Product Service Life at Festo

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We leave nothing to chance.
We test our products to the limits.
We continuously gain new insights.

→ WE ARE THE ENGINEERS OF PRODUCTIVITY.

Survival training for products from Festo – quality that ensures a long service life
At Festo, all product series which leave the factory are subjected to comprehensive functional and endurance tests.
These tests are carried out both in the development phase and during most phases of the product life cycle.
They allow us to continuously optimise our products so they offer a longer service life, greater economic efficiency and higher reliability.

The service life characteristics revealed by the tests are essential for preventive maintenance and the evaluation of safety functions. And they confirm a well-known secret: products from Festo are the benchmark for quality.

Quality is about having the right product in the right place. That is why more than 1000 sales engineers and project consultants at Festo are ready to provide you with professional and industry-specific advice.

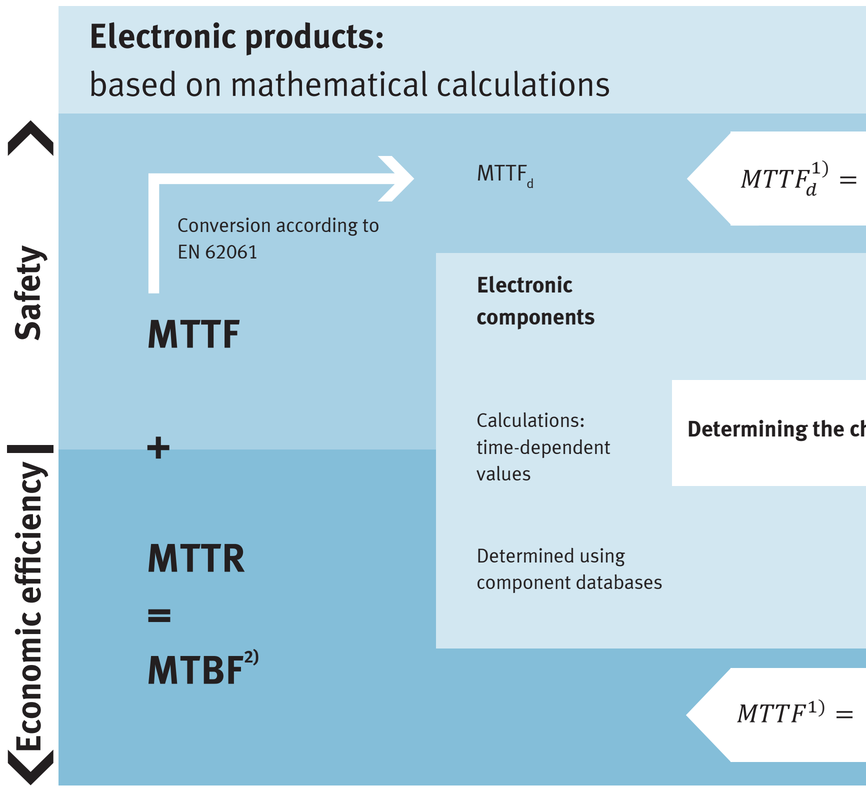
Together with you as the customer, our experts ensure that the features of our products and solutions are tailored exactly to your industry sector.

One thing is certain: first-class quality to ensure an increase in profitability and reliability comes from Festo.

Different characteristic values and their relationship

The service life of a product is important for almost all sectors. However, the service life specifications are based on the technology. They are indicated in the form of switching cycles or the running performance for products subject to mechanical wear and in the form of operating hours or years for electronic products.

All types of service life specifications are used at Festo, regardless of whether they apply to mechanical and pneumatic components or to the service life of electronic components.

