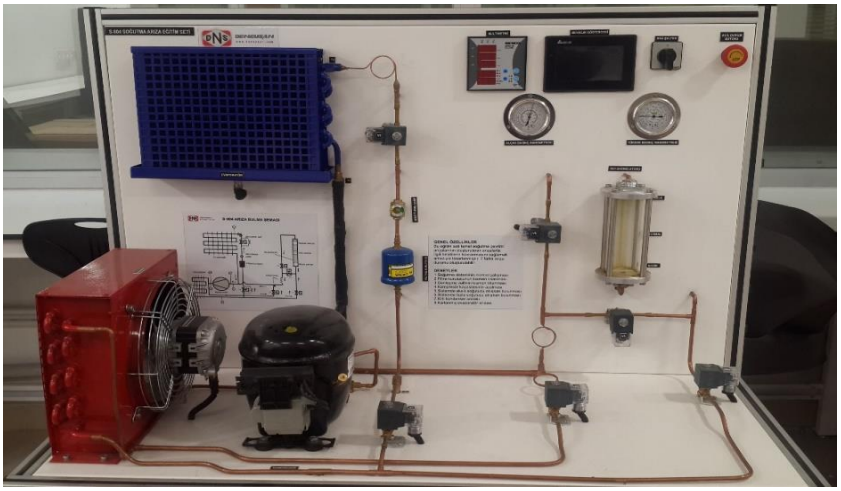


Figure 2.2.1. The image of basic refrigeration experimental setup

The key to successful troubleshooting is the knowledge of how a refrigeration system operates and how each component functions in the system. Because a refrigeration system has at least four components connected by tubing, the effect of the malfunction of each component on the other three components must be understood. A problem in one component may cause performance degradation or even malfunction in others. Knowledge of refrigeration theory and the operation of the components are necessary for successful troubleshooting. Besides component failures, external factors can also cause refrigeration system problems. These factors include water quality, air quality, and power supply. Operating procedures and weather conditions can also have an effect on the system. Load changes may cause further problems. One or more of these conditions may occur at any given time. Therefore, it is vital that we have an overall knowledge of system performance.

2.2.3 Theory

Faults can be divided into two categories: 1) hard failures that occur abruptly and either cause the system to stop functioning or not meet comfort conditions and 2) soft faults that cause degradation in performance but allow continued operation of the system. The first step is fault detection, in which a fault is indicated when the performance of a monitored system has deviated from expectation. The second step, the diagnosis, determines which malfunctioning component is causing the fault. Following diagnosis, fault evaluation assesses the impact of the fault on system performance. Finally, a decision is made on how to react to the fault. Expert knowledge could be used to set larger thresholds that would guarantee that the detected faults are important and should be repaired.

In this experiment, we conduct the fault diagnosis of a vapor compression refrigeration system applying hermetic reciprocating compressor. Two faults are imposed and investigated: compressor failure and refrigerant undercharge.

2.2.3.1 Fault Detection and Diagnosis

To analyze the performance of the refrigeration system, four points (1, 2, 3, and 4) on the p-h diagram (Figure 2.2.2) and their measured and calculated values such as temperatures at points 1, 2, 3, and 4 (T_1, T_2, T_3, *and* T_4), high side pressure (P_c) and low side pressure (P_e), refrigerants mass flow rate ($\dot{m}$), compressor current (I_c), voltage (U), and cosine Φ are required.

The differences between the actually measured values of an operating parameter, such as temperature T (°C), pressure P (Pa), volume flow rate $\dot{V}$ (m^3s^{-1}) or mass flow rate $\dot{m}$ (kgs^{-1}) and the expected values (estimated, simulated, or set points) of temperature T_{exp}, pressure P_{exp}, volume flow rate $\dot{V}_{\exp}$, or mass flow rate $\dot{m}_{\exp}$ under normal operating conditions are called residual.

A temperature residual T_{res}(°C), a pressure residual P_{res}(Pa), or a volume flow rate residual $\dot{V}_{\text{res}}$ (m^3s^{-1}) can be calculated from

$$T_{res} = T - T_{exp} \tag{2.2.1}$$

$$P_{res} = P - P_{exp} \tag{2.2.2}$$

$$\dot{V}_{res} = \dot{V} - \dot{V}_{exp} \tag{2.2.3}$$

where, the subscript *exp* indicates expected (predicted) values and the units of T_{exp}, P_{exp}, and $\dot{V}_{\exp}$ are the same as those of T, P, and $\dot{V}$.

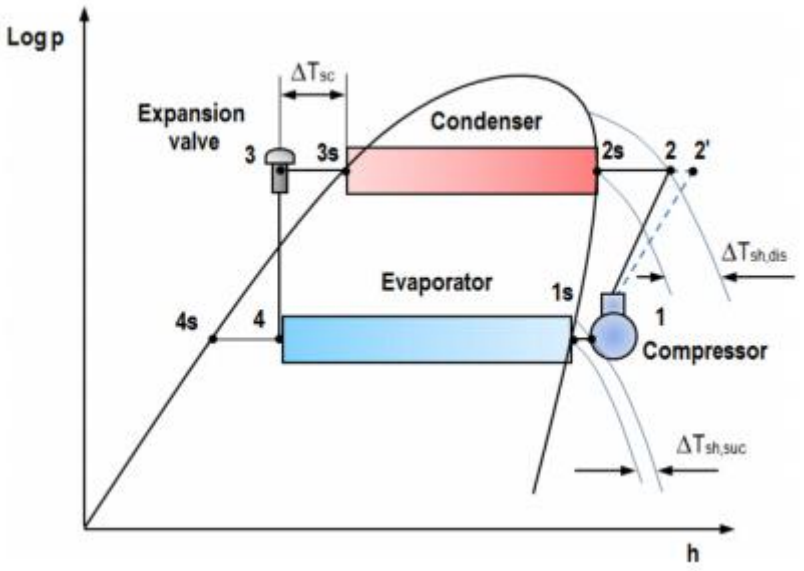


Figure 2.2.2. Points of meaningful instrument readings in refrigeration cycle on the p-h diagram. ($\Delta T_{sh,suc}$: suction superheat, ($\Delta T_{sh,dis}$: discharge superheat, (ΔT_{sc}: sub-cooling, point 1s: saturated vapor point of point 1, point 1: suction, point 2: discharge, point 2s: saturated vapor point of point 2, point 2′: discharge with entropy increase, point 3s : saturated liquid of point 3, point 3 : sub-cooled liquid at the expansion valve, point 4s: saturated liquid of point 4, point 4: evaporator input)

Residuals are often normalized so that the dominant symptom may have approximately the same magnitude for different types of faults. The residual R can be normalized as

$$R_{nor} = \frac{R - R_{min}}{R_{max} - R_{min}} \tag{2.2.4}$$

where R_{nor} is the normalized residual while R_{max} and R_{min} are maximum and minimum residuals, respectively.

A simple analysis of a standard vapor compression refrigeration system can be carried out by assuming a) steady flow, b) negligible kinetic and potential energy changes across each component, and c) no heat transfer in connecting pipe lines. The steady flow energy equation is applied to each of the four components.

Evaporator

Heat transfer rate at evaporator or refrigeration capacity $\dot{Q}_e$ is given by:

$$\dot{Q}_e = \dot{m}\,(h_1 - h_4) \tag{2.2.5}$$

where $\dot{m}$ is the refrigerant mass flow rate in kgs^{-1}, h_1 and h_4 are specific enthalpies at the exit and inlet to the evaporator respectively.

Compressor

Power input to the compressor, $\dot{W}_c$ is given by:

$$\dot{W}_c = \dot{m}(h_2 - h_1) \tag{2.2.6}$$

where h_2 and h_1 are specific enthalpies at the exit and inlet of the compressor respectively.

At any point in the cycle, the mass flow rate of refrigerant $\dot{m}$ can be written in terms of volumetric flow rate and specific volume. By applying the mass flow rate equation to the inlet condition of the compressor,

$$\dot{m} = \frac{\dot{V}_1}{v_1} \tag{2.2.7}$$

where $\dot{V}$ is the volumetric flow rate at compressor inlet and v_1 is the specific volume at compressor inlet.

The compression ratio is given by:

$$\varepsilon = \frac{P_c}{P_e} \tag{2.2.8}$$

where P_c is the absolute condensing pressure and P_e is the absolute evaporating pressure.

Volumetric efficiency of compressor is given by:

$$\eta_v = \frac{\dot{m}_r v_1}{V_c n/60} \tag{2.2.9}$$

where V_c is cylinder volume of compressor and η is the compressor speed.

Isentropic efficiency of the compressor is defined as:

$$\eta_s = \frac{\dot{W}_s}{\dot{W}_c} \tag{2.2.10}$$

where $\dot{W}$s is the isentropic work of compressor.

Condenser

Heat transfer rate at the condenser, Q_c is given by:

$$\dot{Q}_c = \dot{m}_r(h_2 - h_3) \tag{2.2.11}$$

where h_2 and h_3 are specific enthalpies at the inlet and exit to the condenser respectively.

Expansion device

During the throttling process in the expansion valve, it is assumed that there is no heat transfer to the environment, and it was mentioned earlier that the changes in kinetic and potential energies are negligible. Therefore, we have the following expression:

$$h_3 = h_4 \tag{2.2.12}$$

The exit condition of the expansion device lies in the two phase region. One can write:

$$h_4 = (1 - x_4)h_{f,e} + x_4 h_{g,e} = h_f + x_4 h_{fg} \tag{2.2.13}$$

where x_4 is the quality of the refrigerant at point 4, while $h_{f,e}$, $h_{g,e}$ and h_{fg} are saturated liquid enthalpy, saturated vapor enthalpy and latent heat of vaporization at the evaporator pressure, respectively.

The ratio of the evaporator load to the compressor power gives the coefficient of performance for a refrigeration system:

$$COP = \frac{\dot{Q}_e}{\dot{W}_c} \tag{2.2.14}$$

On the other hand, the coefficient of performance based on electric power input can be determined from the ratio of the evaporator load to the electric power consumption of the overall system:

$$COP_{el} = \frac{\dot{Q}_e}{\dot{W}_{el}} \tag{2.2.15}$$

where $\dot{W}_{el}$ the sum of electric power inputs to the motors of compressor, fans of the condenser and the evaporator.

Some terminologies on the p-h diagram (Figure 2.2.1) are explained as followings:

The suction superheat can be calculated by

$$\Delta T_{sh,suc} = T_1 - T_{1s} \tag{2.2.16}$$

where T_1 is the suction temperature at point 1 and $T_{1,s}$ is the saturated vapor temperature of point 1. The discharge superheat can be calculated by

$$\Delta T_{sh,dis} = T_2 - T_{2s} \tag{2.2.17}$$

where T_2 is the discharge temperature and T_{2s} is the saturated vapor temperature of point 2.

The sub-cooling can be calculated by

$$\Delta T_{sc} = T_{3s} - T_3 \tag{2.2.18}$$

where T_3 is the liquid temperature at the inlet of expansion valve and T_{3s} is the saturated liquid temperature of point 3.

The net cooling effect (NCE) can be calculated by

$$\dot{q} = (h_1 - h_4)\Delta T_{1-4} \tag{2.2.19}$$

where h_1 is the specific enthalpy at point 1 and h_4 is the specific enthalpy at point 4.

2.2.4 Experiments

The refrigeration troubleshooting experimental setup consists of a hermetic reciprocating compressor, a finned type air cooled condenser, an automatic expansion valve and a unit type evaporator, as shown in Figure 2.2.3.

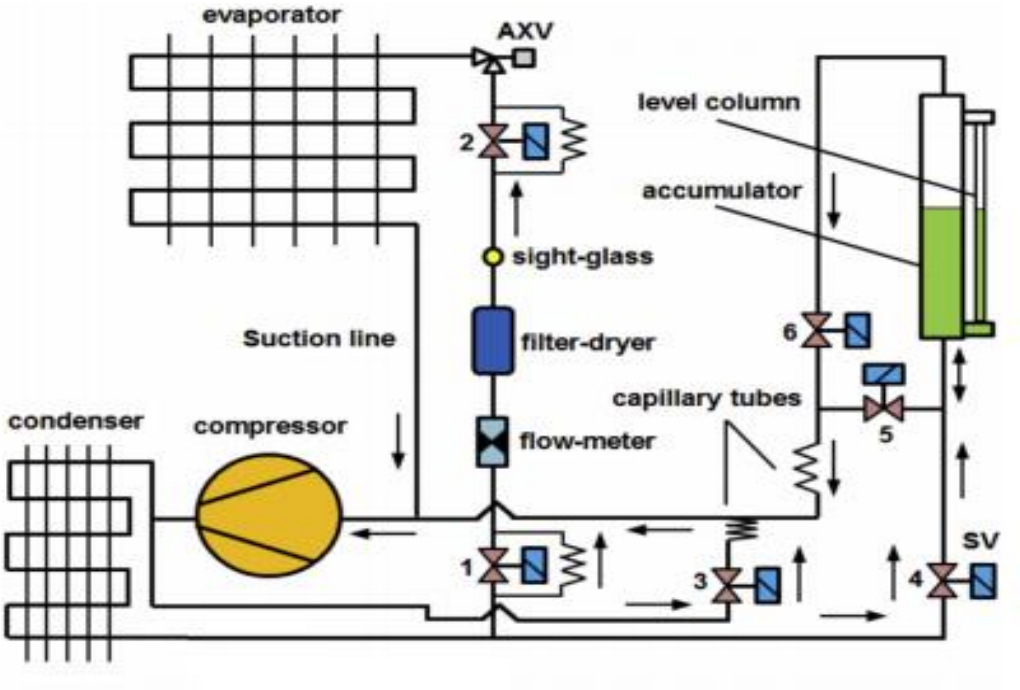


Figure 2.2.3. Schematic diagram of basic refrigeration experimental setup. (AXV: Automatic expansion valve, SV: Solenoid valve).

2.2.4.1 The performance of the Cooling System in Normal Situation

Aim of the Experiment: To learn and determine how the parameters like suction line pressure and temperature, discharge line pressure and temperature, and exit temperature of condenser change in normal situation.

Procedure

1. Turn on the main power and then turn on the compressor and the fan.
2. The fluid level in the accumulator should be at medium level which is the normal loading position.
3. Wait until the system reaches the steady-state
4. Record the values which are shown at the Table 2.2.1
5. Stop the machine.

To do: Draw the path followed by the refrigerant in the normal loading which is shown in Figure 2.2.4 and write the table values

Table 2.2.1. Measurement values of a cycle in normal situation

Numbers of measurements	1	2	3	4
Suction line pressure, P_1 [bar]				
Discharge line pressure, P_2[bar]]				
Suction line temperature of compressor, T_1 [°C]				
Discharge line temperature of compressor, T_2 [°C]				
Exit temperature of condenser, T_3 [° C]				
Expansion line temperature, T_4 [°C]				
Compressor amperage, I_k [A]				
Line voltage, U [Volt]				
Power factor (CosΦ)				

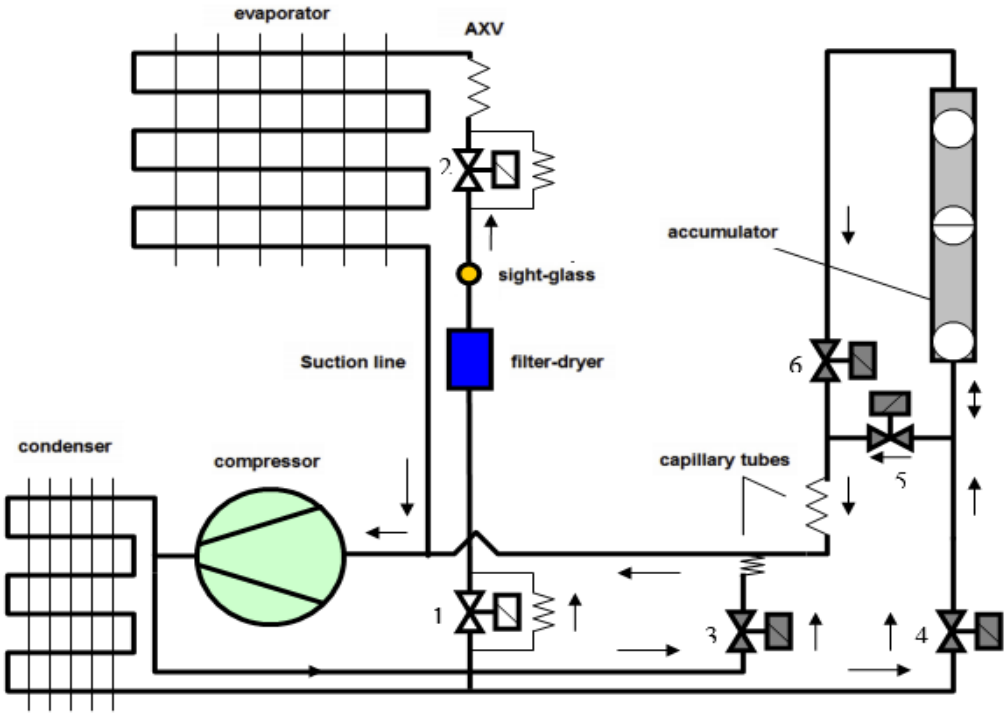


Figure 2.2.4. Schematic diagram of basic refrigeration experimental setup. (3,4,5 and 6 valves are closed)

2.2.4.2 The Performance Degradation of the Compressor Capacity

Aim of the Experiment: To learn how a capacity of compressor is affected by a degradation of volume efficiency of compressor or keeping capacity control valve open in a cooling systems.

Procedure

1. Turn on the main power and then turn on the compressor and the fan. Wait until the system reaches the steady-state
2. Turn on the generator 3 to create fault. By this way solenoid valve 3 will be opened. The small amount of refrigerant in the discharge line is fed directly to the compressor suction line to create a capacity drop.
3. Follow the new refrigeration cycle path on schematic diagram.
4. Record pressure and temperature values which are shown in the Table 2.2.2.
5. Switch off the generator 3 and shut down the machine.

To do: Draw the refrigerant cycle which is shown in Figure 2.2.5 and compare the values with normal situation.

Table 2.2.2. Measurement values of a cycle with a compressor capacity fault

Numbers of measurements	1	2	3	4
Suction line pressure, P_1 [bar]				
Discharge line pressure, P_2 [bar]]				
Suction line temperature of compressor, T_1 [°C]				
Discharge line temperature of compressor, T_2 [°C]				
Exit temperature of condenser, T_3 [° C]				
Expansion line temperature, T_4 [°C]				
Compressor amperage, I_k [A]				
Line voltage, U [Volt]				
Power factor (CosΦ)				

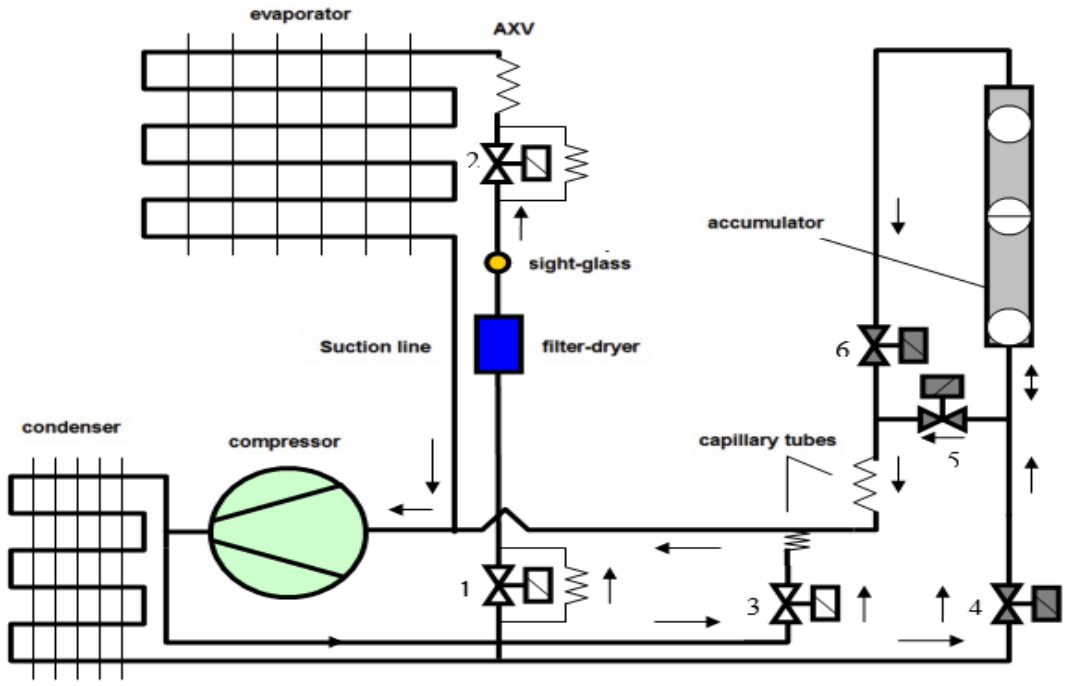


Figure 2.2.5. Schematic diagram of basic refrigeration experimental setup. (4,5 and 6 valves are closed)

2.2.4.3 The Lack of Refrigerant in the Cooling System

Aim of the Experiment: To understand how a system is affected by feeding lacking refrigerant to evaporator and by this way get experience about detecting faults in different systems.

Procedure

1. Turn on the main power and then turn on the compressor. Wait until the system reaches the steady-state
2. Turn on the generator 4 to create fault. By this way solenoid valves 4 and 6 will be opened. The small amount of refrigerant in the condenser outline is fed directly to the accumulator so the amount of refrigerant in the cooling system will be reduced. The level of refrigerant in the accumulator should be increased to the high level.
3. Read the required measurements from the measuring devices and record them on the Table 2.2.3.
4. To restore the system again, turn on the fault generator 5 and wait until the level of the accumulator reaches the normal position.
5. After the system reaches the steady-state position, stop the compressor and the machine.

To do: Draw the refrigerant cycle which is shown in Figure 2.2.6 and compare the values with normal situation.

