Basic reliability course
Alexey Glazachev
duration: 1.5 hours
Version 1.5 November 16 2018

Objectives of this course:

This course describes the most important tasks related to the reliability analysis. After completing this course, you will:

- Learn what is the reliability of the system
- Learn what is the failure curve and its impact on reliability analysis
- Learn how to calculate the reliability of a system consisting from serial and parallel connections of elements
- Understand six key methods to improve system reliability
- Know about the reliability more than 97% of people

Reliability Value:

Due to low reliability occur technical catastrophes (air disaster, chemical plants explosion, gas pipeline break, nuclear accident). This leads to:

- loss of life
- great damage to the environment and human health
- economic damage worth millions and billions dollars/euro

Knowledge of reliability (the science of failures) will help make the world safer and better place

Introduction

Reliability is quality in time

The simplest and most understandable definition of what reliability is actually given in the title. Reliability is a property of an object to maintain quality in time. Quality means everything that satisfies the costumer needs. Reliability is the most important feature of any object, because it is always important for us - what we receive from our supplier should have high quality not only at the purchase time, but throughout the whole period when we use this object.

The task of reliability analysis

The concept of reliability

Reliability can be defined as the probability that a device or system will work successfully for a certain period of time, in accordance with a set of operating conditions. This definition has the following important consequences:

1. Reliability is a probability value, which means that it can be quantified and takes values between 0 and 1
2. In a more common way, reliability means the successful operation of the unit or system
3. Reliability always includes system / unit operating time
4. Reliability depends on operating conditions

The concept of reliability

One of the main difficulties during work with reliability is that reliability is a probability value ranging from 0 to 1. The difficulty is that our brain is weak-equipped to work with randomness and probability (N.N. Taleb - "Fooled by Randomness")

Compare two statements:

1. You have 10 fingers.
2. You have 10 fingers with a probability of 0.999

Which is more clear for you?

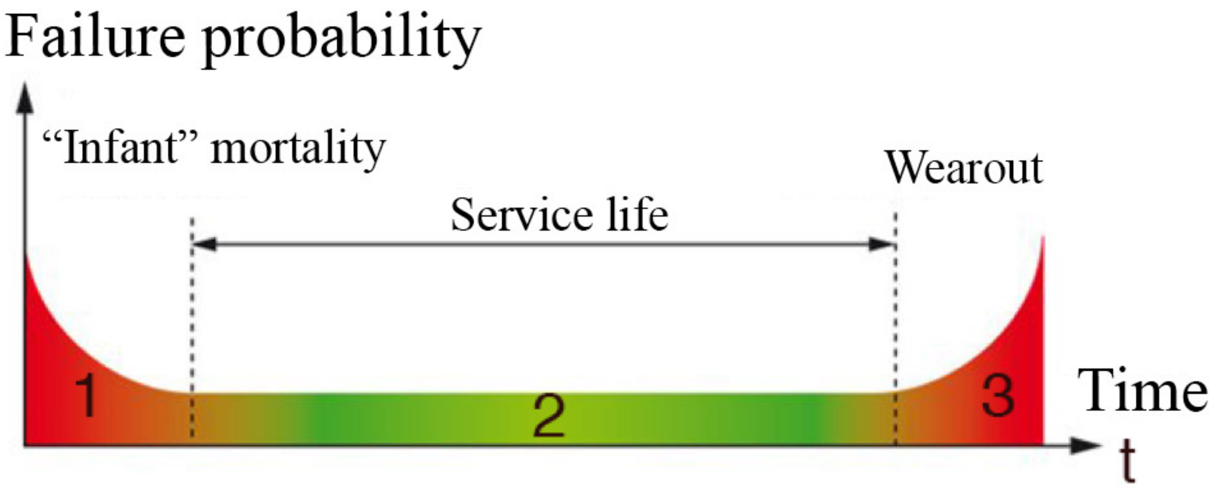
Tasks of reliability analysis

The reliability analysis includes 2 key tasks:

1. Obtaining and investigating the reliability function of a component or system

2. Searching for ways to improve the reliability of the system - desire to maximize system reliability, taking into account the limitations on cost, weight, size, energy consumption; or, conversely, an attempt to minimize cost, weight, size, energy consumption given a certain level of reliability. Now we briefly consider some elements of these problems.

Investigation of reliability



The reliability of the component changes over the component life. In particular, the reliability behavior is described by a failure (bathtub) curve, which shows the component failure rate as a function of time. On this curve, 3 areas of reliability behavior are distinguished depending on the time. (1) the period of run-in or "infant mortality", (2) the period of normal operation and (3) the wear-out period.

Investigation of reliability

Run-in (break-in) period. At this stage, there are many failures due to defects in the design or production. But since such defects are usually quickly eliminated, the failure rate also quickly decreases.