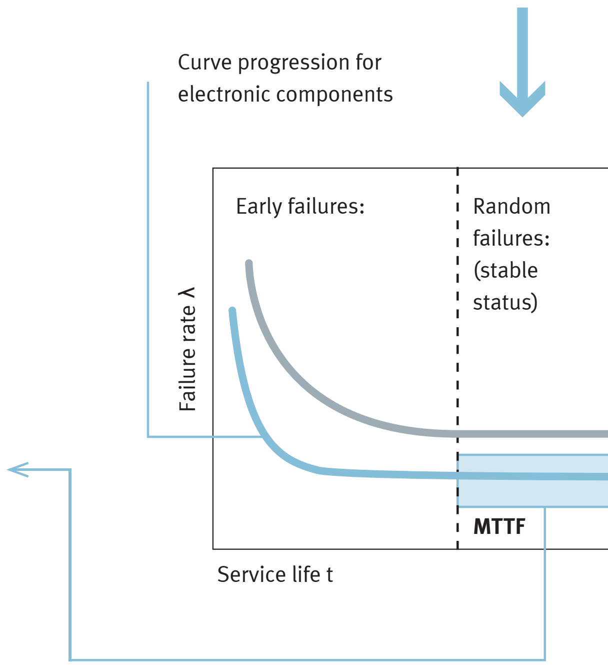


Failure behaviour of electronic components

λ = 1

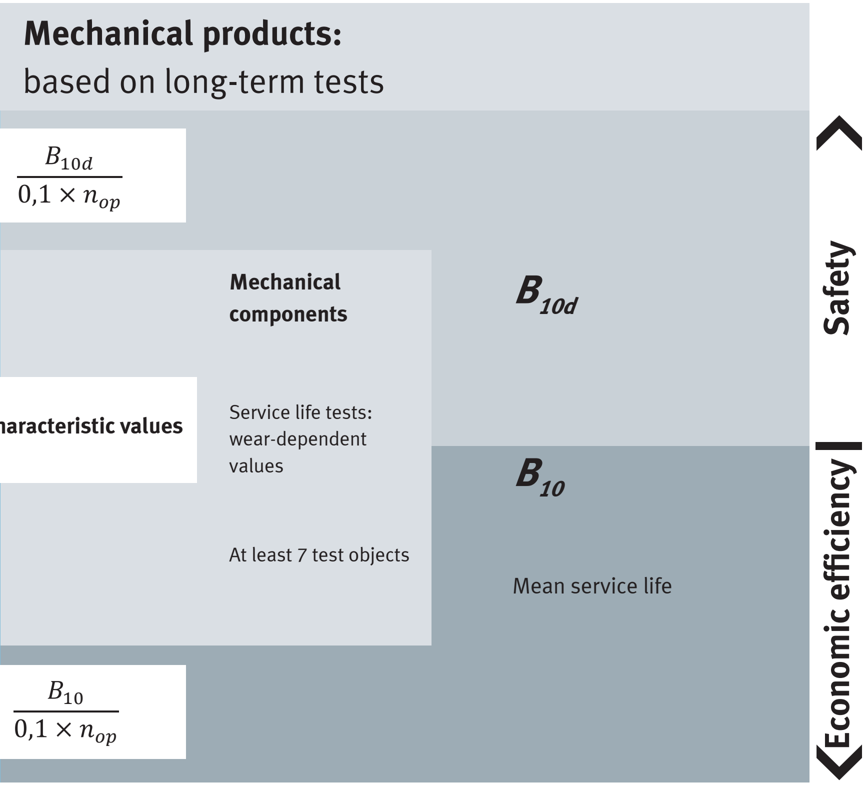
Determined using parts count method EN/IEC 61709 or SN 29500

$$\frac{1}{MTTF_d} = \sum_{i=1}^{N} \frac{1}{MTTF_{di}} = \sum_{j=1}^{N} \frac{n_j}{MTTF_{dj}}$$