Table 2.2.3. Measurement values of a cycle with a lacking of refrigerant fault

Numbers of measurements	1	2	3	4
Suction line pressure, P_1 [bar]				
Discharge line pressure, P_2 [bar]]				
Suction line temperature of compressor, T_1 [°C]				
Discharge line temperature of compressor, T_2 [°C]				
Exit temperature of condenser, T_3 [° C]				
Expansion line temperature, T_4 [°C]				
Compressor amperage, I_k [A]				
Line voltage, U [Volt]				
Power factor (CosΦ)				

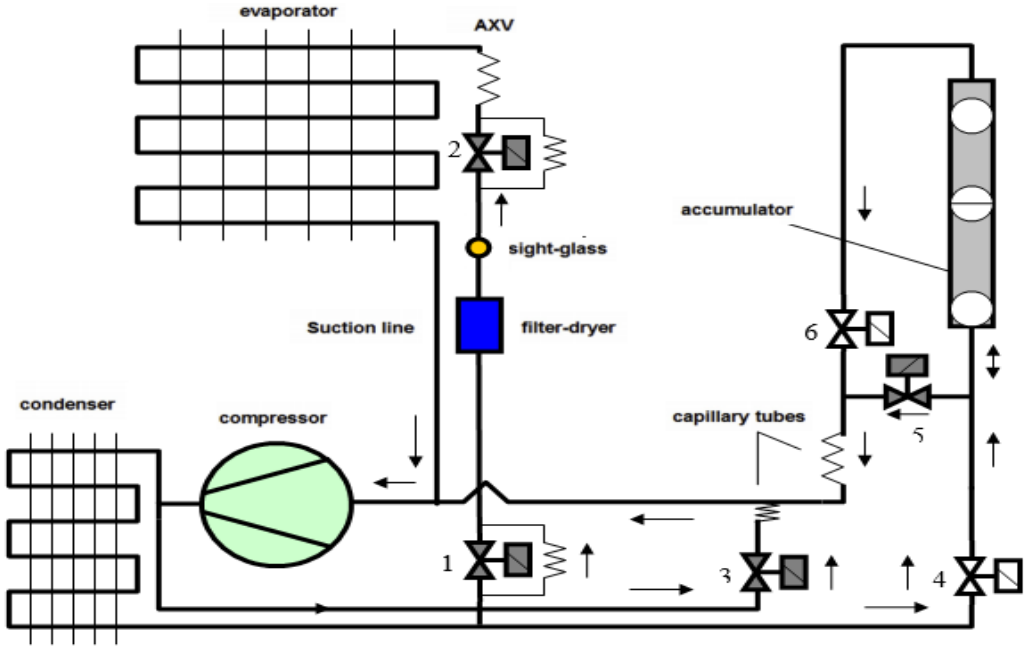


Figure 2.2.6. Schematic diagram of basic refrigeration experimental setup. (1,2,3 and 5 valves are closed)

2.2.5 Report

In your laboratory, reports must have the followings;

a) Cover page
b) A short introduction (Only one page)
c) All the necessary calculations using measured data.
d) Discussion of your results and a conclusion.

2.3 Fatigue Experiment

2.3.1 Objective

The objective of this experiment is the demonstration of how a fatigue test is conducted and how the test results are interpreted.

2.3.2 Introduction

Fatigue is a form of failure that occurs in structures subjected to dynamic and fluctuating stresses (e.g., bridges, aircraft, and machine components). Under these circumstances, it is possible for failure to occur at a stress level considerably lower than the tensile or yield strength for a static load. The term fatigue is used because this type of failure normally occurs after a lengthy period of repeated stress or strain cycling. Fatigue is important inasmuch as it is the single largest cause of failure in metals, estimated to be involved in approximately 90% of all metallic failures; polymers and ceramics (except for glasses) are also susceptible to this type of failure. Furthermore, fatigue is catastrophic and insidious, occurring very suddenly and without warning.

Fatigue failure is brittle-like in nature even in normally ductile metals in that there is very little, if any, gross plastic deformation associated with failure. The process occurs by the initiation and propagation of cracks, and typically, the fracture surface is perpendicular to the direction of an applied tensile stress.

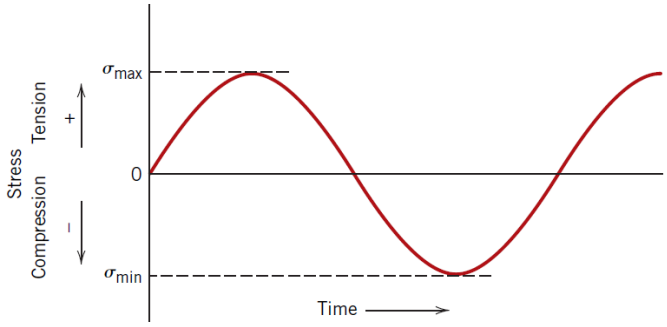
Fatigue is a problem that can affect any part or component that moves. Automobiles on roads, aircraft wings and fuselages, ships at sea, nuclear reactors, jet engines, and land-based turbines are all subject to fatigue failures. Fatigue was initially recognized as a problem in the early 1800s when investigators in Europe observed that bridge and railroad components were cracking when subjected to repeated loading. As the century progressed and the use of metals expanded with the increasing use of machines, more and more failures of components subjected to repeated loads were recorded. Today, structural fatigue has assumed an even greater importance as a result of the ever-increasing use of high-strength materials and the desire for higher performance from these materials.

2.3.3 Theory

2.3.3.1 Cyclic Stresses

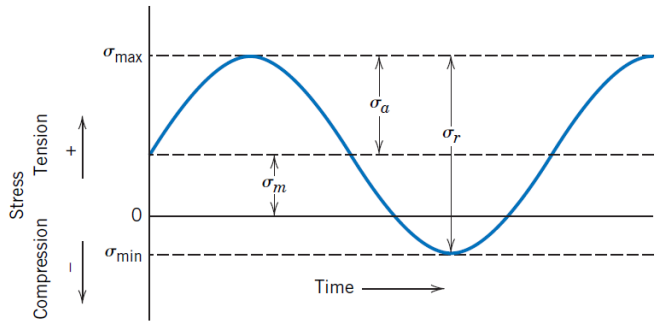
The applied stress may be axial (tension–compression), flexural (bending), or torsional (twisting) in nature. In general, three different fluctuating stress–time modes are possible.

a) Reversed stress cycle:



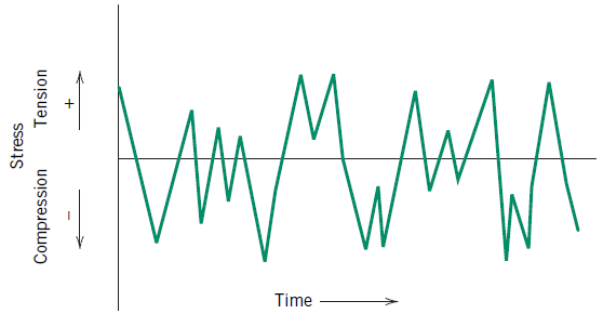
The stress alternates from a maximum tensile stress (+) to a maximum compressive stress (-) of equal magnitude.

b) Repeated stress cycle:



Repeated stress cycle, in which maximum and minimum stresses are asymmetrical relative to the zero-stress level.

c) Random stress cycle:



The stress level may vary randomly in amplitude and frequency.

Several parameters used to characterize the fluctuating stress cycle as indicated repeated stress cycle figure.

Mean stress (σ_m) is defined as the average of the maximum and minimum stresses in the cycle:

$$\sigma_m = \frac{\sigma_{max} + \sigma_{min}}{2} \tag{2.3.1}$$

The **range of stress (σ_r)** is the difference between (σ_{max}) and (σ_{min}):

$$\sigma_r = \sigma_{max} - \sigma_{min} \tag{2.3.2}$$

Stress amplitude (σ_a) is one-half of this range of stress:

$$\sigma_a = \frac{\sigma_r}{2} = \frac{\sigma_{max} - \sigma_{min}}{2} \tag{2.3.3}$$

The stress ratio R is the ratio of minimum and maximum stress amplitudes:

$$R = \frac{\sigma_{min}}{\sigma_{max}} \tag{2.3.4}$$

By convention, tensile stresses are positive and compressive stresses are negative. For example, for the reversed stress cycle, the value of R is -1

2.3.3.2 The *S*-*N* Curve

The fatigue properties of materials can be determined from laboratory simulation tests. A test apparatus should be designed to duplicate as nearly as possible the service stress conditions (stress level, time frequency, stress pattern, etc.). The most common type of test conducted in a laboratory setting employs a rotating–bending beam: alternating tension and compression stresses of equal magnitude are imposed on the specimen as it is simultaneously bent and rotated. In this case, the stress cycle is reversed Schematic diagrams of the apparatus and test specimen commonly used for this type of fatigue testing are shown in Figures 2.3.1a and 2.3.1b, respectively. From Figure 2.3.1a, during rotation, the lower surface of the specimen is subjected to a tensile (i.e., positive) stress, whereas the upper surface experiences compression (i.e., negative) stress.

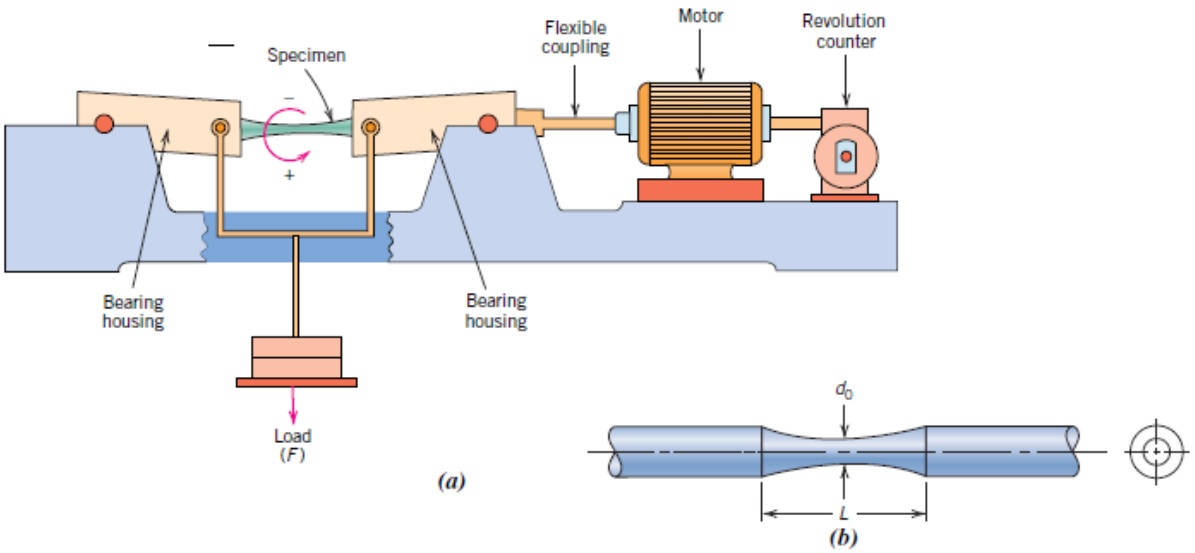


Figure 2.3.1. For rotating–bending fatigue tests, schematic diagrams of (a) a testing apparatus, and (b) a test specimen.

A series of tests is commenced by subjecting a specimen to stress cycling at a relatively large maximum stress (σ_{max}), usually on the order of two-thirds of the static tensile strength; number of cycles to failure is counted and recorded. This procedure is repeated on other specimens at progressively decreasing maximum stress levels. Data are plotted as stress S versus the logarithm of the number N of cycles to failure for each of the specimens.

Two distinct types of S–N behavior are observed and are represented schematically in Figure 2.3.2. As these plots indicate, the higher the magnitude of the stress, the smaller the number of cycles the material is capable of sustaining before failure. For some ferrous (iron-base) and

titanium alloys, the S–N curve (Figure 2.3.2*a*) becomes horizontal at higher N values; there is a limiting stress level, called the fatigue limit (also sometimes called the endurance limit), below which fatigue failure will not occur. This fatigue limit represents the largest value of fluctuating stress that will not cause failure for essentially an infinite number of cycles. For many steels, fatigue limits range between 35% and 60% of the tensile strength.

Most nonferrous alloys (e.g., aluminum, copper) do not have a fatigue limit, in that the S–N curve continues its downward trend at increasingly greater N values (Figure 2.3.2*b*). Thus, fatigue ultimately occurs regardless of the magnitude of the stress. For these materials, the fatigue response is specified as fatigue strength, which is defined as the stress level at which failure will occur for some specified number of cycles (e.g., 10^7 cycles). The determination of fatigue strength is also demonstrated in Figure 2.3.2b.

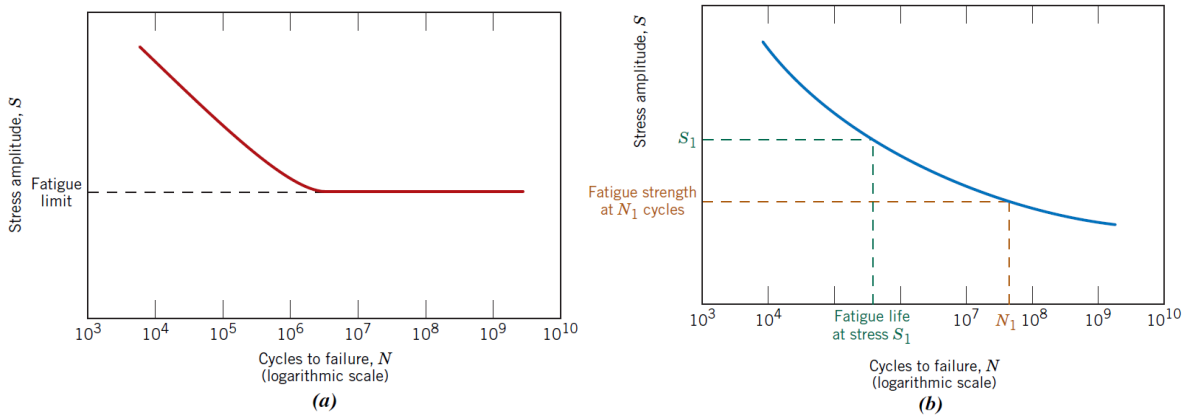


Figure 2.3.2. Stress amplitude (S) versus logarithm of the number of cycles to fatigue failure (N) for (a) a material that displays a fatigue limit and (b) a material that does not display a fatigue limit.

Another important parameter that characterizes a material's fatigue behavior is fatigue life N_f. It is the number of cycles to cause failure at a specified stress level, as taken from the S–N plot (Figure 2.3.2*b*).

The fatigue behaviors represented in Figures 2.3.2a and 2.3.2b may be classified into two domains. One is associated with relatively high loads that produce not only elastic strain but also some plastic strain during each cycle. Consequently, fatigue lives are relatively short; this domain is termed low-cycle fatigue and occurs at less than about 10^4 to 10^5 cycles. For lower stress levels, wherein deformations are totally elastic, longer lives result. This is called high-cycle fatigue because relatively large numbers of cycles are required to produce fatigue failure. High-cycle fatigue is associated with fatigue lives greater than about 10^4 to 10^5 cycles.

Fatigue S–N curves for several metal alloys are shown in Figure 2.3.3; data were generated using rotating-bending tests with reversed stress cycles. Curves for the titanium, magnesium, and steel alloys as well as for cast iron display fatigue limits; curves for the brass and aluminum alloys do not have such limits.

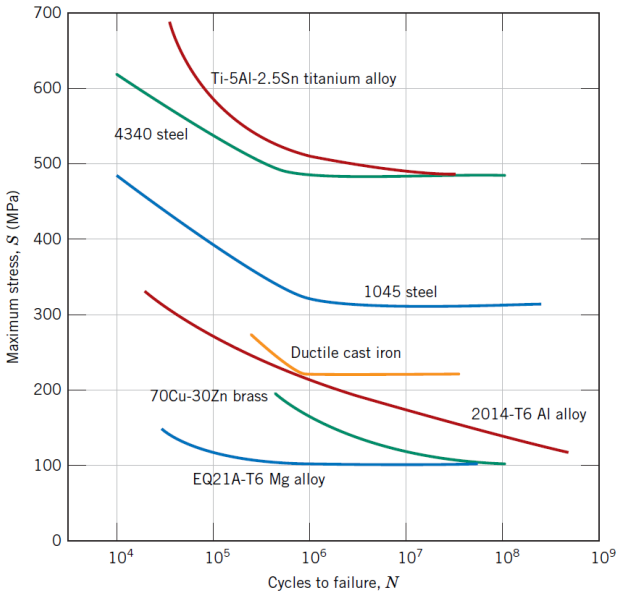


Figure 2.3.3. Maximum stress versus logarithm of the number of cycles to fatigue failure for seven metal alloys**.**

2.3.3.3 Crack Initiation and Propagation

The process of fatigue failure is characterized by three distinct steps:

1**)** Crack initiation, in which a small crack forms at some point of high stress concentration;
2) Crack propagation, during which this crack advances incrementally with each stress cycle;
3) Final failure, which occurs very rapidly once the advancing crack has reached a critical size.

Cracks associated with fatigue failure almost always initiate (or nucleate) on the surface of a component at some point of stress concentration. Crack nucleation sites include surface scratches, sharp fillets, keyways, threads, dents, and the like. In addition, cyclic loading can produce microscopic surface discontinuities resulting from dislocation slip steps that may also act as stress raisers and therefore as crack initiation sites.

Fatigue cracking can occur quite early in the service life of the component by the formation of a small crack, generally at some point on the external surface. The crack then propagates slowly through the material in a direction roughly perpendicular to the main tensile axis (Figure 2.3.4). Ultimately, the cross-sectional area of the member is reduced to the point that it can no longer carry the load, and the member fails in tension.

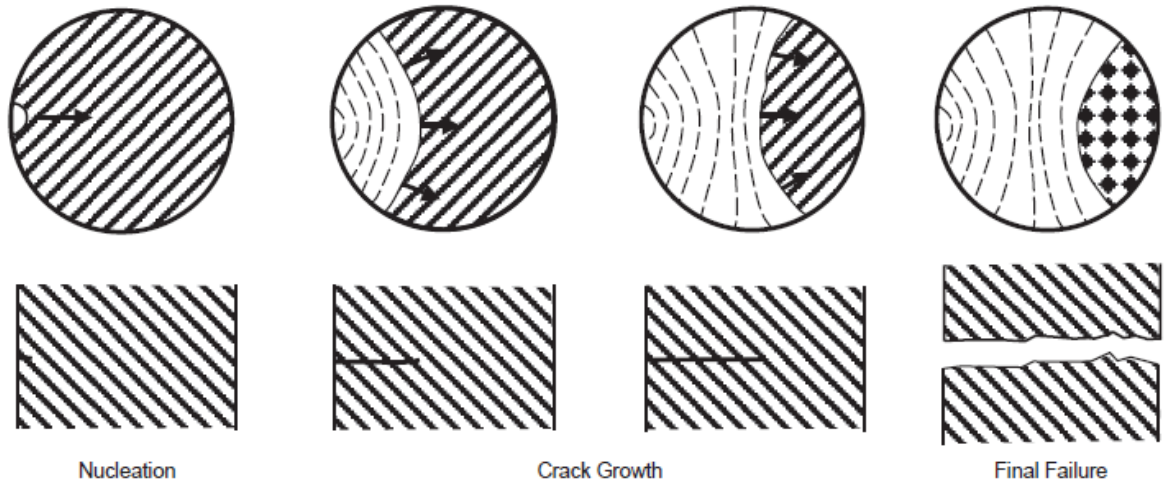


Figure 2.3.4. Typical propagation of a fatigue crack

The region of a fracture surface that formed during the crack propagation step may be characterized by two types of markings termed *beachmarks* and *striations*. Both features indicate the position of the crack tip at some point in time and appear as concentric ridges that expand away from the crack initiation site(s), frequently in a circular or semicircular pattern. Beachmarks and striations do not appear on the region over which the rapid failure occurs. Rather, the rapid failure may be either ductile or brittle; evidence of plastic deformation will be present for ductile failure and absent for brittle failure. This region of failure may be noted in Figure 2.3.5. A crack formed at the top edge. The smooth region also near the top corresponds to the area over which the crack propagated slowly. Rapid failure occurred over the area having a dull and fibrous texture (the largest area).

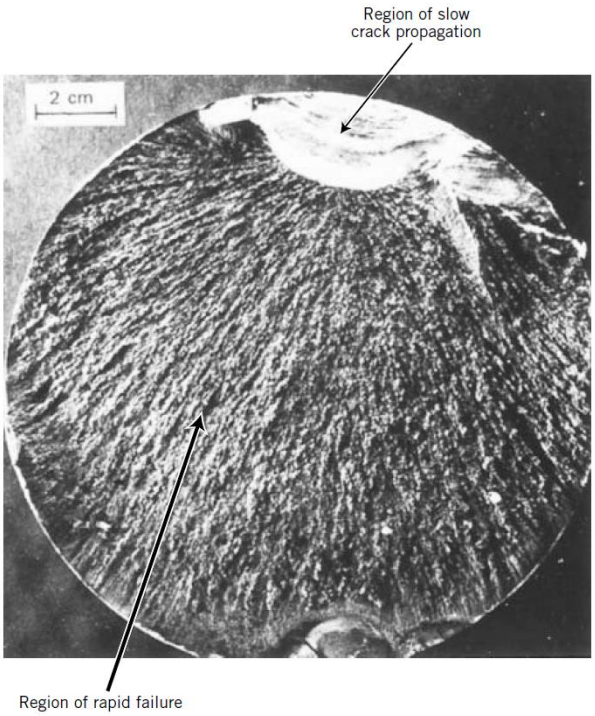


Figure 2.3.5. Fatigue failure surface

2.3.3.4 Factors That Affect Fatigue Life

- Mean Stress

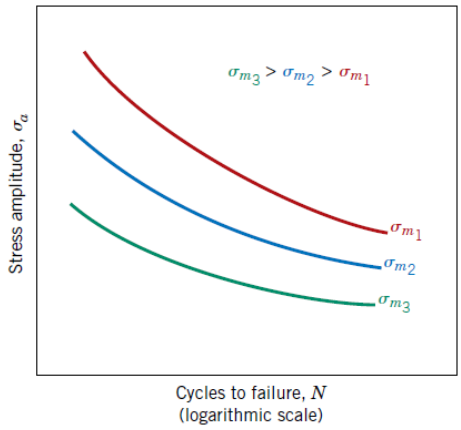


Figure 2.3.6. Demonstration of the influence of mean stress σ_m on S–N fatigue behavior.

