Chapter 6: Reliability Engineering

Repeated Questions:

1. Reliability Concepts:

- **Q.** Define Reliability. / What is reliability and failure? / Explain importance of reliability engineering. **(SUMMER 2023, 3 Marks OR; WINTER 2024, 3 Marks OR; WINTER 2024, 3 Marks; SUMMER 2026, 4 Marks – "Explain concept of Reliability with suitable example")**

Answer:

Definition:

Reliability is the probability that an item will perform its intended function without failure for a specified period of time under stated operating conditions.

- **Failure:** The inability of an item to perform its required function.

Importance of Reliability Engineering:

Ensures customer satisfaction and safety.

Reduces warranty and maintenance costs.

Improves product reputation and competitiveness.

Supports design for robustness and long life.

Enables risk assessment and failure prevention.

- **Formula:** $R(t)=e^{-\lambda t}$ (for constant failure rate)

- **Q.** Draw and explain the Bath-tub Curve. **(SUMMER 2022, 4 Marks OR; SUMMER 2025, 7 Marks; WINTER 2025, 7 Marks – "Explain the bathtub curve in terms of reliability.")**

Answer:

Diagram Description: A curve with three distinct regions: a decreasing failure rate region on the left (infant mortality), a constant low failure rate region in the middle (useful life), and an increasing failure rate region on the right (wear-out). The horizontal axis is time, and the vertical axis is failure rate (hazard rate).

Explanation:

Region	Name	Failure Rate	Cause	Action
1	Infant Mortality	Decreasing	Manufacturing defects, poor quality control	Burn-in, quality screening
2	Useful Life	Constant (low)	Random failures	Preventive maintenance, redundancy
3	Wear-out	Increasing	Aging, fatigue, wear	Replacement, overhaul

- **Infant mortality:** Early failures due to defects; eliminated by burn-in testing.
- **Useful life:** Random failures occur at a constant rate; reliability models use exponential distribution.
- **Wear-out:** Failures increase as components age; preventive replacement is effective.

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2. Reliability Measures and Life Dispersion:

- **Q.** Define and Compare: MTTF, MTBF, MTTR. / Explain their significance. **(SUMMER 2022, 3 Marks; WINTER 2023, 4 Marks; WINTER 2024, 7 Marks OR)**

Answer:

Measure	Definition	Formula	Significance
MTTF (Mean Time To Failure)	Average time to failure for non-repairable items	MTTF=1/λ	Measures reliability of non-repairable components
MTBF (Mean Time Between Failures)	Average time between failures for repairable items	MTBF=Total operating time/Number of failures	Measures reliability of repairable systems
MTTR (Mean Time To Repair)	Average time to repair a failed item	MTTR=Total repair time/Number of repairs	Measures maintainability

Significance:

MTTF is used for components that are not repaired (e.g., bulbs, bearings).

MTBF is used for systems that are repaired and returned to service.

MTTR indicates how quickly a system can be restored; lower MTTR means higher availability.

- **Relationship:** Availability=MTBF/(MTBF+MTTR)

- **Q.** Define: Skewness and Kurtosis of life dispersion. **(SUMMER 2023, 4 Marks OR; WINTER 2025, 3 Marks)**

Answer:

Skewness:

A measure of asymmetry of the life distribution.

- **Positive skew:** tail extends to the right (early failures less likely).
- **Negative skew:** tail extends to the left (early failures more likely).
- **Formula:** Skewness=$E[(X-\mu)^3]/\sigma^3$

Kurtosis:

A measure of peakedness or tail heaviness of the life distribution.

- **High kurtosis:** heavy tails, more outliers.
- **Low kurtosis:** light tails, fewer outliers.
- **Formula:** Kurtosis=$E[(X-\mu)^4]/\sigma^4$
- **Significance:** They describe the shape of failure time distributions beyond mean and variance.

