PI 21.03

PROCESS SYSTEMS

OBJECTIVES

3.1 Define and give examples of a process system in an NGS.

3.2 Define [or illustrate using a diagram for a) to c)], as related to the lifetime of a device:

- a) Infant mortality/burn in period
- b) Useful life
- c) Wear out region
- d) Mean time to failure

3.3 State and graphically illustrate the General Reliability Function.

3.4 Define and give an example of a Type A process system failure.

COURSE NOTES

Nuclear Plant systems can be classified into two major categories - Process Systems, which we will be discussing in this module and Safety Systems, which are those systems which are usually in a standby mode ready to act in the event of an emergency.

Process Systems

Process systems are active in the normal functioning of the plant, i.e., all the systems involved in the "process" of converting fission heat to electrical energy. Some examples are:

The Heat Transport System
Steam and Feedwater Systems
Turbine Lube Oil System
Heat Transport Pressure Control System
Reactor Regulating System

As an analogy, if you were driving down the road in your car, the systems associated with keeping the car running would all be process systems. These would include, the fuel pump, the distributor, the steering mechanism and the drive shaft. Systems that wouldn't be process systems would be things like the hand brake and the horn.

Since process systems are normally active, that is to say operating, it is relatively easy to determine that they have failed. If the Heat Transport pump motors decided to stop or the steering mechanism in your car failed, it would be quite noticeable. In this module, we will be looking at the reliability of process systems because as you can see if the process systems work well, there is less dependence on the Safety Systems.

EXERCISES

1. Give three examples of Process Systems.

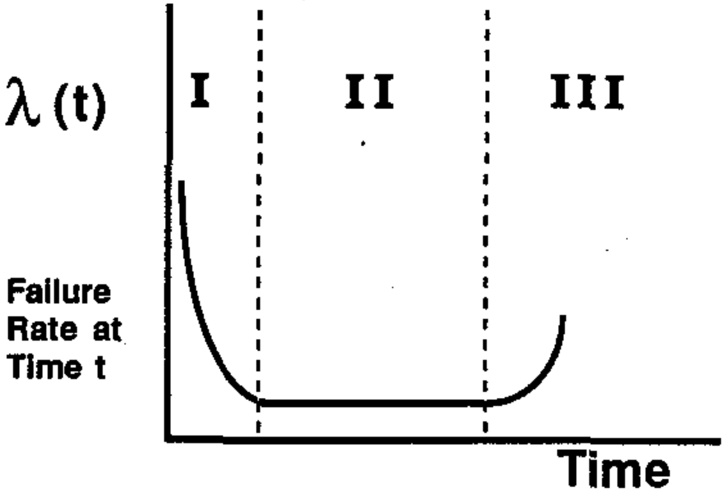
a) ______________________________

b) ______________________________

c) ______________________________

Variation of Equipment Failure Rate With Time

The **Failure Rate** (λ), as applied to process equipment, is defined as the number of failures per unit time (e.g., 5 failures per year). **Failure rate normally varies with time in service in a typical manner as shown in the Bathtub Curve which is shown below.** Its name comes **from its characteristic shape.**



The curve is divided into three regions which are as follows:

I - **Burn In or Infant Mortality Period**

Failures due to manufacturing defects are most common early in equipment service life resulting in an initially high failure which decreases as time in service increases. You probably recognize this phenomenon as the "Getting the bugs worked out" part of the life cycle of a new car. It's always a good idea to ensure your warranty covers this stage.

II - **Useful Life Period**

After the manufacturing defects stage, the failure rate drops to it's minimum level and remains fairly constant. The failures that do occur during this stage are random in nature. If possible, we would like to operate all our equipment during this portion of it's service life. The failure rate is low and being constant makes it easier to predict failures.

III - **Wear Out Period**

As the component gets older, parts wear out and the failure rate goes up.