- Surface Effects
- Design Factor

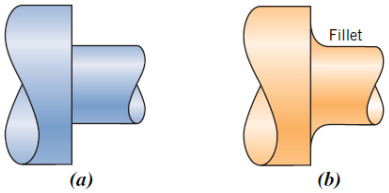


Figure 2.3.7. Demonstration of how design can reduce stress amplification.
(a) Poor design: sharp corner. (b) Good design: fatigue lifetime is improved by incorporating a rounded fillet into a rotating shaft at the point where there is a change in diameter.

- Surface Treatments

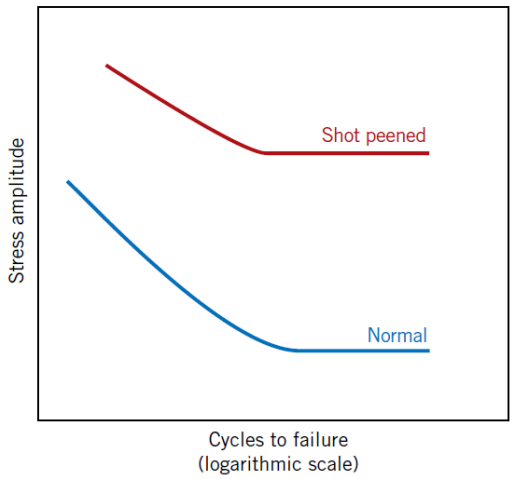


Figure 2.3.8. Schematic S–N fatigue curves for normal and shot-peened steel.

- Environmental Effects
  Thermal fatigue
  Corrosion fatigue

2.3.4 Experiments

As can be seen from Figure 2.3.9, it is possible to control fatigue testing apparatus from a control panel. The control panel shows the testing duration in seconds and it allows to start/stop of the electric motor. A three-phase electric motor, 1.5 Kw, 2900 rev/min, is using during the test. In order to adjust desired loading stress value, weight hanger is used. One unit movement of weight hanger on the scale is equal to 1 MPa. Maximum applicable stress value is 700 MPa for this apparatus.

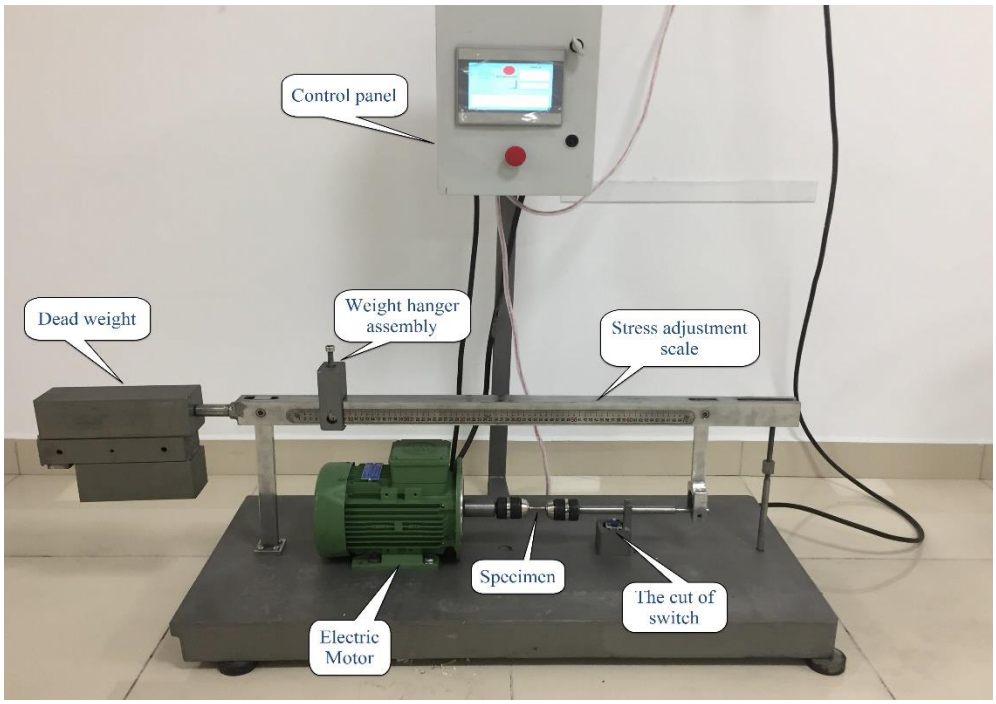


Figure 2.3.9. Rotating–bending fatigue testing apparatus ant its components

2.3.4.1 Experiment Specimen

Test specimens are prepared according to ASTM E466 and ASTM E468 standards. Figure 2.3.10 shows dimensions of the fatigue test specimen. More than 8 specimens (averagely, 8-10 specimens) are used under different stress values, in order to draw S-N curve of a material.

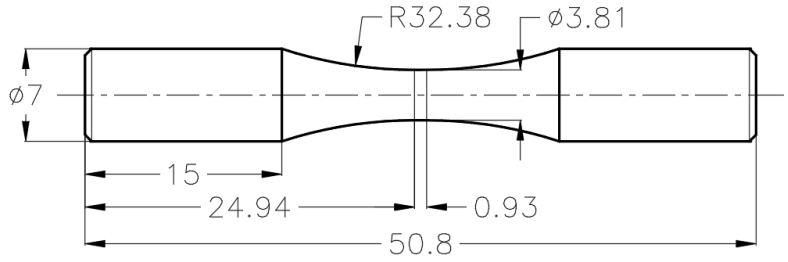


Figure 2.3.10. Dimensions of fatigue life test specimen

2.3.4.2 Experiment Procedure

1) Measure and record the minimum specimen diameter with a caliper, making sure that the surface of the specimen is not scratched during the measurement process.
2) Observe the specimen surface for smoothness/polish quality, scratches or other imperfections.
3) Turn off the power at the emergency button on control panel of the machine before the attached specimen.
4) Loosen the lock screw fixing the weight to the calibrated beam and move the weight to the zero position at the ruler (left of the beam).
5) Loosen the nut holding the safety bar at the right end of the load arm and swing the bar free of the load arm.
6) Swing the load arm up and to the right so that a specimen may be inserted into the drive spindle collet. Position the load arm to prevent contact with the free end of the specimen.
7) Tighten the drive spindle collet onto the specimen. The collet must be tightened sufficiently to prevent any relative movement between the collet and the specimen which could cause fretting corrosion.
8) Insert the free end of the specimen into the load arm collet observing the same procedures and precautions noted above for the drive spindle.
9) Placed the safety guard on the cast body and activate the magnetic.
10) Insert the motor and control panel plugs. Please wait until the screen is loaded.
11) Start the engine with the touch button on the control panel.
12) Slowly move the weight along the calibrated beam to the required bending moment setting.
Note: 1mm movement of the weight is equal to 1 MPa act on the specimen. E.g. For implement 450 MPa load is corresponding to 450 mm.
13) Counter on the control panel will run until specimen breaks.
14) After the specimen breaks, the engine will automatically shut off due to switch.
15) How much time machine works and final number of cycles that the specimen endured will be displayed on the screen at control panel.
16) Record the time and final number of cycles that the specimen endured. Note that the total cycles can read on the screen.
17) Before removing the specimen, close the control panel by using the emergency button.
18) If you want, move the load spindle so crack can be clearly seen.
19) Examine the fracture surface of specimens that have been complete broken to see evidence of fatigue failure, failure location and plane orientation, smoothness/roughness, defects, etc.
20) Disconnect the power plugs safely.
21) Tighten the nut holding the safety bar at the right end of the load arm and set a ruler to make safe.

2.3.5 Report

1. Give 3 different examples about fatigue failure in daily life. And explain them clearly.
2. According to your observations, explain step by step how a rotating bending fatigue test is performed in detail.
3. Table 2.3.1 shows the fatigue data for a steel alloy.

a) Make an S-N plot (stress amplitude versus logarithm of cycles to failure) **on** a $1mm^2$ graph paper using these data.
b) What is the fatigue limit for this alloy?
c) Determine fatigue lifetimes at stress amplitudes of 415 MPa and 275 MPa.
d) Estimate fatigue strengths at 2×10^4 and 6×10^5 cycles.

Table 2.3.1. Fatigue data

Stress Amplitude (MPa)	Cycles to Failure
470	10^4
440	$3\ x\ 10^4$
390	10^5
350	$3\ x\ 10^5$
310	10^6
290	$3\ x\ 10^6$
290	10^7
290	10^8

In laboratory reports, they must contain the followings;

a) Cover page
b) A short introduction
c) Solutions of asked questions
d) Discussion of your results and a conclusion.
Note: Experimental report must be prepared manually (not printout).

2.4 Metallography Experiment

2.4.1 Objective

The objective of the experiment is to learn specimen preparation and to examine and analyze the microstructures of engineering alloys.

2.4.2 Introduction

Metallography can be defined as the study of observing and determining the structure and spatial distribution of the constituents, inclusions or phases in metallic alloys. It can provide constitutional information about the specimen under investigation, including the size and shape of the grains (crystallites), the presence of micro defects (such as segregation, hair cracks, and nonmetallic inclusions), and the nature and distribution of secondary phases.

2.4.3 Theory

2.4.3.1 Preparation of Specimens

In order to determine the microstructure of the material accurately, it should be prepared properly. In preparation of material, a step by step process should be followed. In sequence the steps are cutting, mounting, course grinding, fine grinding, polishing, etching, and microscopic examination.

A specimen about 20 mm is cut from the material to be examined. One face of the specimen is grinded by abrasive papers and then polished on revolving wheels with fine abrasives such as aluminum oxide. In order to reveal structural details, the surface is etched with chemical solutions. The etchant attacks various parts of the specimen at different rates and reveals the structure. A metallographic microscope is used to examine the microstructure.

2.4.3.1.1 Mounting

Small samples can be difficult to hold safely during grinding and polishing operations, and their shape may not be suitable for observation on a flat surface. They are therefore mounted inside a polymer block or mount.

The sample is surrounded by an organic polymeric powder which melts under the influence of heat (about 200°C). Pressure is also applied by a piston, ensuring a high quality mould free of porosity and with intimate contact between the sample and the polymer.

2.4.3.1.2 Grinding

The use of Premium SiC abrasive paper is the most efficient and practical technique for grinding metallic metallographic specimens. Although many qualities of silicon carbide are readily available, only the premium grade SiC powder provides the most consistent results and highest grinding rates.

Grinding of the specimen starts with the coarse papers and continues with fine papers. Initial grinding is recommended with 320 grit SiC and followed by 320 400, 600 and, 800 grit SiC paper. In each stage, grinding is done by rubbing the specimen backwards and forwards on the grinding paper in one direction only until the surface is completely ground, that is, until only grinding marks due to this particular paper can be seen to cover the whole surface. These

materials are relatively soft they do not easily break down the SiC paper. The specimen is washed thoroughly to remove coarse silicon carbide particles before proceeding to a finer paper. Materials used for abrading particles are:

- **garnet:** commonly used in woodworking
- **emery:** commonly used to abrade or polish metal
- **aluminum oxide:** perhaps most common in widest variety of grits; can be used on metal (i.e. body shops) or wood
- **silicon carbide:** available in very coarse grits all the way through to micro-grits, common in wet applications
- **alumina-zirconia:** (an aluminum oxide–zirconium oxide alloy), used for machine grinding applications
- **chromium oxide:** used in extremely fine micron grit papers

2.4.3.1.3 Polishing

Polishing is the process of creating a smooth and shiny surface by rubbing it or using a chemical action (Aluminum oxide), leaving a surface with a significant reflection. The specimen must be free from scratches, stains and others imperfections which tend to mark the surface. The specimen should reveal no evidence of chipping due to brittle inter metallic compounds and phases. Polishing enhances the surface and makes it suitable to observe its grain structure under microscope.

2.4.3.1.4 Etching

The surface is exposed to chemical attack or ETCHING, with grain boundaries being attacked more aggressively than reminder of the grain to reveal the microstructure. Light from an optical microscope is reflected or scattered from the sample surface depending how the surface is etched. The etching materials used for different materials are shown in Table 2.4.1.

Table 2.4.1. Etching Materials

Sample material	Etchant	Composition	Remarks
Carbon steel	(Usually 2%) (nitric acid)	HNO_3 1-5 ml Ethyl alcohol 100ml	Few seconds (15 Sec)
Carbon steel	Picric Acid	Picric acid 4g Ethyl alcohol 100ml	Few seconds (15 Sec)
Aluminum	Hydrofluoric acid	HF (conc.) 0.5ml H_2O 99.5ml	Swab for 15 sec.

2.4.3.2 Observation of the Specimen

The micro structure of many metallic or ceramic materials consists of many grains. A grain is portion of the materials within which the arrangement of the atoms is nearly identical but the orientation or crystal structure of atoms are different. The surface that separates the individual grains is a narrow zoon in which the atoms are properly spaced. One method of controlling the properties of a material is by controlling the grain size. The microstructures of different materials and alloys can be seen in Figure 2.4.1 and Figure 2.4.2.

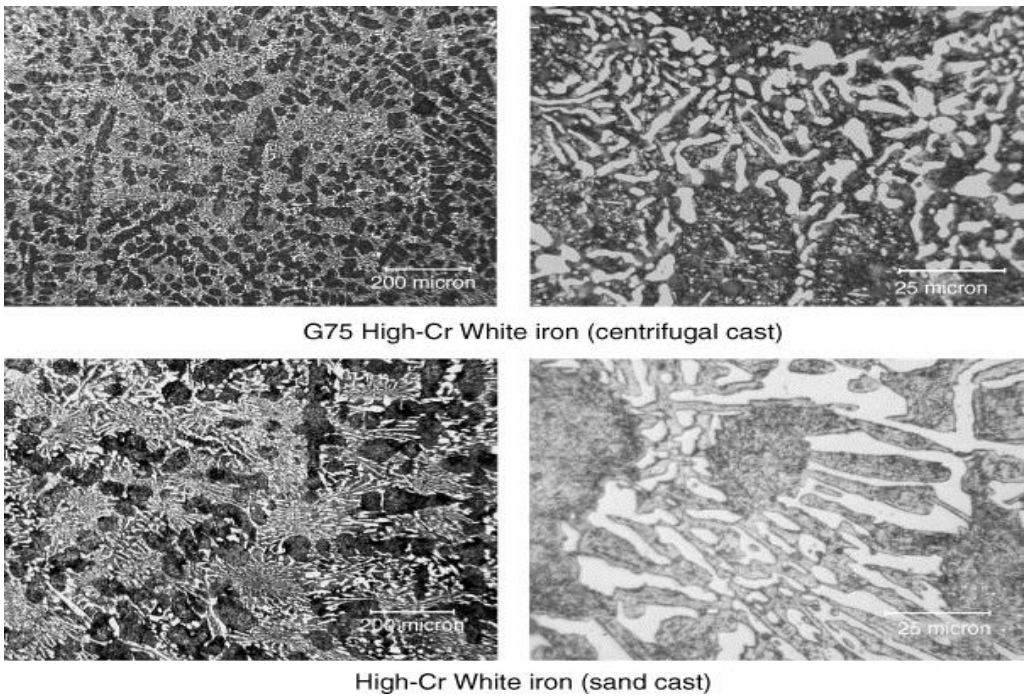


Figure 2.4.1. Microstructures of different materials with different magnification ratios

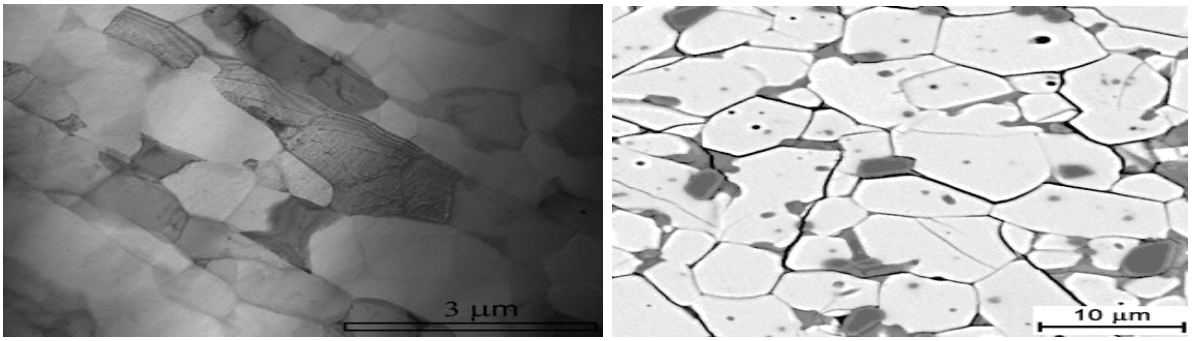


Figure 2.4.2. Microstructure of aluminum oxide and titanium dioxide (Al2O3, TiO2)

2.4.3.2.1 Determination of Grain Size

Firstly, the magnification of the micrograph is determined as using the formula;

$$M = \frac{L}{L_a} \tag{2.4.1}$$

where L is image size and L_a is actual size. After determining the magnification, random lines across the grains are drawn on the picture of the microstructure of the specimen obtained from microscope as shown in Figure 2.4.3. The grains each line crosses are counted and grain size is calculated by using the formula;

$$\bar{l} = \frac{L_T}{PM} \tag{2.4.2}$$

where $\bar{l}$ is grain size, L_T is total length of lines and P is the total number of grains for all lines.

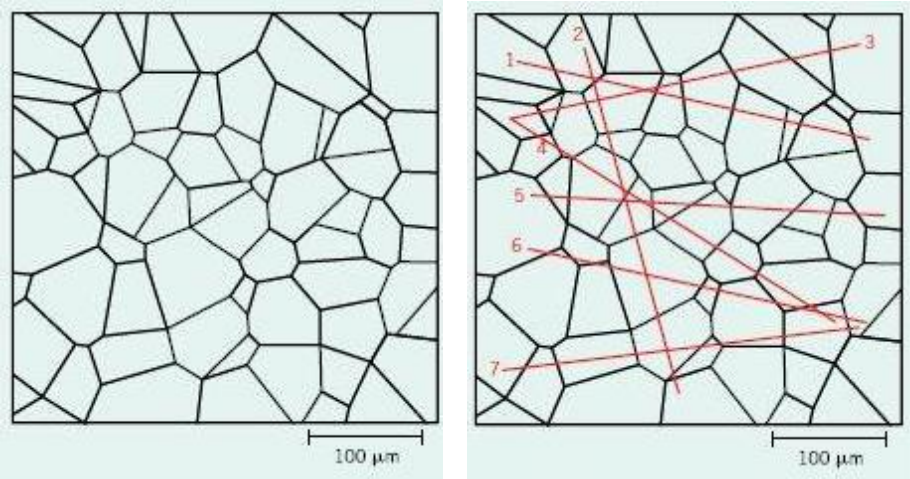


Figure 2.4.3. Microstructure of a material

After finding the grain size, the ASTM grain-size number G can be found as;

$$G = -6.6457 \log(\bar{l}) - 3.298 \tag{2.4.3}$$

2.4.3.2.2 Sample calculation

For the microstructure given in Figure 2.4.3, the scale bar length is measure and found as 16 mm. From the magnification formula;

$$M = \frac{16000\ \mu m}{100\ \mu m} = 160$$

The length of each lines is 50 mm. The total length is found as 350 mm. The grain quantities for each line is given Table 2.4.1.

Table 2.4.2. Grain quantities for each line

Line Number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**Total**
Number of Grain Boundary Intersections	8	8	8	9	9	9	7	58

The total grains intersected by lines are 58. From the Eq. (2.4.2), the grain size is determined as follows;

$$\bar{l} = \frac{350\ mm}{58 * 160} = 0.0377\ mm$$

The value of G;

$$G = -6.6457 \log(0.0377) - 3.298 = 6.16$$

2.4.4 Experiments

Different materials will be used in the experiment. The samples are given cut as required sizes before. The preparation steps after the cutting operation will be followed as mentioned.

i. Prepare the specimens for the examination in the microscope as explained in Chapter 2
   a. Mount the specimen using hot mounting procedure
   b. Grind the specimen from course to fine
   c. Polish
   d. Etch with the required chemical composition

ii. Examine the specimens using required magnification ratio, observe the phases and grain boundaries.

2.4.4.1 Results

i. Define the metallography

ii. Describe the steps involved in the preparation of a metallographic sample:
   - Sectioning (cutting)
   - Plastic coating of the samples
   - Mounting
   - Grinding
   - Polishing
   - Etching

iii. Why should the specimen be roughly washed after each stage during either grinding or polishing?

iv. What is the purpose of etching metallographic samples?

v. Calculate the grain sizes and ASTM grain size number as mentioned above for microstructure you have observed.

2.4.5 Report

In your laboratory, reports must have the followings;

a) Cover page.
b) A short introduction.
c) All the necessary calculations using measured data.
d) Discussion of your results and a conclusion.
e) Answer the questions in the results section.

2.5 Hydraulic Training Set Experiment

2.5.1 Objective

This experiment is aimed to introduce the hydraulic components and the systems that works with the hydraulic systems.

2.5.2 Introduction

Hydraulic Training Set have the opportunity to practice individually with the example studies. In this study, it is aimed that the students learn the working principles of hydraulic systems experimentally, identify the products used. In this context, students will aim to conceptualize the working principles of hydraulic systems.

Students will be able to make measurements such as cycle, pressure, flow and mass on this experimental set and compare the results with theoretical calculations. This system will provide information about filtration, fluid properties, pumps, linear motion systems, circular motion systems, pressure control valves, flow control valves, proportional controlled valves and error types.

2.5.3 Theory

2.5.3.1 Component Identification and Function

A typical hydraulic fluid handling system, is one in which the power supply, or power pack, provides hydraulic fluid at a given pressure and flow to operate differential hydraulic motors. These motors, in turn, drive fluid displacement pumps that deliver fluid at a given pressure and flow for a specific application.

The reservoir stores and cools hydraulic oil and provides the mounting surface for other power supply components. It contains:

- *Clean-out doors* and a *fluid drain port* that are used for cleaning and maintenance.
- A *filler breather port/cap* that is used to fill the reservoir for with oil. The reservoir must breathe to atmosphere for proper operation.
- A *low level/high temperature sensor* that detects a low hydraulic oil level in the reservoir or a high oil temperature condition.
- A *hydraulic oil level/temperature indicator* that provides a visual check for oil level and temperature during operation.

