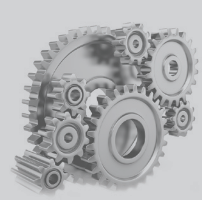
MECHANICAL ENGINEERING

Industrial & Maintenance Engineering



Comprehensive Theory
with Solved Examples *and* Practice Questions

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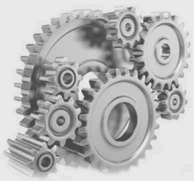

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CHAPTER

1

Introduction & Break Even Analysis

Section - A

1.1 INTRODUCTION

Industrial engineering is concerned with bringing together and effective utilization of various resources to facilitate efficient production operation. Effective utilization of resources means that input to the production - operation system (Example: people, material, equipment and information) are used in the correct manner so that they form an integrated combination to meet production or operation objectives.

- Industrial engineering is not only concerned with the system of material, equipment and processes but also with the people interacting with this sytem both from within and from outside. Example: workers and operators with-in the sysem for work study, time and motion study etc. and customers outside the system to determine demand and feedback.
- Industrial engineering is not only restricted to manufacturing but also includes service sectors.

1.2 BREAK EVEN ANALYSIS (BEA)

Cost-volume and profit analysis examines the interaction of a firm's sales volume, selling price, cost structure and profitability. It is a powerful tool in making managerial decisions, for example: minimum number of units to produce to earn profit and number of units to be produced to earn a specific amount of profit and other investment decisions.

Target profit analysis is concerned with estimating the level of sales required to attain a specific target profit whereas break-even is a special case of target profit analysis with zero target profit.

For Break-even analysis costs are divided into variable and fixed elements.

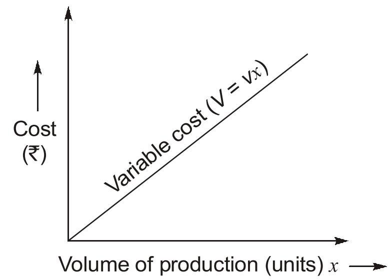
Assumptions of Break even analysis:

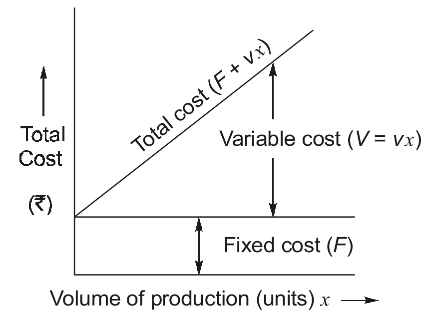
- Selling price is constant.
- Costs are linear and divided into variables and fixed.
- Inventories do not change.
- In multi-product companies, sales mix is constant.

(a) Fixed Cost: This cost remains fixed or constant irrespective of volume of production. It includes cost of machine, rent of building, salary of watchman, higher officials, advertisement cost, insurance cost, interest etc.

(b) Variable Cost ($V = vx$): This cost increases directly and proportionally with the volume of production and it includes direct material, direct labour and running cost.

(c) Total Cost: It indicates the total expenditure made in order to produce a certain number of units and it is the sum of fixed and variable cost.





It comprises of variable and fixed cost elements.

Notations:

F = Fixed cost in rupees; x = Number of units produced in order to earn profit 'P'.

v = Variable cost/unit (₹/unit); V = Total variable cost in ₹ $(v \times x)$

s = Selling price/unit (₹/unit); S = Total sale or revenue in ₹ $(s \times x)$

1.2.1 Break Even Chart

A break even chart is a chart that shows tha sales volume level at hich total costs equal sales. Brake even point is the volume of production where total sales is equal to the total cost and organisation neither earns profit nor suffers loss. It is also known as no profit and no loss point.

$$\text{Total sale} = \text{Total cost} + \text{profit}$$
$$\text{Total sale} = S = sx$$
$$\text{Total cost} = F + V = F + vx$$
$$\text{Profit} = P$$
$$S = F + vx + P$$

or

$$s.x = F + vx + P$$
$$(s - v)x = F + P$$
$$x = \frac{F+P}{(s-v)}$$

Number of units produced for profit 'P'.

$$x = \frac{F+P}{(s-v)}$$

At BEP, Profit, $P = 0$

$$x_{BEP} = \frac{F}{(s-v)} \text{ units}$$
$$(\text{BEP})_{sale} = x_{BEP} \cdot s = \frac{F}{(s-v)} \cdot s$$