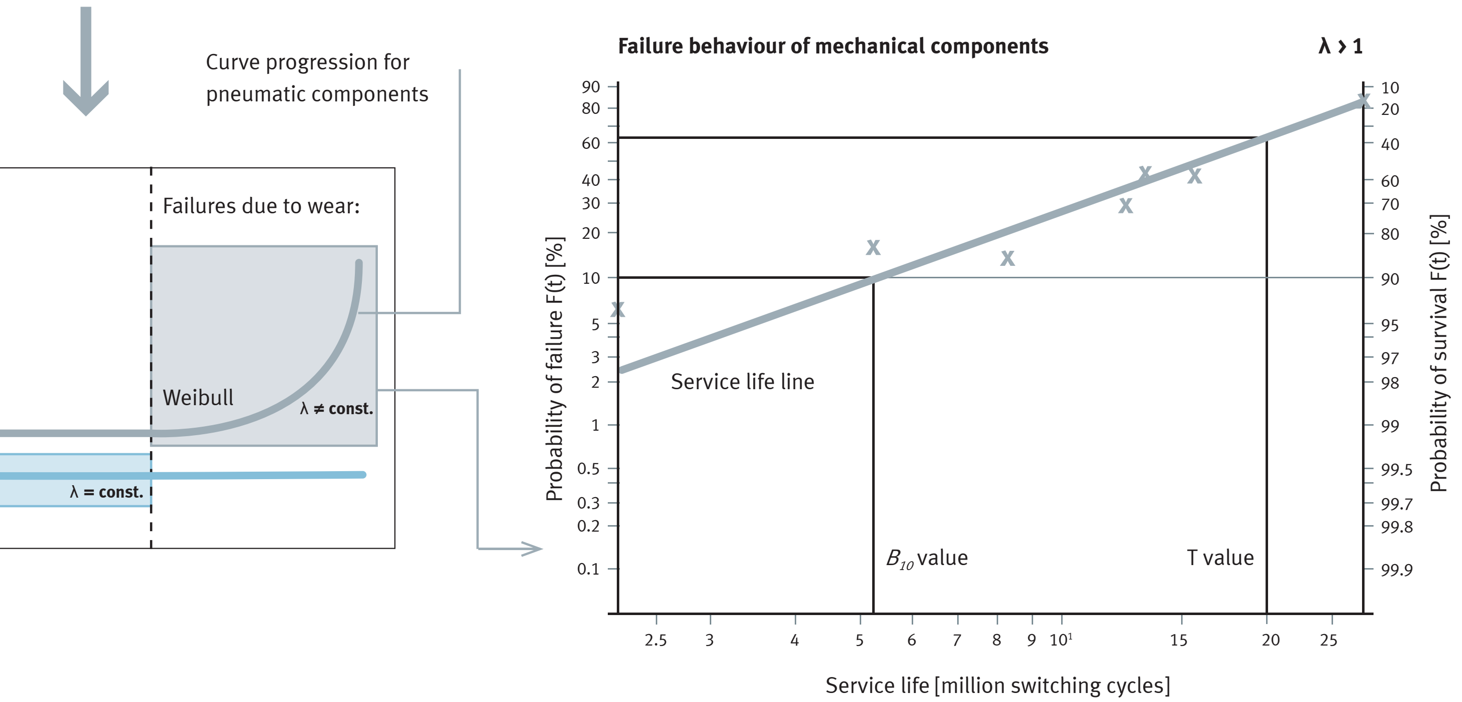


[1)] According to DIN EN 13849-1

[2)] The MTBF values depend on various factors which Festo cannot influence, including, for example, the type of installation. Therefore Festo cannot specify this value.



Mechanical products:
based on long-term tests
$\frac{B_{10d}}{0,1 \times n_{op}}$
Mechanical components
haracteristic values
Service life tests: wear-dependent values
At least 7 test objects
B_{10d}
B_{10}
Mean service life
$\frac{B_{10}}{0,1 \times n_{op}}$
Safety
Economic efficiency



Curve progression for pneumatic components
Failures due to wear:
Weibull
λ ≠ const.
λ = const.
Failure behaviour of mechanical components
λ > 1
Probability of failure F(t) [%]
Probability of survival F(t) [%]
Service life line
B_{10} value
T value
Service life [million switching cycles]