The hydraulic pump provides hydraulic oil to all hydraulic motors in the system. It contains a manually adjustable pressure compensator that is used to adjust the hydraulic oil pressure to the header, or piping, system.

The motor drives the hydraulic pump. For industrial in-plant applications, it is usually electric. For mobile applications, the engine power take-off, or PTO, may drive the hydraulic pump.

The oil supply line supplies hydraulic oil under pressure from the power supply to the hydraulic motor.

The oil return line returns hydraulic oil, usually at low pressure, from the hydraulic motor back to the power supply’s reservoir.

The return oil filter, located on the return line between the last hydraulic-powered device and the reservoir, removes contaminants from the hydraulic oil.

2.5.3.2 How Hydraulic Systems Work

1) The motor, usually electric, drives a hydraulic pump.
2) The hydraulic pump draws oil from the reservoir and pumps it to the hydraulic motor via the oil supply line.
3) Hydraulic oil enters and exits the hydraulic motor, causing it to reciprocate.
4) The reciprocation of the hydraulic motor drives the fluid section or displacement pump.
5) The displacement pump delivers the fluid in conjunction with the application equipment.
6) The hydraulic oil that leaves the hydraulic motor returns to the reservoir via the oil return line.

2.5.3.3 Pressure and Flow Control

In a hydraulic fluid handling system, hydraulic fluid controls are used to regulate the hydraulic oil pressure and flow to each hydraulic motor to keep the system balanced and functioning more productively. These controls include the hydraulic pressure reducing valve and the flow control valve.

The hydraulic pressure reducing valve is used to adjust the hydraulic system oil pressure to the operating pressure required by the fluid pump for the specific application. A pressure gauge is provided to verify the pressure setting.

The flow control valve limits the maximum amount of hydraulic oil flow to the hydraulic motor, ensuring that it operates at the recommended cycle rate. This prevents pump runaway when a supply container empties or a fluid line ruptures.

2.5.3.3.1 Motor Types

Hydro motors are used to convert hydraulic energy into mechanical energy. They are classified according to the type of internal elements that are directly actuated by the flow of fluid. Hydraulic motors very similar in construction to hydraulic pumps. In fact many pumps may be used as motors without any modification. Like hydraulic pumps most hydraulic motorsa re classied as gear, vane, piston or deri sine type. Rotary motors are generally rated in terms of Displacement or Torque. They may be fixed displacement motors. Fixed displacement motors normally have constant torque, the speed being varied by altering the flow to the motor. Variable displacement motors have variable torque and speed. With the input flow and operating pressure remaining constant, varying the displacement can vary the ratio between torque and speed to suit the load requirements.

2.5.3.3.2 Hydro Pumps

Hydro pumps are displacement pumps which function on the basis of “suction and displacement”.

We differentiate amongst three basic types of hydro pumps on the basis of displacement volume:

• Constant displacement pump Constant displacement volume

• Variable displacement pump Adjustable displacement volume
• Control pump: Displacement volume is controlled on the basis of pressure, volumetric flow rate and power.

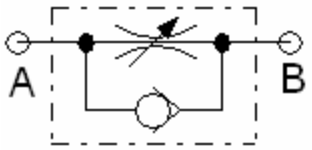
The hydro pump generates volumetric flow (but no pressure). The delivery rate per revolution and the drive speed dictate the pump's delivery rate which is specified in litres per minute. Pressure only occurs as the result of resistance to pump delivery, for example flow resistance, load resistance and pressure-relief valve settings. Pressure is specified in MPa or bar.

2.5.3.3.3 Flow Control Valves

These valves are used to control the speed of a cylinder or a motor by controlling the amount of fluid flow rate passing through it.

a. **One way flow control valve**. The one way flow control valve is used to control the flow rate in the hydraulic circuit only in one direction (throttling part: from A to B), and allow a free flow in the opposite direction (from B to A). Throttling is achieved by the adjusting screw.

(a) one way flow control valve

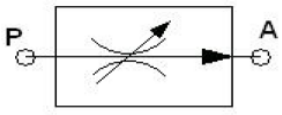


(b) ISO symbol of the one way flow control valve

Figure 2.5.1.

b. **Two way flow control valve.** The two way control valve provides a constant flow rate in the case of variable loads.

(a)Two way flow control valve



(b) ISO symbol of two way flow control valve

Figure 2.5.2.

This valve has two ports (A) and (B) and adjusting throttle screw.

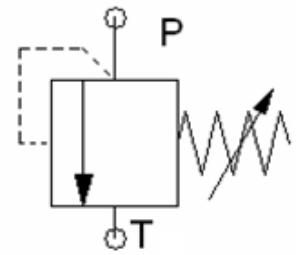
2.5.3.3.4 Pressure Control Valves

These valves are used to control and regulate the pressure in the hydraulic system.

a. Pressure relief valve

Pressure relief valve is used mainly as safety valve. It prevents the maximum permissible pressure in the hydraulic system from being exceeded. If the maximum pressure is reached at the valve inlet, the valve outlet is opened and the oil will flow out to the tank. The valve remains

open until the built-in spring closes it after reaching the preset pressure in accordance with the spring characteristic.



P: input pressure
T: tank port

(a) Pressure relief valve (b) ISO symbol of two way pressure relief valve

Figure 2.5.3.

2.5.3.4 Examples

Embossing machine

A special machine is used to emboss graphic symbols on metal foil. The foil is fed through the embossing machine with an adjustable cycle time. The downward motion of the stamp must be capable of being varied in accordance with the fed speed as shown in Figure. The return motion must always be executed as a rapid traverse. A One way flow control valve is used to control the speed of the stamp, while a pressure relief valve is used to prevent the weight of the stamp from pulling the piston rod out of the cylinder. A 4/2 way valve is used to switch between upwards and downwards motion.

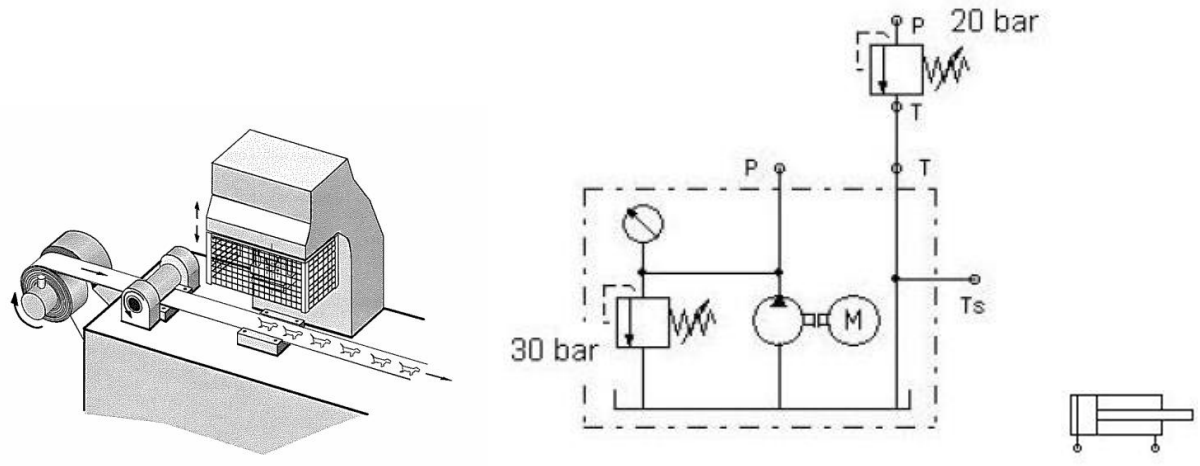


Figure 2.5.4. Embossing machine sketch and circiut diagram

Grinding Machine

The grinding table of a surface grinding machine is driven by a hydraulic cylinder as shown in Figure. Since the speed is required to be the same in both directions, the hydraulic control circuit must be designed to provide compensation for the difference in volume of the two cylinder chambers. A differential circuit is suggested with a 3/2- way valve for speed adjustment. Note you can use 4/3-way valve as 3/2 way valve by closing one of the output port.

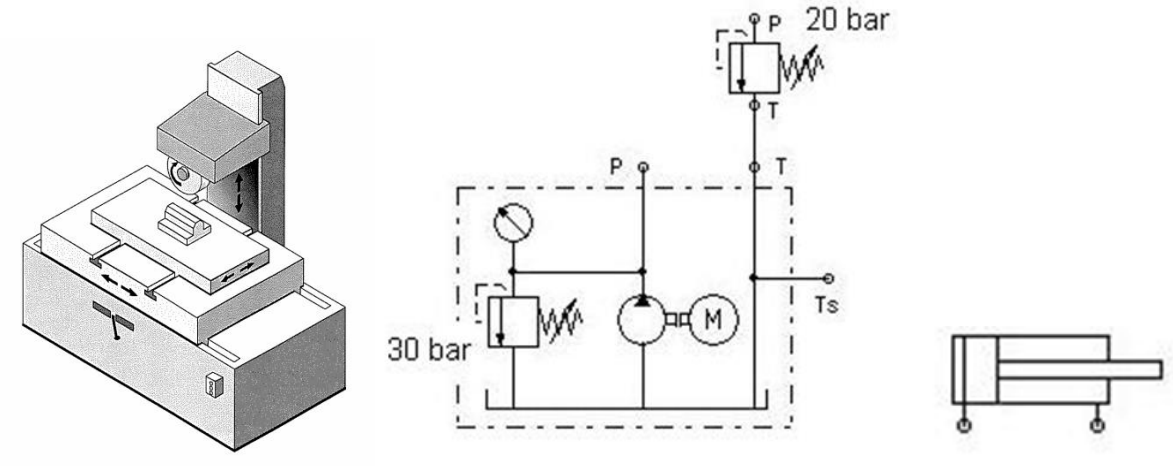


Figure 2.5.5. Grinding machine sketch and circuit diagram

2.5.4 Experiments

2.5.4.1 Usage of pressure relief valve

In a hydraulic press system, the press is required to operate at a maximum pressure of 30 bar in both directions. Double acting piston is used. The forward and backward movement of the cylinder will be via the direction valve. If the system is not energized for safety, there will be no piston movement.

Components of the circuit

- Electric motor
- Kaplin-drum
- Suction & return filters
- Pump (60 cc)
- Tank
- Pressure Relief Valve (0-50 bar)
- Manometer
- 4/3 directional valve
- Double acting cylinder (to be operated at different loads)

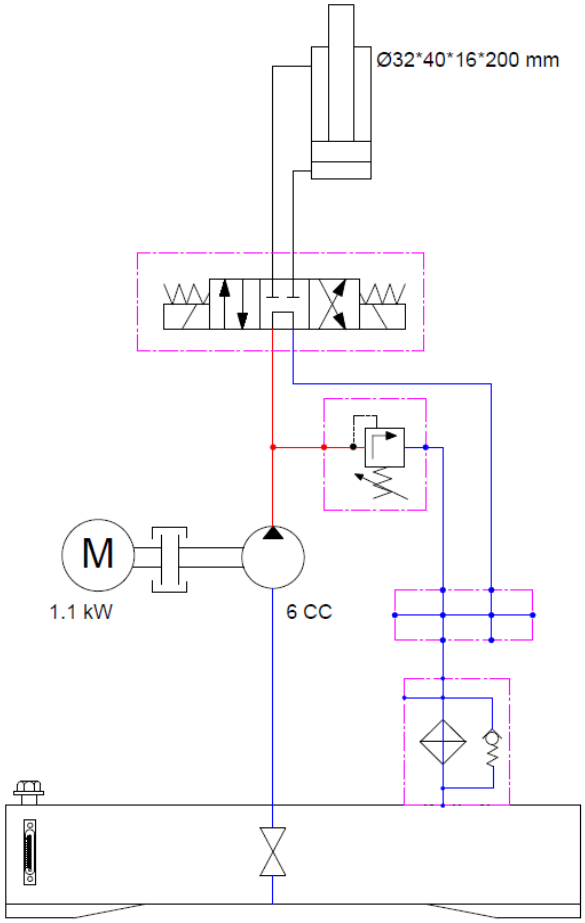


Figure 2.5.6. Circiut diagram

2.5.4.2 Usage of two-way flow control valve

Pistons that have the motion back and forth will be used in the industrial automation system. It is required to manually adjust the speed of one of these pistons. The operator will push a button, the piston will move forward, and the other button will bring it back. It is expected that the speed control should be only in the direction of opening the piston and should be fast while closing.

Components of the circuit

- Electric motor
- Clutch
- Pump (60 bar pressure and 2 lpm flow rate)
- Tank
- Pressure Relief Valve (50 bar)
- Manometer
- 4/2 directional control valve with lever control
- Double Action Cylinder (9 kg load)

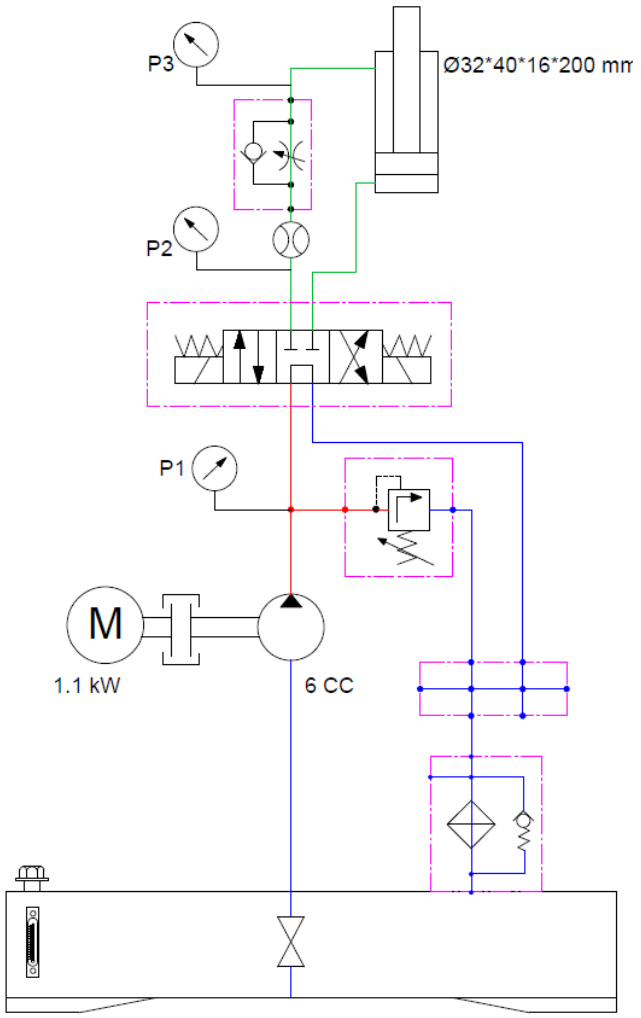


Figure 2.5.7. Circiut diagram

2.5.4.3 Usage of motion control valve

In a crane system, it is desired to pull the weight attached to the hook end. Actuation is hydro motor. It is desirable to provide a controlled descent during descending of the load connected to the hydro motor. Movements will be provided with the help of a lever control valve.

Components of the circuit

- Pump
- Couplings
- Hydro motor
- Directional control valve
- Over center valve
- Filters

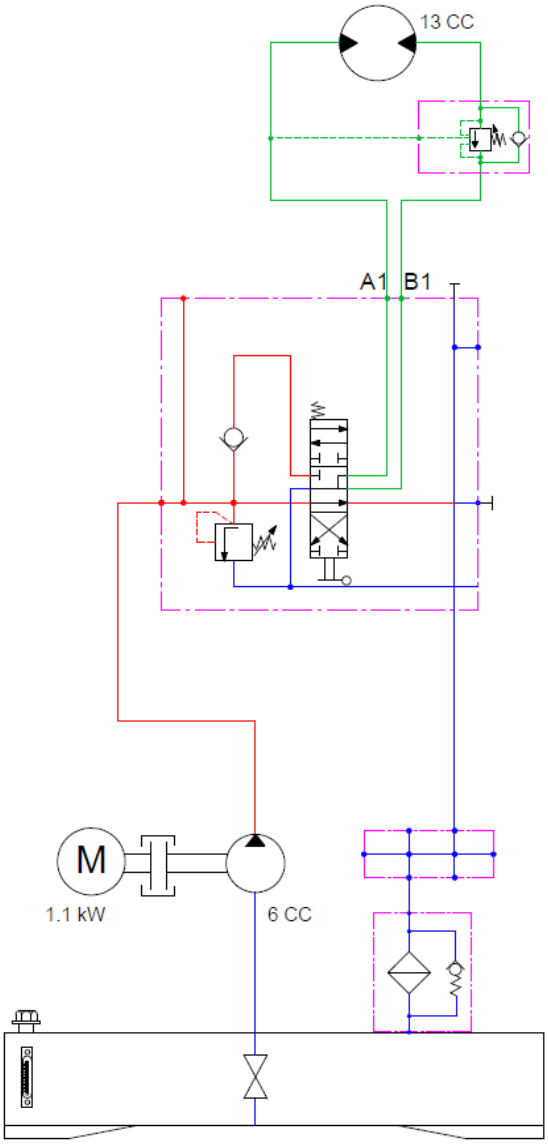


Figure 2.5.8. Circiut diagram

2.5.5 Report

1) State the function of the one way flow control valve.
2) Draw the I.S.O. symbol of the one way flow control valve.
3) Name the main parts of the one way flow control valve.
4) State the function of the two way flow control valve?
5) Draw the I.S.O. symbol of the two way flow control valve.
6) State the function of pressure relief valve.
7) The simple circuit shown is to enable a pump to be tested by measuring the flow rate and pressure. A flow meter is connected in series with the pump and flow from the pump will be controlled by a pressure relief valve as shown. Identify by name the item represented by each symbol.

A_____ B_____

C_____ D_____

E_____

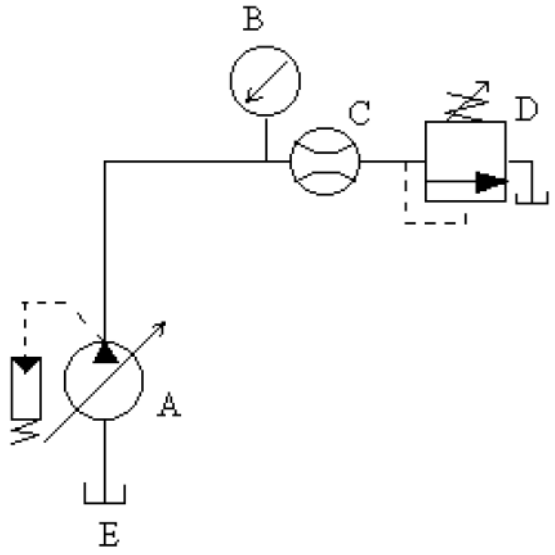


Figure 2.5.9.

2.6 Air-conditioning Experiment

2.6.1 Objective

The purpose of this experiment is to introduce air-conditioning unit and to understand basic processes such as heating, cooling, humidification and dehumidification in this device. Also, it is aimed to determine the properties of atmospheric air using psychrometric chart.

2.6.2 Introduction

Human beings have an inherent weakness–they want to feel comfortable. They want to live in an environment that is neither hot nor cold, neither humid nor dry. However, comfort does not come easily since the desires of the human body and the weather usually are not quite compatible. Achieving comfort requires a constant struggle against the factors that cause discomfort, such as high or low temperatures and high or low humidity. Today, modern air-conditioning systems can heat, cool, humidify, dehumidify, clean, and even deodorize the air–in other words, condition the air to peoples' desires.

Air-conditioning systems can be classified according to their applications as comfort air-conditioning systems and process air-conditioning systems. Comfort air-conditioning systems provide occupants with a comfortable and healthy indoor environment in which to carry out their activities. Process air-conditioning systems provide needed indoor environmental control for manufacturing, product storage, or other research and development processes.

Air-conditioning processes include simple heating (raising the temperature), simple cooling (lowering the temperature), humidifying (adding moisture), and dehumidifying (removing moisture). Sometimes two or more of these processes are needed to bring the air to a desired temperature and humidity level.

2.6.3 Theory

2.6.3.1 Dry Air and Atmospheric Air

Air is a mixture of nitrogen, oxygen, and small amounts of some other gases. Air in the atmosphere normally contains some water vapor (or moisture) and is referred to as atmospheric air. By contrast, air that contains no water vapor is called dry air. It is often convenient to treat air as a mixture of water vapor and dry air since the composition of dry air remains relatively constant, but the amount of water vapor changes as a result of condensation and evaporation from oceans, lakes, rivers, showers, and even the human body. Although the amount of water vapor in the air is small, it plays a major role in human comfort. Therefore, it is an important consideration in air-conditioning applications.

For air-conditioning applications, dry air can be treated as an ideal gas with a constant c_p value of 1.005 kJ/kg·K. Taking 0°C as the reference point, the enthalpy and enthalpy change of dry air can be determined from

$$h_a = c_p T = 1.005T \tag{2.6.1}$$

$$\Delta h_a = c_p \Delta T = 1.005\Delta T \tag{2.6.2}$$

where T is in °C.

Since the partial pressure of water vapor is very low, it would be very convenient to also treat the water vapor in the air as an ideal gas with negligible error (under 0.2 percent), even when it is a saturated vapor. Therefore, water vapor in air behaves as if it existed alone and obeys the ideal-gas relation. Then, the atmospheric air can be treated as an ideal-gas mixture whose pressure is the sum of the partial pressure of dry air and that of water vapor;

$$P = P_a + P_v \tag{2.6.3}$$

Moreover, since water vapor is an ideal gas, the enthalpy of water vapor is a function of temperature only, that is, $h = h(T)$. Therefore, the enthalpy of water vapor in air can be taken to be equal to the enthalpy of saturated vapor at the same temperature. That is,

$$h_v(T, low\ P) \cong h_g(T) \tag{2.6.4}$$

The enthalpy of water vapor at 0°C is 2500.9 kJ/kg. The average c_p value of water vapor can be taken to be 1.82 kJ/kg·°C. Then the enthalpy of water vapor can be determined approximately from,

$$h_g(T) \cong 2500.9 + 1.82T \tag{2.6.5}$$

where *T* is in °C.

