

**Department of Mechanical and Production Engineering
Ahsanullah University of Science and Technology (AUST)**

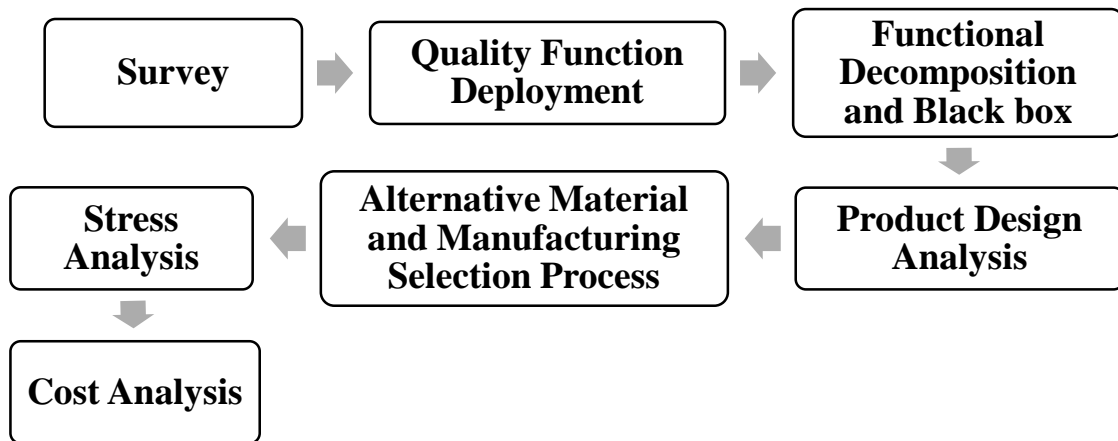
**IPE 3104: Product Design and Development sessional
Credit Hour: 1.5**

General Guidelines:

1. Students must form group and submit at least five ideas for product development by each group with in the first week of the beginning of class
2. Students must be present on time as per the scheduled time of each briefing
3. Report/ Assignment of a briefing must be submitted in the next briefing
4. Viva for each brief may be taken on the next day with the report/ assignment
5. The structure of the Report/ Assignment of each briefing will be provided by the respective teacher
6. Final presentation will be taken at the end of the semester before the preparatory leave.
7. Students must bring their complete product at the day of presentation for product demonstration
8. A tentative marks distribution is given below:

Report/ Assignment	Attendance and Viva	Final Presentation	Product demonstration
30	20	25	25

Steps regarding briefing of Product Design and Development sessional will be followed as mentioned below-



Brief-1

Survey

Market surveys are an important part of market research that measure the feelings and preferences of customers in a given market. Varying greatly in size, design, and purpose, market surveys are one of the main pieces of data that companies and organizations use in determining what products and services to offer and how to market them. These steps will teach you the basics of how to make a market survey and offer tips for optimizing your results.

Clarify the goal of your market survey. Before starting any planning, be certain what the goal of your market survey is. What do you want to find out? Do you want to try to assess how well your market will accept a new product? Maybe you want to figure out how well your marketing is working or reaching its designated audience. Whatever it is, be sure that you have a clear goal in mind.

Determine and define the nature, extent, and size of your market. Before conducting a survey in a given market, you need to know what market you're targeting. Choose geographic and demographic parameters, identify customers by types of product, and get an idea of how many people there are in the market.

Determine what aspects of the market you want to investigate. This will depend entirely on your marketing goals and there are a large variety of options here. If you have a new product, you may want to figure out how well it is recognized or desired in a given market. Alternately, you may want to know about the specific buying habits of your market, like when and where and how much they buy. Just be sure to have a clear idea of what you want to find out.

Find out where and when you can reach customers in your market. You might conduct a survey at the mall or on the street, via telephone, online, or through the mail. Your results may change based on the time of day and year. Choose a method and time that best suits your research.

Determine what type of survey to use. Surveys can be split into two different general categories: questionnaires and interviews. The only difference is who does the recording of the respondents' information; in the questionnaire, the respondent records their own answers to the questions, whereas in the interview, the interviewer writes down what the respondent says. Beyond that, there are other options as to how the survey is administered, whether that's online or in person. Surveys can also be done individually or in groups.

Consider online survey platforms. Online survey platforms offer a cost and time-effective way to organize your survey and survey results. Simply search for these platforms online and compare several that you find to assess which one offers the right tools for your survey. Just make sure that your choices are reputable survey platforms. You should also consider whether or not your target market is computer-savvy enough for online surveys to be effective

In order to get the best results students have to consider some important assumption before doing survey such as:

- **Choose a sample size**
- **Prepare a list of questions with answers that will provide the data you need for your market research**
- **Devise a way to quantify the answers you receive.**
- **Identify variables that might affect your results.**
- **Have someone else look over your survey.**
- **Set a time period and location for your survey**
- **Conduct your survey, maximizing sample size and accuracy of responses.**
- **Analyze your results.**

Brief-2

QUALITY FUNCTION DEPLOYMENT

Definition of QFD -QFD stands for quality function deployment. It is a very systematic and organized approach of taking customer needs and demands in the consideration when designing a new products and services or when improving existing products or services.

- Quality -meeting customer requirements
- Function - What must be done-Focusing the attention
- Deployment - who will do it, When

Benefits of QFD

- create customer driven environment
- reduces the cycle time for new products
- reduces design to manufacturing costs
- increases communication through cross functional teams
- establish priority requirements and improves quality

Characteristics of QFD

❖ **Four main phases of QFD**

- Product planning including the 'House of Quality' (requirements engineering life cycle)
- Product design (design life cycle)
- Process planning (implementation life cycle)
- Process control (testing life cycle)

Product planning <ul style="list-style-type: none">- define and prioritize customer needs- analyze competitive opportunities- plan a product to respond to a need- establish target values	Part planning <ul style="list-style-type: none">- identify critical parts and sub-assemblies- identify interaction effect between parts- identify important parts characteristics that can fulfill product needs
Process requirement <ul style="list-style-type: none">- determine critical process and material flow- determine process parameters- identify equipment requirements	Production planning <ul style="list-style-type: none">- establish operational requirement- determine operation sequence- establish process control methodology

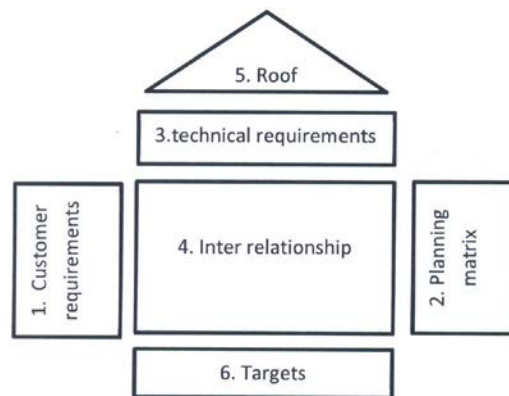
House of Quality

The primary planning tool used in QFD is the house of quality. The house of quality translates the voice of the customer into design requirements that meet specific target values and matches that against how an organization will meet those requirements. Many managers and engineers consider the house of quality to be the primary chart in quality planning.

To build House of Quality

- Identify customer **wants**
- Identify **how** the good/services will satisfy customer wants
- Relate customer **wants** to product **how**
- Identify relationships between the firm's **how** and the customer's **how**
- Develop importance rating
- Evaluate competing products

The structure of QFD can be thought of as a framework of a house, as shown in the figure below



1. **Customer requirements** -the voice of customer in their own words
2. **Planning matrix**
 - Customer satisfaction-existing products fulfilling specified requirements.
 - Improvement ratio = $(\text{existing rating} - \text{planned rating}) / \text{highest rating} + 1$
 - Sales point-weight for marketability
 - Overall weighting= $\text{improvement factor} * \text{sales point} * \text{customer importance}$
3. **Technical requirement** -engineering characteristics, voice of the company

4. **Interrelationships** -between customer requirements and technical requirements
5. **S. Roof** - consider impact of technical requirements on each other

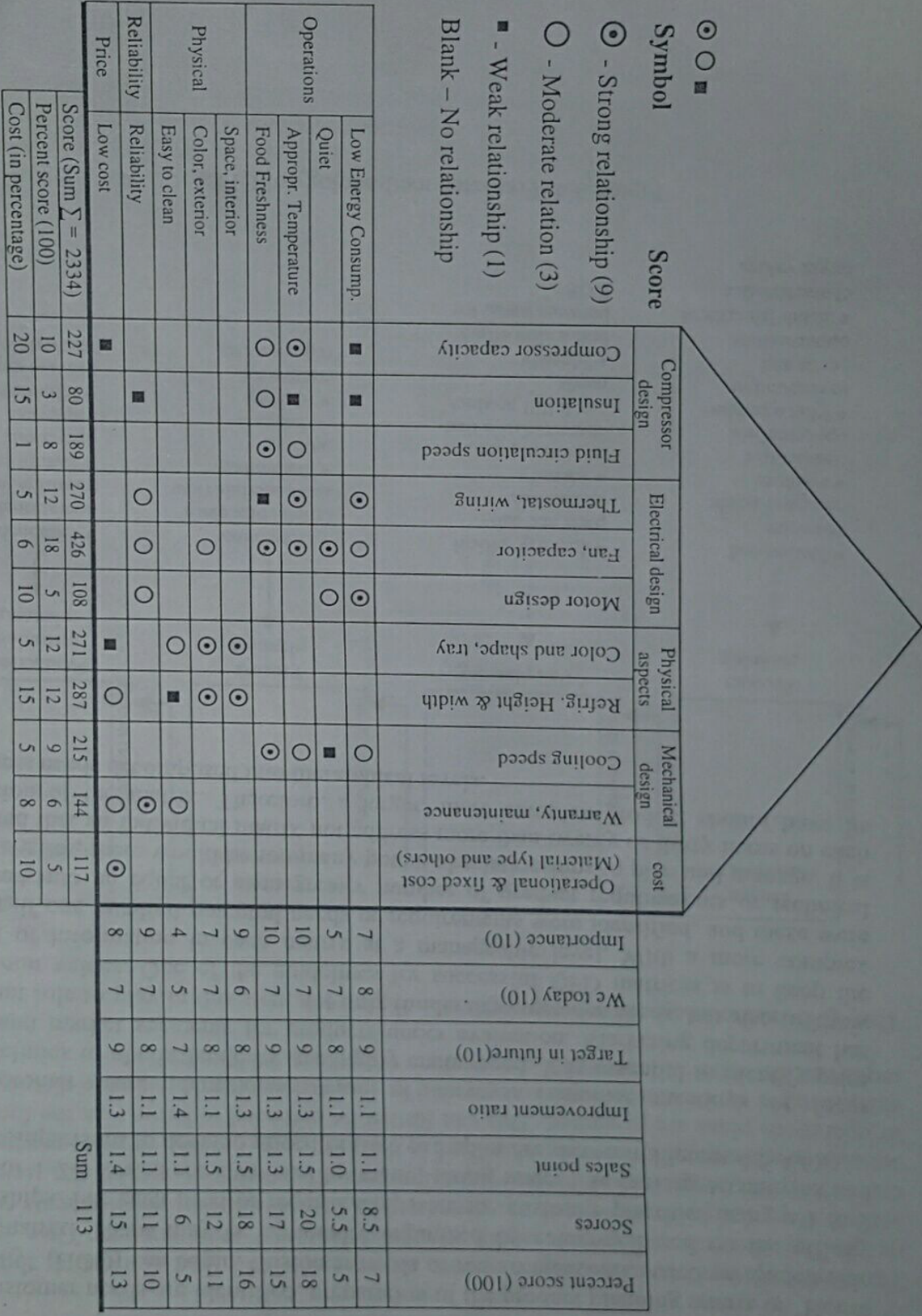


Figure 4.5. Product planning diagram for refrigerator production.

Brief-3

Functional Decomposition and Black Box

Functional Decomposition

Function:

A function of a product is a statement of a clear, reproducible relationship between the available input and the desired output of a product, independent of any particular form. The product function is the overall intended function of the product.

Sub function:

A sub function is a component of a product function. An overall function has to be divided into identifiable sub functions and the overall function is often governed by a constraint or input-output relationship.

An elementary approach to developing a function description of a product is to decompose the prime function hierarchically into sub functions that, when all are fulfilled, completes the overall product function. Function trees can be developed to understand the product function. The following is an example of the functional decomposition of Ice crusher machine.