Electronic products

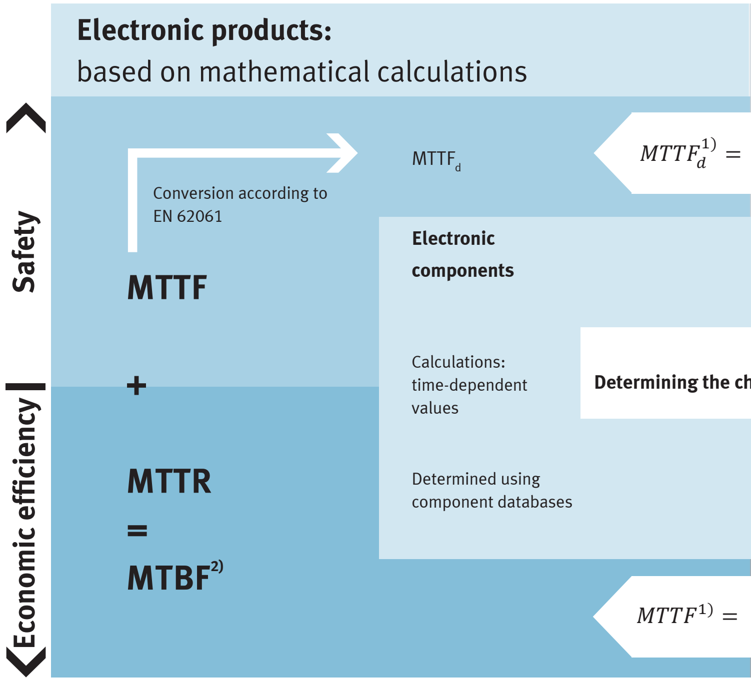
MTTF
The mean time to failure is the statistical value of the mean time until a failure occurs with a probability of 63%. For electronic products this value can usually be calculated on the basis of component data (constant failure rate). The specification is generally indicated in years.

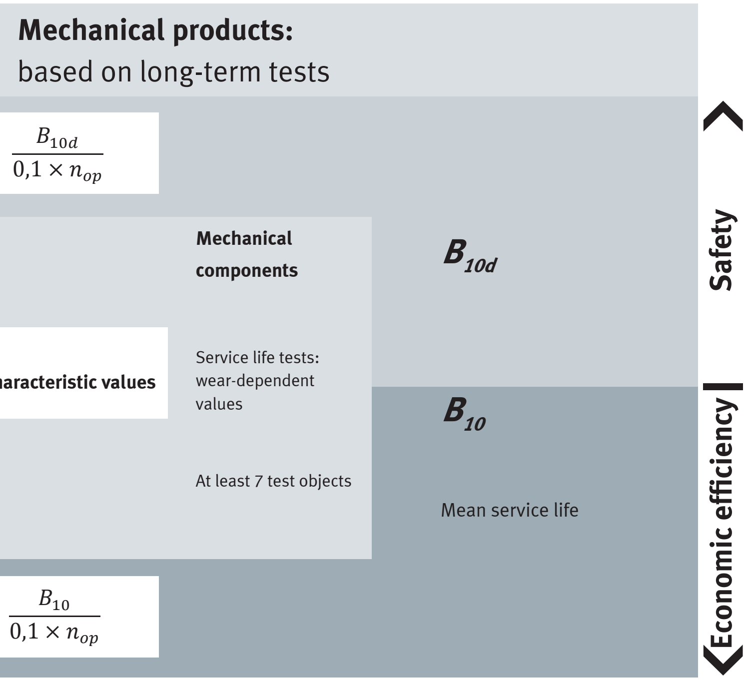
$MTTF_d$
The mean time to failure "dangerous" is the mean time until a dangerous failure occurs. Based on the above description of a dangerous failure, the following is assumed:
$MTTF_d = 2 \times MTTF$

MTTR
The mean time to repair is the mean time to restore a system after a failure.

MTBF
The mean time between failures describes the time between two failures in the case of repairable products at a constant failure rate.
MTTF + MTTR = MTBF

λ(t)/failure rate
The failure rate λ(t) is a measure of the risk of a part at time t assuming that it has functioned up to that time.





Mechanical products

The mean service life
This is stated for all sizes and variants of a series and is a value specific to Festo. The mean service life is determined on the basis of all long-term tests.

***B*$_{10}$ value**
Statistically expected value for the number of cycles at which 10% of the components have exceeded the limit values defined for the test (switching time, leakage, switching pressure etc.) under specific conditions. Conversely, it is also the probability that 90% of the test objects achieve the specified service life B_{10}.