2.6.3.2 Specific and Relative Humidity of Air

The amount of water vapor in the air can be specified in various ways. One of the most logical way is to specify directly the mass of water vapor present in a unit mass of dry air. This is called *absolute* or *specific humidity* (also called humidity ratio) and is denoted by ω:

$$\omega = \frac{m_v}{m_a} \tag{2.6.6}$$

with the unit of: kg-water vapor/kg-dry air.

It can also be expressed in terms of partial pressures:

$$\omega = 0.622\frac{P_v}{P_a} = 0.622\frac{P_v}{P - P_v} \tag{2.6.7}$$

In another definition, *relative humidity* which is the ratio of amount of moisture the air holds to the maximum amount of moisture the air can hold at the same temperature. That is,

$$\phi = \frac{m_v}{m_g} = \frac{P_v}{P_g} \tag{2.6.8}$$

where P_g is;

$$P_g = P_{sat.@T} \tag{2.6.9}$$

The relative humidity ranges from 0 for dry air to 1 for saturated air. Absolute humidity and relative humidity can be related with the following equations:

$$\phi = \frac{\omega P}{(0.622 + \omega)P_g} \tag{2.6.10}$$

$$\omega = 0.622\frac{\phi P_g}{P - \phi P_g} \tag{2.6.11}$$

Atmospheric air is a mixture of dry air and water vapor, and thus the enthalpy of air is expressed in terms of the enthalpies of the dry air and the water vapor. In most practical applications, the amount of dry air in the air–water-vapor mixture remains constant, but the amount of water vapor changes. Therefore, the enthalpy of atmospheric air is expressed per unit mass of dry air instead of per unit mass of the air–water vapor mixture. The total enthalpy (an extensive property) of atmospheric air is the sum of the enthalpies of dry air and the water vapor:

$$H = H_a + H_v = m_a h_a + m_v h_v \tag{2.6.12}$$

Dividing by m_a;

$$h = h_a + \omega h_v \tag{2.6.13}$$

with the unit of kJ/kg-dry air.

2.6.3.3 Dry-bulb, Dew Point and Wet-bulb Temperatures

The ordinary temperature of atmospheric air is frequently referred to as the *dry-bulb temperature*.

The *dew-point temperature* is defined as the temperature at which condensation begins when the air is cooled at constant pressure. In other words, it is the saturation temperature of water corresponding to the vapor pressure:

$$T_{dp} = T_{sat.@P_v} \tag{2.6.14}$$

The process is given in Fig. 2.6.1. As the air cools at constant pressure, the vapor pressure P_v remains constant. Therefore, the vapor in the air (state 1) undergoes a constant-pressure cooling process until it strikes the saturated vapor line (state 2). The temperature at this point is T_{dp}, and if the temperature drops any further, some vapor condenses out. The air remains saturated during the condensation process and thus follows a path of 100 percent relative humidity (the saturated vapor line). The ordinary temperature and the dew-point temperature of saturated air are identical.

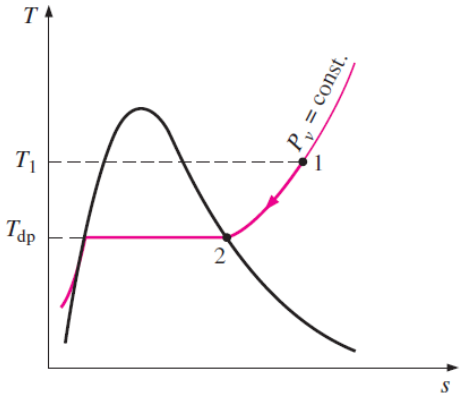


Figure 2.6.1. Constant-pressure cooling of moist air.

Relative humidity and specific humidity are frequently used in engineering and atmospheric sciences, and it is desirable to relate them to easily measurable quantities such as temperature and pressure. One way of determining the relative humidity is to determine the dew-point temperature of air which is discussed above.

A more practical approach is to use a thermometer whose bulb is covered with a cotton wick saturated with water and to blow air over the wick, as shown in Fig. 2.6.2. The temperature measured in this manner is called the *wet-bulb temperature*, and it is commonly used in air-conditioning applications.

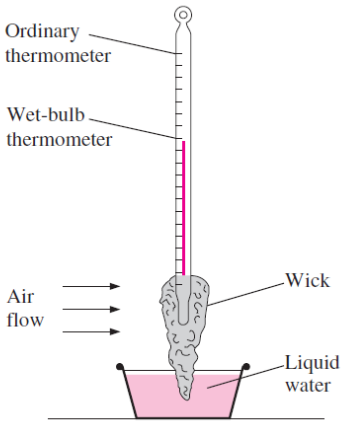


Figure 2.6.2. A simple arrangement to measure the wet-bulb temperature.

The wet-bulb temperature can also be measured by placing the wet-wicked thermometer in a holder attached to a handle and rotating the holder rapidly, that is, by moving the thermometer instead of the air. A device that works on this principle is called a sling psychrometer.

2.6.3.4 The Psychrometric Chart

The state of the atmospheric air at a specified pressure is completely specified by two independent intensive properties. The rest of the properties can be calculated easily from the previous relations. The sizing of a typical air-conditioning system involves numerous such calculations, therefore, there is clear motivation to computerize calculations or to do these calculations once and to present the data in the form of easily readable charts. Such charts are called psychrometric charts, and they are used extensively in air-conditioning applications.

The basic features of the psychrometric chart are illustrated in Fig. 2.6.3. The dry-bulb temperatures are shown on the horizontal axis, and the specific humidity is shown on the vertical axis. On the left end of the chart, there is a curve (called the saturation line) instead of a straight line. All the saturated air states are located on this curve. Therefore, it is also the curve of 100 percent relative humidity. Other constant relative-humidity curves have the same general shape.

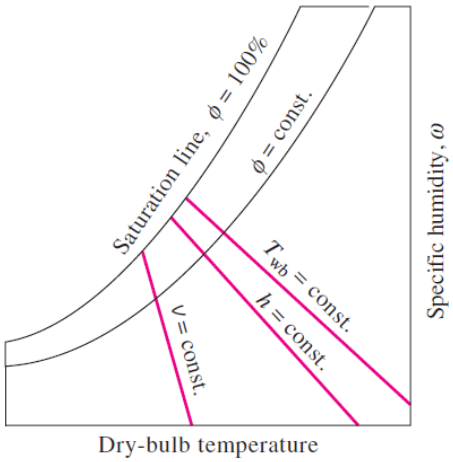


Figure 2.6.3. Schematics for a psychrometric chart.

Psychrometric chart for a pressure of 1 atm (101.325 kPa) is given at the end of the document. Psychrometric charts at other pressures (for use at considerably higher elevations than sea level) are also available in the literature.

2.6.3.5 Air-conditioning Processes

There are four main air-conditioning processes.

- Heating
- Cooling
- Humidification
- Dehumidification

Combinations of these four are frequently applied during the air-conditioning processes. Various air-conditioning processes are illustrated on the psychrometric chart in Fig. 2.6.4. Notice that simple heating and cooling processes appear as horizontal lines on this chart since the moisture content of the air remains constant (ω=constant) during these processes. Air is commonly heated and humidified in winter and cooled and dehumidified in summer. Notice how these processes appear on the psychrometric chart.

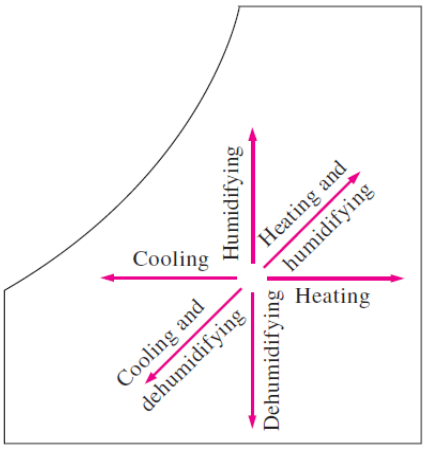


Figure 2.6.4. Various processes shown on a psychrometric chart.

2.6.4 Experimental Set-up

The experimental setup is essentially composed of an air duct and air-conditioning sections are installed along the channel. The schematic view of the device is given in Fig. 2.6.5. The air that will be conditioned in the duct is withdrawn from the medium via a radial fan and directed toward the duct. The channel has heating, cooling, and humidification units in serial. The sensors placed on various locations measure the dry-bulb temperature and relative humidity. Those points are also shown on the figure. Having read the dry-bulb temperature and relative humidity data, the remaining properties of the air are obtained using the psychrometric chart.

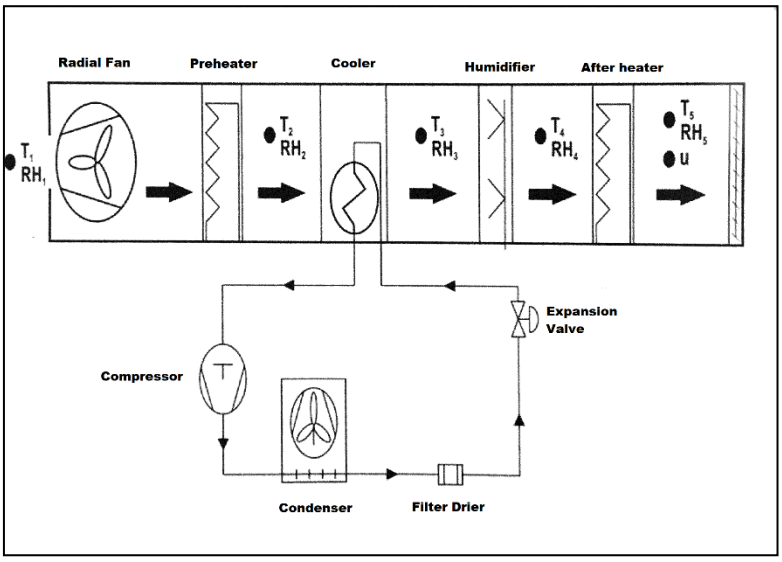


Figure 2.6.5. Schematic view of the experimental set-up.

2.6.4.1 Measurements

For winter session air-conditioning:

Table 2.6.1.

Reading:	**1**	**2**	**3**
T_1 [°C]			
RH_1 [%]			
T_2 [°C]			
RH_2 [%]			
T_4 [°C]			
RH_4 [%]			
T_5 [°C]			
RH_5 [%]			
$P_{preheater}$ [W]			
$P_{afterheater}$ [W			
u [m/s]			

For summer session air-conditioning:

Table 2.6.2.

Reading:	**1**	**2**	**3**
T_1 [°C]			
RH_1 [%]			
T_3 [°C]			
RH_3 [%]			
T_5 [°C]			
RH_5 [%]			
$P_{afterheater}$ [W			
P_{cooler} [W]			
u [m/s]			

2.6.4.2 Calculations

Under steady-state conditions, mass and energy balances in psychrometry is given by the following relations.

Continuity equation for dry air:

$$\dot{m}_{a1} = \dot{m}_{a2} = \dot{m}_a \tag{2.6.15}$$

and for water vapor,

$$\dot{m}_{a1}\omega_1 + \dot{m}_w = \dot{m}_{a2}\omega_2 \tag{2.6.16}$$

where $\dot{m}_w$ is zero for simple heating and simple cooling processes.

Energy balance equation:

$$\dot{m}_{a1}h_1 + \dot{m}_w h_w + \dot{Q} = \dot{m}_{a2}h_2 \tag{2.6.17}$$

where $\dot{Q}$ is zero for humidification and dehumidification processes.

In order to calculate mass flow rate of dry air:

$$\dot{m}_a = \frac{\dot{V}}{v} \tag{2.6.18}$$

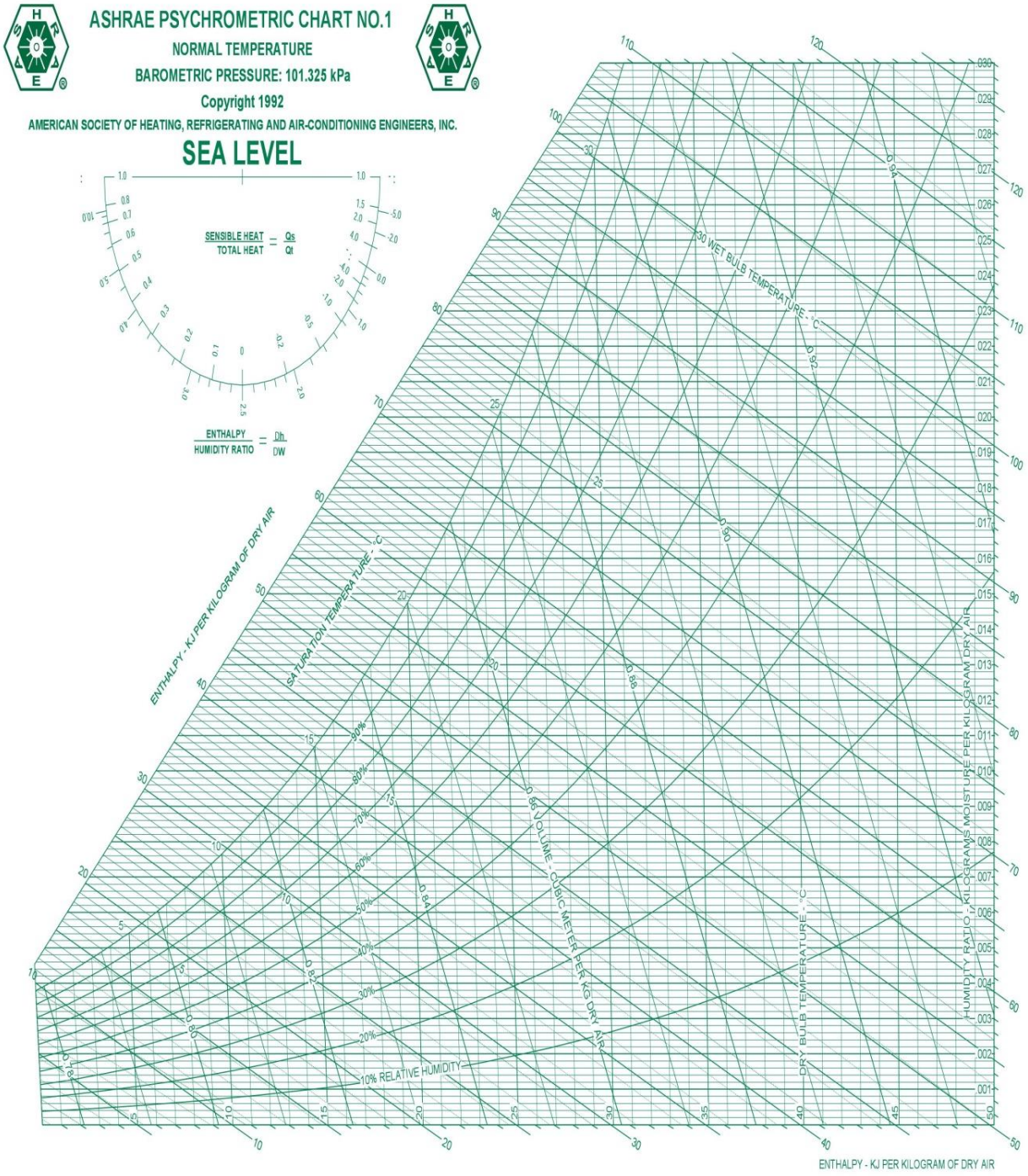
where v is the specific volume of dry air and $\dot{V}$ is the volume flow rate given by:

$$\dot{V} = uA_c \tag{2.6.19}$$

where u is the air velocity and A_c is the cross-sectional area of the duct which is 0.108 m^2.

2.6.5 Report

1. Show the processes on the psychrometric chart.
2. Find the specific humidity and enthalpy values for each point using measured data.
3. Determine the heating, cooling and humidification loads.
4. Determine the efficiencies of heaters, and COP of the refrigeration cycle.


ASHRAE PSYCHROMETRIC CHART NO.1
NORMAL TEMPERATURE
BAROMETRIC PRESSURE: 101.325 kPa
Copyright 1992
AMERICAN SOCIETY OF HEATING, REFRIGERATING AND AIR-CONDITIONING ENGINEERS, INC.
SEA LEVEL
SENSIBLE HEAT / TOTAL HEAT = Qs/Qt
ENTHALPY / HUMIDITY RATIO = Dh/Dw
ENTHALPY - KJ PER KILOGRAM OF DRY AIR
SATURATION TEMPERATURE - °C
WET BULB TEMPERATURE - °C
VOLUME - CUBIC METER PER KG DRY AIR
10% RELATIVE HUMIDITY
DRY BULB TEMPERATURE - °C
HUMIDITY RATIO - KILOGRAMS MOISTURE PER KILOGRAM DRY AIR
ENTHALPY - KJ PER KILOGRAM OF DRY AIR

2.7 Francis Turbine Experiment

2.7.1 Objective

The purpose of this experiment is to study the constructional details and performance parameters of Francis turbines.

2.7.2 Introduction

Turbines are subdivided into impulse and reaction machines. In the impulse turbines, the total head available is converted into the kinetic energy. This is usually accomplished in one or more nozzles using Pelton Turbines.

In the reaction turbines, only some part of the available total head of the fluid is converted into kinetic energy so that the fluid entering the runner has pressure energy as well as kinetic energy. The pressure energy is then converted into kinetic energy in the runner.

The Francis turbine is a type of reaction turbine that was developed by James B. Francis. These turbines are the most common water turbines in use today. They operate in a water head from 40 to 600 m and are primarily used for electrical power production. The electric generators which most often use this type of turbine have a power output generally ranging just a few kilowatts to 800 MW.

2.7.3 Theory

The reaction turbine consists of fixed guide vanes called stay vanes, adjustable guide vanes called wicket gates, and rotating blades called runner blades. Flow enters tangentially at high pressure, is turned toward the runner by the stay vanes as it moves along the spiral casing or volute, and then passes through the wicket gates with a large tangential velocity component. As the runner rotates, momentum is exchanged between the fluid and the runner. There occurs a large pressure drop in the fluid during this momentum exchange.

Unlike the impulse turbine, the water completely fills the casing of a reaction turbine. For this reason, a reaction turbine generally produces more power than an impulse turbine of the same diameter, net head, and volume flow rate. The angle of the wicket gates is adjustable so as to control the volume flow rate through the runner. In most designs, the wicket gates can close on each other cutting off the flow of water into the runner. At design conditions, the flow leaving the wicket gates impinges parallel to the runner blade leading edge to avoid shock losses.

In Francis turbines, there is a drop in static pressure and a drop in velocity head during energy transfer in the runner. Only part of the total head presented to the machine is converted to velocity head before entering runner. This is achieved in the adjustable guide vanes as shown in Figure 2.7.1.

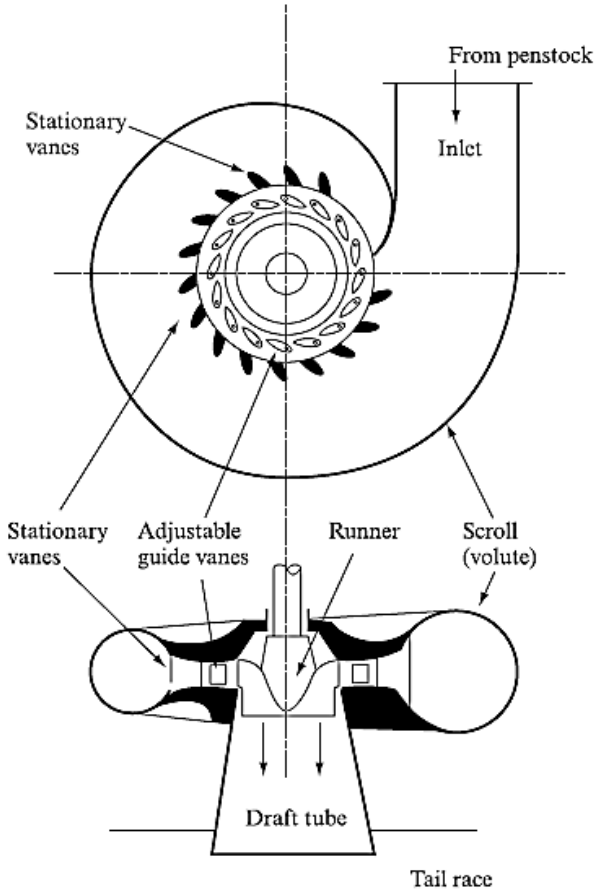


Figure 2.7.1. Configuration of a Francis turbine [1].

Similar to Pelton turbine, Francis turbine usually drives an alternator thus its speed must be constant. Since the total head available is constant and dissipation of energy by throttling is undesirable, the regulation at part load is achieved by varying the guide vane angle. This is possible because there is no requirement for the speed ratio to remain constant. In Francis turbines, sudden load changes are stabilized either by a bypass valve or by a surge tank.

2.7.3.1 Components of the Francis Turbine

Spiral Casing (Volute): Most of these machines have vertical shafts although some smaller machines of this type have horizontal shafts. The fluid enters from the penstock (pipeline leading to the turbine from the reservoir at high altitude) to a spiral casing which completely surrounds the runner. This casing is also known as scroll casing or volute. The cross-sectional area of this casing decreases uniformly along the circumference to keep the fluid velocity constant in magnitude along its path towards the stay vane. This is so since the rate of flow along the fluid path in the volute decreases due to continuous entry of the fluid to the runner through the openings of the stay vanes.

Stay (Stationary) Vanes and Wicket (Adjustable) Gates: Water flow is directed toward the runner by the stay vanes as it moves along the spiral casing, and then it passes through the wicket gates. The basic purpose of the wicket gate is to convert a part of pressure energy of the fluid to the kinetic energy and then to direct the fluid on to the runner blades at the angle

appropriate to the design. Moreover, they are pivoted and can be turned by a suitable governing mechanism to regulate the flow when the load changes. The wicket gates impart a tangential velocity and hence an angular momentum to the water before its entry to the runner.

Runner: It is the main part of the turbine that has blades on its periphery. During operation, runner rotates and produces power. For a mixed flow type Francis turbine, the flow in the runner is not purely radial but a combination of radial and axial. The flow is inward, i.e. from the periphery towards the center. The main direction of flow changes as water passes through the runner and is finally turned into the axial direction while entering the draft tube.