From this discussion, you can see that it would be advantageous if we could always operate during the useful life phase. This brings us to the golden rule of reliability which states:

> *Replace components as they fail within their useful lives and replace components preventatively, even if they haven't failed, no later than by the end of their useful lives.*

For an individual component, this means that we test it to detect any manufacturing defects prior to putting it into service. If it fails we replace it and as we approach the wear out region where we know the failure rate will increase, we should replace it. (Note that when we say replace, it may mean that we just replace those parts which fail or have worn out. It is not necessary to replace an entire piece of equipment simply because one part has failed or is worn out.) This philosophy manifests itself in our preventative maintenance programs. For example, during a turbine outage, many components are checked and replaced even if they haven't failed yet, simply because it is detrimental to station reliability to leave components in service which are approaching or are in the wear out period of their service life.

EXERCISES

2. In certain locations where the fluorescent light fixtures are located high off the ground and are rather inaccessible, there are programs in place that require someone to change the fluorescent tubes on a regular basis. This is done whether or not the tube has actually burnt out. Why is such a program in place?

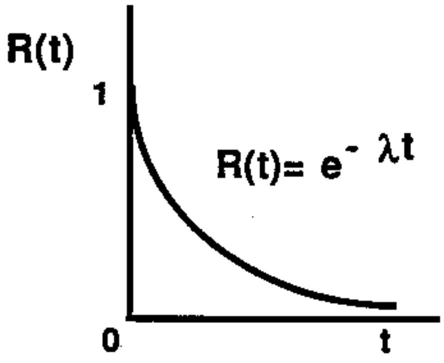
While the bathtub curve shows failure rate with respect to time, the reliability of the component (that is, the probability of it surviving to time t) is given by the general reliability function which is:

For operation in the useful life region, where the failure rate is constant,

$$R(t) = e^{-\int_0^t \lambda(t)\,dt}$$

the equation simplifies to:

$$R(t) = e^{-\lambda \int_0^t dt}$$
$$= e^{-\lambda t}$$



This function describes the reliability of a component for a mission time, t, after it is put into service. So, although up to now we have used examples where the numerical value of the reliability is given, in actual fact it is calculated from historical data. This data is usually in the form of an expression call Mean Time to Failure (MTTF)*.

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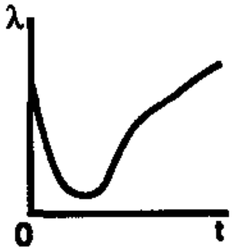
* MTTF is often confused with MTBF (Mean Time Between Failures). When something is repairable, the time between failures is the time to failure plus the time to repair (i.e., MTTF = MTBF + MTTR). If the repair time is small when compared to the time to failure, then the MTTF is approximately equal to the MTBF.

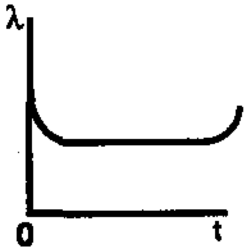
The definition of MTTF is given as: The average time a component would operate under useful life conditions, before failing. The units are in time per failure. To convert this to something we can use, take the reciprocal which gives us failure per time which as you know is the failure rate.

$$\text{MTTF} = \frac{1}{\lambda}$$

Given a MTTF, you can now calculate a failure rate. If you know how long the equipment has been in service, you can then calculate the reliability using the equation given.

Note that the MTTF is defined for operation in the useful life period of the bathtub curve where the failure rate is constant. There is no mathematical relationship between the length of the useful life period and the MTTF. In practical terms, this means that if you see a manufacturer's claim that its product has a MTTF of 10,000 hours, it doesn't mean that it will have a long useful life. All it tells you is that during the useful life period, the failure rate is low. The following bathtub curves show how it is possible to have a long useful life with a short MTTF and vice versa.





The curve on the left illustrates a short useful life but a long MTTF (since the failure rate during the useful life region is small, the reciprocal, which is the MTTF, is large). On the right, we have the opposite scenario where there is a long useful life but a short MTTF.