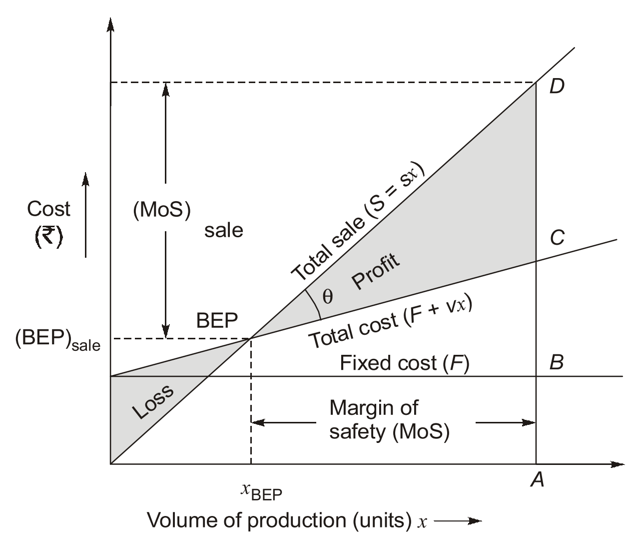


Figure: Break even chart

NOTE: Break even point is least affected by "volume of production". It depends on total cost, selling cost and variable cost.

EXAMPLE : 1.1

A standard machine tool and an automatic machine tool are being compared for the production of component. Following data refers to the two machine

	Standard machine tool	Automatic machine tool
Setup time	45 min.	2.5 hours
Machining time per piece	25 min.	5 min.
Machine rate	₹ 200/hour	₹ 800/hour

OBJECTIVE BRAIN TEASERS

Q.1 Two machines of the same production rate are available for use. On machine 1, the fixed cost is ₹ 100 and the variable cost is ₹ 2 per piece produced. The corresponding numbers for the machine 2 are ₹ 200 and ₹ 1 respectively. For certain strategic reasons both the machines are to be used concurrently. The sale price of the first 800 units is ₹ 3.50 per unit and subsequently it is only ₹ 3.00. The breakeven production rate for each machine is
(a) 75 (b) 100
(c) 150 (d) 600

Q.2 A company sells 44,000 units of a product. It has variable cost of ₹ 45 per unit. Fixed cost is ₹ 2,47,000 and the required profit is ₹ 2,23,000, then per unit product price will be_____ ₹. [Correct upto 2 decimal places]

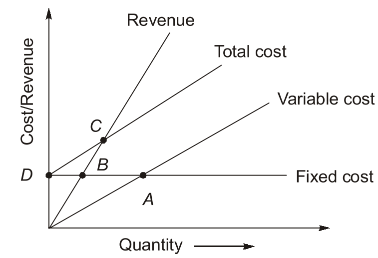
Q.3 If product's demand is price-inelastic, the firm raises the price of the product from ₹ 250 to ₹ 300 with the same variable cost of ₹150 and the unchanged fixed cost of ₹ 1,50,000. The change in *BEP* would be
(a) +500 units (b) +1000 units
(c) –1000 units (d) –500 units

Q.4 The break-even point is least affected by
(a) product mix (b) selling price
(c) fixed cost (d) volume of production

Q.5 If the fixed cost of the assets for a given period doubles and selling prices and variable costs decreases by half each, then how much will the break even quantity become?
(a) half (b) same
(c) twice (d) four

Q.6 The fixed cost of ₹ 24000 and a break-even-quantity of 40000 units are estimated for a production. The profit at a sales volume of 50000 units is ____₹. [Round off to nearest integer]

Q.7 Which point will indicate break even point in the figure shown below?



(a) Point A (b) Point B
(c) Point C (d) Point D

Q.8 *ABC* company plan to sell an article at a local market. The article is purchased at ₹ 5. The rent for the space is ₹ 2000. The article will be sold at ₹ 9. If the company sells 750 articles, the margin of safety will be ____________ %.

Q.9 Consider the following statements:
1. The break even point can lowered by increasing the variable cost.
2. The shortest processing time prioritization rule is used for reducing a queue size in front of a single server.
3. In a quantity discount model of inventory control, the relevant costs are annual purchase cost, annual order cost and annual carrying cost.

Which of the above statements are correct?
(a) 1 and 2 (b) 2 and 3
(c) 1 and 3 (d) 1, 2 and 3

Q.10 **Statement (I):** At break even point, inventory carrying cost is equal to preparatory cost.
Statement (II): The break-even point can be lowered by reducing the variable cost.
(a) Both Statement (I) and Statement (II) are true and Statement (II) is the correct explanation of Statement (I).
(b) Both Statement (I) and Statement (II) are true but Statement (II) is not a correct explanation of Statement (I).
(c) Statement (I) is true but Statement (II) is false.
(d) Statement (I) is false but Statement (II) is true.