Draft Tube: After passing through the turbine runner, the exiting fluid still has appreciable kinetic energy. To recover some of this kinetic energy, the flow enters an expanding area (diffuser) called draft tube, which slows down the flow speed, while increasing the pressure prior to discharge into the downstream water. Therefore, the primary function of the draft tube is to reduce the velocity of the discharged water to minimize the loss of kinetic energy at the outlet. This permits the turbine to be set above the tail water without any appreciable drop of available head. Moreover careful design of draft tube is vital otherwise cavitation can occur inside the tube.

2.7.3.2 Power and Efficiency Expressions

Considering a runner generates a torque of T with a rotational speed of N (rpm). Then power obtained from the runner can be expressed as:

Power Output = (Torque) (Angular velocity)

$$P_{out} = T\omega \quad [W] \tag{2.7.1}$$

$$T = Fr \tag{2.7.2}$$

$$\omega = \frac{2\pi N}{60} \quad [rad/s] \tag{2.7.3}$$

where runner radius, r is 85 mm.

The total head available at the nozzle is equal to gross head minus losses in the pipeline (penstock) leading to the nozzle and denoted by H. Then available power input to the turbine becomes:

$$P_{in} = \rho g Q H \tag{2.7.4}$$

Where:

P_{in} → *hydraulic power input to turbine*
H → *total available head at turbine inlet [m]*
ρ → *density of water [kg/m^3]*
Q → *volume flow rate of water [m^3/s]*

$g \rightarrow$ *gravitational acceleration [m/s^2]*

During conversion of energy there occur some losses. They can be in many form and main causes of them are friction, separation and leakage.

For a turbine:

Fluid Input Power = (Mechanical loss) + (Hydraulic losses) + (Useful shaft power output)

where:

Hydraulic Losses = (Impeller loss) + (Casing loss) + (Leakage loss)

Considering all losses as one term:

$$P_{in} = P_{lost} + P_{out} \tag{2.7.5}$$

Then, overall efficiency of the turbine becomes:

$$\eta_o = \frac{P_{out}}{P_{in}} = \frac{T\omega}{\rho g Q H} \tag{2.7.6}$$

2.7.4 Experiments

2.7.4.1 Calculation of Francis Turbine Efficiency

Aim of the Experiment: To comprehend how to calculate Francis turbine efficiency
The necessary data for calculations will be recorded to the given table.

Table 2.7.1.

Measurement No:	**1**	**2**
Rotational speed, (rpm) N [rev/sec]		
Force, (N) F [N]		
Water flow rate, (m^3/h) Q[m^3/h]		
Water inlet pressure, (mWC) P_1 [bar]		

Calculations: Using the appropriate equations, calculate the overall efficiency.

2.7.4.2 Changes in Francis Turbine Efficiency and Power Output with Volume Flow Rate

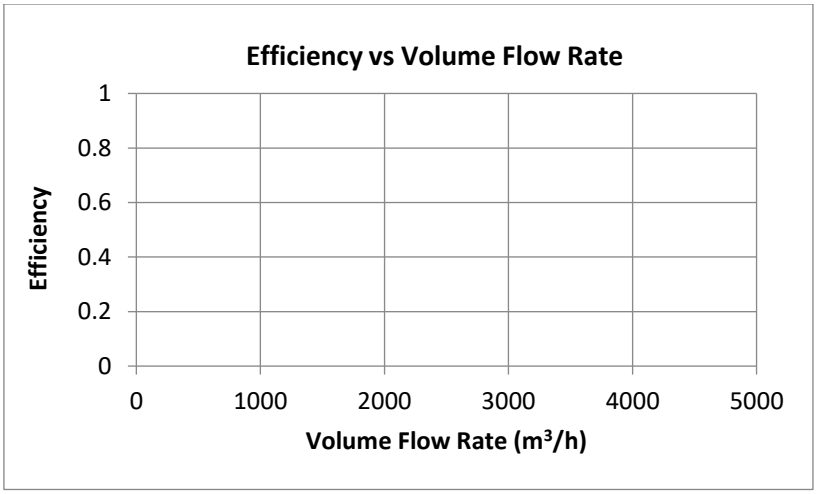
Aim of the Experiment: To understand how Francis turbine efficiency and power output alter when the flow rate is varied.

The necessary data for calculations will be recorded to the given table.

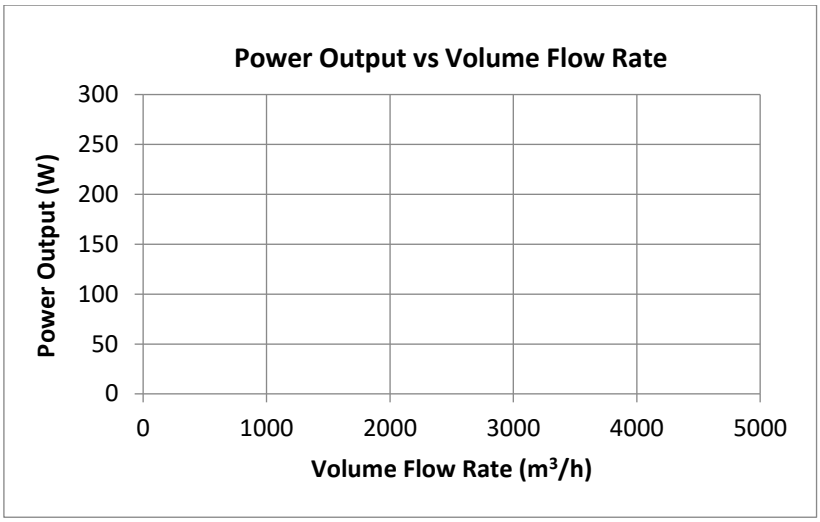
Table 2.7.2.

Measurement No:	**1**	**2**	**3**	**4**
Rotational speed, (rpm) N [rev/sec]				
Force, (N) F [N]				
Water flow rate, (m^3/h) Q[m^3/h]				
Water inlet pressure, (mWC) P_1 [bar]				

Calculations: Using the appropriate equations, calculate the efficiency and power output for each measurement. Draw two graphs showing the change in efficiency and power output with volume flow rate, respectively.



Graphic 2.7.1.



Graphic 2.7.2.

Comments: What do you get from the graphs? Explain.

2.7.4.3 Change in Francis Turbine Efficiency with Guide Vane Position

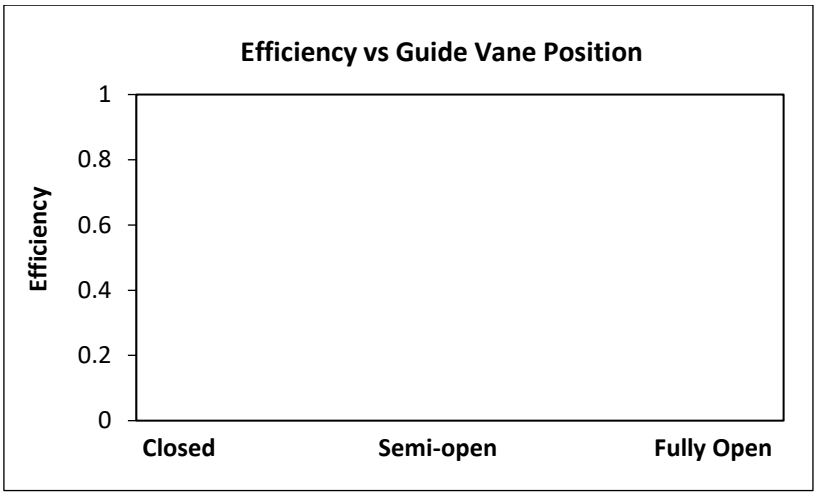
Aim of the Experiment: To understand how Francis turbine efficiency alters with guide vane position.

The necessary data for calculations will be recorded to the table given below.

Table 2.7.3.

Measurement No:	**1**	**2**	**3**
Rotational speed, (rpm) N [rev/sec]			
Force, (N) F [N]			
Water flow rate, (m^3/h) Q[m^3/h]			
Water inlet pressure, (mWC) P_1 [bar]			
Guide vane position	Closed	Semi-Open	Fully Open

Calculations: Using the appropriate equations, calculate the efficiency of the turbine and draw the graph of efficiency versus guide vane position.



Graphic 2.7.3.

Comments: What do you get from the graphs? Explain.

2.7.5 Report

In your laboratory reports must have the followings;

- **a)** Cover page.
- **b)** A short introduction.
- **c)** All the necessary calculations/graphs using measured data.
- **d)** Discussion of your results and a conclusion.

2.8 Serial and Parallel Pumps Experiment

2.8.1 Objective

1) To develop pump characteristic curves for a single pump, two pumps in series, and two pumps in parallel by measuring head (h) and flow rate (Q) using the experimental apparatus.
2) To develop theoretical pump characteristic curves for pumps in series and pumps in parallel experimentally derived single pump characteristic curve.
3) To compare the experimental and theoretical pump characteristic curves for pumps in series and pumps in parallel.

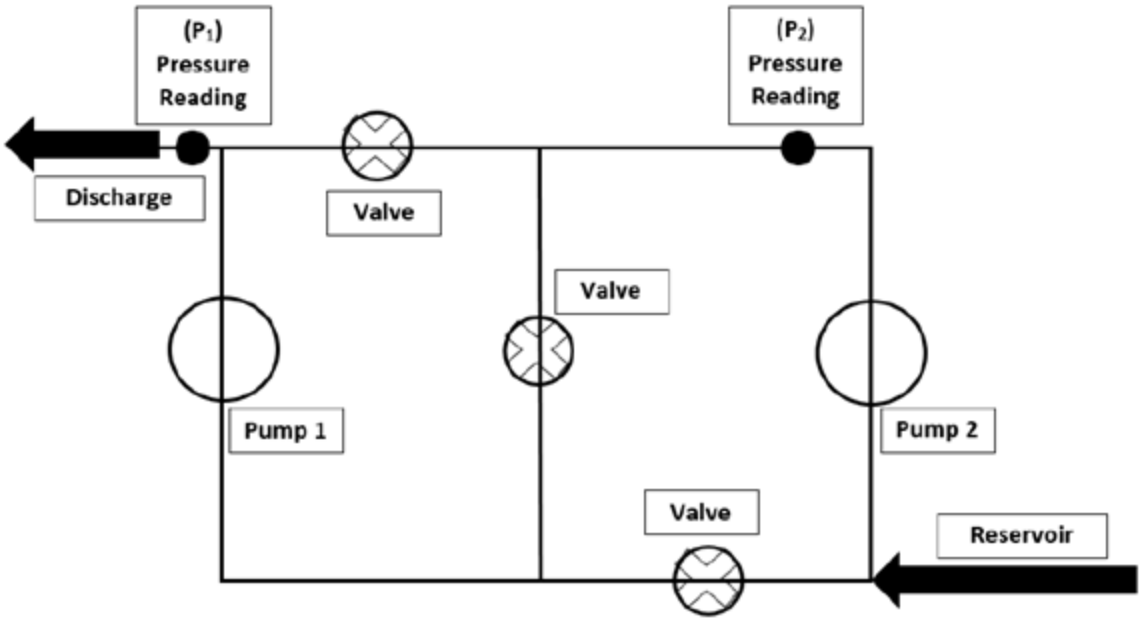


Figure 2.8.1. The schematic of the experimental setup

2.8.2 Introduction

Whereas turbines extract the energy from the fluid, pumps adds energy into fluid, increasing the energy possessed by the fluid. There are two main pump types: positive displacement pumps—pistons, plungers, diaphragms, vanes, screws, lobes, which have a fixed flow rate per stroke or revolution; and turbo-hydraulic or kinetic pumps / centrifugal pumps, which convert fluid kinetic energy into pressure [1].

Today, the design of a centrifugal pump has the water entering the low-pressure center of the impeller. The vanes then lead the water to the higher-pressure region to the casing. The casing is designed with a gradually expanding spiral shape so that minimum loss occurs in the transformation of kinetic energy to pressure. The pump receives the water at a low velocity on the interior edge of the set of moving impeller vanes and discharges it from the outer edge with kinetic energy sufficient to raise it to a desired height; and through the gradually expanding spiral passage transforms the kinetic energy into pressure [1].

2.8.3 Theory

Pumps are used to lift water up or to increase the energy so that the water can travel farther. This lab determines the head/flow characteristics of centrifugal pumps operating at a single speed: a single centrifugal pump, two similar centrifugal pumps operating in parallel and in series.

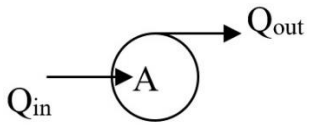
Recall the total head is the difference between the total energy head at the outlet and the total energy head at the inlet (neglecting the small differences in velocity heads). As shown be the following equation:

$$\left(\frac{p_2}{\rho g}+\frac{V_2^2}{2g}+z_2\right)-\left(\frac{p_1}{\rho g}+\frac{V_1^2}{2g}+z_1\right)=H_P-H_L \qquad (2.8.1)$$

where subscripts 1 and 2 refer to inlet and outlet sections. H_P is the pressure head produced by the pump and H_L is the energy loss due to friction and pipe fittings. By conservation of mass, $V_1=V_2$ if the pipe diameters are equal at the inlet and outlet sections.

Total Head: H_P = (pressure head increased by the pump)
Total Head Outlet: H_P = (pressure head at pump outlet - pressure head at pump inlet)
= (outlet pressure/γ) – (inlet pressure/γ)
Total Head Manifold: H_P = ({manifold pressure head + datum correction} - inlet pressure head})
= [{(manifold pressure/γ) + datum correction} - (inlet pressure/γ)]

Single pump:



$$Q_{in} = Q_{out}$$
$$h_{pump} = \Delta h_{water}$$

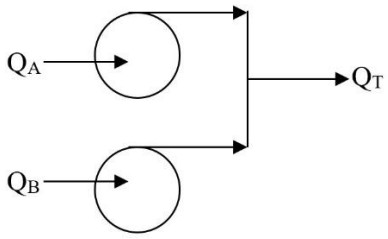
2.8.3.1 Pumps in Parallel

When two or more similar pumps are connected in parallel, the head across each pump is the same and the total flow rate is shared equally between the pumps, Q_P/n, where n is the number of pumps in parallel. For identical pumps in parallel, the pressures at the two inlets and outlets are identical and the maximum head the two pumps can deliver is no greater than for a single pump. Theoretically, the flow rate is doubled, although in practice, this will not occur, due to losses in the piping systems.

Total head (using *outlet*, not *manifold*) is determined the in the same manner as for the single pump. The theoretical curve for the parallel pump configuration is obtained from the single pump data by multiplying the flow rate by two.

For *theoretical* parallel pump curve, plot: H_p(single pump) vs. 2*Q(single pump)

Parallel Pumps:



$$n = 2 \text{ pumps}$$
$$h_{pumpA} = h_{pumpB} = \Delta h_{water}$$
$$Q_A + Q_B = Q_{Total}$$

Since the head loss across the parallel pumps is equal, the pump curve derived for each should be the same.

2.8.3.2 Pumps in Series

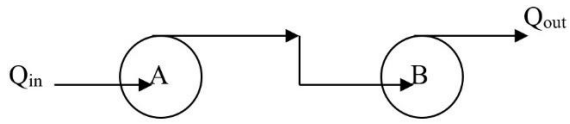
When two or more similar pumps are connected in series, the same flow rate passes through each pump and under goes a head boost of total head divided by number of pumps, H_P/n. Therefore, the series configuration of two identical pipes provides a pump characteristic of twice the head as for a single pump.

For series pumps, the total head can be computed as follows:

Total Head: H_P = (pressure head at pump 2 outlet - pressure head at pump 1 inlet)
= [(outlet 2 pressure/γ) – (inlet 1 pressure/γ)]

The theoretical curve for the series pump configuration is obtained from the single pump data by multiplying the head by two. This doubled head is plotted with the measured flow rate.

Serial Pumps:



$$n = 2 \text{ pumps}$$
$$Q_{in} = Q_{out} = Q_{total}$$
$$h_{pumpA} + h_{pumpB} = \Delta h_{water}$$

2.8.3.3 Pump Efficiency

For a pump, the efficiency is defined as

$$\eta = P_o/P_i$$

where P_o = power out from the pump = power imparted to the fluid

$= \gamma * Q * H_p = [N/m^3] * [m^3/s] * [m] = [N\text{-}m/s] = [J/s] = [W]$

P_i = power input to the pump shaft = power output from the motor = [W]

Output power is determined experimentally. Input power should be given in the manufacturer's specifications for the pump.

An important objective when selecting a pump for an engineering system is maximizing the efficiency for the desired flow conditions.

2.8.4 Experiments

1) Adjust the valves on the apparatus so that a SINGLE pump is active.
2) Use the valve downstream of the pump(s) to control discharge and the corresponding head. For a given head (pressure) reading, use the volume-time method to measure the flow rate. Measure the flow rate three times. Record the values in the appropriate table on the attached data sheet.
3) Measure the head (pressure) downstream of each pump. Make sure that you record the pressure while the pipe is at the same elevation as it was when you measured the flow rate. Record the values in the appropriate table on the attached data sheet.
4) Now adjust the valves on the apparatus such that there are two pumps in SERIES. The flow rate should remain constant. Record the head (pressure) at each gage in Table 2.8.1.
5) With the pumps in series, repeat Steps 2 and 3 for five different discharge/head readings, plus with zero flow (shutoff head).
6) Now adjust the valves on the apparatus such that there are two pumps in PARALLEL.
7) Copy the total head (pressure) readings from the SINGLE pump trial into Table 2.8.2 [$\Delta E_{p(single)}$].
8) Adjust the flow valve downstream of the pumps until the pressure (E_p) reading on the gages match (or are very close to) the values recorded in Step 7. Again, make sure that you record the pressure while the pipe is at the same elevation as it was when you measured the flow rate.
9) Now perform the volume-time method in order to determine the flow rate with the pumps in parallel. Record the information in Table 2.8.2.
10) Repeat Steps 8 and 9 for all of the pressure measurements, including with no flow.

2.8.4.1 Getting Results

Compare the experimental and theoretical pump characteristic curves for pumps in series and pumps in parallel. Comparisons should be made both graphically and in terms of the percentage error. Record measurements taken during lab in the tables on the attached data sheet. Type these results in a spreadsheet and include them in the report.

2.8.4.2 Calculations

Show sample calculations for one trial (i.e., for one flow rate/head reading) as outlined below. Note: sample calculations for each pumping system should be provided when alternative forms of a given equation are needed. Label variables and use units in your calculations.

1) Calculate flow rate using the volume-time method.
2) Calculate the total head (ΔE_p) for each system based on your measured/experimental values.
3) For the pumps in SERIES, calculate the theoretical total head ($\Delta E_{p(th\text{-}single)}$) which is expected based on theory.
   Hint: Remember that the total head for pumps in series should be double that of the single pump at the same flow rate.
4) For the pumps in PARALLEL, calculate the flow expected in theory. Hint: Remember that the flow through pumps in parallel should be double what was recorded for a single pump given the same pressure (head).

5) Calculate percent error (theoretical versus experimental) in total head for pumps in series ($\Delta E_{p(th\text{-}series)}$ vs. $\Delta E_{p(exp\text{-}series)}$) and percent error in flow for pumps in parallel ($Q_{(th\text{-}parallel)}$ vs. $Q_{(exp\text{-}parallel)}$). [See Table 2.8.3]
6) Add a polynomial trend-line to each data set. For ease of unit conversion: 1 bar = 100 kN/m2, 1000 liters/sec = 1 m3/sec.

2.8.4.2 Graphs and Tables

Create two graphs showing pump characteristic curves as follows:

1) Graph 1 - Pumps in Parallel
   - Single pump line (reference pump A)
   - Theoretical line for pumps in parallel ($\Delta E_{p(single)}$ vs. $Q_{(th\text{-}parallel)}$)
   - Experimental line for pumps in parallel ($\Delta E_{p(exp\text{-}parallel)}$ vs. $Q_{(exp\text{-}parallel)}$)

2) Graph 2 - Pumps in Series
   - Single pump line (reference pump A)
   - Theoretical line for pumps in series ($\Delta E_{p(th\text{-}series)}$ vs. $Q_{avg(single)}$)

Experimental line for pumps in series ($\Delta E_{p(exp\text{-}series)}$ vs. $Q_{avg(single)}$)

Table 2.8.1. Single Pump & Pumps in Series Data

				Single Pump				Theoretical Pump Curves		Pumps in SERIES		
Trial	**Time (s)**	**Volume (L)**	**Q**	$Q_{avg\ (single)}$	$E_{p(1)}$	$E_{p(2)}$	$\Delta E_{p(single)} = E_{p(2)}$	$\Delta E_{p(th\text{-}series)} = 2*\Delta E_{p(single)}$	$Q_{(th\text{-}parallel)} = 2*Q_{avg}$	$E_{p(1)}$	$E_{p(2)}$	$\Delta E_{p(exp\text{-}series)} = E_{p(1)}$
0	NA	NA	0	0	--						--	
1					--						--	
2					--						--	
3					--						--	
4					--						--	
5					--						--	

Table 2.8.2. Pumps in Parallel Data

Trial	$\Delta E_{p(single)}$ [see Table 1]	$E_{p(1)}$	$E_{p(2)}$	$\Delta E_{p(exp\text{-}poarallel)} = (E_{p(1)} + E_{p(2)})/2$	Time (s)	Volume (L)	Q	$Q_{(exp\text{-}parallel)} = Q_{avg}$
0					NA	NA	0	
1								
2								
3								
4								
5								

Table 2.8.3. Percent Error: Theoretical vs. Experimental

Trial	Pumps in SERIES			Pumps in PARALLEL		
	$\Delta E_{p(th\text{-}series)}$ [see Table 1]	$\Delta E_{p(exp\text{-}series)}$ [see Table 1]	% Error in ΔE_p	$Q_{(th\text{-}parallel)}$ [see Table 1]	$Q_{(exp\text{-}parallel)}$ [see Table 2]	% Error in Q
0						
1						
2						
3						
4						
5						

2.8.5 Report

In your laboratory, reports must have the followings;

a) Cover page
b) A short introduction
c) All the necessary calculations using measured data.
d) Discussion of your results and a conclusion.