Consequence: the device that has worked for a while without failures is preferable to a completely new device that has not yet been in operation.

Investigation of reliability

Period of normal operation. After elimination of "childhood diseases", the failure rate stabilizes at approximately constant value. For many types of components (especially electronic components), the period of the normal operation can be quite long compared to other steps. The parameter of failure rate can be found in the handbooks just for this stage. Failures during this period are called random, since they tend to occur unpredictably.

Investigation of reliability

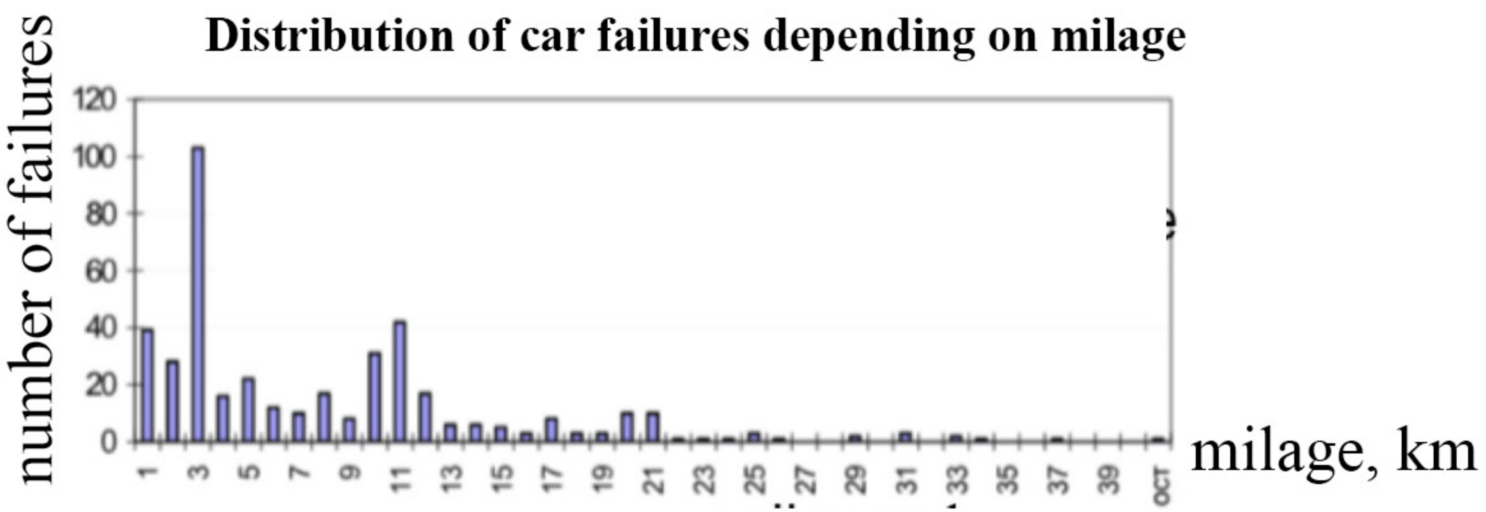
Wear-out period. At this stage, there is an increase in the frequency of failures. Device can continue to be used, but the cost of repairs can be economically incompatible compare to the creation of a new device. Gradually the device goes to the limit state.

Investigation of reliability

Lindy effect. The term was invented by N.N. Taleb. Lindy is a popular New York cafe that prides itself on its baking, but among mathematicians and physicists it is known as the place where a well-known thumb rule was invented. Actors - regulars of this cafe liked to gossip about colleagues and work, and found a regularity: Broadway shows that stayed on the scene for 100 days, often could expect for another same period on the stage (respectively, if the show was not finished for 200 days - then it was possible to give for show 200 more days of life, and so on).

This rule was called the Lindy effect.

Investigation of reliability



Sometimes equipment is also influenced by the Lindy effect. Think about it.

Test your knowledge

At what stage of the equipment operation there is approximately constant failure rate?