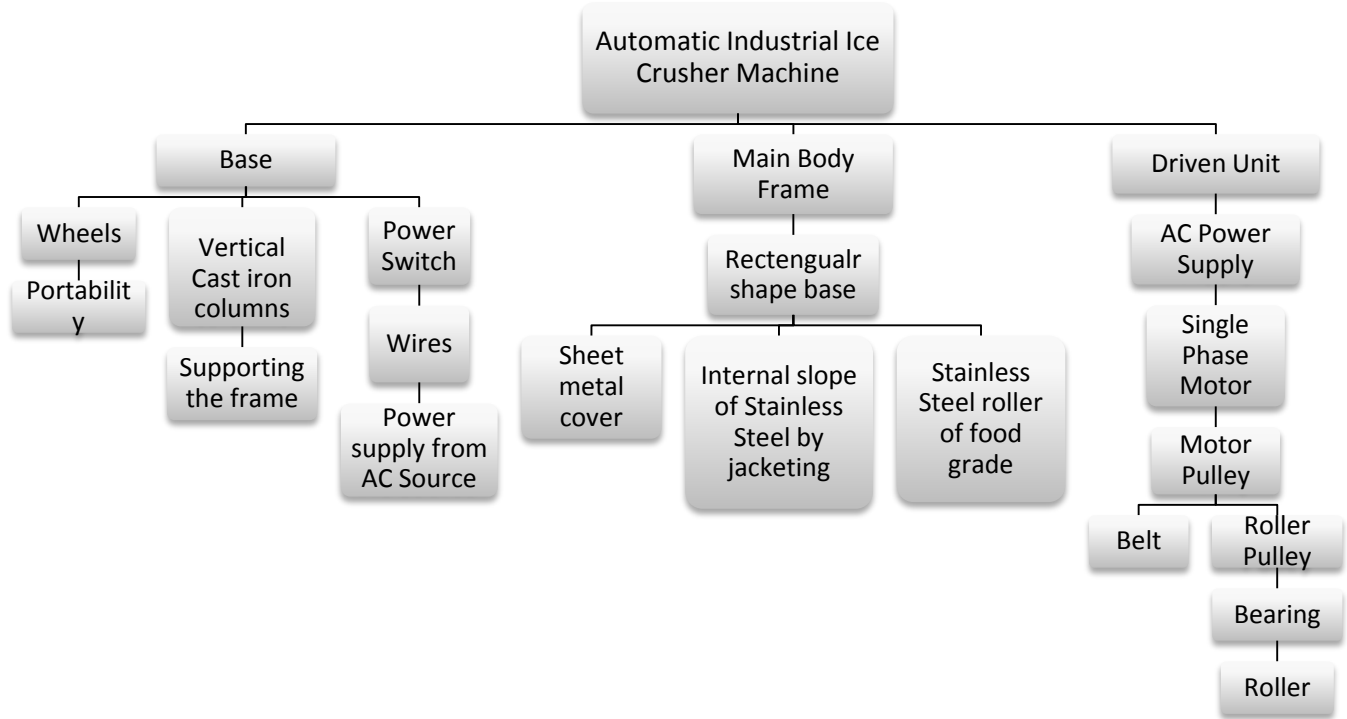
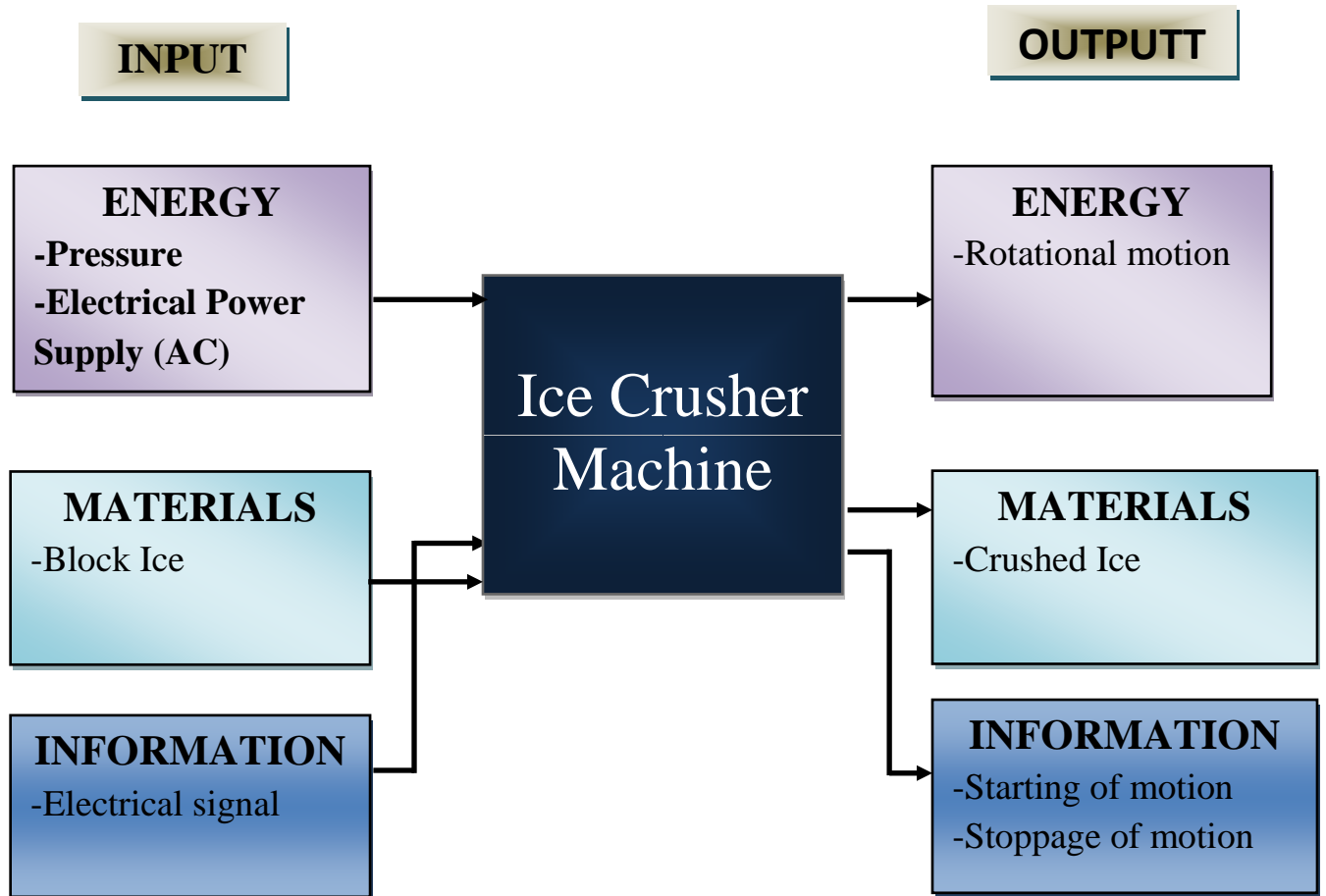


Figure 3: Functional decomposition of Automatic Industrial Ice Crusher Machine.

Black Box:

Black Box Model is a robust and complete method for modeling product’s functionality. It is called “black-box” because its internal form is deemed unknown. It allows us to focus on the greatest and overall need for a product. The Black Box initiates a technical understanding of a product based on its inputs and outputs, known as material, energy and information. an example is illustrated below.



BLACK BOX MODEL OF AUTOMATIC ICE CRUSHER MACHINE

Brief -4

Product Design Analysis

Product design analysis means studying how well a product does its job. The justification of a product lies in its use, however abstract that use may be (e.g. the use of a car to boost a driver's image); the product has no right of existence in itself. In this context it is important to note that the physical appearance of a product is only one of the many possible design implementations of the set of functions it is supposed to perform.

Designers and manufacturers use product design analysis to help them develop ideas for new or improved products and to analyze the work of other designers. Quality assurance is a system of checks and inspections to ensure high standards throughout design and manufacture. The purpose of the design analysis is to define a product that performs these functions as well as possible within the constraints of cost, (development) time and performance (quality), and the design problem to be solved is how to accomplish this.

The necessary condition to be fulfilled prior to the start of the design analysis properly is to know, what the user's intended use of the product will be:

- What he wants to do with the product (so its desired functions),
- How well he wants these functions performed and why,
- Which functions are the crucial ones?

Especially the last item is of importance, as it is the source for the set of criteria to be used in taking design decisions. During the design process the design team must continuously check whether the chosen design implementation meets the requirements from the user's point of view. To be able to do this, product characteristics must be linked back to the functions the product has to perform. Also, when choosing between design alternatives the key functions, in addition to the major constraints the product has to comply with, again deliver the criteria to screen and rank the alternatives.

A list of Universal Design principles are mentioned below-

1. **Equitable Use:** The design is useful and marketable to people with diverse abilities.
2. **Flexibility in Use:** The design accommodates a wide range of individual preferences and abilities.
3. **Simple & Intuitive to use:** Use of the design is easy to understand, regardless of the user's experience, knowledge, language skills, or current concentration level.
4. **Perceptible Information:** The design communicates necessary information effectively to the user, regardless of ambient conditions or the user's sensory abilities.

5. **Tolerance for Error:** The design minimizes hazards and the adverse consequences of accidental or unintended actions.
6. **Low Physical Effort:** The design can be used efficiently and comfortably and with a minimum of fatigue.
7. **Size and space for approach & use:**The design provides for appropriate size and space for approach, reach, manipulation, and use regardless of user's body size, posture, or mobility.

The attributes of a properly designed product are mentioned below-

1. **Functionality:** The product must function properly for intended purpose.
2. **Reliability:** The product must perform properly for the designated period of time.
3. **Productivity:** The product must be produced with a required quantity and quality at a defined and feasible cost.
4. **Quality:** The product must satisfy customer's stated and unstated needs.
5. **Standardization:** The product should be designed in such a fashion so that most of the components are standardized and easily available in the market.
6. **Maintainability:** The product must perform for a designated period with a minimum and defined maintenance. Adequate provision for maintenance should be kept in the product.
7. **Cost effectiveness:** The product must be cost effective. The must be manufactured in the most cost effective environment.

Product Architecture

Product contains components (CD players have a chassis, motors, disk drive, and speaker and so on), that can be combined into chunks (the base, the disk handling system, the recording system, and the sound producing system). A product is also composed of functional elements (for a CD player, these might include reading disks, recording sound, producing sound, and adjusting sound quality). The product architecture is how the functional elements are assigned to the chunks and how the chunks are interrelated.

Design for Manufacturing

Value Analysis or engineering: Simplification of products and processes. Value analysis seeks to improve the secondary function, e.g. how to open a can or make a tool box.

Terms in Value Analysis:

- Objective: Primary purpose of the product
- Basic Function: Makes the objective possible
- Secondary Function: How to perform the basic function

Modular Design: Multiple products using common parts, processes and modules.

- Allows greater variety through ‘mixing and matching’ of modules
- Develops a series of basic product components (modules) for later assembly into multiple products
- Reduces complexity and costs associated with large number of product variations
- Easy to subcontract production of modules

Design Variables & Attributes

Design Variables: Set of input variables (parameters) to the design simulation software (e.g. Motor type, Gear type, Gear ratio, DC voltage, ambient temperature)

Performance Attributes: Set of attributes that is the output of the simulation software, and identifies a product design (e.g. manufacturing cost, Weight, Time per operation per battery charge)

Design Alternative Generation

Two methods for generating design alternatives-

Multi objective Optimization

- Formulate a multiobjective optimization problem, solve for the alternatives that satisfy the objectives (performance attributes) the most.
- There is no closed form representation of the objective functions
- The design input parameters consist of both continuous and discrete variables
- Multiobjective Genetic Algorithm is a good choice to handle this type of problems
- The solution points constitute a non-dominated set w.r.t. all objective functions.

Permutation over Attributes

- Generating design alternatives by permuting the attributes over all (or certain) levels
- Mapping between the attributes and the design variables is simple(i.e. we can easily obtain the corresponding design variables, once we get the attribute levels)
- Very easy to implement but less likely to be able to handle real applications.

Brief-5

Alternative Material and Manufacturing Selection Process

It is estimated that there are more than 40,000 currently useful metallic alloys and probably close to that number of nonmetallic engineering materials such as plastics, ceramics and glasses, composite materials, and semiconductors. This large number of materials and the many manufacturing processes available to the engineer, coupled with the complex relationships between the different selection parameters, often make the selection of a materials for a given component a difficult task. If the selection process is carried out haphazardly, there will be the risk of overlooking a possible attractive alternative material. This risk can be reduced by adopting a systematic material selection procedure.

A variety of quantitative selection procedures have been developed to analyze the large amount of data involved in the selection process so that a systematic evaluation can be made. Several of the quantitative procedures can be adapted to use computers in selection from a data bank of materials. The materials and process selection is often thought of in terms of new product development

Quantitative Methods

Having specified the performance requirements of the different parts, the required material properties can be established for each of them. These properties may be quantitative or qualitative, essential or desirable. The essential material properties are tensile and fatigue strengths, while the desirable properties that should be maximized are process ability, weight, reliability, and resistance to service conditions. All these properties should be achieved at a reasonable cost. The selection process involves the search for the material or materials that would best meet those requirements. The starting point for materials selection is the entire range of engineering materials.