Some examples which may help in understanding this idea are people and tires. First the people - for a human in the prime of life, the failure rate may be in the order of 10^{-3}, corresponding to a MTTF of 1000 years. This would mean that people would live an average of 1000 years if they could "operate" continuously under "useful life" conditions. In reality, of course, an individual enters the "wear out region" long before the 1000 years are up and failure then is due to aging rather than random statistical failure (accidents, disease, etc.) characteristic of prime life operation.

Now the tires - for your average car tires, the useful life failure rate might be in the order of 2.5×10^{-6} per km, corresponding to a MTTF of 400,000 km. In reality, of course, the tire goes bald due to wear rather than due to the random statistical failures such as puncture and overheating.

As for people with spare tires around their middles, we don't have much data yet, but we're working on it.

EXAMPLE ONE

A component has an MTTF equal to 10,000 hours and a useful life of 1,000 hours. Find the reliability for a 10 hour mission time.

Solution

The equation for reliability is:

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

λ can be found from MTTF,

$$\lambda = \frac{1}{10,000} = 1 \times 10^{-4} \text{ h}^{-1}$$

So for a mission time of 10 hours,

$$R(10) = e^{-(1 \times 10^{-4})(10)}$$

$$= e^{-1 \times 10^{-3}}$$

$$= 0.9990$$

Process System Faults

In this module we've been discussing process system failures. Although most people think of safety systems when talking about reliability and public safety, environmental protection, worker safety, etc., it is important to note that, if we have very reliable process systems, then our safety systems don't need to operate as often. A rupture of the Primary Heat Transport System, which is a process system, can result in loss of cooling to the fuel and do a lot of damage if the safety systems aren't working. So you can see that a Process System fault can be very important.

To make it easier to document and analyze these faults, it is necessary to categorize them as to their severity - specifically in terms of how they affect fuel temperature. Since 99% of the radioactive fission products formed in our reactors is trapped inside the ceramic fuel pellet, it is of paramount importance that the fuel does not overheat and allow fission products to escape. The categories of process system failures are named from Type A, being the most serious, to Type E, the least serious, and are fully defined in station technical reports. The following definition of a Type A Process system fault is taken from the Bruce B Technical reports and is the same as that used at other nuclear stations.

"A Type A fault is one that raised fuel temperature and significant fuel failures would have occurred in the absence of action on the part of a safety system. The term "serious process failure" is synonymous with a Type A fault."

SUMMARY

In this module, the following topics have been discussed:

- Process Systems are those systems which are directly involved in the "process" of converting fission heat to electricity. Refer back to the notes for examples of these.
- The "bathtub" curve is a graphical illustration of how failure rate varies with time.
    - During Stage One (burn in period) of the curve, the failure rate is high but decreases with time. These failures are due to manufacturing defects.
    - During Stage Two (useful life period), the failure rate is low and constant. These failures are due to random failures.
    - During Stage Three (wear out period), the failure rate begins to increase again. These failures are due to wearing out of the component or fatigue.
- Mean Time To Failure is a common expression which arithmetically is equal to the reciprocal of the failure rate during the useful life period of a component's lifetime.
- The General Reliability Function simplifies to the form:

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

  where $R(t)$ gives the reliability of a component with a failure rate of λ for a mission time, t.
- Process system faults may be categorized depending on the severity of the resultant accident had there been no safety systems available. Type A failures are the most severe, in which significant fuel failures are possible.

ASSIGNMENT

1) Draw the "bathtub" curve and label each of the three stages.

2) For each stage labeled above, state the typical causes of failures in that region.

3) Define the term "Mean Time To Failure".

4) A Type A process failure is one which:

   a) Results in a rise in fuel temperature but no significant fuel failures

   b) Would have raised fuel temperature and caused significant fuel failures if special safety systems were not available

   c) Causes the unit to shutdown and remain out of service for greater than 40 hours

   d) Results in a release of radioactivity to the environment

   e) Would have resulted in injury or death to the public

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