1. During the wear-out phase
2. During the run-in phase
3. At the stage of normal operation

Test your knowledge

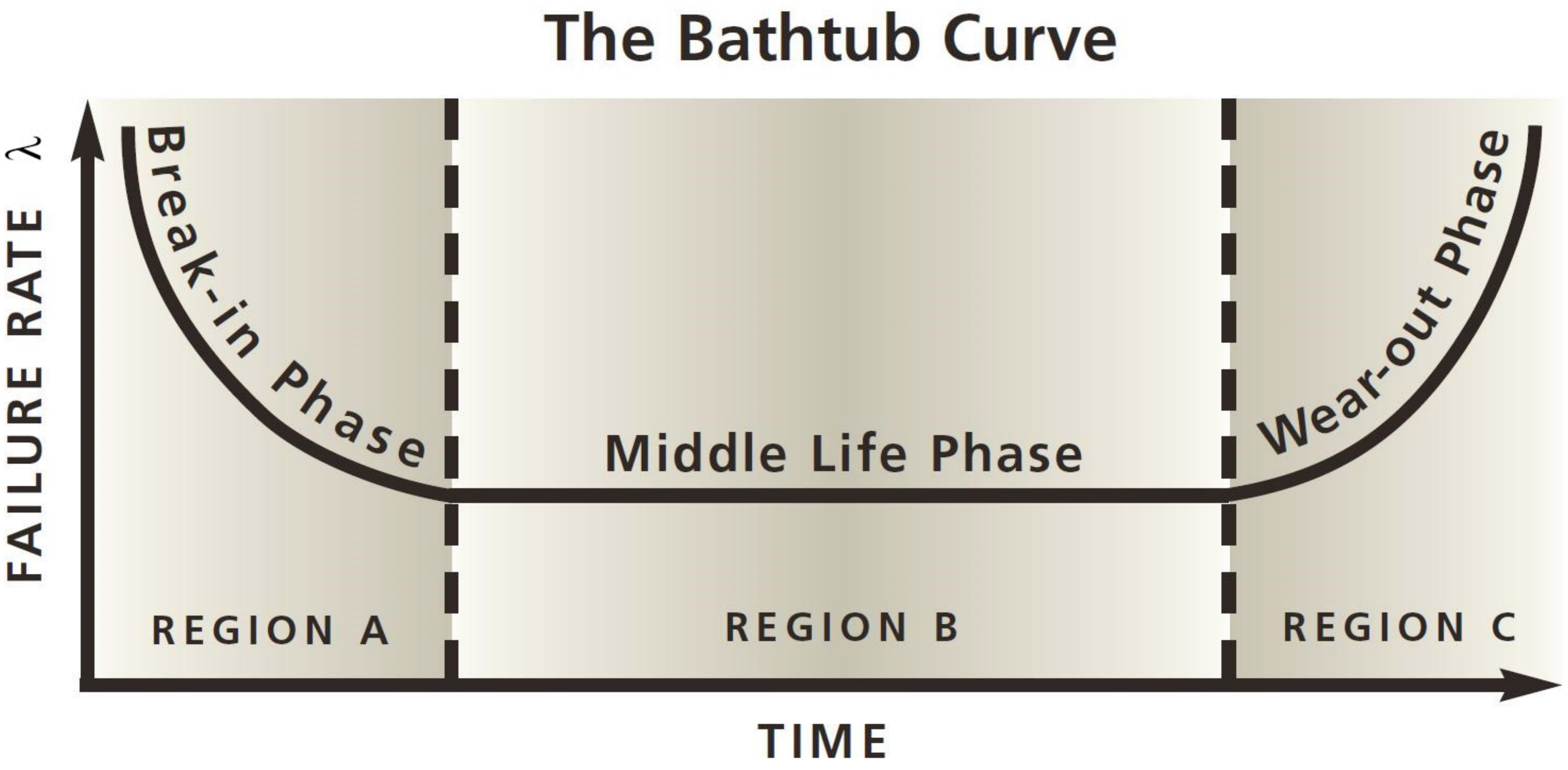
At what stage of the equipment operation there is approximately constant failure rate?

Correct answer:

1. At the stage of normal operation

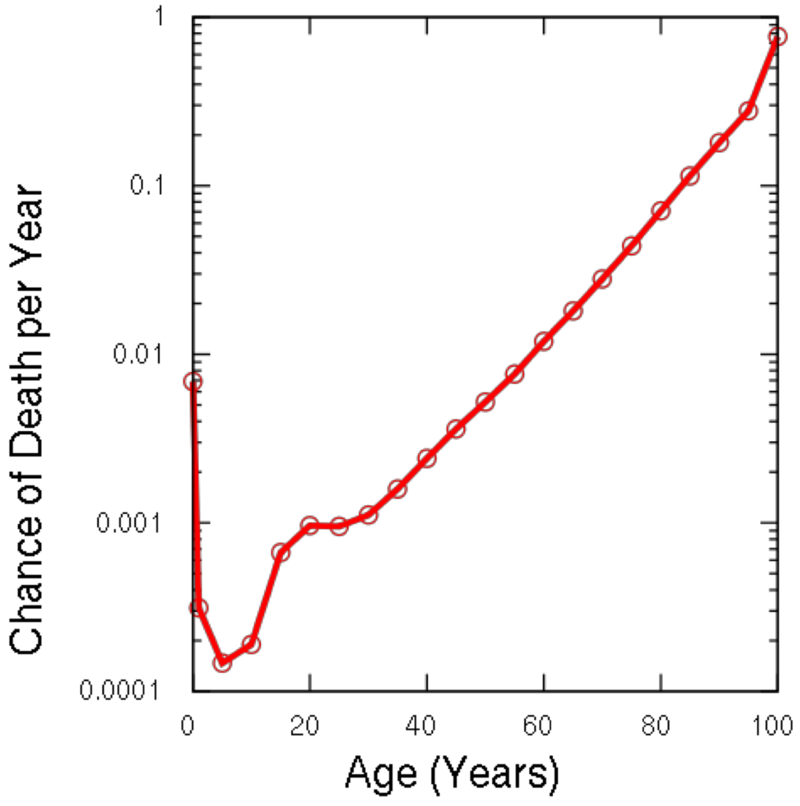
Investigation of reliability

The failure curve is very important from a practical point of view. For example, for some components it is important to determine the period of their run-in, so that by the time of its intended use, the run-in period has been completed and all the failed components have been replaced. Ideally, all components should only be used during the normal operation phase, with replacement before the wear period begins. Ideally, for each critical element, the failure curve must be carefully defined to know exactly when the transition from stage to stage will occur.



The Bathtub Curve
FAILURE RATE λ
Break-in Phase
Middle Life Phase
Wear-out Phase
REGION A
REGION B
REGION C
TIME

Investigation of reliability



It is interesting that the curve of human mortality is similar to the bathtub curve. Compare.

Investigation of reliability

Another important element in understanding the component's reliability function is the definition of the probability distribution function, which is closely related to the observed behavior of the component's reliability. One of the most widely used probability distributions in the reliability analysis is the Weibull distribution. This popularity in the reliability analysis is due to the fact that it can be used to model the reliability of a component in all sections of the failure curve, depending on which values the distribution parameters have. For a component in the normal operation phase, the Weibull distribution has a parameter equal to one, and is actually equivalent to an exponential distribution, which is easy and convenient for work.

Investigation of reliability

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

Basic reliability formula in exponential law

P (t) - is the probability of failure-free operation of the component during the operation time **t**

λ - is the failure rate

Investigation of reliability

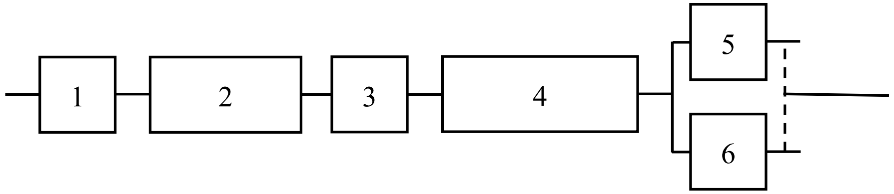
$$P(t) = e^{-\lambda t}$$

If you want to determine the probability of failure-free operation of a component, you need to know its operating time (in hours) and its failure rate λ.

For example, according to the "Reliability of Electro-Radio Products" reference book, the diode rectifier D233 has λ = 0.1 * 10-6 1 / h (failures per 1 mil hours)

Multicomponent system analysis of reliability

In most cases, reliability analysis is performed for systems consisting of many components. This section provides an overview of the analysis of some general types of multicomponent systems. In general, the components can be connected to each other in series (one after another) and in parallel.



Serial connection

Parallel connection

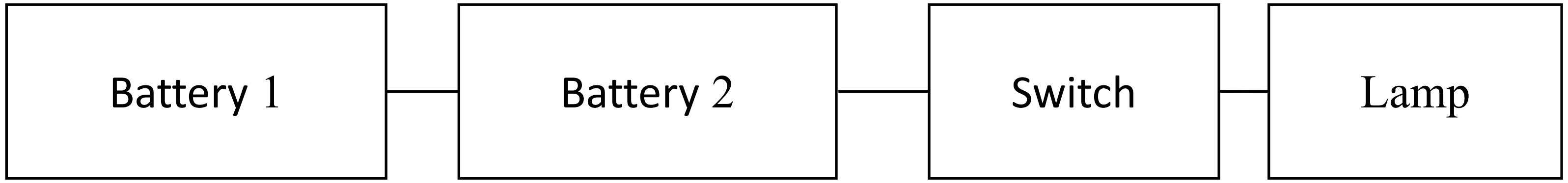
Serial connection

A serial connection in a reliability analysis is one in which the system works if all components work. A simple example of such a system is a flashlight. From the point of view of reliability analysis, the flashlight consists of the following four components:

C1: Battery
C2: Battery 2 (identical to C1 in reliability)
C3: Switch
C4: Lamp

Serial connection

In order to analyze the reliability of our system, we will compile a structural reliability diagram, on which the interrelationships of the elements will be seen.



Failure of any of these components results in the failure of the entire flashlight.