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3. Maintainability, Availability and System Models:

- **Q.** Define Maintainability and Availability and compare with Reliability. **(WINTER 2023, 3 Marks; SUMMER 2025, 7 Marks OR; WINTER 2025, 7 Marks – "Define Maintainability and availability and compare it with reliability.")**

Answer:

Aspect	Reliability	Maintainability	Availability
Definition	Probability of performing without failure for a given time	Probability of restoring to working condition within a given time	Probability that an item is operational at a given time
Focus	Failure prevention	Repair speed and ease	Uptime
Measure	MTBF, MTTF	MTTR	A=MTBF/(MTBF+MTTR)
Design Aspect	Design for reliability	Design for maintainability	Combination of both

Comparison with Reliability:

Reliability is about how long a system works without failing.

Maintainability is about how quickly it can be repaired after failure.

Availability is about how often the system is available for use, combining reliability and maintainability.

- **Q.** What are the types of System reliability models? Discuss with examples. **(SUMMER 2025, 7 Marks; WINTER 2025, 7 Marks)**

Answer:

Types of System Reliability Models:

Series Model:

All components must function for the system to function.

- **System reliability:** $R_s=R_1\times R_2\times\cdots\times R_n$
- **Example:** A chain with links in series.

Parallel Model (Active Redundancy):

System functions if at least one component functions.

- **System reliability:** $R_s=1-(1-R_1)(1-R_2)\cdots(1-R_n)$
- **Example:** Two pumps running in parallel.

Standby Redundancy Model:

One component operates while others are on standby.

- **Example:** Backup generator that starts when main power fails.

k-out-of-n Model:

System functions if at least k out of n components function.

- **Example:** Aircraft with 4 engines needing at least 2 to fly.
- **Example Calculation (Series):** Two components with $R_1=0.9$, $R_2=0.8 \rightarrow R_s=0.9\times0.8=0.72$.

Other Important Questions:

1. Types and Parameters of Reliability:

- **Q.** Discuss evolution of reliability over product life cycle. **(SUMMER 2023, 7 Marks OR)**

Answer:

Phases of Product Life Cycle and Reliability:

Design Phase:

Reliability is designed into the product through part selection, derating, redundancy, and FMEA.

- **Goal:** Achieve inherent reliability.

Prototype/Development Phase:

Reliability testing, environmental testing, and failure analysis.

- **Goal:** Validate and improve design reliability.

Manufacturing Phase:

Process control, quality assurance, and burn-in testing.

- **Goal:** Ensure manufactured reliability matches design reliability.

Useful Life Phase:

Field reliability monitoring, warranty data analysis, and preventive maintenance.

- **Goal:** Maintain reliability and reduce failures.

Wear-out Phase:

Scheduled replacement, overhaul, and retirement decisions.

- **Goal:** Manage increasing failure rates.
- **Key Point:** Reliability is not constant; it changes from design to wear-out, and each phase requires different reliability activities.

- **Q.** Enlist types of Reliability and explain any three. **(WINTER 2023, 3 Marks OR)**

Answer:

Types of Reliability:

Inherent Reliability — designed-in reliability.

Achieved Reliability — reliability after manufacturing.

Field Reliability — reliability observed in actual use.

Operational Reliability — reliability under specified operating conditions.

Design Reliability — reliability predicted from design analysis.

Explanation of Three:

- **Inherent Reliability:** Built into the product through design; maximum possible reliability.
- **Achieved Reliability:** Actual reliability after production; affected by manufacturing quality.
- **Field Reliability:** Performance in real-world conditions; affected by usage, environment, and maintenance.

- **Q.** Explain field reliability. **(WINTER 2024, 4 Marks OR)**

Answer:

- **Definition:** Field Reliability is the reliability observed when a product is used by customers in actual field conditions, including environmental, operational, and usage variations.

Characteristics:

Measured from field failure data, warranty claims, and service records.

Often lower than inherent or achieved reliability due to harsh conditions and misuse.

Used to validate design and manufacturing reliability.

- **Factors Affecting Field Reliability:** Environment (temperature, humidity), user behavior, maintenance practices, and installation quality.
- **Importance:** Provides true measure of customer satisfaction and guides product improvement.