***B*$_{10d}$**
According to ISO 13849-1, the B_{10d} value indicates the mean number of cycles until 10% of the components have failed dangerously. If there are no further details on the types of failure, the standards organisation recommends the following assumption:
$B_{10d} = 2 \times B_{10}$
Festo usually specifies B_{10} values.

b value/shape parameter
Weibull distribution parameter. The b value defines the type of failures. A distinction can be made between early failures (b < 1), random failures (b = 1; corresponds to exponential distribution) and wear failures (b > 1).

T value/characteristic service life
The characteristic service life T is the time until 63% of the test objects have failed.

Weibull
The Weibull analysis is the classical reliability analysis for products subject to mechanical wear (no constant failure rate). Service life characteristics with the corresponding failure probabilities, such as the characteristic service life T, the B_{10} value and the gradient of the service life line (shape parameter b), can be inferred from the Weibull net.

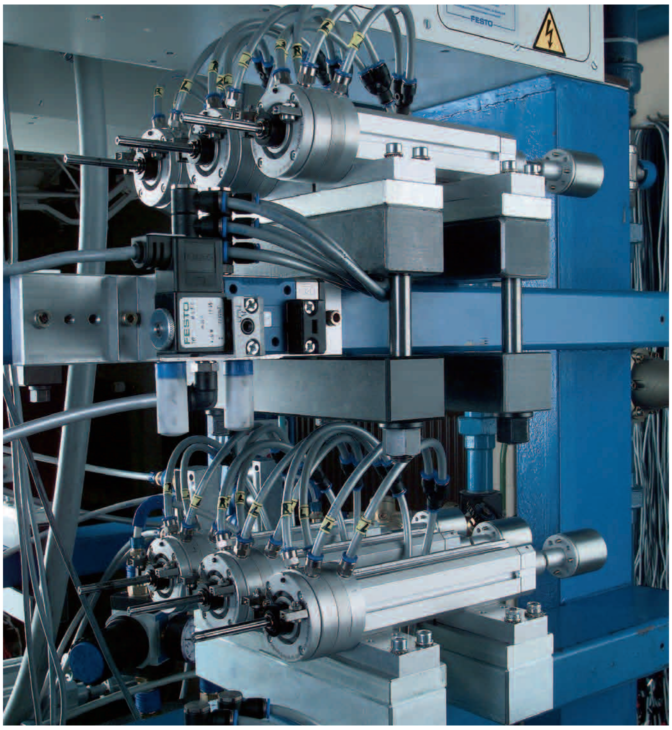
Put through its paces!

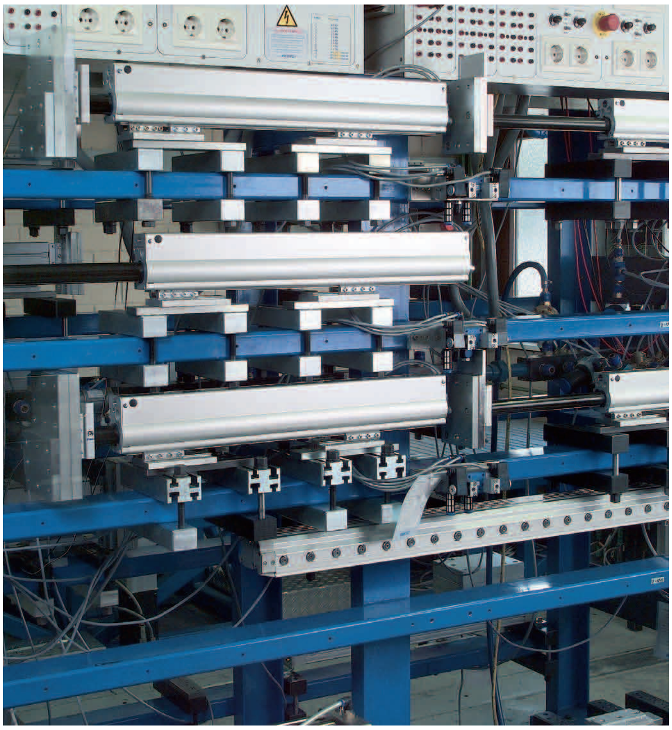
A long service life goes hand in hand with safety.
In order to provide excellent safety, productivity and quality, Festo subjects all products to thorough tests as early as the development phase. This gives Festo the necessary knowledge to continuously optimise the product functions. As a result, products from Festo have an advantage in terms of safety, quality and economic efficiency.