Serial connection

Suppose now that we know the reliability of each of the four components of the flashlight. Let P1, P2, P3 and P4 be the values of the probability of failure-free operation (reliability) of components C1, C2, C3 and C4, respectively. In particular, let P1 = 0.92 P2 = 0.92 P3 = 0.95 P4 = 0.99 (Note that the reliability is constant here, which means that either they are approximately independent of the running time or that they are reliable for a given operating time).

Serial connection

Example of calculating reliability in a serial connection

The reliability of a serial connection is equal to the product of the reliability of its elements.

For the flashlight system, described above, reliability is calculated as follows:

$$P_{system} = 0.92 * 0.92 * 0.95 * 0.99 = 0.796$$

Serial connection

Even if you use highly reliable components, but there are one unreliable element in the system - this will have a destructive effect on the reliability of the system.

Example of calculating reliability:

$P1 = 0.999999$ $P2 = 0.999999$ $P3 = 0.99$

$P_{system} = 0.999999*0.999999*0.99 = 0.989$

Serial connection

Lusser's law. In the 1940s Germany used V-2 rockets. Some failured, some not. The engineers decided to investigate the reasons. It turned out that reliability of a series system is equal to the product of the reliability of its component subsystems, if their failure modes are known to be independent. Lusser's law has been described as the idea that a series system is "weaker than its weakest link", as the product reliability of a series of components can be less than the lowest-value component.

Serial connection

Important consequences:

1. When the elements are connected in series, the reliability of the system can not be greater than the reliability of the most unreliable element.
2. The greater the number of elements in a serial connection, the lower the reliability. The more offices you need to go through, the higher the probability that your documents will lose ☺
3. A great, but not always possible, way to improve the reliability of the system is to make it simpler, to reduce the number of elements.

Serial connection

Another example, illustrating the dependence of the system reliability on the number of system components. Let all components have the same reliability, equal to 0.95.

If system consists of 10 components. $P_{system} = (0.95)^{10} = 0.59873$

If system consists of 20 components. $P_{system} = (0.95)^{20} = 0.385848$

Test your knowledge

How true is the statement:

"Analysis of reliability does not affect the design of the system and the choice of the final version of the system"

1. True
2. False

Test your knowledge

Correct answer:

False! Analysis of reliability affects how the system is designed!

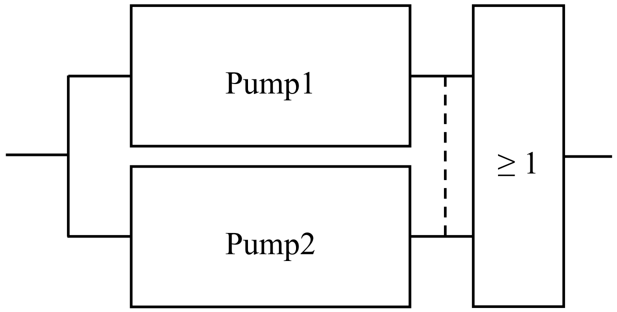
Parallel connection

Another simple type of multicomponent system is a system with parallel connection of elements. With this approach, the system functions if any of the individual components are functioning (there may be situations where for the functioning of a system of **n** components it is necessary that **k** components function, but in this course we will not consider them). Of course, the cost of the system increases, but this profits a much higher reliability.

Parallel connection

Example of parallel connection

≥ 1 means that for the normal functioning of the system it is necessary to have at least one element functioning. For the failure of the entire system, it is necessary that all elements fail.



Parallel connection

Example of calculating the reliability of a system with parallel connection:

Consider a parallel system of four components with component reliability
$P1 = 0.92$, $P2 = 0.92$, $P3 = 0.95$ and $P4 = 0.99$.

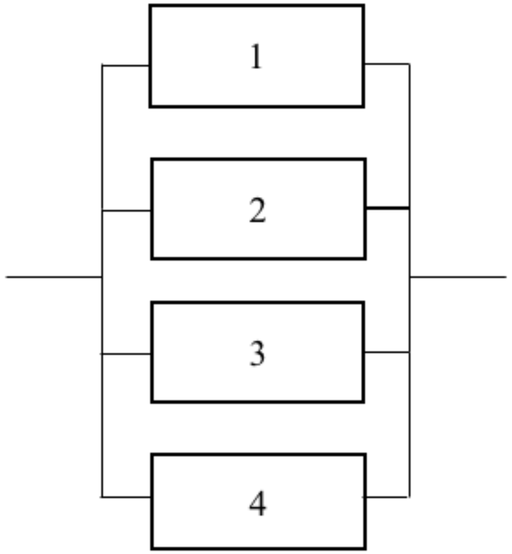
(Pay attention - we took the same values as for the example with a flashlight. Of course, it's quite difficult to create a flashlight in a parallel scheme). For the 4-component system defined above, the system will fail only if each component does not work.