After narrowing down the field of possible materials using one or more of the quantitative initial screening methods quantitative methods can be used to further narrow the field of possible materials and matching manufacturing processes to a few optimum candidates that have good combinations of soft requirements.

Weighted-Properties Method

In the weighted-properties method each material requirement, or property, is assigned a certain weight, depending on its importance to the performance of the part in service. A weighted-property value is obtained by multiplying the numerical value of the property by the weighting

factor (α). The individual weighted-property values of each material are then summed to give a comparative materials performance index (β). Materials with the higher performance index (β) are considered more suitable for the application.

Digital Logic Method

The digital logic approach can be used as a systematic tool to determine α . In this procedure evaluations are arranged such that only two properties are considered at a time. Every possible combination of properties or goals is compared and no shades of choice are required, only a yes or no decision for each evaluation. To determine the relative importance of each property or goal a table is constructed, the properties or goals are listed in the left-hand column, and comparisons are made in the columns to the right, as shown in Table 1. In comparing two properties or goals, the more important goal is given numerical one (1) and the less important is given zero (0). The total number of possible decisions $N = n(n - 1)/2$, where n is the number of properties or goals under consideration. A relative emphasis coefficient or weighting factor, α , for each goal is obtained by dividing the number of positive decisions for each goal (m) into the total number of possible decisions (N). In this case $\sum\alpha = 1$.

Table 1 Determination of Relative Importance of Goals Using Digital Logic Method

Goals	Number of Positive Decisions $N = n(n - 1)/2$										Positive Decisions	Relative Emphasis Coefficient α
	1	2	3	4	5	6	7	8	9	10		
1	1	1	0	1							3	0.3
2	0				1	0	1				2	0.2
3		0			0			1	0		1	0.1
4			1			1		0		0	2	0.2
5				0			0		1	1	2	0.2
Total number of positive decisions											10	$\sum\alpha = 1.0$

Performance Index

The property with higher numerical value will have more influence than is warranted by its weighting factor. This drawback is overcome by introducing scaling factors. Each property is so scaled that its highest numerical value does not exceed 100. When evaluating a list of candidate materials, one property is considered at a time. The best value in the list is rated as 100 and the others are scaled proportionally. Introducing a scaling factor facilitates the conversion of normal material property values to scaled dimensionless values. For a given property, the scaled value, B , for a given candidate material is equal to:

$$B = \text{Scaled property} = \frac{\text{Numerical value of property} \times 100}{\text{Maximum value in the list}}$$

For properties such as cost, corrosion or wear loss, weight gain in oxidation, etc., a lower value is more desirable. In such cases, the lowest value is rated as 100 and B is calculated as:

$$B = \text{Scaled property} = \frac{\text{Minimum value in the list} \times 100}{\text{Numerical value of property}}$$

For material properties that can be represented by numerical values, application of the above procedure is simple. However, with properties such as corrosion and wear resistance, machinability and weldability, etc. numerical values are rarely given and materials are usually rated as very good, good, fair, poor, etc. In such cases, the rating can be converted to numerical values using an arbitrary scale. For example, corrosion resistance rating—excellent, very good, good, fair, and poor—can be given numerical values of 5, 4, 3, 2, and 1, respectively. After scaling the different properties, the material performance index (γ) can be calculated as:

$$\text{Material performance index} = \gamma = \sum_{i=1}^n B_i \alpha_i$$

where i is summed over all the n relevant properties.

CASE STUDY IN MATERIAL SELECTION

The objective is to select the least expensive component that satisfies the requirements for a simple structural component for cryogenic storage tank.

Materials requirements

- used in cryogenic applications for liquefied nitrogen gas) must not suffer ductile-brittle transition at -196°C
- Using stronger material gives thinner walls, which means a lighter tank, lower cool down losses, and easier to weld
- Lower specific gravity gives lighter tank
- Lower specific heat reduces cool down losses
- Lower thermal expansion coefficient reduces thermal stress
- Lower thermal conductivity reduces heat losses
- The cost of material and processing

Table 2: Digital logic method to cryogenic tank problem

Property	Decision number																				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Toughness	1	1	1	1	1	1															
Yield strength	0						1	0	0	1	1										
Young's modulus	0						0					0	0	0	1						
Density		0					1				1					1	1	1			
Expansion			0					1				1			0				1	1	
Conductivity				0					0				1			0			0		0
Specific heat					0					0					0			0		0	1

Table 3 Weighting factors for cryogenic tank

Property	Positive decisions	Weighting factor
Toughness	6	0.28
Yield strength	3	0.14
Young's modulus	1	0.05
Density	5	0.24
Expansion	4	0.19
Conductivity	1	0.05
Specific heat	1	0.05
Total	21	1.00

Table 4 Properties of candidate materials for cryogenic tank

Material	1	2	3	4	5	6	7
	Toughness index^a	Yield strength (MPa)	Young's modulus (GPa)	Specific gravity	Thermal expansion^b	Thermal conductivity^c	Specific heat^d
Al 2014-T6	75.5	420	74.2	2.8	21.4	0.37	0.16
Al 5052-O	95	91	70	2.68	22.1	0.33	0.16
SS 301-FH	770	1365	189	7.9	16.9	0.04	0.08
SS 310-3/4H	187	1120	210	7.9	14.4	0.03	0.08
Ti-6Al-4V	179	875	112	4.43	9.4	0.016	0.09
Inconel 718	239	1190	217	8.51	11.5	0.31	0.07
70Cu-30Zn	273	200	112	8.53	19.9	0.29	0.06

Table 5 Scaled values of properties and performance index

Material	Scaled properties							Performance index (γ)
	1	2	3	4	5	6	7	
Al 2014-T6	10	30	34	96	44	4.3	38	42.2
Al 5052-O	12	6	32	100	43	4.8	38	40.1
SS 301-FH	100	100	87	34	56	40	75	70.9
SS 310-3/4H	24	82	97	34	65	53	75	50.0
Ti-6Al-4V	23	64	52	60	100	100	67	59.8
Inconel 718	31	87	100	30	82	5.2	86	53.3
70Cu-30Zn	35	15	52	30	47	5.5	100	35.9

From the above calculations the value of performance index has shown we can choose SS 301-FH for cryogenic tank.

Brief-6

Stress Analysis

As the manufacturing and engineering industry tend to become more complex and challenging, the importance of stress analysis in product and systems development is experienced better than ever.

Across manufacturing, biomedical, automotive, chemicals, aerospace, electronics, energy, and Geo-technical industries, analysis and prediction of potential stress and fatigue in the product are often performed as the last step of more complex multi-disciplinary analysis of electromechanical devices. It helps in determining the response of a structure, product or system on application of load. It is critical in evaluating structural analysis based on assessing fatigue and failure analysis process.

What is Stress Analysis?

Stress analysis is the process of comprehensive industrial testing based on the calculations of mechanical strain, stress, and related deformations on application of load. It is an advanced computational method of applying load on a structure to determine its response.

The analysis method is used for counter evaluating the effectiveness of FEA structural analysis based on the report for fatigue and stress assessment and failure analysis. The calculations can be used in determining the stress and fatigue level of different industrial structures, aircraft and aerospace, sub-sea components, rail, marine components, and nuclear structures and components.

Key Features of Stress Analysis

Stress analyzing modules come with different features that are of key benefit to engineering and manufacturing companies. However, some of the most important features include:

- Plane stress and strain
- Anisotropic stretch properties
- Electric and magnetic forces
- Thermal stresses
- Rigorous and dispersed loading

Stress Analysis example:

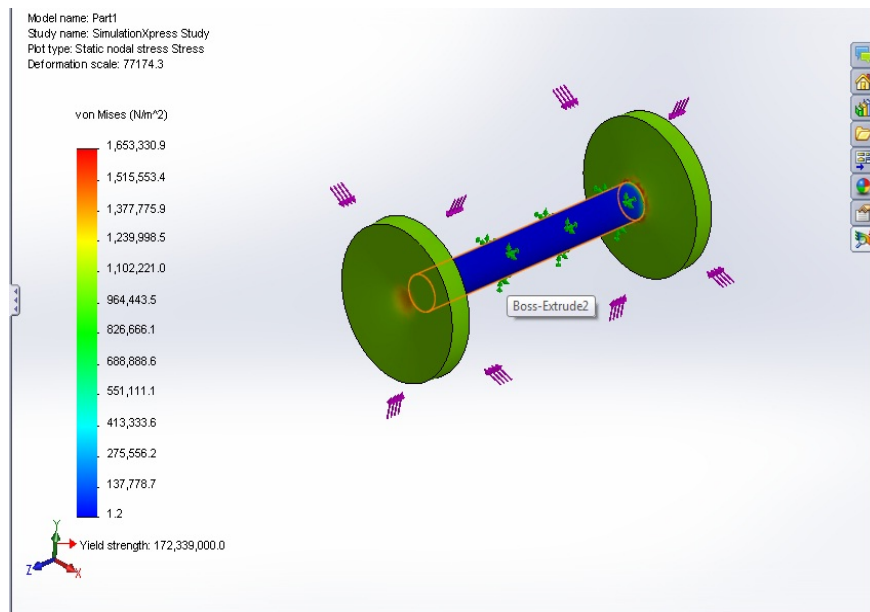


Figure 1: Static Stress Analysis for a Roller

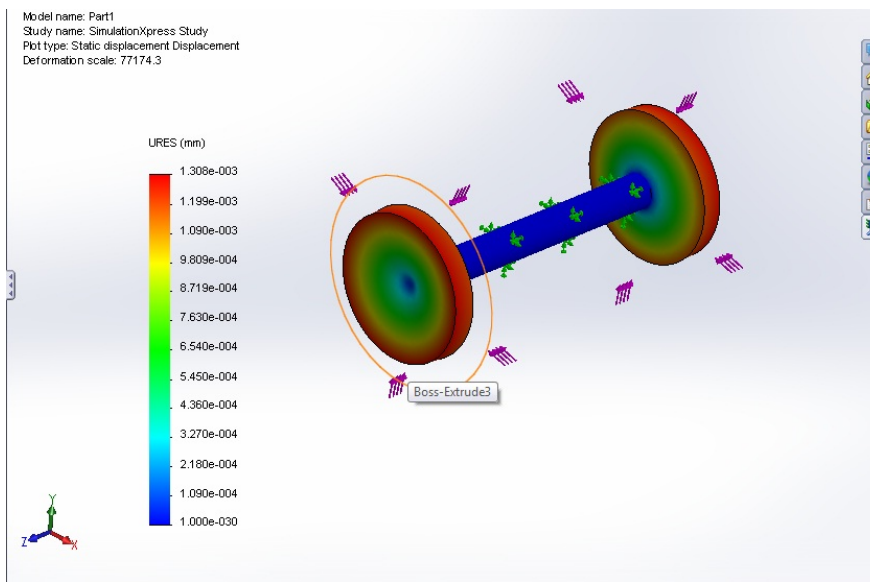


Figure -2: Static Displacement Analysis for a Roller

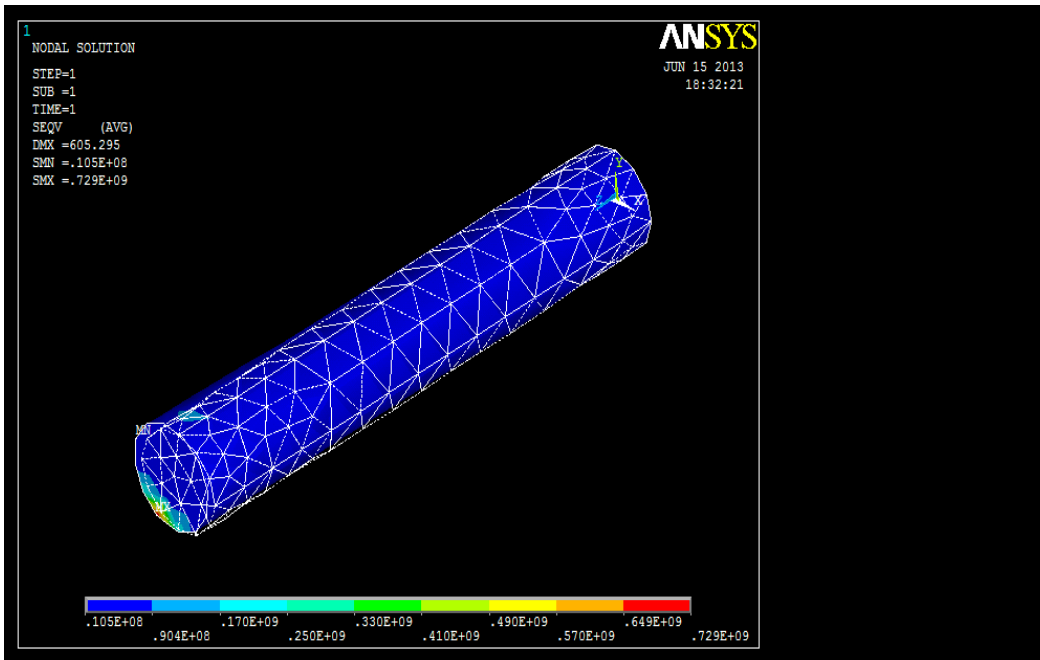


Figure -3: Nodal Solution for stress analysis of a motor Shaft

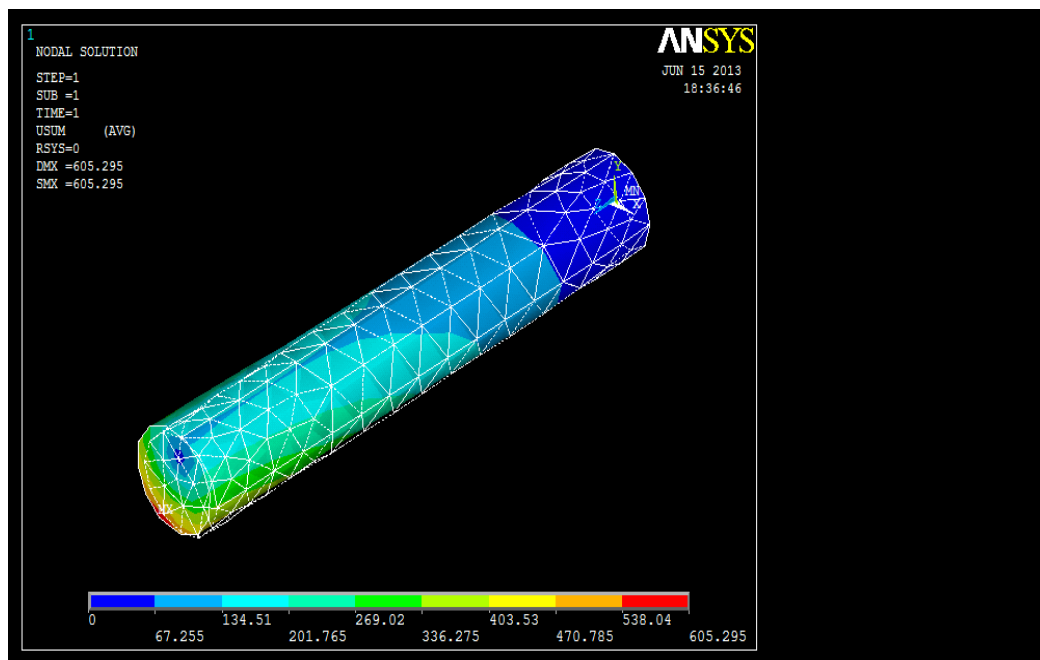


Figure -4: Nodal Solution for Displacement Analysis of a motor Shaft

```

PRNSOL Command
File
PRINT S      NODAL SOLUTION PER NODE
**** POST1 NODAL STRESS LISTING ****
PowerGraphics Is Currently Enabled
LOAD STEP=   1  SUBSTEP=   1
TIME= 1.0000  LOAD CASE=   0
NODAL RESULTS ARE FOR MATERIAL 1

```

NODE	S1	S2	S3	SINT	SEQU
1	0.55116E+08	0.58021E+07	-0.35734E+08	0.90850E+08	0.78775E+08
2	0.46245E+08	-0.27993E+06	-0.46526E+08	0.92771E+08	0.80342E+08
4	0.53465E+08	0.48825E+07	-0.37608E+08	0.91073E+08	0.78930E+08
6	0.50495E+08	0.21217E+07	-0.41317E+08	0.91812E+08	0.79553E+08
8	0.35748E+08	-0.49749E+07	-0.54891E+08	0.90639E+08	0.78632E+08
10	0.41346E+08	-0.20357E+07	-0.50262E+08	0.91608E+08	0.79375E+08
12	0.37550E+08	-0.50746E+07	-0.54344E+08	0.91893E+08	0.79652E+08
14	0.43559E+08	21750.	-0.43570E+08	0.87128E+08	0.75455E+08
16	0.35908E+08	-0.49033E+07	-0.52277E+08	0.88185E+08	0.76441E+08
18	0.39176E+08	-0.22733E+07	-0.47880E+08	0.87056E+08	0.75421E+08
21	0.48090E+08	0.22571E+07	-0.39243E+08	0.87333E+08	0.75664E+08
23	0.52376E+08	0.47746E+07	-0.35769E+08	0.88145E+08	0.76417E+08
55	0.32815E+08	0.28848E+07	-0.23219E+08	0.56033E+08	0.48564E+08
56	0.18265E+08	0.19442E+06	-0.17699E+08	0.35964E+08	0.31146E+08
57	0.20134E+08	-0.21893E+07	-0.27484E+08	0.47618E+08	0.41265E+08
58	0.21439E+08	-0.24581E+07	-0.29634E+08	0.51072E+08	0.44260E+08
59	0.23955E+08	-0.21785E+06	-0.24664E+08	0.48619E+08	0.42105E+08
60	0.19662E+08	0.13955E+07	-0.15021E+08	0.34683E+08	0.30051E+08
61	0.55682E+07	-0.59918E+06	-0.75654E+07	0.13134E+08	0.11381E+08
62	0.10357E+08	0.12102E+07	-0.40949E+07	0.14452E+08	0.12684E+08
63	0.24565E+08	-0.14255E+08	-0.38748E+08	0.63313E+08	0.55328E+08
65	0.19007E+07	-27573.	-0.10617E+08	0.12517E+08	0.11708E+08
67	-0.72543E+06	-0.16698E+07	-0.30371E+08	0.29646E+08	0.29186E+08
69	0.86704E+07	0.27707E+07	-0.48567E+07	0.13527E+08	0.11763E+08
71	0.31485E+08	-0.12469E+08	-0.40883E+08	0.72368E+08	0.63152E+08
73	0.21763E+08	0.18828E+07	-0.12891E+07	0.23052E+08	0.21641E+08
75	0.38989E+09	0.78807E+07	-0.38416E+09	0.77405E+09	0.67053E+09
77	0.46123E+07	-0.19645E+06	-0.36187E+08	0.40799E+08	0.38781E+08
79	0.26370E+08	-0.23539E+07	-0.23101E+09	0.25738E+09	0.24432E+09
82	0.22990E+09	-0.15627E+07	-0.11291E+08	0.24119E+09	0.23654E+09
84	0.40269E+08	-0.16017E+07	-0.26727E+07	0.42942E+08	0.42418E+08

Figure -5: List of result For Stress Analysis of a motor shaft

The Process of Stress Analysis

Analysis of stress within a structure encompasses determining the capability across all the points of the structure on application of load. The stress and fatigue rate is determined on a scale of 9-stress components to give a comprehensive view of the structure's performance and response in the face of the load. It helps in determining the purpose of interior allocation of stress within a structure.

The process of stress analysis includes the following stages:

- Building a part or structure to serve the function but at the same time, with reduced material usage and minimal cost
- Determining and setting the nature of the loads that can act on a structure, which includes density, tension, torsion, winding, trim, or amalgamation of these loads.
- When force is continuously applied to the structure, it tends to fail or get ruptured over time; more so due to lack of stable load condition. Stress analysis determines the level of stress under such cyclic load conditions

- To make sure that a particular part can efficiently work without breaking under force, it is tested based on the level of stress that it can take

Benefits of Stress Analysis Services

The key benefits of stress analysis services to engineering and manufacturing industries are underlined below:

- Facilitates accurate and reliable calculation of strain, distribution of load, and deflection
- Vast domain expertise in structure and thermal stress
- Leverage the power of efficient FEA solutions for product designing and development
- Minimum errors and loopholes, which ensures no product failure
- Cost-effective solutions

Brief-7

Cost Analysis

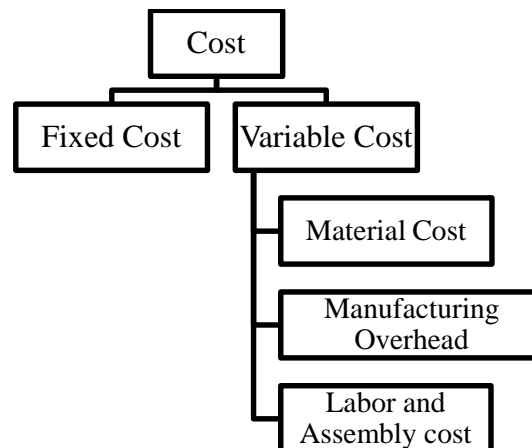
Cost analysis is a detailed outline of the potential risks and gains of a projected venture. The accumulation, examination, and manipulation of cost data for comparisons and projection are called cost analysis.

Cost estimate is the approximation of the cost of a program, project, or operation. The cost estimate is the product of the cost estimating process. The cost estimate has a single total value and may have identifiable component values.

Project underestimation of resources and costs is one of the most common contributors to project failure. Project teams should estimate costs for all resources that will be charged to the project. This includes but is not limited to

- Labor
- Materials
- Equipment
- Services
- Facilities
- Software etc.

Cost Analysis hierarchy for mass production



Fixed Cost

Fixed costs are costs that are independent of output. These remain constant throughout the relevant range and are usually considered sunk for the relevant range (not relevant to output decisions). Fixed costs often include rent, buildings, machinery, etc.

Variable Cost

Variable costs are costs that vary with output. Generally variable costs increase at a constant rate relative to labor and capital. Variable costs may include wages, utilities, materials used in production, etc.

Break Even Analysis

The main objective of break-even analysis is to find the cut-off production volume from where a firm will make profit. Let

s = selling price per unit

v = variable cost per unit

FC = fixed cost per period

Q = volume of production

The total sales revenue (S) of the firm is given by the following formula:

$$S = s \times Q$$

$$\text{Total Cost} = \text{Total variable cost} + \text{Fixed cost} = v \times Q + FC$$

The linear plots of the above two equations are shown in Fig. 1.

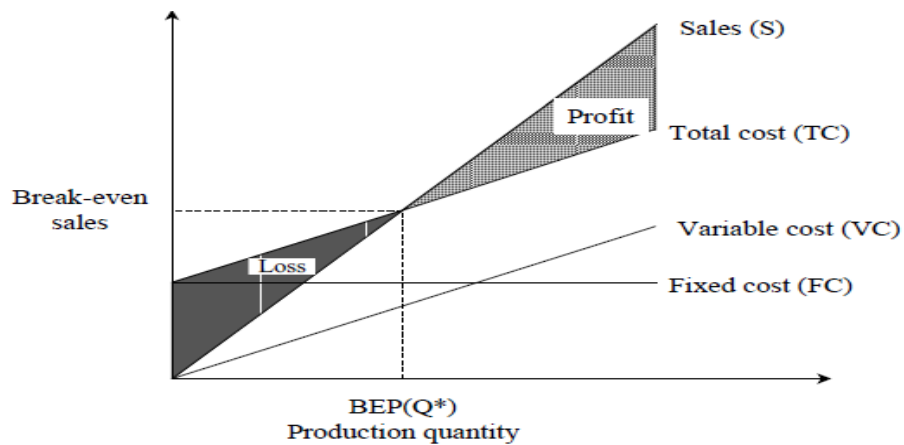


Fig. 1: Break-even chart.

The intersection point of the total sales revenue line and the total cost line is called the break-even point. The corresponding volume of production on the X-axis is known as the break-even sales quantity. At the intersection point, the total cost is equal to the total revenue. This point is also called the no-loss or no-gain situation. For any production quantity which is less than the break-even quantity, the total cost is more than the total revenue. Hence, the firm will be making loss.