- **Q.** What are the Reliability Parameters? **(WINTER 2025, 4 Marks)**

Answer:

Reliability Parameters:

- **Failure Rate (λ):** Number of failures per unit time.
- **MTTF:** Mean time to failure for non-repairable items.
- **MTBF:** Mean time between failures for repairable items.
- **MTTR:** Mean time to repair.
- **Reliability Function R(t):** Probability of survival up to time t.
- **Availability (A):** Probability that the system is operational.
- **Hazard Rate h(t):** Instantaneous failure rate at time t.
- **Cumulative Distribution Function F(t):** Probability of failure by time t.

- **Q.** Elaborate design Reliability and Inherent Reliability. **(SUMMER 2026, 4 Marks)**

Answer:

Design Reliability:

Reliability predicted from design analysis and component data.

Includes stress analysis, derating, redundancy, and FMEA.

- **Goal:** Ensure the design meets reliability targets.

Inherent Reliability:

The maximum reliability that a product can achieve by virtue of its design.

Determined by part selection, tolerances, and design margins.

Cannot be improved by manufacturing or maintenance; only by redesign.

- **Comparison:** Design reliability is the process; inherent reliability is the result built into the product.

- **Q.** Describe Failure Mechanism and failure severity. **(SUMMER 2026, 7 Marks)**

Answer:

Failure Mechanism:

The physical or chemical process that leads to failure.

- **Examples:** Fatigue, corrosion, wear, fracture, overheating, electrical breakdown.

Understanding mechanisms helps in preventing failures through design and material selection.

Failure Severity:

The degree of impact of a failure on the system, safety, and customer.

Rated in FMEA on a scale of 1–10.

- **Categories:** Catastrophic, Critical, Marginal, Minor.

Failure Severity Assessment:

Severity Level	Description	Example
Catastrophic	Safety hazard, total system loss	Brake failure in car
Critical	Major function loss	Engine failure
Marginal	Degraded performance	Minor leak
Minor	Cosmetic or nuisance	Paint defect

- **Relationship:** Failure mechanism determines the failure mode; severity assesses the consequence. Together they guide reliability improvement priorities.

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2. Reliability Functions and Models:

- **Q.** Derive equation for hazard rate function using reliability, probability density function and cumulative distribution function. **(WINTER 2023, 4 Marks OR)**

Answer:

Steps:

Definitions:

$R(t)$ = reliability function = $P(T>t)$

$F(t)$ = cumulative distribution function = $P(T \leq t)=1-R(t)$

$f(t)$ = probability density function = $dF(t)/dt = -dR(t)/dt$

Hazard rate definition:

$h(t)=f(t)/R(t)$

Substitute f(t):

$h(t)=-[dR(t)/dt]/R(t)$

Integrate both sides:

$\int_0^t h(u)du=-\ln R(t)$

Solve for R(t):

$R(t)=e^{-\int_0^t h(u)du}$

For constant hazard rate h(t)=λ:

$R(t)=e^{-\lambda t}$

- **Final Result:** $h(t)=f(t)/R(t)=f(t)/(1-F(t))$

- **Q.** Define cumulative function and reliability function. **(SUMMER 2026, 3 Marks)**

Answer:

Cumulative Distribution Function (CDF), F(t):

Probability that failure occurs by time t.

$F(t)=P(T \leq t)$

$F(t)=1-R(t)$

Reliability Function, R(t):

Probability that the item survives beyond time t.

$R(t)=P(T>t)=1-F(t)$

- **For constant failure rate:** $R(t)=e^{-\lambda t}$

- **Q.** What is inspection and repair availability model? Explain a case for it. **(WINTER 2023, 7 Marks)**

Answer:

Inspection and Repair Availability Model:

A system model that considers periodic inspection and repair to maintain availability.

Availability depends on inspection frequency, repair time, and failure detection.

Model:

System is inspected at intervals of T.

Failures are detected only at inspection.

Repair time is τ.

Availability A=T/(T+τ) (simplified model).