Reliability of the whole system is determined by the formula:

$$P_{system} = 1 - [(1 - P1)*(1 - P2)*(1 - P3)*(1 - P4)]$$

Parallel connection

Let’s create a structural reliability diagram, on which we’ll see all interrelationships of the elements.



Parallel connection

Example of calculating the reliability of a system with parallel connection:

Consider a parallel system of four components with component reliability P1 = 0.92, P2 = 0.92, P3 = 0.95 and P4 = 0.99.

In our case:

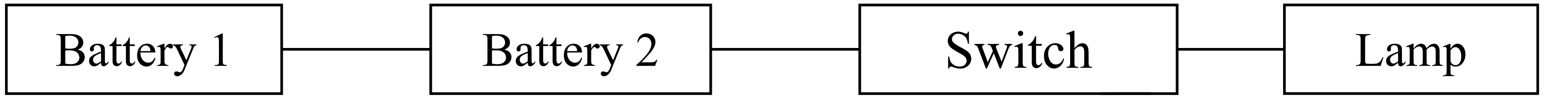
$$P_{system} = 1 - [(1 - 0.92)*(1 - 0.92)*(1 - 0.95)*(1 - 0.99)] = 0.999997$$

Compare it with what we got when calculating a serial connection: 0.796

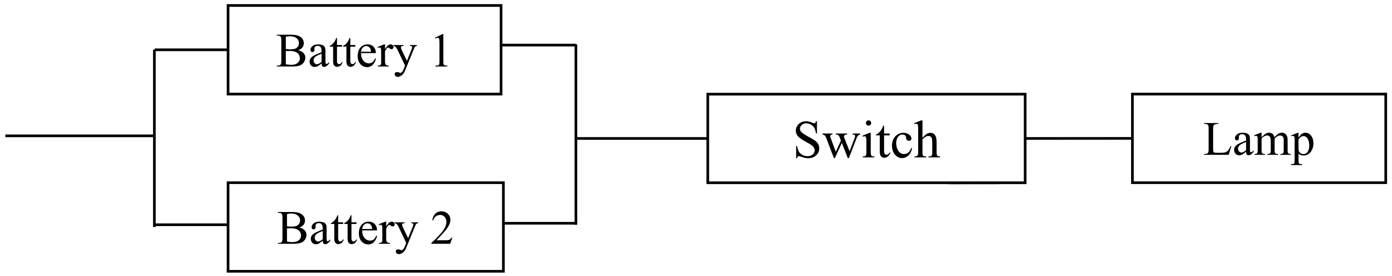
Mixed connection

Of course, it is not always possible to use a parallel connection. Let's go back to our example with a flashlight. We can easily connect the batteries in series, but in parallel. Let's look at two options for building a system:

1. Batteries in series:



2. Batteries in parallel:



Mixed connection

Let’s calculate:

Let P1 = 0.92   P2 = 0.92   P3 = 0.95   P4 = 0.99

P1 – battery 1, P2 – battery 2, P3 – switch, P4 - lamp

Version 1 we already know. Its reliability = 0.796

In the second version of the system:

P_{system} = (1 - [(1 – 0.92)*(1 – 0.92)])* 0.95*0.99 = 0.9344808

The conclusion is clear: wherever possible and necessary - use parallel connections. Maybe that's why there are 2 kidneys in our body.

Parallel connection

In addition, consider an example of a system consisting of 10 identical components connected in parallel. Reliability of each component = 0.6 For 10 parallel components:

$$P_{system} = 1 - (1 - 0.6)^{10} = 0.999895$$

Pay attention: using large number of low-reliable, but (usually) cheap components with parallel connection gives a high reliability, which can be achieved also due to a small number of highly reliable, but extremely expensive components. Which is sometimes impossible or extremely difficult to buy or create.

Analysis of reliability of multicomponent systems

In real life, only series or only parallel systems are extremely rare. In practice we have combinations of these versions. During analyzing such systems, they are broken down step by step into blocks, just as we did in the example with a flashlight.

As can easily be assumed, the analysis of complex systems that are not combinations of series and parallel elements can be difficult.

Test your knowledge

Choose the correct option:

Systems are built from components that can be connected to each other:

1. Serial
2. Parallel
3. Both
4. None

Test your knowledge

Correct answer:

Systems are built from components that can be connected to each other:

Both

Increase system reliability

Methods to improve the reliability of the system

All the variety of ways to increase the reliability can be reduced to the following:

1. Simplify the system - eliminate unnecessary components
2. Use more reliable components
3. Use component redundancy
4. Reduce system / component operation time
5. Regular maintenance
6. Replace / repair obsolete equipment

Simplify the system

Obviously, the simpler the system, the more reliable it is and vice versa. Hence it is quite obvious that if we want to improve reliability - we must reduce the number of components. As special cases of this principle - reducing the length of cables, pipelines and other highways. Reducing the number of modes, functions in the system management. Reduction in the number of intermediate links (including operators) in the analysis and transmission of energy / data. Simplification also has a beneficial effect on reducing the weight / dimensions / energy consumption and the cost of the entire system.