Ahsanullah University of Science and Technology (AUST)
Department of Mechanical and Production Engineering

LABORATORY MANUAL

For the students of

Department of Mechanical and Production Engineering

3rd Year, 1st Semester

Student Name :

Student ID :

Experiment No. 1

STUDY OF BERNOULLI'S THEOREM

General

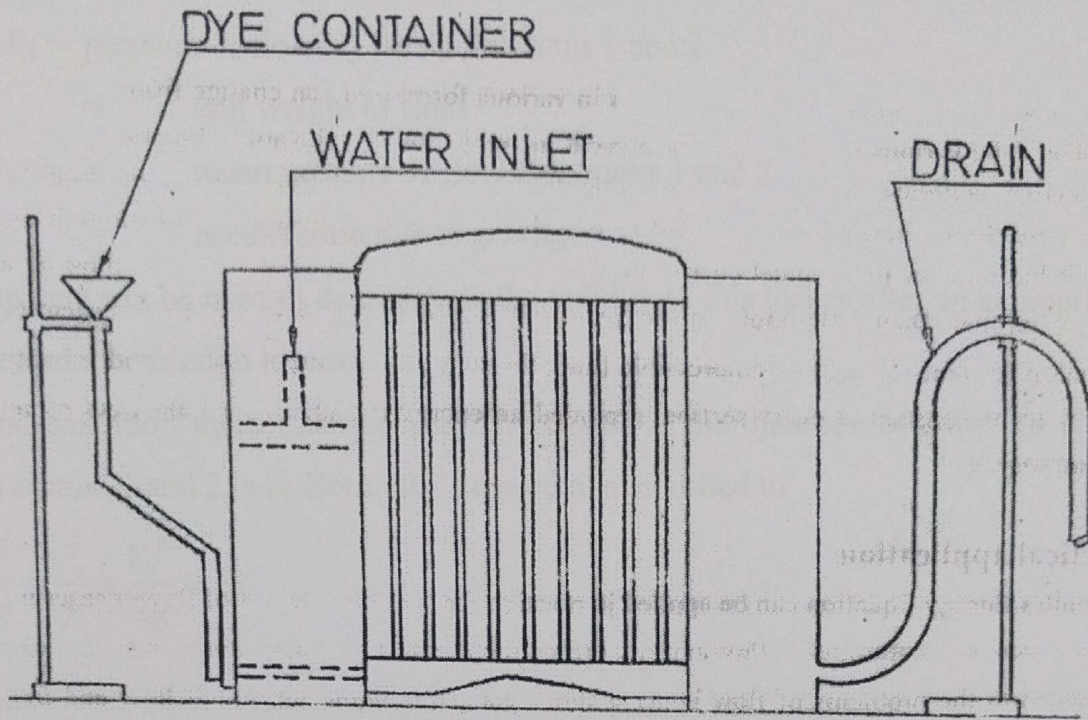
Energy is the ability to do work. It manifests in various forms and can change from one form to another. This various forms of energy present in fluid flow are elevation, kinetic, pressure and internal energies. Internal energies are due to molecular agitation and manifested by temperature. Heat energy may be added to or subtracted from a flowing fluid through the walls of the tube or mechanical energy may be added to or subtracted from the fluid by a pump or turbine. Daniel Bernoulli in the year 1738 stated that in a steady flow system of frictionless (or non-viscous) incompressible fluid, the sum of pressure, elevation and velocity heads remains constant at every section, provided no energy is added to or taken out by an external source.

Practical application

Bernoulli's Energy Equation can be applied in practice for the construction of flow measuring devices such as venturimeter, flow nozzle, orifice meter and Pitot tube. Furthermore, it can be applied to the problems of flow under a sluice gate, free liquid jet, radial flow and free vortex motion. It can also be applied to real incompressible fluids with good results in situations where frictional check is very small.

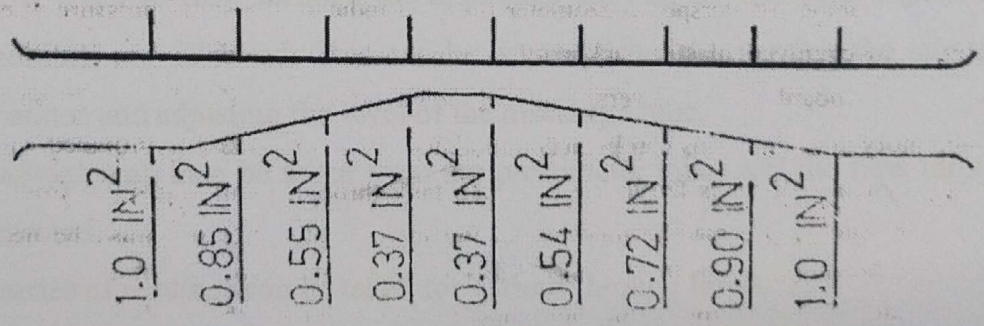
Description of apparatus

The unit is constructed as a single Perspex fabrication. It consists of two cylindrical reservoirs interconnected by a Perspex Venturi of rectangular cross-section. The Venturi is provided with a number of Perspex piezometer tubes to indicate the static pressure at each cross-section. An engraved plastic backboard is fitted which is calibrated in British and Metric units. This board can be reversed and mounted on either side of the unit so that various laboratory configurations can be accommodated. The inlet vessel is provided with a dye injection system. Water is fed to the upstream tank through a radial diffuser from the laboratory main supply. For satisfactory results, the main water pressure must be nearly constant. After flowing through the venture, water is discharged through a flow-regulating device. The rate of flow through the unit may be detrimental either volumetrically or gravimetrically. The equipment for this purpose is excluded from the manufacturer's supply. The apparatus has been made so that the direction of flow through the venture can be reversed for demonstration purpose. To do this the positions of the dye injector and discharge fitting have to be interchanged.



SKETCH OF APPARATUS

TUBES AT 1" CENTRES



VENTURI DETAILS

Governing Equation

Assuming frictionless flow, Bernoulli's Theorem states that, for a horizontal conduit

$$\frac{P_1}{\gamma} + \frac{V_1^2}{2g} = \frac{P_2}{\gamma} + \frac{V_2^2}{2g} = \frac{P_3}{\gamma} + \frac{V_3^2}{2g} = \dots\dots\dots$$

where, P_1, P_2 = pressure of flowing fluid at sections 1 and 2

γ = unit weight of fluid

V_1, V_2 = mean velocity of flow at sections 1 and 2

g = acceleration due to gravity.

The equipment can be used to demonstrate the validity of this theory after an appropriate allowance has been made for friction losses.

For actual condition there must be some head loss in the direction of flow. So if the head loss between section 1 and 2 is h_L Bernoulli's theorem is modified to

$$\frac{P_1}{\gamma} + \frac{V_1^2}{2g} = \frac{P_2}{\gamma} + \frac{V_2^2}{2g} + h_L$$

Procedure

1. The apparatus should be recurrently leveled by means of screws provided at the base.
2. Connect the water supply to the radial diffuser in the upstream tank.
3. Adjust the level of the discharge pipe by means of the stand and clamp provided to a convenient position.
4. Allow water to flow through the apparatus until all air has been expelled and steady flow conditions are achieved. This can be accomplished by varying the rate of inflow into the apparatus and adjusting the level of the discharge tube.
5. Readings may then be taken from the piezometer tubes and the flow through the apparatus measured.
6. A series of readings can be taken for various through flows.

Objective

1. To calculate the total head loss $h_L = h_1 - h_{11}$
2. To plot the static head, velocity head and total head against the length of the passage in one plain graph paper.
3. Verification of total head loss by plotting head loss in each passage or segment.
4. To plot the total head loss h_L , against the inlet kinematics head, $V^2/2g$, for different in- flow conditions in plain graph paper.

Practice Question

1. What are the assumptions underlying the Bernoulli's energy equation?
2. Do you need any modification (s) of Eqn (1) when (a) the frictional head loss is to be considered, and (b) the conduit is not horizontal?

Experiment No. 1
STUDY OF BERNOULLI'S THEOREM
Experimental Data Sheet

Course no.: _____

Student ID no.: _____

Group no.: _____

Date: _____

Cross-sectional area of the measuring tank = _____

Initial point gage reading = _____

Final point gage reading = _____

Collection time = _____

Volume of water = _____

Discharge Q = _____

Piezometer tube no.	1	2	3	4	5	6	7	8	9	10	11
A											
$V=Q/A$											
$V^2/(2g)$											
p/γ											
$h=p/\gamma + v^2/(2g)$											

Head loss in each segment	0	$h_{1-2} = h_2 - h_1$	h_{2-3}	h_{3-4}	h_{4-5}	h_{5-6}	h_{6-7}	h_{7-8}	h_{8-9}	h_{9-10}	h_{10-11}
h_L	0										

Gr. NO	1	2	3	3	5
$V_1^2/2g$					
h_L					

Signature of the teacher

Experiment No. 2 FLOW THROUGH VENTURIMETER

General

The converging tube is an efficient device for converting pressure head to velocity head, while the diverging tube converts velocity head to pressure head. The two may be combined to form venturi tube. As there is a definite relation between the pressure differential and the rate of flow. The tube may be made to serve as metering device.

Venturi meter consists of a tube with a constricted throat that produces an increased velocity accompanied by a reduction in pressure followed by a gradual diverging portion in which velocity is transformed back into pressure with slight frictional loss.

Practical application

The venturimeter is used for measuring the rate of flow of both compressible and incompressible fluids.

The venturimeter provides an accurate means for measuring flow in pipelines. Aside from the installation cost, the only disadvantage of the venturi meter is that it introduces a permanent frictional resistance in the pipelines.

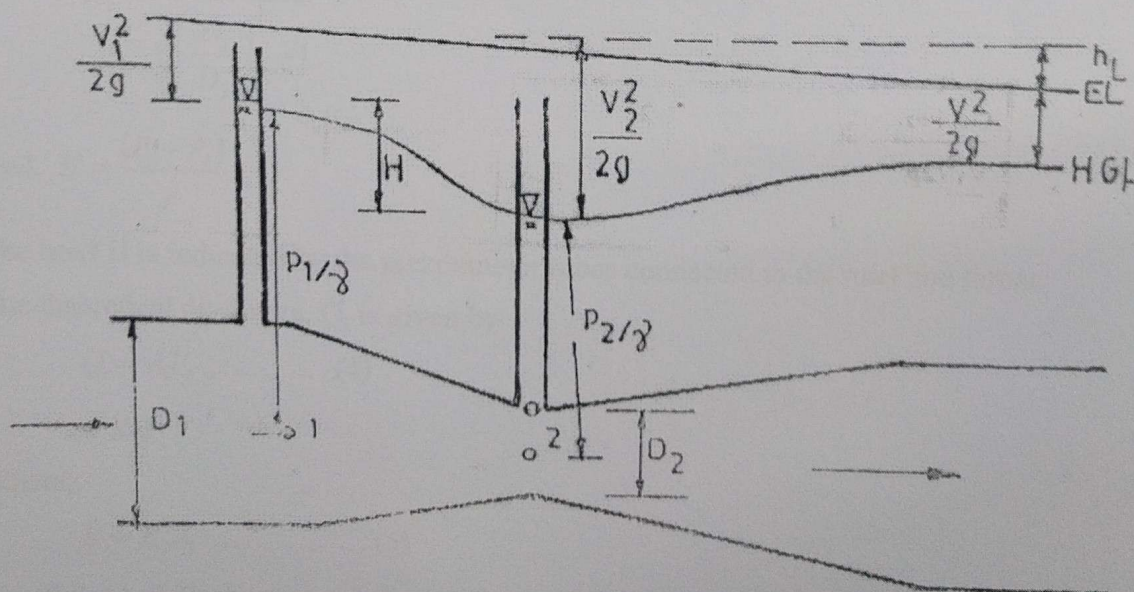


Fig. 1 Flow through a Venturimeter

Theory

Consider the Venturimeter shown in the above figure. Applying the Bernoulli's equation between Point 1 at the inlet and point 2 at the throat, we obtain.

$$\frac{p_1}{\gamma} + \frac{V_1^2}{2g} = \frac{p_2}{\gamma} + \frac{V_2^2}{2g} \dots\dots\dots(1)$$

Where P_1 and V_1 are the pressure and velocity at point 1, P_2 and V_2 are the corresponding quantities at point 2, γ is the specific weight of the fluid and g is the acceleration due to gravity from continuity equation, we have.

$$A_1V_1 = A_2V_2 \dots\dots\dots(2)$$

Where, A_1 and A_2 are the cross sectional areas of the inlet and throat respectively since

$$A_1 = \frac{\pi}{4} D_1^2, A_2 = \frac{\pi}{4} D_2^2$$

From Equations (1) and (2), we have

$$V_1 = \frac{\sqrt{\frac{2g}{\gamma} (P_1 - P_2)}}{\sqrt{\left(\frac{D_1}{D_2}\right)^4 - 1}} = K_1 H^{1/2} \dots\dots\dots(3)$$

Where,

$$K_1 = \frac{\sqrt{\frac{2g}{\gamma}}}{\sqrt{\left(\frac{D_1}{D_2}\right)^4 - 1}}$$

And, $H = \frac{(P_1 - P_2)}{\gamma}$

The head H is indicated by the piezometer tubes connected to the inlet and throat.

The theoretical discharge, Q_t is given by

$$Q_t = A_1V_1 \dots\dots\dots (4)$$

$$= KH^{1/2}$$

Where,

$$K = K_1A_1 \dots\dots\dots (5)$$

Coefficient of discharge

Theoretical discharge is calculated from theoretical formula neglecting losses, friction losses. For this reason we introduce a coefficient named coefficient of discharge which is the ratio of actual discharge to theoretical discharge.

Now, if C_d is the coefficient of discharge (also known as the meter coefficient) and Q_a is the actual discharge then,

$$C_d = \frac{Q_a}{Q_t}$$

$$Q_a = C_d Q_t$$

$$= C_d K H^{1/2}$$

$$= C H^n \dots\dots\dots (6)$$

The value of C_d may be assumed to be about 0.99 for large meter and about 0.97 or 0.98 for small ones provided the flow is such as to give reasonably high Reynolds number.