2.9 Three-point Bending Experiment

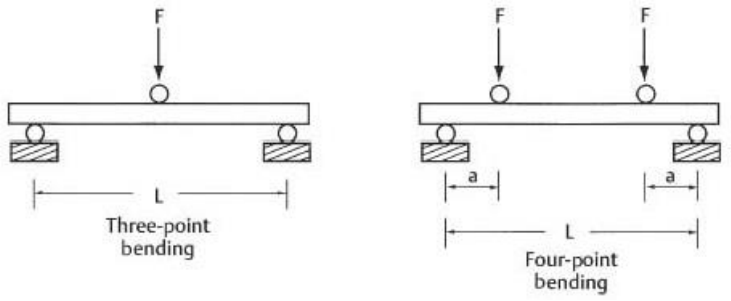
2.9.1 Objective

The objective of this experiment is to become familiar to investigate responses of metals when subjected to bending, determination of unknown quantities (such as bend strength, yield strength in bending and young's modulus) at the prescribed conditions of a rectangular bar or rod beam.

2.9.2 Introduction

Bending test is common in brittle materials whose failure behaviors are linear such as concretes, stones, woods, plastics, glasses and ceramics. Other types of brittle materials such as powder metallurgy processed metals and materials are normally tested under a transverse bending. Bending test is therefore suitable for evaluating strength of brittle materials where interpretation of tensile test result of the same material is difficult due to breaking of specimens around specimen gripping. The evaluation of the tensile result is therefore not valid since the failed areas are not included in the specimen gauge length.

Smooth rectangular specimens without notches are generally used for bending test under three-point or four-point bending as shown in Figure 2.9.1 a and b, respectively.



a) Three-point bending b) Four-point bending

Figure 2.9.1. a) three-point bending test and b) four-point bending test

Considering a three point bending test of an elastic material, when the load F is applied at the mid-point of specimen in an x-y plane, the stress is essentially zero at the neutral axis. Stresses in the y axis in the positive direction represent tensile stresses whereas stresses in the negative direction represent compressive stresses. Within the elastic range, brittle materials show a linear relationship of load and deflection where yielding occurs on a thin layer of the specimen surface at the mid-point. After that, it leads to crack starting which finally proceeds to specimen failure. However, ductile materials provide load-deflection curves which deviate from a linear relationship before failure. These behavior type is opposite to the behavior of the brittle materials previously mentioned. Also, it is also difficult to determine the beginning of yielding in this case. Therefore, it can be seen that bend testing is not suitable for ductile materials due to difficulties in determining the yield point of the materials under bending and the obtained stress-strain curve in the elastic region may not be linear. The results obtained might not be validated. As a result, the bend test is therefore more appropriate for testing of brittle materials whose stress-strain curves show its linear elastic behavior just before the materials fail. Figure 2.9.2 represents an example of the three point bending test.

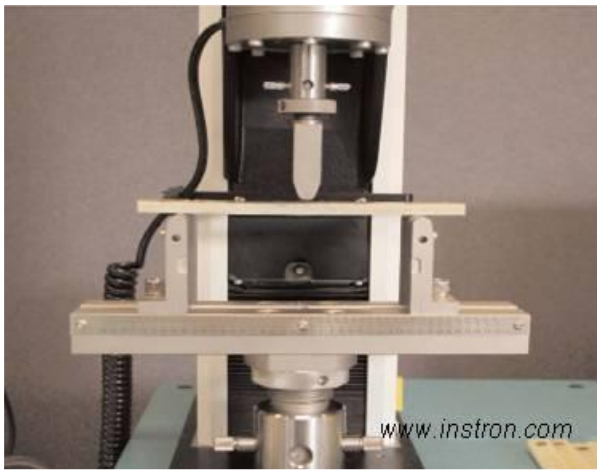


Figure 2.9.2. Example of three-point bending test

In three point bending test, maximum moment occurs and also shear force value changes at the point of the force applied. In four point bending test, however, maximum moment have a special value between special points and also, the shear force value is zero between these points. It means that there is no pure bending in three point bending test, but is pure bending in four bending test.

The three point test is a classical experiment in mechanic, used to measure the young's modulus of a material in the shape of beam. As mentioned before, Tests for determining the bending strength of metals have not been used widely, although the information from such tests is clearly useful. ASTM E 855, "Standard Methods of Bend Testing of Metallic Flat Materials for Spring Applications".

Bending tests that have been developed for brittle materials, coatings, construction (girder and beam) sections, and other specific product forms. However, descriptions of these test methods can be found in the ASTM standards.

Bend test standards change due to the material type. For instance, ISO 7438, ASTM D7264 / D7264M, ASTM D790 - 15e2, ASTM C1161 – 13 standards are used for metallic materials, polymer matrix composite materials, unreinforced and reinforced plastics and electrical insulating materials, Advanced Ceramics at Ambient temperature. These test standards determine the specimen's dimensions and test procedure.

2.9.3 Theory

Stress:

Stress is simply a distributed force on an external or internal surface of a body. To obtain a physical feeling of this idea, consider being submerged in water at a particular depth. The ''force'' of the water one feels at this depth is a pressure, which is a compressive stress, and not a finite number of ''concentrated'' forces. Other types of force distributions (stress) can occur in a liquid or solid. Tensile (pulling rather than pushing) and shear (rubbing or sliding) force distributions can also exist.

Consider a general solid body loaded as shown in Figure 2.9.3 (a). P_i and pi are applied concentrated forces and applied surface force distributions, respectively; and R_i and r_i are possible support reaction force and surface force distributions, respectively. To determine the state of stress at point Q in the body, it is necessary to expose a surface containing the point Q. This is done by making a planar slice, or break, through the body intersecting the point Q. The orientation of this slice is arbitrary, but it is generally made in a convenient plane where the state of stress can be determined easily or where certain geometric relations can be utilized. The

first slice, illustrated in Figure 2.9.3 (b), is described by the surface normal oriented along the x axis. This establishes the y-z plane. The external forces on the remaining body are shown, as well as the internal force (stress) distribution across the exposed internal surface containing Q. In the general case, this distribution will not be uniform along the surface, and will be neither normal nor tangential to the surface at Q. However, the force distribution at Q will have components in the normal and tangential directions. These components will be tensile or compressive and shear stresses, respectively.

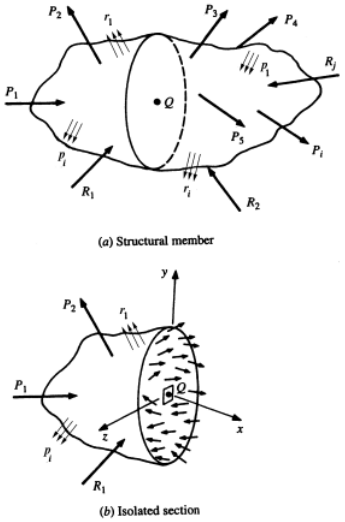


Figure 2.9.3. (a) Structural member and (b) Isolated section

Following a right-handed rectangular coordinate system, the y and z axes are defined perpendicular to x, and tangential to the surface. Examine an infinitesimal area $\Delta A_x = \Delta y \Delta z$ surrounding Q, as shown in Fig 2.9.4 (a). The equivalent concentrated force due to the force distribution across this area is ΔF_x, which in general is neither normal nor tangential to the surface (the subscript x is used to designate the normal to the area). The force ΔF_x has components in the x, y, and z directions, which are labeled ΔF_{xx}, ΔF_{xy}, and ΔF_{xz}, respectively, as shown in Figure 2.9.4 (b). Note that the first subscript denotes the direction normal to the surface and the second gives the actual direction of the force component. The average distributed force per unit area (average stress) in the x direction is

$$\bar{\sigma}_{xx} = \frac{\Delta F_{xx}}{\Delta A_X} \tag{2.9.1}$$

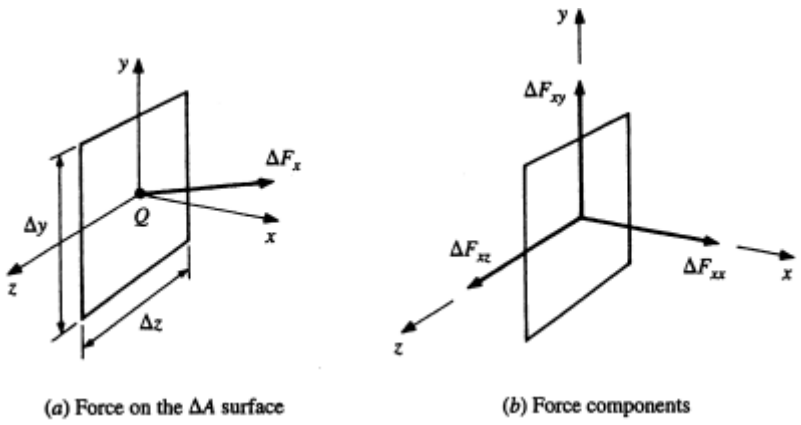


Figure 2.9.4. (a) Force on the ΔA surface, (b) Force components

Recalling that stress is actually a point function, we obtain the exact stress in the x direction at point Q by allowing ΔA_x to approach zero. Thus,

$$\sigma_{xx} = \lim_{\Delta A_x \to \infty} \frac{\Delta F_{xx}}{\Delta A_X} \tag{2.9.2}$$

or,

$$\sigma_{xx} = \frac{dF_{xx}}{dA_X} \tag{2.9.3}$$

Strain

As with stresses, two types of strains exist: normal and shear strains, which are denoted by ε and γ, respectively. Normal strain is the rate of change of the length of the stressed element in a particular direction. Let us first consider a bar with a constant cross-sectional area which has the undeformed length *l*. Under the action of tensile forces, it gets slightly longer. The elongation is denoted by Δ*l* and is assumed to be much smaller than the original length *l*. As a measure of the amount of deformation, it is useful to introduce, in addition to the elongation, the ratio between the elongation and the original (undeformed) length:

$$\varepsilon = \frac{\Delta l}{l} \tag{2.9.4}$$

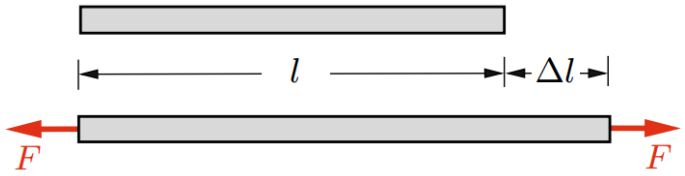


Figure 2.9.5. The undeformed length *l* and the deformed length *l*

The dimensionless quantity ε is called strain.

Hook's Law

The strains in a structural member depend on the external loading and therefore on the stresses. For linear elastic behavior, the relation between stresses and strains is given by Hooke's law. In the uniaxial case (bar) it takes the form σ = E ε where E is Young's modulus.

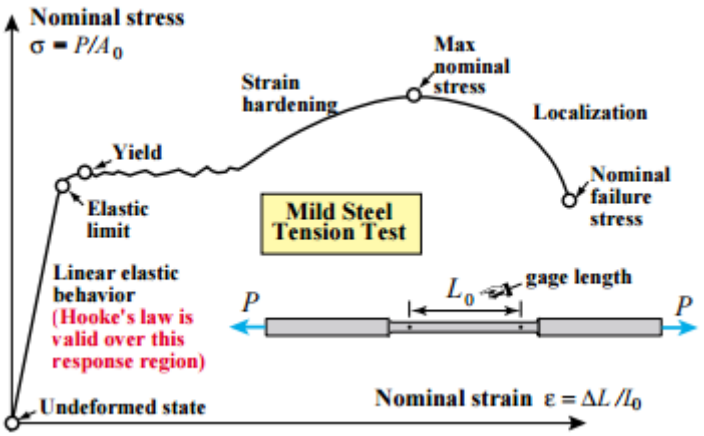


Figure 2.9.6. Stress vs strain diagram

Bending Deformation

Figure 2.9.7 shows a part of a uniform rectangular beam subjected to pure elastic bending. The beam may be considered to represent an orthodontic arch wire. In order to have static mechanical equilibrium, the ends of this part are subjected by equal and opposite bending moments. When Figure 2.9.7 examined, it is apparent that, at the top and bottom outer surfaces, the length of the beam has increased (tensile strain) and decreased (compressive strain), respectively. For a symmetric beam (round, rectangular, or square cross section), the material at the mid-plane does not have any deformation. The un-deformed mid-plane of the elastically bent beam is termed the neutral surface, and the trace of the neutral surface on the cross section perpendicular to the beam axis is termed the neutral axis. Both the neutral surface and neutral axis are indicated in Figure 2.9.7. A portion of a symmetric rectangular beam subjected to pure elastic bending. The location of the neutral surface is indicated, along with the position of the neutral axis on an axial cross section of the beam.

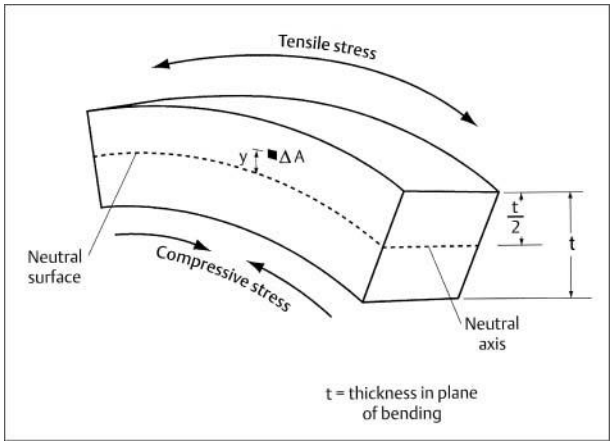


Figure 2.9.7. A symmetric rectangular beam subjected to pure elastic bending

The corresponding strain is obtained by dividing the stress by the modulus of elasticity (Young's modulus) of the beam material, which has the same value for tensile and compressive stress. In textbooks on solid mechanics, force and moment balances are performed on a section of the beam (free-body diagram) to derive the elastic flexure formula. It is also assumed that plane surfaces perpendicular to the undeformed beam axis remain planar after the elastic deformation. The relationship between the stress (σ) developed in the beam as a function of the bending moment (M) and distance from the neutral axis (y) is

$$\sigma = \frac{My}{I} \tag{2.9.5}$$

where I represents the moment of inertia of the cross section. The moment of inertia is a geometric quantity that corresponds to the resistance of a particular cross section to bending and is given by the relationship.

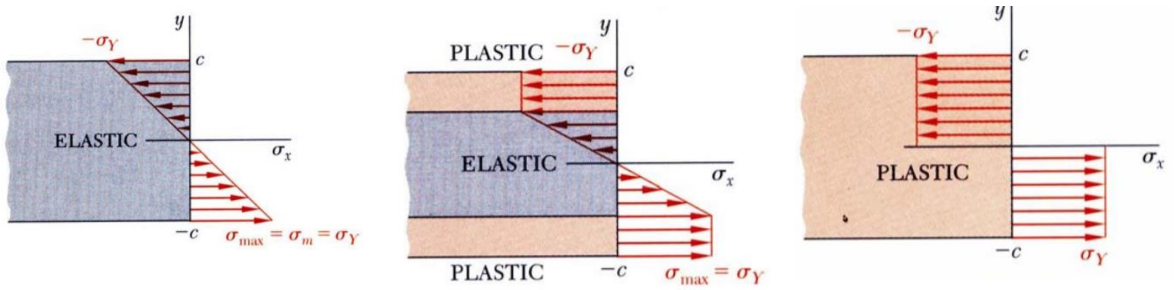
$$I = \sum_i y_i^2 (\Delta A_i) \tag{2.9.6}$$

where the y_i are the distances of the elemental areas (ΔA_i) from the neutral axis and the summation is over all the elemental areas comprising the cross section of the beam. The contributions to the moment of inertia are greatest for the elemental areas farthest from the neutral axis, since each area is multiplied by the square of its distance from this centerline of

the cross section (for a symmetric beam). This principle is exploited with the rectangular I-beam used in the construction of buildings, where the maximum amount of material is located farthest from the center (neutral axis) of the beam.

Since the largest value of *y* corresponds to the greatest distance (*c*) from the neutral axis to the surface of the beam, the maximum stress developed by the bending moment is given by

$$\sigma_{max} = \frac{Mc}{I} \tag{2.9.7}$$



a) **b)** **c)**

Figure 2.9.8. Stress distributions a) in elastic region b) after yielding c) in fully plastic region

Rectangular beam made of an elastoplastic material

$$\sigma_x \leq \sigma_y\,, \quad \sigma_m = \frac{Mc}{I} \tag{2.9.8}$$

$$\sigma_x = \sigma_y\,, \quad M_Y = \frac{I}{c}\sigma_y \tag{2.9.9}$$

If the moment is increased beyond the maximum elastic moment, plastic zones develop around an elastic core.

$$M = \frac{3}{2}M_Y\left(1 - \frac{1y_Y^2}{3c^2}\right), \qquad y_Y = elastic\ core\ half\ -\ thickness \tag{2.9.10}$$

In the limit as the moment is increased further, the elastic core thickness goes to zero, corresponding to a fully plastic deformation.

$$M_p = \frac{3M_y}{2} = Plastic\ Moment \tag{2.9.11}$$

$$k = \frac{M_p}{M_y} = Shape\ Factor\ (depends\ only\ on\ cross\ section \tag{2.9.12}$$

The neutral axis cannot be assumed to pass through the section centroid.

For brittle materials having a liner stress-strain relation, the fracture stress (σ_f) can be determined from the fracture stress in bending according to a linear elastic beam analysis as shown in equation.

$$\sigma_f = \frac{Mc}{I} = \frac{6M}{bh^2} \tag{2.9.13}$$

$$I = \frac{1}{12} bh^3 \tag{2.9.14}$$

where M is the bending moment, b is the specimen width, h is the thickness of the specimen and I is the moment of inertia of the cross-sectional area.

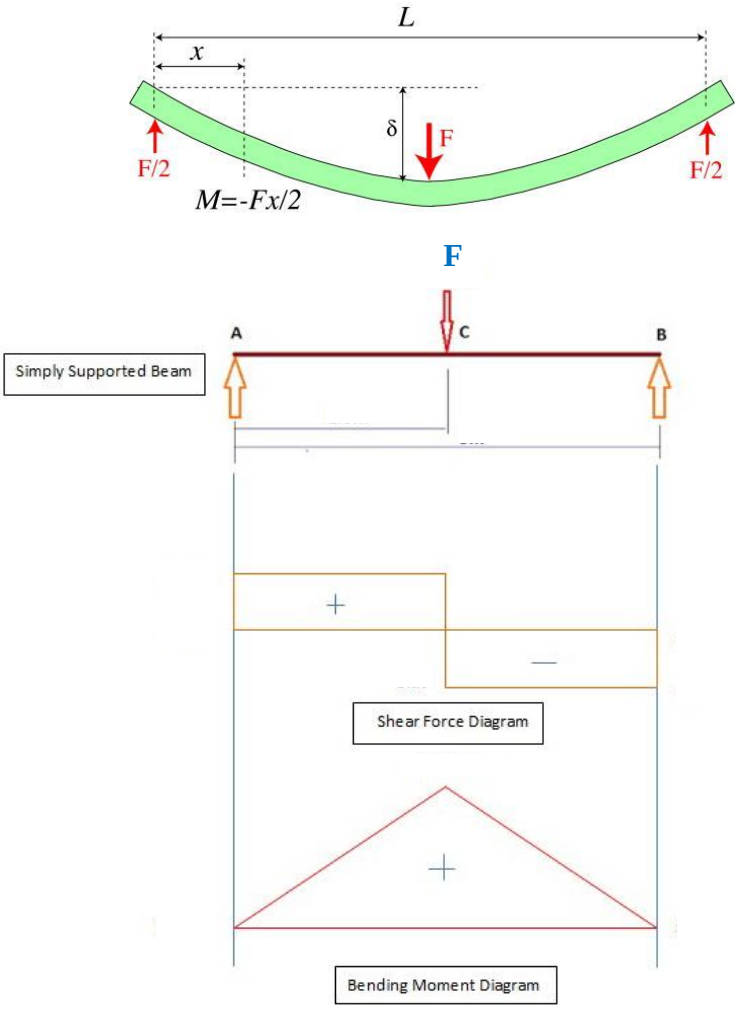


Figure 2.9.9. Free body diagram and diagram of the moment and shear force

Figure 2.9.8 shows that the stress in the beam varies linearly with distance from the mid-plane, reaching maximum values at the outermost surface. Under there-point bending in Figure 2.9.9. when the load F is applied at the mid-span of a rectangular bar of a length L between the two rollers, the highest bending moment at the mid-span is

$$M = \frac{FL}{4} \tag{2.9.15}$$

then,

$$\sigma_{fb} = \frac{3F_f L}{2bh^2} \tag{2.9.16}$$

where σ_{fb} is is the calculated fracture stress, F_f is the fracture load obtained from the bending test, h is the thickness of the specimen.

The fracture stress in bending is called the bend strength or flexure strength, which is equivalent to the modulus of rupture in bending. The bend strength is slightly different from the fracture stress obtained from the tensile test if failure takes place further away from yielding. However, brittle materials possess higher strength in compression than in tension. The material failure under bending is therefore owing to the tensile stresses especially along the surface opposite to the load direction.

The determination of the yield strength (σ_y) is carried out by replacing the load at yielding F_f equation. The yielding load is determined at the definite yield point or at certain % offset. Hence, we now have the yield strength. It should be noted that the yield strength obtained from the bend test is not different from the yield strength achieved from the tensile test. This is because the relationship between the load and the deflection remains linear at yielding.

$$\sigma_0 = \frac{3LF_y}{2bh^2} \tag{2.9.17}$$

The flexural strain ε_f is calculated from the following equation (y is the deflection of the beam)

$$\varepsilon_f = \frac{6hy}{L^2} \tag{2.9.18}$$

Moreover, from the experimental result, we can also obtain the elastic modulus of the material according to the linear-elastic analysis. The deflection of the beam (y) from the center can be expressed in the following equation

$$y = \frac{PL^3}{48EI} \tag{2.9.19}$$

where the elastic modulus (E_B) can be calculated from the slope of the load-deflection curve (dF/dy) in the linear region as follows.

$$E_B = \frac{L^3}{48I}\left(\frac{dF}{dy}\right) = \frac{L^3}{4bh^3}\left(\frac{dF}{dy}\right) \tag{2.9.20}$$

$$E_B = \frac{L^3 m}{4bh^3} \tag{2.9.21}$$

Where m is the slope of the tangent to the straight-line portion of the load-deflection beam.