Everything in this principle is good except one - it is often extremely difficult to apply it in practice. Nevertheless, it is always worth remembering it.

Using more reliable components

With this principle, everything is also quite obvious: the components are more reliable, the more reliable the system. If we can not reduce operating time of the system, we can use a more reliable component. So, let the system run time = 10000 hours. Remember the basic reliability formula:

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

Where t – operation time, λ – failure rate of equipment

Consider two diodes : D1 and D2.

D1 has $\lambda = 0.1 * 10^{-6}$ 1/h then P1 = 0.999

D2 has $\lambda = 0.05 * 10^{-6}$ 1/h then P2 = 0.9995

Using more reliable components

It is clear that using D2 is more reliable than D1. However, it can easily turn out that the cost of D2 will be 10 times greater than the cost of D1. What is more effective in this case? Put a cheaper, but less reliable element and replace it in case of failure or put more expensive, but more reliable? This should be decided by the chief designer. For systems where repairs are impossible (for example, a space station for exploring Venus, the choice is obvious - D2). In addition, it is sometimes impossible to use more reliable components. The reasons can be different: sanctions, restrictions, insufficient level of development of science and technology throughout the world.

Using more reliable components

Note that at present some manufacturers purposefully carry out activities that reduce the reliability of their products, so that the customer pays again and again.

Using component redundancy

Although the approaches described above are good, in practice, as a rule, a reservation is introduced. As noted above, using a parallel connection is an effective way to increase the reliability of the system. Redundancy has a significant potential for improving reliability, but also significantly affects the size, mass, power consumption and cost of the entire system. Proper use of reservations is in some way akin to art.

Using component redundancy

In the most general case, there are three types of reservation:

- Cold redundancy, in which the backup elements are turned off until you need them

- Warm redundancy, in which the backup element is switched on but in idle mode

- Hot redundancy, when the backup component is turned on and used as intended

Using component redundancy

Cold and warm redundancy provides for the restructuring the structure of the system when its element fails. Therefore, these types of reservations are called dynamic reservation. A special case of dynamic reservation is sliding reservation, in which a group of basic elements is reserved by one element, which can replace any basic one.

For example (joke), a broad-profile specialist Jack, who can replace Jessy (turner), John (miller), and Jeremy (welder) is a sliding reserve.

Using component redundancy

The main weakness of dynamic redundancy is need for switching devices, which themselves can fail and reduce the system reliability.

It is worth mentioning the majority reservation, in which an additional logical (majority) element is used. This element compares the signals coming from the same elements. When the results coincide, they are considered to be operable and the readings are transmitted further to the output of the device.

Reducing system / component operation time

Here everything is simple - the less the system / component works, the higher its reliability. Let's recall our example about diodes D1 and D2. Now let them have the same failure rate: $\lambda = 0.1 * 10^{-6}$ 1/h, but D1 running 10,000 hours, and D2 running 1000 hours.

Then, according to the basic formula of reliability:

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

Where **t** is the operating time, and **λ** is the failure rate of the device / unit

D1 has reliability P1 = 0.999

D2 has reliability P2 = 0.9999

Reducing system / component operation time

Reducing the time of work is a good way to improve reliability, which is definitely worth keep in mind and use when developing your system. This is achieved through the rationalization and optimization of the working time of the components.

Maintenance and repair

It is necessary to say that the systems can be recoverable and non-recoverable, which do not imply the restoration of an operational state. Of course, when we have the opportunity to carry out maintenance and repairs and this service is carried out - the reliability of such a system will be much higher.

Maintenance and repair

There is a common mistake when confusing the notions of a operable and operative state of unit or system. From the point of view of the science of failures, the unit is operable when it is able to perform the required functions with the required quality. The unit is considered efficient when it is operable and fully complies with all documentation for this unit.

Example: paint has peeled on the pump, but it continues to pump water successfully. The pump is operative, but it is inoperable, because the documentation says that it should be painted in black.

But if the device is inoperative, it is always inoperable.

Maintenance and repair

Thus, the concept of operability is broader than the concept of efficiency. In addition to operable / inoperable, operative / inoperative, the concept of a limit state exists.

He have limit state when unit’s further exploitation becomes impossible, inexpedient or simply dangerous. In fact, the product goes to the limit state when it is on the 3d section of the bathtub curve.

Combining methods

We learned methods to improve the system reliability. Each has its own pluses and minuses. Best practice - use a combination of methods to improve reliability. What combination of methods to choose and how to organize it - is reliability engineer’s responsibility. In a way, this is art.

In some cases, the goal of the work is to maximize the reliability of the system, but meet strong restrictions on the cost of the system, size, weight, and so on.