Calibration

One of the objectives of the experiment is to find the values of C and n for a particular meter so that in future we can measure actual discharge only by measuring H . Here C and n are called calibration parameters.

For five sets of actual discharge and H data we plot Q_a vs. H in log-log paper and draw a best-fit straight line.

The Equation of line

$$\log Q_a = \log C H^n$$

$$\log Q_a = \log C + n \log H$$

Now from the plotting we take two points on the straight line say (H_1, Q_{a1}) and (H_2, Q_{a2})

So from the equation (3) we get

$$\log Q_{a1} = \log C + n \log H_1$$

$$\log Q_{a2} = \log C + n \log H_2$$

$$\text{Solving, } n = \frac{\log \frac{Q_{a1}}{Q_{a2}}}{\log \frac{H_1}{H_2}}$$

$$C = \text{antilog} [\text{anti log } Q_{a1} - n \log H_1]$$

$$\text{So the calibration equation is } Q_a = C H^n$$

$$\text{Now } C = C_d K$$

$$C_d = C/K$$

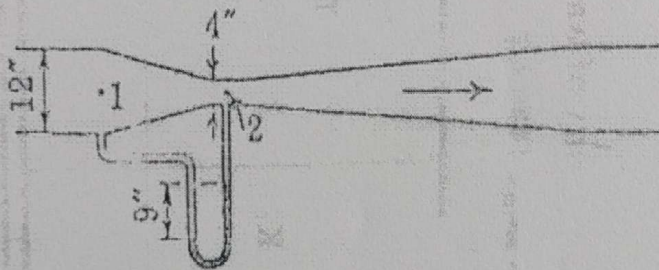
Now from the calibration equation we can calculate actual discharge for different H and plot on a plain graph paper. In practice we can use the plot to find actual discharge for any H . Thus the venturi meter is calibrated.

Objective

1. To find C_d for the Venturimeter
2. To plot Q_a against H in log-log paper and to find (a) exponent of H and (b) C_d
3. To calibrate the Venturimeter.

Practice Questions

1. Why is the diverging angle smaller than the converging angle for a venturimeter?
2. How can the accuracy of venturimeter be increased in use?
3. On what factors does the meter co-efficient depend?
4. What is cavitations? Discuss its effect on flow through a venturimeter. How can you avoid cavitation in a venturimeter?
5. A Venturi meter having a throat 4 in. in diameter is installed in a horizontal 12 in pipe line carrying light oil (sp gr 0.82). A mercury U tube as shown in fig 1. shows a difference in height of mercury columns of 9 in, the remainder of the tube being filled with oil. Find the rate of discharge, Q in cubic meter per second, if $C_d=0.975$.



Experiment No.2
FLOW THROUGH A VENTURIMETER
 Experimental Data and Calculation Sheet

Date: _____

Group no.: _____

Student ID no.: _____

Course no.: _____

Cross sectional area of the measuring tank, $A =$ _____
 Pipe diameter, $D_1 =$ _____ Area of the pipe, $A_1 =$ _____
 Throat diameter, $D_2 =$ _____ Area of the throat, $A_2 =$ _____
 Temperature of water, $t =$ _____ Kinematic viscosity of water $\nu =$ _____
 Initial point gage reading = _____ Final point gage reading = _____

No of obs	Volume of water V	Collection time T	Actual Dis-charge Q_a	Piezometer reading			k	Theoretical discharge Q_t	$C_d = \frac{Q_a}{Q_t}$	$V_2 = \frac{Q_a}{A_2}$	Reynolds number R_e
				Left h_1	Right h_2	Diff. H					

roup No											
Actual discharge Q_a											
Head difference H											
Coefficient of discharge											
Reynolds number											

Signature of the Teacher

Experiment No. 6 FLOW THROUGH AN ORIFICE

General

An orifice is an opening in the wall of a tank or in a plate normal to the axis of a pipe, the plate being either at the end of pipe or in some intermediate location. An orifice is characterized by the fact that the thickness of the wall or plate is very small relative to the size of the opening. For a standard orifice there is only a line contact with fluid.

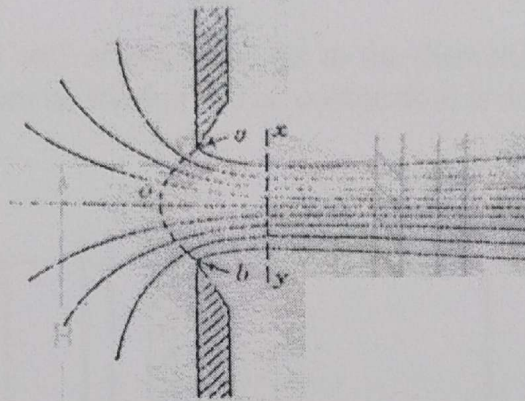


Fig 1 Jet contraction

Where the streamlines converge in approaching an orifice, they continue to converge beyond the upstream section of the orifice until they reach the section xy where they become parallel. Commonly this section is about $0.5D_0$ from the upstream edge of the opening, where D_0 is diameter of the orifice. The section xy is then a section of minimum area and is called the vena contracta. Beyond the vena contracta the streamlines commonly diverge because of frictional effects.

Practical application

The usual purpose of an orifice is the measurement or control of flow from a reservoir. The orifice is frequently encountered in engineering practice operating under a static head where it is usually not used for metering but rather as a special feature in a hydraulic design. Another problem of orifice flow, which frequently arises in engineering practice, is that of discharge from an orifice under falling head, a problem of unsteady flow.

Theory

Coefficient of contraction:

The ratio of the area of a jet at the vena contracta to the area of the orifice is called the coefficient of contraction.

Coefficient of velocity:

The velocity that would be attained in the jet if the friction did not exist may be termed the theoretical velocity. The ratio of actual to the theoretical velocity is called coefficient of velocity.

Coefficient of discharge:

The ratio of the actual rate of discharge Q_a to the theoretical rate of discharge Q (the flow that would occur if there were no friction and no contraction) is defined as the coefficient of discharge.

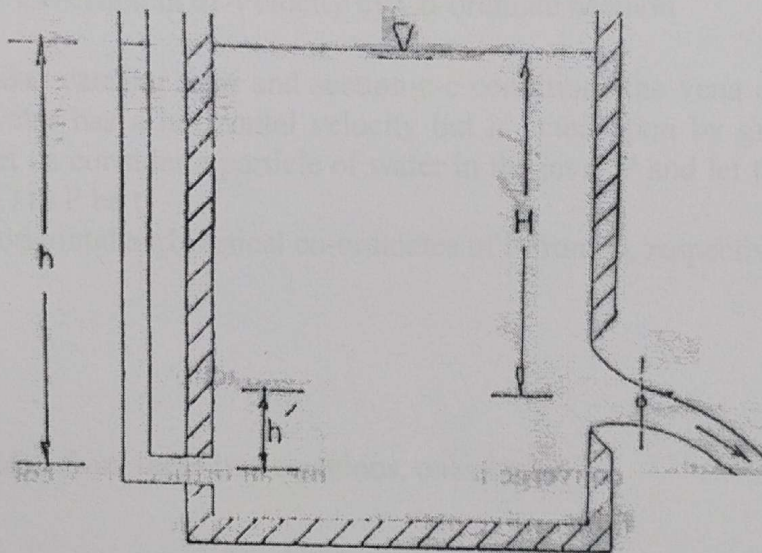


Fig. 2 Flow Through an orifice

Consider a small orifice having a cross-sectional area A and discharging water under a constant head H as shown in the above figure. Applying Bernoulli's theorem between the water surface

$$H = 0 + \frac{v^2}{2g}$$

$$\text{so, } V_t = \sqrt{2gH}$$

where g is the acceleration due to gravity. Let Q_a be the actual discharge.

So theoretical discharge Q_t is given by

$$Q_t = A\sqrt{2gH}$$

Then the coefficient of discharge, C_d is given by

$$C_d = \frac{Q_a}{Q_t}$$

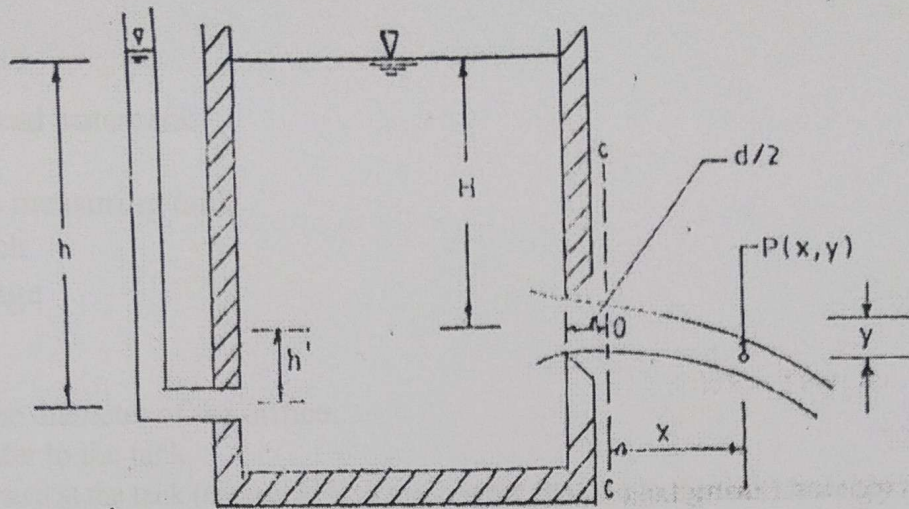


Fig 3: Co-efficient of Velocity by Co-ordinate Method

Let H be the total head causing flow and section-c-c conditions the vena contracta as shown in the figure. The jet of water has a horizontal velocity but is acted upon by gravity with a downward acceleration of g . Let us consider a particle of water in the jet at P and let the time taken for this to move particle from O to P be t .

Let x and y be the horizontal and vertical co-ordinates of P from O , respectively. Then,

$$x = V_a t$$

and

$$y = \frac{1}{2} g t^2$$

Equating the value of t^2 from these two equations, one obtains

$$\frac{x^2}{V_a^2} = \frac{2y}{g}$$

$$V_a = \sqrt{\frac{g x^2}{2y}}$$

But, the theoretical velocity, $V_t = \sqrt{2gH}$

Hence, the coefficient of velocity, C_v is given by

$$C_v = \frac{v_a}{v_t} = \sqrt{\frac{x^2}{4yH}}$$

And the head loss is given by

$$H_i = (1 - C_v^2)H$$

$$C_v = \frac{v_a}{v_t} = \frac{v_a}{\sqrt{2gH}}$$

Coefficient of contraction, C_c is defined as the area of jet at vena contracta to the area of orifice, thus,

$$C_c = \frac{A_a}{A}$$

It follows that

$$C_d = C_c \times C_v$$

Apparatus

1. Constant head water tank
2. Orifice
3. Discharge measuring tank
4. Stop watch
5. Point gauge

Procedure

1. Measure the diameter of the orifice.
2. Supply water to the tank.
3. When the head at the tank (measured by a manometer attached to the tank) is steady record the reading of the manometer.
4. Measure the x and y co-ordinate of the jet from the vena contracta.
5. Measure the flow rate.
6. Repeat the procedure for different combinations of discharge.

Objective

1. To find the value of C_d for the orifice.
2. 3. To plot Q_a vs. H in log-log paper and to find the value of (a) the exponent of H and (b) C_d .
3. To find C_v for the orifice.
4. To find the head loss, H_L .
5. To plot V_a vs. H in log-log paper and to find (a) C_v and (b) the exponent of H .

Practice Questions

1. What are the coefficient of velocity, coefficient of contraction and coefficient of discharge for an orifice? On what factors do these coefficients depend? What are average values of these coefficients for a sharp-crested orifice?
2. What is a submerged orifice? What are the average values of the coefficient of velocity, coefficient of contraction and coefficient of discharge for a submerged orifice?
3. Why is the actual discharge through an orifice less than the theoretical discharge?
4. Define vena contracta. Why does it form?
5. Will the value of C_v be different for sharp-edged and rounded orifices? Why?