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CONVENTIONAL BRAIN TEASERS

Q.1 The cost of producing between 1500 units and 2500 units of a product consists of Rs. 25,000 fixed cost and Rs. 10 per unit variable cost. With the selling price at Rs. 20 per unit, what is the break-even point? Suppose the price per unit was increased to Rs. 25. Illustrate with a neat sketch how does this affect the break-even point.

Solution:

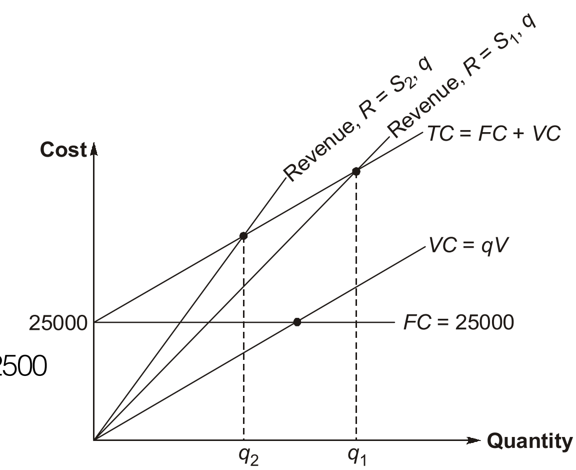
Given: Fixed cost, $f = 25000$; Variable cost, $v = 10$ per unit, Selling price, $s = 20$

At break-even points,

$$\text{Total cost} = \text{Total revenue}$$

$$f + v.q_1 = s.q_1$$

$$\Rightarrow \quad q_1 = \frac{f}{(s-v)} = \frac{25000}{(20-10)} = 2500$$



Now price becomes, $s = 25$

$$\therefore \quad q_2 = \frac{f}{s-v} = \frac{25000}{25-10} = 1667$$

Q.2 Following is information regarding a manufacturing enterprise:

Total fixed costs = Rs. 4,500; Total variable costs = Rs. 7,500; Total sales = Rs. 15,000; Units sold = 5,000

Find out:

(i) Break-even point in units
(ii) Margin of safety
(iii) Profit
(iv) Volume of sales to earn a profit of Rs 6,000

Solution:

Given: Total fixed cost, $f = 4500$, Total variable cost, $v = 7500$, Total sales, $s = 15000$, Units sold = 5000

$$\therefore \quad \text{Selling price of one unit, } s = \frac{15000}{5000} = 3$$

$$\text{Variable cost of one unit, } v = \frac{75000}{5000} = 1.5$$

(i) Break - even points,

$$F_c + q \cdot v = s \cdot q$$

$$\Rightarrow \quad q = \frac{FC}{(s-v)} = \frac{4500}{(3-1.5)} = 3000$$

(ii) Margin safety = Budgeted sale – Breakeven sales

$$\text{Sales} = 15000 - (3000 \times 3) = 6000$$

$$\text{Margin of safety ratio} = \frac{\text{Margin safety}}{\text{Budgeted sale}} \times 100 = \frac{6000}{15000} \times 100 = 40\%$$

CHAPTER

10

Practices & Principles of Maintenance Engineering

Section - B

10.1 INTRODUCTION

- Maintenance engineering is the discipline of applying engineering concepts to the optimization of components, procedures and departmental budgets to achieve better maintainability, reliability and availability of component and equipment.
- Maintenance engineering positions require planning and implementing routine and predictive maintenance programs.
- In addition, regular monitoring of equipment is required to visually and non-visually detect faults and implementing equipment or production failures before they occur.
- Maintenance engineers not only monitor existing systems and equipment; they also recommend improved systems and help decide when systems are outdated and in need of replacements.
- The maintenance engineer is responsible for the efficiency of daily operations and for discovering and solving any operational problems in the plant.

10.2 MAINTENANCE PLANNING

Maintenance planning is the task of organizing resources to carry out a job at satisfactory cost within a specified period of time. Maintenance planning involves the assignment of jobs to the maintenance crew.

10.2.1 Basic principles of Maintenance planning

(a) Plant management in maintenance work : The main role of maintenance function is to provide safe and effective operation of the equipment to achieve the desired targets on time with economic usage of resources.

(b) Production and maintenance objectives : Minimizing the idle time of maintenance workers.

- Maximizing the efficient use of work tools, machines and equipment.
- Maintaining the operating equipment at a responsive level to the need of production in terms of delivery schedule and quality.

(c) Establishment of work order and recording system : The work order for the maintenance function indicates the nature of work to be performed and series of operations to be followed to execute a particular job. It is necessary to maintain the proper records and entries to monitor the maintenance functions.