In other cases, the level of reliability is already set and defined and the goal of the work is to minimize costs, dimensions, weight, etc. while saving the specified level of reliability.

Some definitions

Reliability is a property of an object to keep in time within the established limits the values of all parameters characterizing the ability to perform the required functions in the specified modes and conditions of application, maintenance, storage and transportation. Reliability is one of the most important qualities of any object.

Reliability calculation (analysis) is a procedure for determining the values of reliability indicators of an object using methods based on their calculation based on reference data on the reliability of the elements of the object, based on data on the reliability of analogical objects, data on the properties of materials and other information available at the time of calculation. As a result of the calculation, quantitative values of reliability are determined.

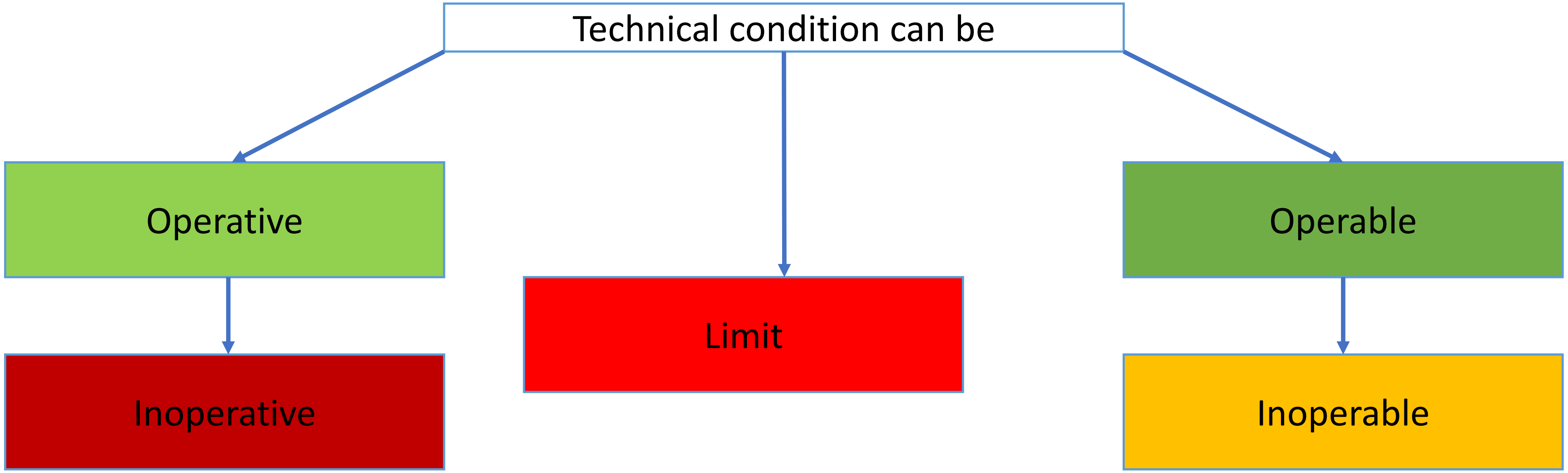
Some definitions

PNF - probability of no-failure operation of the element, unit or system. The probability of no-failure operation is the probability that within a given operating time or a specified time interval the object will not fail. Sometimes called simply reliability. As a rule, it is given by the letter P.

Resource - the total operating time of the device before the transition to the limit state. On equipment packages (for example, on bulbs) an average resource is indicated - a mathematical expectation based on extrapolating the results of testing equipment.

Service life is the time for which the average resource will be exhausted.

Some definitions



Some definitions

Products can be

Repairable - repair possible

Non-repairable - repair is not possible (only repair is possible by replacing the product)

Reliability parameters

P(t) – probability of failure-free operation in time t. $0 < P(t) < 1$

λ – the failure rate of the device. As a rule it has dimension $x*10^{-6}$ 1/h

MTBF – mean time between failures (for recoverable products), hours

MTTF – mean time to failure (for non-recoverable products), hours

Important reliability documents

You can find λ (failure rate) for your reliability calculations here:

MIL-HDBK-217F — Reliability prediction of electronic equipment
NPRD-2011 — Non-electronic parts reliability data

The End

For reliability calculations, visit my website:

http://areliability.com/online-reliability-calculation/

I regularly review and improve this course. The latest version of the course you can download on my website:
http://areliability.com/basic-reliability-course/

Let this knowledge will bring good for you and the world around you!

Sincerely, Alexey Glazachev

Keep in touch

I will be happy to know your opinion about the course.

For feedback, job opportunities, offers for reliability training in your company:

My email: alexglazachev@me.com
My mobile, WhatsApp, Telegram: +7(903)731-48-26
LinkedIn

Sincerely, Alexey Glazachev, reliability engineer