Experiment No. 6

FLOW THROUGH AN ORIFICE

Observation and Calculation Sheet

Course no.:

Student ID no.:

Group no.:

Date:

Cross-sectional area of the measuring tank= _____

Diameter of the orifice, D = _____

Area of the orifice= _____

Head correction, h= _____

No of obs	Observed Head			Point gage reading			Collection time T	Vol. of Water V	Actual Head $H=h-h'$	Actual discharge Q_a	Theoretical Discharge Q_t	Coeff. of discharge C_d
	Initial	Final	Mean									

No Of Obs.	Horizontal Coordinate x	vertical Coordinate y	Actual velocity V_a	Coeff. of velocity C_v	Head loss H_L

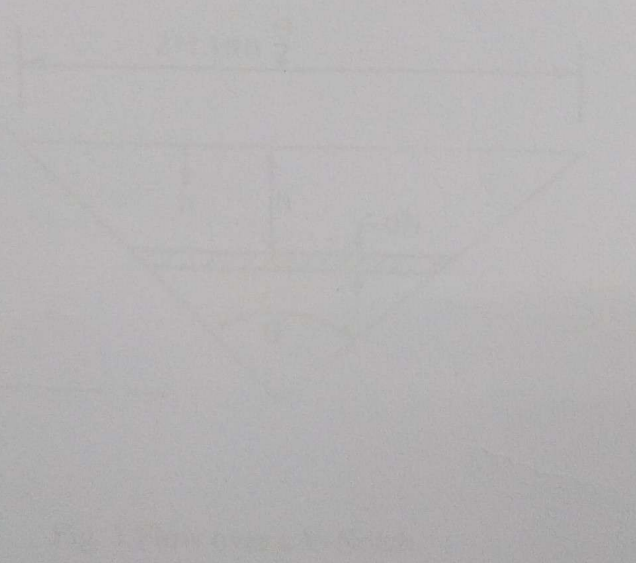
No of observation					
Actual discharge, Q_a					
Theoretical Discharge Q_t					
Actual Velocity V_a					
Theoretical velocity V_t					
Actual head H					

Practice Questions

1. Explain why the discharge through an orifice is increased by fitting a standard short tube to it?
2. What will happen to the coefficient of discharge if the tube is shorter than the standard length or the head causing the flow is relatively high?
3. What is the effect of rounding the entrance of the mouthpiece?
4. What is a submerged tube? Does the coefficient of the tube change due to submergence?

Practical application

The Venturi meter is preferred when small discharges are involved, because the contraction of the flow (vena contracta) leads to a relatively greater variation in head. Venturi meter has the advantage that it can function for a very small flow and also measure relatively large flows as well.



Experiment No. 4 FLOW OVER A V-NOTCH

General

The most common types of sharp-crested weir are the rectangular weir and the triangular weirs. The triangular or V-notch weir is preferable to the rectangular weir for the measurement of widely variable flows. In the case of a rectangular weir, the total wetted perimeter does not vary directly with the head, as the length of the base is the same for all heads. Therefore, the coefficient of contraction, which depends on the wetted perimeter, is not constant for all heads. But in case of a V-notch there is no base to cause contraction which will be due to the sides only. The coefficient of contraction will therefore, be a constant for all heads. For this reason, the V-Notch is the most satisfactory type for flow measurement in canals.

Practical application

The V-notch weir is preferred when small discharges are involved, because the triangular cross-section of the flow 'nappe' leads to a relatively greater variation in head. V-notch Weir has the advantage that it can function for a very small flows and also measure reasonably larger flows as well.

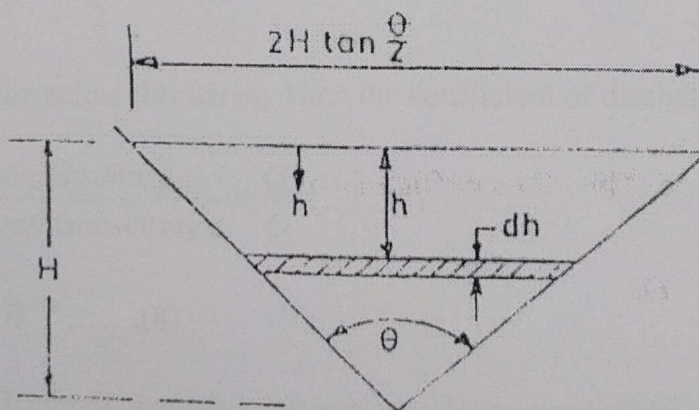


Fig. 1 Flow over a V-Notch

Theory

Consider the V-notch shown in the figure. Let H be the height of water surface and θ be the angle of notch. Then width of the notch at the water surface.

$$L = 2H \tan \frac{\theta}{2} \dots\dots(1)$$

Consider a horizontal strip of the notch of thickness dh under a head h. Then, width of the strip,

$$W = 2(H - h) \tan \frac{\theta}{2} \dots\dots(2)$$

Hence, the theoretical discharge through the strip

$$dQ_t = \text{area of the strip} \times \text{velocity} = 2(H-h) \tan \frac{\theta}{2} dh \sqrt{2gh} \dots\dots(3)$$

Integrating between the limits 0 and H and simplifying, the total theoretical discharge over the notch is given by

$$Q_t = \frac{8}{15} \sqrt{2g} \tan \frac{\theta}{2} H^{5/2} \dots\dots(4)$$

$$= KH^{5/2} \dots\dots(5)$$

Where,

$$K = \frac{8}{15} \sqrt{2g} \tan \frac{\theta}{2} \dots\dots(6)$$

Let Q_a be the actual discharge, Then the coefficient of discharge, C_d is given by

$$C_d = \frac{\text{actual discharge}}{\text{theoretical discharge}} = \frac{Q_a}{Q_t} \dots\dots(7)$$

$$Q_a = KC_d H^{5/2} \dots\dots(8)$$

The co-efficient of discharge depends on relative head (H/P), relative height (P/B) and angle of the notch (θ)

From hydraulic point of view a weir may be fully contracted at low heads while at increasing head it becomes partially contracted. The flow regime in a weir is said to be partially contracted when the contractions along the sides of the V-notch are not fully developed due to proximity of the walls and bed of approach channel. Whereas a weir which has an approach channel and whose bed and sides of the notch are sufficiently remote from the edges of the V-notch to allow for a sufficiently great approach velocity component parallel to the weir face so that the contraction is fully developed is a fully contracted weir. In case of a fully contracted weir C_d is fairly constant for a particular angle of notch.

At lower heads, frictional effects reduce coefficients. For the most common angle of notch 90 degree, the discharge coefficient, C_d is about 0.6.

Apparatus

1. A constant steady water supply with a means of varying the flow rate.
2. An approach channel
3. A V-notch weir plate
4. A flow rate measuring facility
5. A point gauge for measuring H.

Procedure

1. Position the weir plate at the end of approach channel, in a vertical plane, with the sharp edge on the upstream side.
2. Admit water to channel until the water discharges over the weir plate.
3. Close the flow control valve and allow water to stop flowing over weir.
4. Set the point gauge to a datum reading.
5. Position the gauge about half way between the notch plate and stilling baffle.
6. Admit water to the channel and adjust flow control valve to obtain heads, H, increasing in steps of 1 cm.
7. For each flow rate, stabilize conditions, measure and record H.
8. Take readings of volume and time using the volumetric tank to determine the flow rate.

Objective

1. To find C_d for the V-notch.
2. To plot Q_t vs. Q_a in a plain graph paper.
3. To plot Q_a vs. H in a log-log paper and to find (a) the exponent of H and (b) C_d

Practice Questions

1. Why does the V-notch give more accurate flow measurement than any other weirs and orifices when the flow is slightly fluctuating?
2. What is the average value of C_d for a 90° V-notch? Does it depend on flow condition (partially or fully contracted)?
3. Determine the discharge of water over a 60° triangular weir if the measured head is 0.623 ft.

Experiment No. 4
FLOW OVER A V-NOTCH
 Observation and Calculation Sheet

Course no.:

Group no.:

Student ID no.:

Date:

Angle of the notch, $\theta =$ _____

K= _____

Cross-sectional area of the measuring tank= _____

Initial point gauge reading = _____

Final point gauge reading= _____

Difference in reading = _____

Datum water level reading = _____

Water level above vertex= _____

Final water level reading= _____

No of obs	Vol. of water	Collection time T	Actual discharge Q_a	Effective head H	Theoretical discharge Q_t	Co-eff. of discharge

No of observation					
Actual discharge Q_a					
Effective head H					
Theoretical discharge					

Signature of the Teacher

Head losses in pipes and fittings

Objective

- To find the head losses in pipe, elbow, expansion and contraction in pipe, globe valve and overall system.
- To plot the Head losses vs. Velocity graph and to analyze the losses characteristics in flow.
- To calculate the friction factor of pipe.
- To calculate the minor loss coefficients of elbow, expansion and contraction in pipe, and globe valve.

Theory

Friction loss is the loss of energy or "head" that occurs in pipe flow due to viscous effects generated by the surface of the pipe. Friction Loss is considered as a "major loss" and it is not to be confused with "minor loss", which includes energy lost due to obstructions.

This energy drop is dependent on the wall shear stress between the fluid and pipe surface. The shear stress of a flow is also dependent on whether the flow is turbulent or laminar. For turbulent flow, the pressure drop is dependent on the roughness of the surface. In laminar flow, the roughness effects of the wall are negligible because, in turbulent flow, a thin viscous layer is formed near the pipe surface that causes a loss in energy, while in laminar flow, this viscous layer is non-existent.

One of the accepted methods to calculate friction losses resulting from fluid motion in pipes is by using the Darcy-Weisbach equation. For a circular pipe:

$$h_f = \frac{f Lv^2}{2gd}$$

Where:

h_f = Head loss due to friction, given in units of length

f = Darcy friction factor

L = Pipe length

d = Pipe diameter

v = Flow velocity

g = Gravitational acceleration

The minor losses of energy are those which are caused on account of the change in velocity of flowing fluid. In case of long pipes these losses are usually quite small as compared with the loss of energy due to friction and hence these are termed 'minor losses' which may even be neglected without serious error. However, in short pipes, these losses may sometimes outweigh the friction loss. Some of the losses of energy which may be caused due to the change of velocity are indicated below:

- (a) Loss of energy in bends and various pipe fittings
- (b) Loss of energy due to sudden expansion and contraction
- (c) Loss of energy due to gradual expansion and contraction
- (d) Loss of energy at the entrance and exit of pipe

With pipe bends, valves etc., it is usually to account for head losses through these devices, in addition to the losses sustained by the pipes. This must almost always be done by resorting to experimental results. Such minor loss is given in the form

$$h_l = K \frac{v^2}{2g}$$

Where,

h_l = Minor loss

K = Minor loss coefficient

v = Flow velocity

g = Gravitational acceleration

As there are two different velocities in expansion and contraction, the largest velocity of the smaller diameter pipe is considered to calculate minor losses.

Setup components

Piping arrangement with the wall-

- i. GI pipes
- ii. Pressure gauges
- iii. Water meter
- iv. Ball valve
- v. Globe valve
- vi. Pipe fittings
- vii. Couplers
- viii. Flexible pipes

Manometer-

- i. Coupler
- ii. Acrylic tube
- iii. Mercury
- iv. Flexible rubber tube
- v. Ring clips
- vi. Measuring scale
- vii. Hardboard

Working procedures

1. Water meter is connected in the path of flow to evaluate the volumetric flow-rate.
2. Calculating the time period of certain flow by stopwatch the volumetric flow-rate can be measured.
3. Thus from the known diameter of the pipes, the velocity of the flow can be computed.
4. Female ports of the couplers are connected with the male ports at certain points covering 1.94m of the pipe, elbow, globe valve, and expansion and contraction sockets; in order to find the pressure difference of those points in mercury column in manometer.
5. Pressure losses are converted to SI unit by essential calculations and are further assigned to calculate the friction factor of pipe and minor loss coefficients of the fittings, valves, and expansion and contraction in pipe.

Experimental Data

Specifications:

Pipe length, $L = 1.94\text{m}$

Thin pipe dia. = $\frac{3}{4}$ inch = 0.01905m ; Thick pipe dia. = $1\frac{1}{2}$ inch

Cross-sectional area of smaller pipe, $A = \frac{1}{4}\pi d^2 = \frac{1}{4} \times 3.1416 \times (0.01905)^2 = 2.85 \times 10^{-4} \text{m}^2$

Density of Mercury, $\rho_{hg} = 13550 \text{kg/m}^3$; Specific weight of Water, $\gamma_w = 9810$

Table: Flow Rate, Velocity and Losses in Pipes and Fittings

No. of Observations	Flow rate, Q (m ³ /s)	Velocity, v = Q/A (m/s)	Head loss, h_{hg} (mm mercury column)					
			Loss in pipe	Loss in elbow	Loss for expansion	Loss for contraction	Loss in globe valve	Overall loss
1								
2								
3								
4								
5								

Calculation Data

Table: Friction Factor of Pipe and Minor Loss Coefficients of Fittings

No. of obs.	Pipe friction factor F	Elbow loss coefficient, K	Expansion loss coefficient, K	Contraction loss coefficient, K	Globe valve loss coefficient, K	Overall loss from manometer (m of water)
1						
2						
3						
4						
5						
Avg.						