OBJECTIVE BRAIN TEASERS

Q.1 Which of the following is not a condition monitoring technique?
(a) Thermography
(b) Oil Analysis
(c) Surveying
(d) Vibration Monitoring

Q.2 Which one is not a maintenance technique?
(a) Reactive maintenance
(b) Periodic maintenance
(c) Corrective maintenance
(d) Predictive maintenance

Q.3 Reactive maintenance is also known as
(a) Periodic Maintenance
(b) Breakdown maintenance
(c) CBM
(d) Corrective maintenance

Q.4 Predictive maintenance is also known as
(a) Periodic maintenance
(b) CBM
(c) Corrective maintenance
(d) Breakdown maintenance

Q.5 What is the full form FMECA?
(a) Future mode effects and criteria analysis
(b) Functional mode effects and criticality analysis
(c) Failure mode effects and criticality analysis
(d) Failure mode effects and criteria analysis

Q.6 What is the function of FMECA?
(a) Identify the failure
(b) Determine the effect of failure
(c) Manufacturing of different parts
(d) a & b

Q.7 Which one is not a type of FMECA?
(a) System (b) Design
(c) Process (d) Manufacture

Q.8 For a risk priority number of 100 obtained in a FMECA study if rank of occurrence of defect is 1, what are the values for the severity of the defect and detect ion of defect?
(a) 100 & 100 (b) 10 & 10
(c) 25 & 4 (d) 50 & 2

Q.9 The useful period is also known an
(a) Downtime (b) Middle time
(c) Uptime (d) Total time

Q.10 The 'bath-tub' curve indicates failure probability. Which stage is NOT normally associated with the bathtub curve?
(a) Pulling the plug' where production is halted due to unacceptable level of failures
(b) Normal-life' where few failures occur
(c) 'wear-out' where failure increases due to age
(d) Infant-mortality' where failures occur early

Q.11 FMECA provide a checklist procedure. Which of the following questions is NOT likely to feature on the checklist?
(a) How likely is such a failure to be detected before it affects the customer?
(b) What is the likelihood that failure will occur?
(c) What would the consequences of the failure be?
(d) What would be the cost of avoiding failure be?

Q.12 Which one of the following is a type of machinery maintenance techniques?
(a) Preventive maintenance
(b) Predictive maintenance
(c) Reactive maintenance
(d) All of the above

CONVENTIONAL BRAIN TEASERS

Q.1 A machine is to be designed to have a minimum reliability of 0.92 and minimum availability of 0.95 over a period of 10000 hours.

Calculate the following:

1. Mean time to repair.
2. Probability that machine will fail after 15000 hours.

Solution:

Given : time, t = 10000 hours, Reliability, R = 0.92, Availability, A = 0.95

We know that,
$$R = e^{-\lambda t}$$
$$0.92 = e^{-\lambda \times 10000}$$
$$\therefore \quad \text{Failure rate, } \lambda = 8.33 \times 10^{-6} \text{ per hour}$$

Mean time between failure,
$$\text{MTBF} = \frac{1}{\lambda} = \frac{1}{8.33 \times 10^{-6}}$$
$$\text{MTBF} = 120048 \text{ hours}$$
$$\text{Availability, } A = \frac{MTBF}{MTBF + MTTR}$$
$$0.95 = \frac{120048}{120048 + MTTR}$$

or
$$0.95 \times 120048 + 0.95\, MTTR = 120048$$
$$\therefore \quad MTTR = 6318.31 \text{ hours}$$

Reliability that machine will run for 15000 hours
$$R = e^{-\lambda(t)} = e^{-8.33 \times 10^{-6} \times 15000}$$
$$R = 0.88$$

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Vibration Monitoring, Fault Detection and Signature Analysis

CHAPTER

11

11.1 VIBRATION MONITORING

In a majority of the rotating machinery, vibration monitoring is preferred. This is due to the fact that every dynamic machine component will manifest itself in the measured vibration response of the machine at its characteristic frequencies. Thus, for fault diagnosis, this provides an important and easy methodology to detect faults in operating machines by signal analysis of the measured vibrations from the machines. Machines consist of rotating shafts supported on bearings, perhaps carrying a gear or a pulley, and connected to another similar machine through a mechanical coupling. The general configuration of a machine in any industry consists of a prime mover, usually an electric motor or sometimes an internal combustion engine, driving a mechanical unit like a fan, blower, pump, compressor, or a gearbox.