Case Example:

A standby safety system (e.g., fire pump) is tested monthly.

If a failure occurs between tests, it remains undetected until the next inspection.

Availability is determined by test interval and repair time.

Shorter inspection intervals increase availability but increase testing cost.

- **Application:** Safety systems, emergency equipment, and redundant systems where failures are hidden.

- **Q.** Write short note on Reliability repairable system. **(SUMMER 2026, 7 Marks)**

Answer:

- **Definition:** A repairable system is one that can be restored to working condition after failure through repair or replacement of failed components.

Key Measures:

- **MTBF (Mean Time Between Failures):** Average time between failures.
- **MTTR (Mean Time to Repair):** Average repair time.
- **Availability:** A=MTBF/(MTBF+MTTR)

Characteristics:

Failures occur over time; system is repaired and returned to service.

Reliability is measured by failure rate; maintainability by repair rate.

Availability is the key performance measure.

Models:

Markov models for repairable systems.

Renewal theory for failure and repair processes.

- **Examples:** Automobiles, aircraft engines, industrial machines, computers.
- **Importance:** Repairable systems dominate real-world applications; availability and maintainability are as important as reliability.

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3. Reliability Numericals:

- **Q.** A pump motor exhibiting a constant hazard rate has a reliability of 90 per cent from operating time of 1000 hrs. (i) What is the average failure rate of the pump motor? (ii) What is MTBF? (iii)

What is the reliability of the item for an operating time of 2000 hours? and for 4000 hours? (iv) Corresponding to a reliability of 0.5, what is the operating time? **(SUMMER 2022)**

Answer:

Given:

- **Reliability at t=1000 hrs:** R(1000)=0.90

  Constant hazard rate (exponential distribution)

To Find:

(i) Failure rate λ

(ii) MTBF

(iii) R(2000) and R(4000)

(iv) Time t for R(t)=0.5

Formula:

$R(t)=e^{-\lambda t}$

$\lambda=-\ln R(t)/t$

$MTBF=1/\lambda$

Solution:

(i) Failure rate:

$\lambda=-\ln(0.90)/1000=-(-0.10536)/1000=1.0536\times10^{-4}$ failures/hr

(ii) MTBF:

$MTBF=1/\lambda=1/(1.0536\times10^{-4})=9491$ hrs

(iii) Reliability at 2000 hrs:

$R(2000)=e^{-1.0536\times10^{-4}\times2000}=e^{-0.21072}=0.810$

Reliability at 4000 hrs:

$R(4000)=e^{-1.0536\times10^{-4}\times4000}=e^{-0.42144}=0.656$

(iv) Time for R = 0.5:

$0.5=e^{-\lambda t}\Rightarrow\ln(0.5)=-\lambda t$

$t=-\ln(0.5)/\lambda=0.6931/(1.0536\times10^{-4})=6578$ hrs

Final Answer:

(i) $\lambda=1.0536\times10^{-4}$ failures/hr

(ii) MTBF = 9491 hrs

(iii) R(2000)=0.810, R(4000)=0.656

(iv) t=6578 hrs for R=0.5

- **Q.** Reliability block diagram problem for a thermal power plant. [Diagram required – refer to the original question paper] **(SUMMER 2022 OR)**

Answer:

- **Note:** Since the original diagram is not provided, the general solution method is given below.

General Approach for Reliability Block Diagram (RBD):

Identify series and parallel paths in the block diagram.

- **For series components:** $R_s=R_1\times R_2\times\cdots\times R_n$
- **For parallel components:** $R_p=1-(1-R_1)(1-R_2)\cdots(1-R_n)$

  Reduce the diagram step by step from innermost parallel/series blocks to a single equivalent reliability.

  Calculate final system reliability using given component reliabilities.

- **Example:** If a thermal power plant has a boiler (R=0.95), turbine (R=0.90), and generator (R=0.92) in series, system reliability R_s=0.95×0.90×0.92=0.7866.
- **Final Answer:** Depends on the specific diagram; use series/parallel reduction.

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