2.9.4 Experiments

1) Measure the width and thickness of the specimen including the span length in the table provided for the calculation of the stress and elastic modulus. Mark on the locations where the load will be applied under three-point bending.
2) Bend testing is carried out using a universal testing machine until failure takes place.
3) Construct the load-extension or load-deflection curve if the dial gauge is used.
4) Calculate the bend strength, yield strength and elastic modulus of the specimen.
5) Describe the failure under bending and sketch the fracture surfaces in the table provided.
6) Discuss the obtained experimental results and give conclusions.

Table 2.9.1.

Description	Specimen 1	Specimen 2
Thickness, *t* (mm)		
Width, *w* (mm)		
Span length, *L* (mm)		
Flexure load at maximum, *Pmax* (N)		
Bend strength at maximum, σ_{maxb} (MPa)		
Bend strain at maximum, ε_{maxb}, (%)		
Elastic modulus, E_B (MPa)		

2.9.5 Report

In your laboratory, reports must have the followings;

a) Cover page
b) A short introduction
c) All the necessary calculations using measured data.
d) Discussion of your results and a conclusion.

2.10 Water Level Control Experiment

2.10.1 Objective

The objective of this experiment is to give the idea of a control systems and by using different control algorithms to teach students how to control a real system such as height of a water tank.

2.10.2 Introduction

Automatic control has played a vital role in the advance of engineering and science. In addition to its extreme importance in space-vehicle systems, missile guidance systems, robotic systems, and the like, automatic control has become an important and integral part of modern manufacturing and industrial processes. For example, automatic control is essential in the numerical control of machine tools in manufacturing industries, in the design of autopilot systems in the aerospace industries, and in the design of cars and trucks in the automobile industries. It is also essential in such industrial operations as controlling pressure, temperature, humidity, viscosity and flow in the process industries.

Since advances in the theory and practice of automatic control provide the means for attaining optimal performance of dynamic systems, improving productivity, relieving the drudgery of many routine repetitive manual operations, and more, most engineers and scientists must now have a good understanding of this field.

2.10.3 Theory

2.10.3.1 Definitions

Controlled Variable and Manipulated Variable: The controlled variable is the quantity or condition that is measured and controlled. The manipulated variable is the quantity or condition that is varied by the controller so as to affect the value of the controlled variable. Normally, the controlled variable is the output of the system.

Control: Control means measuring the value of the controlled variable of the system and applying the manipulated variable to the system to correct or limit the deviation of the measured value from a desired value.

Plants: A plant may be a piece of equipment, perhaps just a set of machine parts functioning together, the purpose of which is to perform a particular operation.

Process: Process is a natural, progressively continuing operation or development marked by a series of gradual changes that succeed one another in a relatively fixed way and lead toward a particular result or end; or an artificial or voluntary, progressively continuing operation that consists of a series of controlled actions or movements systematically directed toward a particular result.

System: A system is a combination of components that acts together and perform a certain objective. A system is not limited to physical ones. The concept of the system can also be applied to different areas like economic systems, social systems etc.

Disturbance: A disturbance is a signal that tends to adversely affect the value of the output of a system. If a disturbance is generated within the system, it is called internal, while an external disturbance is generated outside of the system and introduced as an input to the system.

Feedback Control: Feedback control refers to an operation that, in the presence of disturbances, tends to reduce the difference between the output of a system and the given reference input to the system. Feedback control systems are often referred to as closed-loop control systems. In practice, the terms feedback control and closed-loop control are used interchangeably.

Open-loop Control System: Those system in which the output has no effect on the control action are called open-loop control systems. In other words, in an open-loop control system the output is neither measured nor fed back for comparison with the input.

Super Position Principle: The principle of super position states that the response produced by the simultaneous application of two different forcing functions, which are the inputs to the system, is the sum of the two individual responses.

Linear Systems: A system is called linear if the principle of superposition applies.

Linear Time Invariant System and Linear Time Varying System: A differential equation is called linear if the coefficients are constants or functions only of the independent variable. Dynamic systems that are composed of linear time-invariant lumped parameter components may be described by linear time invariant (constant coefficient) differential equations. Such systems are called linear time invariant (or linear constant-coefficient) systems. Systems that are represented by differential equations whose coefficients are functions of time are called linear time varying systems.

Transfer Function: The transfer function of a linear, time invariant, differential equation system is defined as the ratio of the Laplace transform of the output (response function) to the Laplace transform of the input (driving function) under the assumption that all initial conditions are zero.

Automatic Controller: An automatic controller compares the actual value of the plant output with the reference input (desired value), determines the deviation, and produces a control signal that will reduce the deviation to zero or to a small value. The manner in which the automatic controller produces the control signal is called *control action.*

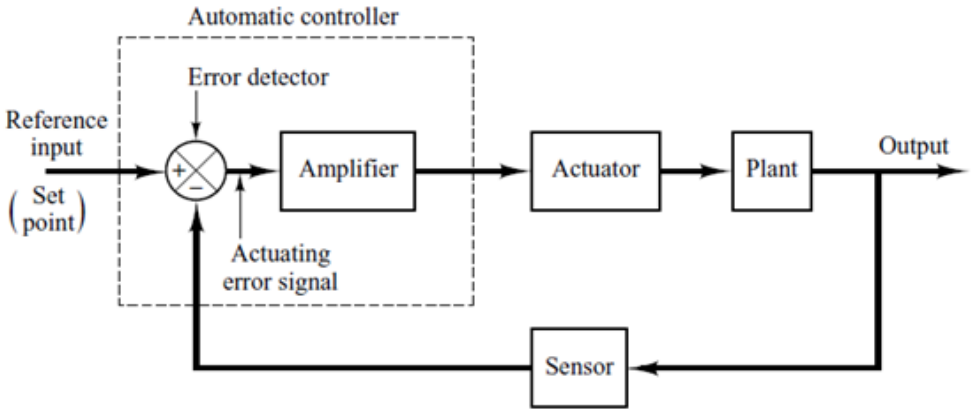


Figure 2.10.1. Block diagram of an industrial control system [1]

Figure 2.10.1 is a block diagram of an industrial control system, which consist of an automatic controller, an actuator, a plant, and a sensor (measuring element). The controller detects the actuating error signal, which is usually at a low power level, and amplifies it to a sufficiently

high level. The output of an automatic controller is fed to an actuator, such as an electric motor, a hydraulic motor, or a pneumatic motor or valve. (The actuator is a power device that produces the input to the plant according to the control signal so that the output signal will approach the reference signal.) The sensor or measuring element is a device that converts the output variable into another suitable variable, such as displacement, pressure or voltage that can be used to compare the output to the reference input signal. This element is in the feedback path of the closed-loop system.

2.10.3.2 Classifications of Industrial Controllers

Industrial controllers may be classified according to their control action as:

1) Two position or on-off controllers
2) Proportional controllers
3) Integral controllers
4) Proportional plus-integral controllers
5) Proportional-plus-derivative controllers
6) Proportional-plus-integral-plus-derivative controllers

Two Position or On-Off Control Action: In a two position control system, the actuating element has only two fixed positions, which are, in many cases simply on and off. Two position or on-off is relatively simple and inexpensive and, for this reason, is very widely used in both industrial and domestic control systems.

Let the output signal from controller be *u(t)* and actuating error signal be *e(t).* In two position control, the control signal *u(t)* remains either at a maximum or minimum value, depending on whether the actuating error signal is positive or negative, so that

$$\begin{aligned} u(t) &= U_1, \quad \text{for } e(t)>0 \\ u(t) &= U_2, \quad \text{for } e(t)<0 \end{aligned} \tag{2.10.1}$$

where U_1 and U_2 are constants. The minimum value U_2 is usually either zero or $-U_1$.

Proportional Control Action: For a controller with proportional control action, the relationship between the output of the controller *u(t)* and the actuating error signal *e(t)* is

$$u(t) = K_p e(t) \tag{2.10.2}$$

where K_p is termed as the proportional gain. Whatever the actual mechanism may be and whatever the form of the operating power, the proportional controller is essentially an amplifier with an adjustable gain.

Integral Control Action: In a controller with integral control action, the value of the controller output *u(t)* is changed at a rate proportional to the actuating error signal *e(t).*

$$u(t) = K_i \int_0^t e(t)dt \tag{2.10.3}$$

where K_i is an adjustable constant.

Proportional-Plus-Integral Control Action: The control action of a proportional-plus-integral controller is defined by

$$u(t) = K_p e(t) + \frac{K_p}{T_i} \int_0^t e(t)dt \tag{2.10.4}$$

where T_i is called the *integral time*.

Proportional-Plus-Derivative Control Action: The control action of a proportional plus derivative controller is defined by

$$u(t) = K_p e(t) + K_p T_d \frac{de(t)}{dt} \tag{2.10.5}$$

where T_d is called the *derivative time.*

Proportional-Plus-Integral-Plus-Derivative Control Action: The combination of proportional control action, integral control action, and derivative control action is termed proportional-plus-integral-plus-derivative control action. The combined action has the advantages of each of the three individual control actions. The equation of a controller with this combined action is given by

$$u(t) = K_p e(t) + \frac{K_p}{T_i} \int_0^t e(t)dt + K_p T_d \frac{de(t)}{dt} \tag{2.10.6}$$

2.10.3.3 Time Domain Specifications

Maximum Overshoot: Let *y(t)* be the unit-step response. Let y_{max} denote the maximum value of *y(t)*; y_{ss} is the steady-state value of *y(t)*; and $y_{max} \geq y_{ss}$. The maximum overshoot of *y(t)* is defined as

$$Maximum\ Overshoot = y_{max} - y_{ss} \tag{2.10.7}$$

The maximum overshoot is often represented as a percentage of the final value of the step response; that is,

$$Percentage\ Maximum\ Overshoot = \frac{Maximum\ Overshoot}{y_{ss}} \times 100\% \tag{2.10.8}$$

The maximum overshoot is often used to measure the relative stability of a control system. The unit step response illustrated in Figure 2.10.2 shows that the maximum overshoot occurs at the first overshoot.

Delay Time: The delay time t_d is defined as the time required for the step response to reach 50% of its final value.

Rise Time: The rise time t_r is defined as the time required for the step response from 10 to 90% of its final value. An alternative measure is to represent the rise time as the reciprocal of the slope of the step response at the instant that the response is equal to 50% of its final value.

Settling Time: The settling time t_s is defined as the time required for the step response to decrease and stay within a specified percentage of its final value. Frequently used criteria as given in Fig. 2 are 2% and 5%.

Steady State Error: The steady-state error of a system response is defined discrepancy between the output and the reference input when the steady state $(t \to \infty)$ is reached.

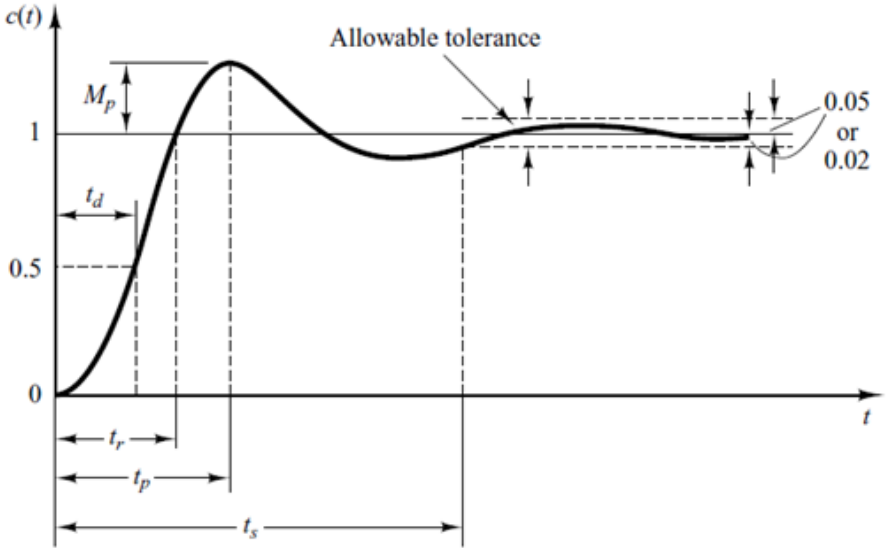


Figure 2.10.2. Typical unit step response of a second order control system illustrating the time domain specifications [1]

2.10.4 Experiments

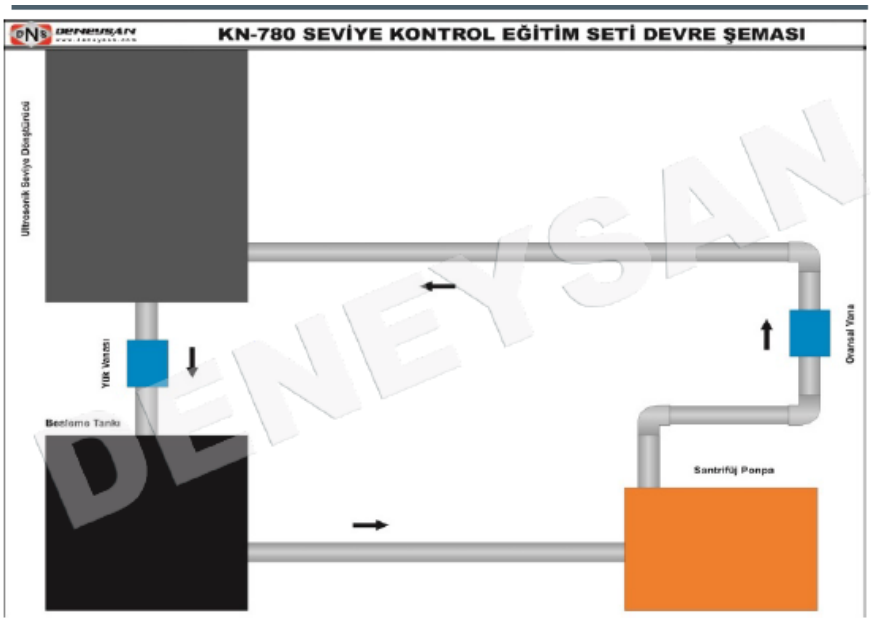


Figure 2.10.3. Schematic diagram of experimental setup

Components of experimental setup are

- Centrifugal Pump
- Proportional valve
- 2 Water Tanks
- Relief Valve

The water received from water supply tank is pumped to target water tank through proportional valve using the centrifugal pump. Then its flow rate is regulated by proportional valve. There is a relief valve between two tanks for discharging the water from the upper tank to the water supply tank.

2.10.4.1 Experiment 1: Water Level Control with On-Off Control

- Open the switch.
- Operate the pump.
- Choose the on-off control.
- Set the differential value to 5 cm and desire value 15 cm.
- Wait until the system becomes stable (2-4 minutes).

Table 2.10.1.

	1	2
Upper Limit		
Lower Limit		
Differential		

2.10.4.2 Experiment 2: WaterLevel Control with Proportional Control

- Choose P control
- Set the K_p value
- Set the desired value

Table 2.10.2.

	1	2	3
Desired Value			
Actual Value			
Proportional Gain(K_p)			

Questions:

- Find the maximum overshoot
- Try to estimate settling and delay time
- Find the steady-state error
- For different K_p values, compare the results in terms of maximum overshoot, steady state error, settling time and delay time.

2.10.4.3 Experiment 3: Water Level Control with PI Control

- Choose PI control
- Set K_p and K_i values
- Set the desired value
- Repeat the experiment with different gains.

Table 2.10.3.

	1	2	3	4
Desired Value				
Actual Value				
Proportional Gain K_p				
Integral Gain K_i				

Questions:

- Find the maximum overshoot.
- Try to estimate settling and delay time.
- Find the steady-state error.
- Find the integral time ($K_i = \frac{K_p}{T_i}$).
- For different K_i values, compare the results in terms of maximum overshoot, steady state error, settling time and delay time.

2.10.4.4 Experiment 4: Water Level Control with PD Control:

- Choose PD control
- Set K_p and K_d values
- Set the desired value
- Repeat the experiment with different gains.

Table 2.10.4.

	1	2	3	4
Desired Value				
Actual Value				
Proportional Gain K_p				
Differential Gain K_d				

Questions:

- Find the maximum overshoot
- Try to estimate settling and delay time
- Find the steady-state error

- Find the derivative time $\left(K_d = K_p T_d\right)$
- For different K_d values, compare the results in terms of maximum overshoot, steady state error, settling time and delay time.

2.10.4.5 Experiment 5: Water Level Control with PID Control

- Choose PID control
- Set K_p, K_i and K_d values
- Set the desired value
- Repeat the experiment with different gains

Table 2.10.5.

	1	2	3	4
Desired Value				
Actual Value				
Proportional Gain K_p				
Integral Gain K_i				
Differential Gain K_d				

Questions:

- Find the maximum overshoot.
- Try to estimate settling and delay time.
- Find the steady-state error.
- Find the integral time ($K_i = \frac{K_p}{T_i}$).
- Find the derivative time $\left(K_d = K_p T_d\right)$.
- What are roles of centrifugal pump and proportional valve in this setup?
- How does the system react while the relief valve is progressively opened?

2.10.5 Report

After completing all of the experiments defined above, and by using the data obtained from those experiments, write down a simple report which consists of the response graphs of each experiment separately. And then please make your own comments by comparing the results of the experiments considering the graphs. The report format should be in a good fashion. For this reason, a standard report writing template may be preferred.

Addition of a CONCLUSION section to your report will be appreciated.

APPENDICES

Appendix 1 Experiment Report Preparation Rules
Appendix 2 Exemplar Cover Page for the Experiment Reports

I. Laboratory Report Elements

A laboratory report (shortly *a lab report*) is created using the following characteristics.

1. Name, Title, Page Number, and Date: Lab report document requires Name, Title, Page Number, and Dates. These are essential elements of formatting. Place your name or title with the page number in the header.

2. Standard Formatting: This document follows standard academic formatting guidelines. These include Times New Roman 12 pt. font. The text of lab report is single-spaced.

3. Graphic Numbering: This document uses visuals. Each graphic, such as: figures, tables, pictures, equations, etc. is labeled and numbered sequentially.

4. Format: The lab report follows the IMRD traditional report writing standard. It contains the following sections in this order: **I**ntroduction, **M**ethods, **R**esults, and **D**iscussion. Introduction provides background and the question addressed, methods describes how that question was answered, results show the resulting data from the experiment and discussion is the author's interpretation of those results. Often results and discussion are combined.

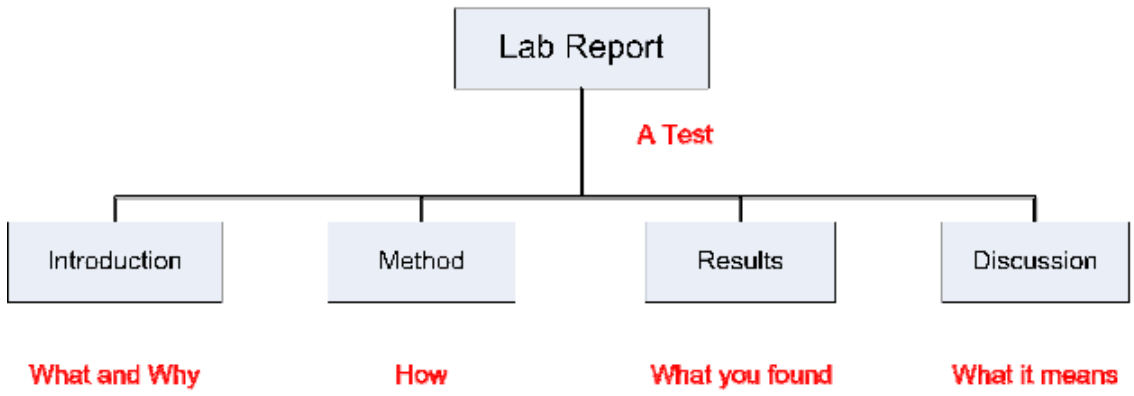
5. Tense: Technical writing varies its tense depending on what you are discussing. Tense should be consistent for each section you write.

- **Past Tense**

The lab report uses past tense. As a rule of thumb, past tense is used to describe work you did over the course of the report timeline.

- **Present Tense**

The lab report uses present tense. As a rule of thumb, present tense is used to describe knowledge and facts that were known before you started.



The lab report involves the solving of a specific question, described in the introduction and answered in the discussion.

II. How to Write a Lab Report

Report Sections		Explanation
Title Page		
Table of Contents		
Introduction	• Background/Theory • Purpose • Governing Equations Discovery and Question	In this section, **what** you are trying to find and **why** are describe. Background and motivation are used to provide the reader with a reason to read the report.
Methods	• Experiment • Overview Apparatus • Equipment Table • Procedures	In this section, **how** question addressed is answered, is explained. Clearly explain your work so it could be repeated.
Results	• Tables and Graphs • Equations in Variable • Form • Uncertainties and Error Analysis • Indicate Final Results	In this section, you present the **results** of your experiment. Tables, graphs, and equations are used to summarize the results. Link equations and visuals together.
Discussion	• Theoretical Comparison • Explanation of Anomalies/Error • Conclusion/Summary	In this section, you **explain** and **interpret** your results. Insert your opinion, backed by results. Discuss issues you had and how this could be corrected in the future. The conclusion is a summary of your results and discussion.
References		
Appendices – Raw Data, Sample Calculations, Lab Notebook, etc.		

T.C.
ANKARA YILDIRIM BEYAZIT UNIVERSITY
FACULTY OF ENGINEERING AND NATURAL SCIENCES
MECHANICAL ENGINEERING DEPARTMENT

MCE - 404 MACHINERY LABORATORY - II

..... EXPERIMENT REPORT

Student No	**:**
Name-Surname	**:**
Experiment Group	**:**
Experiment Date	**:**
Delivery Date	**:**
Grade	**:**

REFERENCES

[1] Genceli O. F., "Ölçme Tekniği (Boyut, Basınç, Akış ve Sıcaklık Ölçmeleri)", *Birsen Yayınevi*, İstanbul, 2000.

[2] Holman J. P., "Experimental Methods for Engineers", *McGraw-Hill Book Company*, 7nd Edition, New York, 2001.

[3] Bilen K., "Dar Kanallarda Yoğuşma", *İTÜ Fen Bilimleri Enstitüsü*, Doktora Tezi, (*Danışman*: *Prof. Dr. A. F. Özgüç*), İstanbul, 2007.