Electronic characteristic values are calculated mathematically or taken from databases. Festo uses two types of long-term tests to determine the characteristic values of mechanical and pneumatic components:

- Long-term function tests
- Service life tests

Service life tests can be used to establish the statistical specifications for the service life of the tested products. The long-term function test is used to test whether the product is still functional after a specific number of switching cycles or after a certain running performance.





Long-term tests at Festo

Service life test

- At least 7 test objects
- Terminated if 5 of 7 test objects have failed
- Statistical analyses

Service life test (SLT)
Service life tests are carried out in accordance with ISO 19973 using at least seven identically designed test objects under the same conditions. These tests normally take place in a standardised manner at 23 °C and 6 bar pressure. The SLT ends when a minimum number of test objects have failed. If seven objects are being tested, at least five test objects need to have failed.

The service life test results are statistically verified service life characteristics, determined according to Weibull. If the service life tests are terminated without failure, the B_{10} value can be determined by means of estimation.
How to execute and evaluate service life tests is described in ISO 19973.

Long-term function test

- At least 3 test objects
- Terminated after reaching a predefined time
- Used solely for product releases

Long-term function test (LFT)
In long-term function tests during the product release, three identically designed test objects are usually subjected to continuous operation under the same load. These tests are also performed under min./max. conditions. They may be stopped after a predefined number of load cycles is reached.

Test conditions

Service life tests based on ISO 19973

General test conditions
Having clearly defined general conditions is a prerequisite for a reproducible test procedure. The following minimum requirements, which can be tightened for specific products, apply to compressed air:

- Drying of the compressed air for operation in heated internal rooms to a dew point of 3 °C. The dew point must be at least 10 K lower than the medium temperature (min. class 4 according to DIN-ISO 8573-1).
- Filtration of the compressed air with filters finer than 40 µm (DIN-ISO 8573-1 class 5). A maximum oil rate of 0.1 mg/m³ is permissible for unlubricated compressed air (DIN-ISO 8573-1 class 1).
- When compressed air is lubricated, the supplementary lubrication must not exceed 25 mg/m³ (DIN-ISO 8573-1 class 5).

Test parameters

Valves	Linear drives	Semi-rotary drives
Switching frequency	Stroke frequency	Swivel frequency
Volume at output	Load on piston rod	Load on drive shaft
	Stroke length	Swivel angle
	Stroke speed	Angular velocity
	Mounting position	Mounting position

Long-term function tests

Combination of test conditions for long-term function tests using the example of valves

Pressure*	Temperature*		
	Low	Medium	High
Low	-	LFT (3 test objects)	-
Medium	LFT (3 test objects)	LFT (3 test objects)	LFT (3 test objects)
High	-	LFT (3 test objects)	-

* Depending on the catalogue specification

The service life test is carried out only at 23 °C and 6 bar.

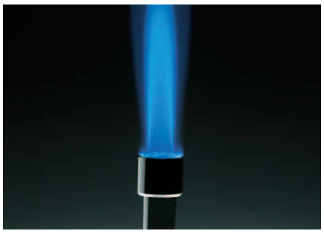
Test evaluation

A precise description of the test that has been performed is essential for a successful test evaluation. Without it, the test is meaningless as it will no longer be comprehensible.
The following parameters must be described:

- Products used
- Documentation and description of the test conditions, such as pressure, temperature, additional load, frequency etc.
- Precise specification of the measurements to be taken, such as leakage, pressure coefficients etc., and their measurement cycles and termination criteria
- Determining the service life value

In general a distinction is made between the following cases:

- Survival case
  A test object is considered a survival case if the required function is fulfilled by the end of the test and the limit values of the termination criteria are not exceeded.
- Tolerance failure
  The test object still fulfils its function, but the termination criteria, such as permissible leakage, are no longer met.
- Total failure
  The function of the test object is no longer ensured because, for example, the valve no longer switches or the cylinder no longer runs.