Sample calculation

$$\begin{aligned} \text{➤ Pressure drop due to pipe friction, } p &= \gamma_{hg} h_{hg} \\ &= \rho_{hg} g h_{hg} \\ &= \end{aligned}$$

$$\begin{aligned} \text{Head loss of water due to friction, } h_f &= \frac{p}{\gamma_w} \\ &= \end{aligned}$$

$$\begin{aligned} \therefore \text{Friction factor, } f &= \frac{2gdh_f}{Lv^2} \\ &= \end{aligned}$$

$$\begin{aligned} \text{➤ Pressure drop in elbow, } p &= \gamma_{hg} h_{hg} \\ &= \end{aligned}$$

$$\begin{aligned} \text{Head loss of water, } h_l &= \frac{p}{\gamma_w} \\ &= \end{aligned}$$

$$\begin{aligned} \therefore \text{Elbow loss coefficient, } K &= \frac{2gh_l}{v^2} \\ &= \end{aligned}$$

$$\begin{aligned} \text{➤ Pressure drop for expansion, } p &= \gamma_{hg} h_{hg} \\ &= \end{aligned}$$

$$\begin{aligned} \text{Head loss of water, } h_l &= \frac{p}{\gamma_w} \\ &= \end{aligned}$$

$$\therefore \text{Expansion loss coefficient, } K = \frac{2gh_l}{v^2}$$

=

➤ Pressure drop for contraction, $p = \gamma_{hg} h_{hg}$

=

Head loss of water, $h_l = \frac{p}{\gamma_w}$

=

∴ Contraction loss coefficient, $K = \frac{2gh_l}{v^2}$

=

➤ Pressure drop in globe valve, $p = \gamma_{hg} h_{hg}$

=

Head loss of water, $h_l = \frac{p}{\gamma_w}$

=

∴ Globe valve loss coefficient, $K = \frac{2gh_l}{v^2}$

=

➤ Overall Pressure drop, $p = \gamma_{hg} h_{hg}$

=

∴ Overall head loss of water, $h_l = \frac{p}{\gamma_w}$

=

Experiment Name: Study of A Centrifugal Pump and Pump Characteristics.

Theory:

A centrifugal pump is a machine which converts mechanical energy into kinetic and pressure energy through centrifugal force.

A centrifugal pump consists of two main parts:

- A rotating element, including an impeller and a shaft.
- A stationary element made up of a casing, stuffing box and bearings.

The shaft of the pump is driven by power from an external source by which means the impeller along with the vanes inside is rotated. The fluid receives energy from the vanes during flow through the rotating impeller resulting in an increase in both velocity and pressure. Fluid flows from the suction pipe due to the formation of partial vacuum in the center of impeller. A large part of the total energy of the fluid leaving the impeller is kinetic energy. It is necessary to reduce the absolute velocity and transform the large portion of the velocity head into pressure head. In overcoming the delivery head of the pump the high pressure head of the leaving fluid is utilized.

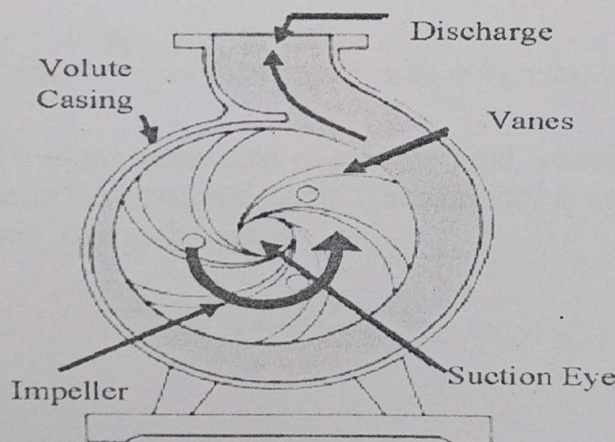


Figure 1: Liquid flow paths of a centrifugal pump

The actual head rise (H) produced by a centrifugal pump is a function of the flow rate (Q). It is possible to determine the head-flow relationship by appropriate selection of the geometry of the impeller blades. Normally, pumps are designed so that the head decreases with increasing flow since such a design results in a stable flow rate when the pump is connected to a piping system. A typical head flow curve for a pump is shown in Figure 2.

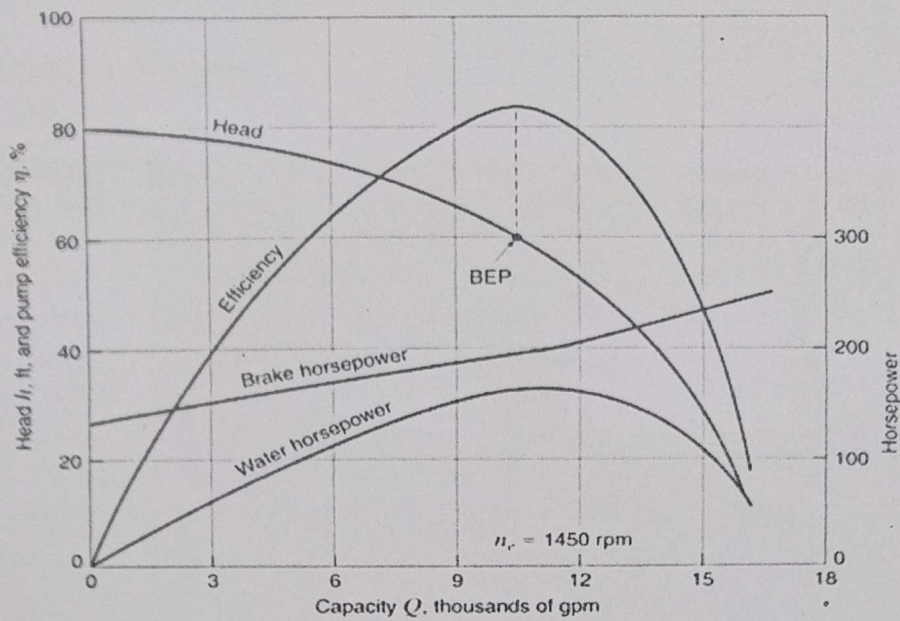


Figure 2: Characteristics curve of Centrifugal Pump.

If the mechanical energy equation is applied, section 1 is located as the pump inlet and section 2 as the pump outlet between two points in a piping system on opposite sides of the pump, then

$$\frac{P_1}{\gamma} + \frac{V_1^2}{2g} + Z_1 + H_m = \frac{P_2}{\gamma} + \frac{V_2^2}{2g} + Z_2 + h_f$$

$$H_m = \frac{P_2 - P_1}{\gamma} + \frac{V_2^2 - V_1^2}{2g} + Z_2 - Z_1 + h_f$$

H_m is the pump head and it is the summation of pressure head, velocity head, elevation head and h_f is the total head loss in the associated piping. The efficiency is defined as the ratio of the fluid work to the shaft power input to the pump:

$$\eta = \frac{\gamma Q H_m}{P}$$

Experimental Setup

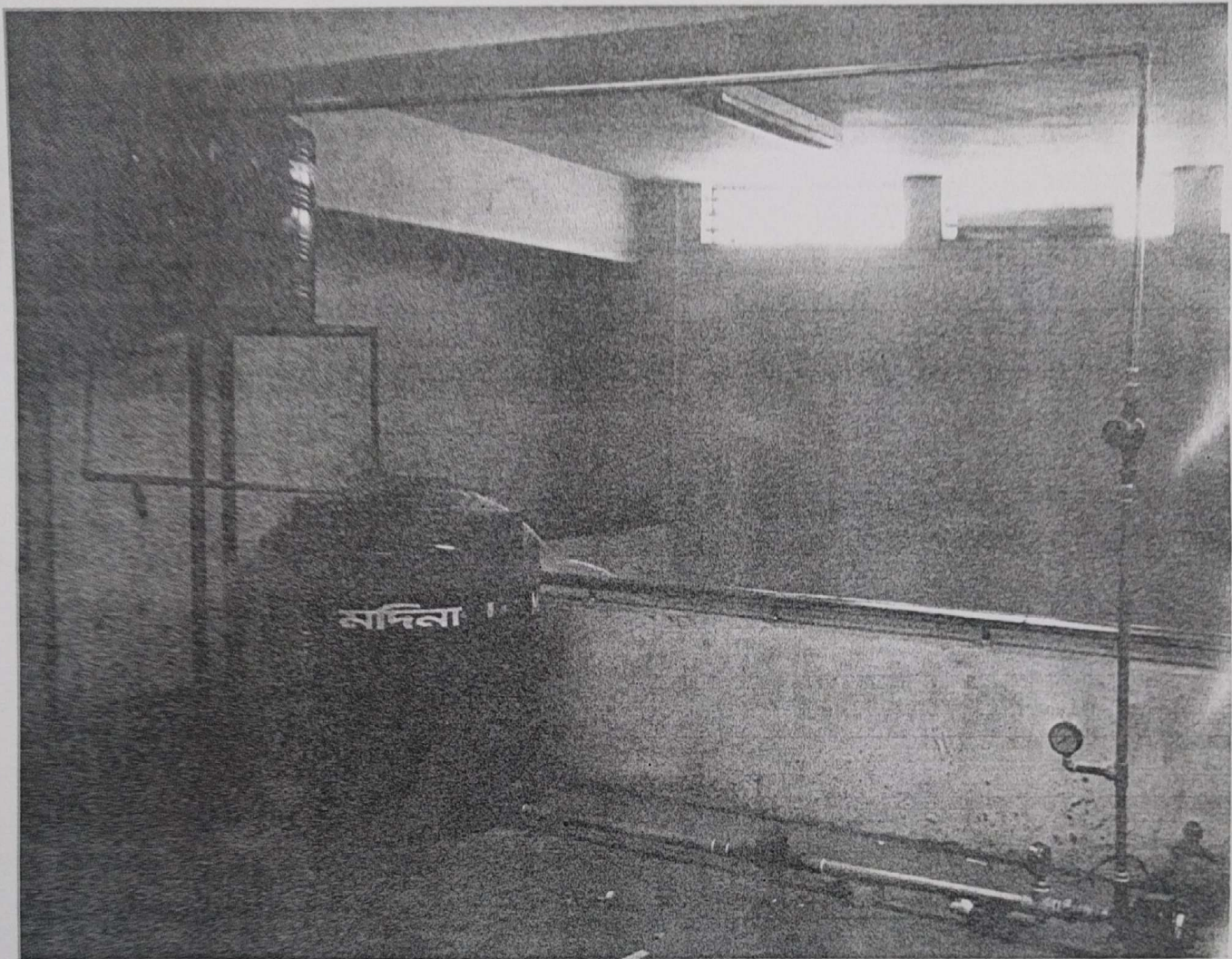


Figure 3: Centrifugal Pump Test Rig

Objective:

The objective of this experiment is to

- ✓ To do the performance test of different centrifugal pumps by varying their flow rates.
- ✓ To check the performance of centrifugal pump with different head and rpm.
- ✓ To plot the characteristics curve for different centrifugal pumps.

Apparatus:

Stopwatch, Wattmeter, Tachometer, Measuring Tape

Experimental Procedure

- Set up the centrifugal pump to the test rig.
- Wire connection to the pump.
- Measure power, voltage and current with Wattmeter.
- Measure RPM of the pump with non-contact Tachometer.
- Do this for all the pumps 0.5hp, 1hp, 1.5hp, 2hp & 3hp respectively.
- Open the gate valve at suction side of sump tank.
- Open the gate valve at delivery side of measuring tank.
- Turn on the pump.
- Take the value of flow rate at suction side and delivery side with flow meter and stopwatch.
- Take the value of pressure with pressure gauge at both sides.
- Reduce the flow of the water by controlling gate valve at delivery side step by step. Keep the flow rate of water at suction side constant.
- Now reduce the flow of the water by controlling gate valve at suction side step by step. Keep the flow rate of water at delivery side constant.
- Record all the values.
- Calculate friction in the delivery and suction side.
- Calculate the velocity head and total head.
- Calculate the pump efficiency.

Data Table:

Pipe Diameter (Suction) = 1.5 inch

Pipe Diameter (Delivery) = 1 inch

Pipe Length (Suction) = 96 inch

Pipe Length (Delivery) = 273 inch

Elevation Head, $H = 2.7432$ m

Height of Base = 72 cm

Width of Base = 38 cm

Pump Speed, N [r.p.m]	No Of Obs	Inlet Pressure, P_{in} [KPa]	Outlet Pressure, P_{out} [KPa]	Flow Rate, Q [m ³ /s]	Inlet Velocity, V_{in} [m/s]	Outlet Velocity, V_{out} [m/s]	friction in Suction H_s [m]	friction in Delivery H_v [m]	Elevation Head, H [m]	Pressure Head [m]	Velocity Head [m]	Total Head, H_t [m]	Output Power [w]	Hydraulic Power [w]	Pump Efficiency [%]

Calculation:

Flow rate, $Q = AV$

Reynolds Number, $Re = \frac{\rho VD}{\mu}$

Friction, $H_f = \frac{fV^2}{2gd}$

Total Head,

$$H_m = \frac{P_2 - P_1}{\gamma} + \frac{V_2^2 - V_1^2}{2g} + Z_2 - Z_1 + H_f$$

Efficiency, $\eta = \frac{\gamma Q H_m}{P}$