11.1.1 Principles of Vibration Monitoring

In order to detect faults in machines by vibration monitoring, the vibration from the machine needs to be measured and then the vibration signal is processed to obtain, meaningful information regarding the machine's health condition. The vibrations should be measured close to the bearings supporting the rotating shafts. Wherever possible, the vibrations at any location should be measured in three mutually perpendicular directions. Simultaneous measurement of the vibration in three directions can be done using a triaxial accelerometer. It is always desirable to record the rotating speed of the shafts at the instant that vibration measurements are done, because all the predominant frequencies in the vibration spectra are related to the rotating speeds of the shaft. An in-situ field calibration of all the transducers is recommended. The machine conditions and parameters, like its rated power, load conditions, special features, and foundation type should also be recorded. With a handheld portable fast Fourier transform (FFT) analyzer, the vibration spectra can be obtained at the machine site. For diagnostic purposes, when a few more signal processing techniques need to be applied on the vibration signal, it is recommended that the vibration data be recorded in a suitable recorder along with a sketch of the transducer location and its sensitivity, and type. While recording vibration data in the field, it is a good practice to also record the calibration signal as applied to the transducers, so that later on when the data is analyzed in a computer after an analog-to-digital conversion, the user gets an idea of the amplitude of the mechanical parameter on which the corresponding signal voltage level is obtained.

11.2 FAULT DETECTION : INTRODUCTION

Machine fault problems are broad sources of the high maintenance cost and unwanted downtime across the industries or organisation. The prime objective of maintenance department is to keep machines and plant equipment's in good operating condition that prevents failure and production loss. If the department organizes a predictive maintenance program, this goal as the well as cost benefits can be achieved, while accurate information at the right time is a crucial aspect of a maintenance department. The condition-based maintenance strategy is being employed for uninterrupted production process in industries. Condition-based maintenance (CBM) consists of continuously evaluating condition of a monitored machine and thereby successfully identifying the faults before catastrophic breakdown occurs. Numerous condition monitoring and diagnostics methodologies are utilized to identify the machine faults to take corrective action. Machine fault identification can be done with different types of methodologies as vibration signature analysis, lubricant signature analysis, noise signature analysis, and temperature monitoring, with the use of appropriate sensors, different signal conditioning, and analyzing instruments.

NOTE : Vibration signature analysis techniques for machine fault identification are the most popular among other techniques. Vibration monitoring is based on the principle that all the system produces vibration.

When a machine is operating properly, the vibration is small and constant, however, when fault develops and some of the dynamic process in the machine changes, there will be changes in vibration spectra observed. After the review of previous work, it is concluded that gear fault, bearing fault, and coupling fault are studied to fault signature analysis. The majority of industrial machines use ball or rolling bearings elements (REB). The vibration signals obtained from the vicinity of a bearing assembly contain rich information about the bearing condition. Most of the inventors have used vibration signature analysis techniques for rolling element bearing fault identification in case of single defect on bearing components. Time-domain and frequency-domain vibration analysis techniques were tested but the effective identification of bearing condition is, however, not so straightforward. Several engineers have used artificial intelligence techniques as well as time-frequency domain analysis and developed expert diagnostics system for bearing fault identification with the use of artificial neural network, fuzzy logic, wavelet transform, and hybrid techniques.

11.2.1 Necessity of machine fault Identification

- Machine fault can be defined as any change in a machinery part which makes it unable to perform its function satisfactorily or it can be defined as termination of availability of an item to perform its intended function. The familiar stages before the final fault are incipient fault, distress, deterioration, and damage, all of them eventually make part or component unreliable or unsafe for the continued use.

  Classification of failure causes are as follows:
  (i) inherent weakness in material, design, and manufacturing
  (ii) misuse or applying stress in the undesired direction
  (iii) gradual deterioration due to wear, tear, stress fatigue, corrosion, and so forth.
- Anti-friction bearings failure is a major factor in failure of rotating machinery. Anti-friction bearing defects may be categorized as localized and distributed. The localized defects include the cracks, pits, and spalls caused by fatigue on rolling surfaces. The distributed defect includes surface roughness, waviness, misaligned races, and off-size rolling elements. These defects may result from manufacturing and abrasive wear.
- Modern manufacturing plants are highly complex. Failure of process equipments and instrumentation increased the operating costs and resulted in loss of the production. Undetected or uncorrected malfunctions can induce failures in related equipments and, in extreme cases, can lead to catastrophic accidents. Early fault detection in machines can save millions of rupees on emergency maintenance and production-loss cost. Gearbox and bearings are essential parts of many machineries. The early detection of defects, therefore, is crucial for the prevention of damage and secondary damage to other parts of a machine or even a total failure of the associated large system can be triggered.