Determining B_{10} values for pneumatic components according to ISO 19973

Definition of the B_{10} value
Statistically expected value for the number of cycles at which 10% of the components have exceeded the limit values defined for the test (switching time, leakage, switching pressure etc.) under specific conditions.

But: a component can also fail before the B_{10} value is reached. The service life cannot be guaranteed.

The B_{10} values are defined on the basis of the results from long-term tests with at least 7 test objects.

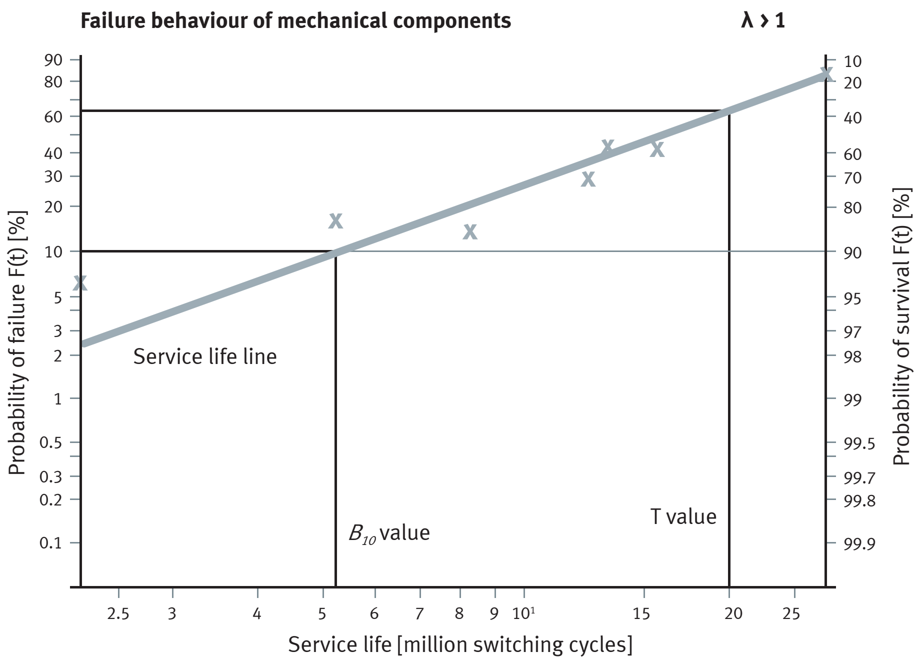
The B_{10} value may be used for the safety-specific evaluation and for establishing the preventive maintenance of systems (TPM = total productive maintenance).

Dangerous failures
Only dangerous failures are relevant to the safety of machines according to ISO 13849-1.

Whether a failure is a dangerous failure depends on the application. If no information is possible or available on the number of dangerous failures, ISO 13849-1 permits the assumption that every second failure is dangerous. This results in: $B_{10d} = 2 \times B_{10}$

For which products do I need a B_{10d} value?
For all products which are subject to mechanical wear and are used in safety-related parts of a control system. Furthermore, they must contribute to the execution of the safety function, such as valves or clamping cartridges. This does not apply to fittings, tubes, angle brackets, fixtures, etc. Drives are not normally part of the safety function and do therefore not have to be evaluated either.

For which products do I need an $MTTF_d$ value?
For all electronic products which are used in safety-related parts of a control system and directly contribute to the execution of the safety function, such as controllers, fieldbus nodes for the detection of dangerous situations, such as sensors in the test channel of category 2.



Note

See page 5.

Mean time to failure value (MTTF) for electronic products

- The MTTF is a statistical characteristic which is determined by tests and/or calculations. It does not specify a guaranteed service life or failure-free time.
- The standard DIN EN ISO 13849-1 sets out different methods for determining the MTTF values of products.
- Some are based on calculations with characteristic values, others refer to tables and databases, such as the Siemens standard SN 29500.
- The $MTTF_d$ value defines the mean operating time until a dangerous failure occurs.
- The $MTTF_d$ value can be used for safety-specific calculations according to ISO 13849.

Excerpt from SN 29500, table C.3: Diodes, power semi-conductors and integrated circuits

Diode	**Example**	**MTTF for components [years]**	**$MTTF_d$ for components [years]**		**Comments**
			Typical	Worst case	
General application	–	114 155	228 311	22 831	50% dangerous failures
Suppressor	–	15 981	31 963	3 196	50% dangerous failures
Rectifier diodes	–	114 155	228 311	22 831	50% dangerous failures
Rectifier bridges	–	57 078	114 155	11 416	50% dangerous failures
Thyristors	–	11 415	22 831	2 283	50% dangerous failures
Triacs, diacs	–	1 484	2 968	297	50% dangerous failures
Integrated circuits (programmable and non-programmable)	Use manufacturer's specifications				50% dangerous failures

Calculating the MTTF value of a sub-assembly

Once all individual MTTF values of a sub-assembly are known, they can be converted into a total MTTF value. The calculation is based on the “parts count method”.

The general equation is:

$$\frac{1}{MTTF_d} = \sum_{i=1}^{N} \frac{1}{MTTF_{di}} = \sum_{j=1}^{N} \frac{n_j}{MTTF_{dj}}$$

The "parts count method" is based on approximation and always deviates towards the safe side.

Converting a B_{10} value into an $MTTF_d$ value

Practical example: “calculating the $MTTF_d$ for components using B_{10} values”
A B_{10} value of 30 million switching cycles has been determined for a pneumatic valve. The valve is used in two shifts a day on 220 work days a year. An average cycle time of 5 s is assumed.

d_{op}	= 220 days/year	(mean operating time in days a year)
h_{op}	= 16 h/day	(mean operating time in hours a day)
t_{cycle}	= 5 s/cycle	(mean time between the beginning of two cycles in s/cycle)
B_{10d}	= 60 million cycles	

Assumption: $B_{10d} = 2 \times B_{10}$

This data can be used to calculate the following values according to DIN EN 13849-1:

$$n_{op} = \frac{d_{op} \times h_{op} \times 3600\,\frac{s}{h}}{t_{cycle}} = \frac{220\,\frac{d}{a}\,16\,\frac{h}{d} \times 3600\,\frac{s}{h}}{5\,\frac{s}{cycle}} = 2{,}53 \times 10^6\,\frac{cycles}{year}$$

$$T_{10d} = \frac{B_{10d}}{n_{op}} = \frac{60 \times 10^6\,cycles}{2{,}53 \times 10^6\,\frac{cycles}{year}} = 23{,}7\ years$$

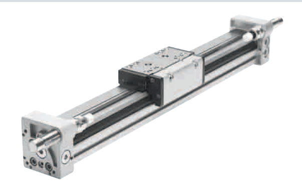
$$MTTF_d = \frac{B_{10d}}{0{,}1 \times n_{op}} = \frac{60 \times 10^6\,cycles}{2{,}53 \times 10^6\,\frac{cycles}{year}} = 237\ years$$

As a result, the component has an $MTTF_d$ value of 237 years.

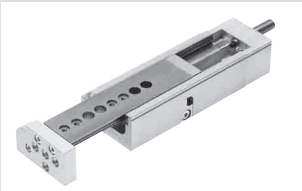
Service life specifications for roller bearings

The service life expectancy of roller bearings depends on the specific load situation of the application.
Each application should be considered individually to ensure optimum sizing and hence maximum economic efficiency.
This also applies to the question of the expected service life of a roller bearing in preventive maintenance concepts.
Products from Festo with roller bearings are designed and tested with a defined load for a service life of 5,000 km (running performance) at a nominal operating point.

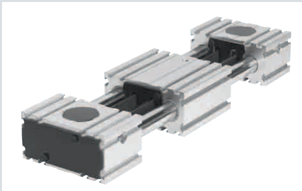
For example, recirculating ball bearing guides, ball bearing cage guides and roller bearing guides for pneumatic and electromechanical drives are used as roller bearing elements at Festo. Recirculating ball spindles, which comply with the same principles of the roller bearing theory as roller guides, are additionally used for electromechanical drives.



Pneumatic gantry axis with rail guidance



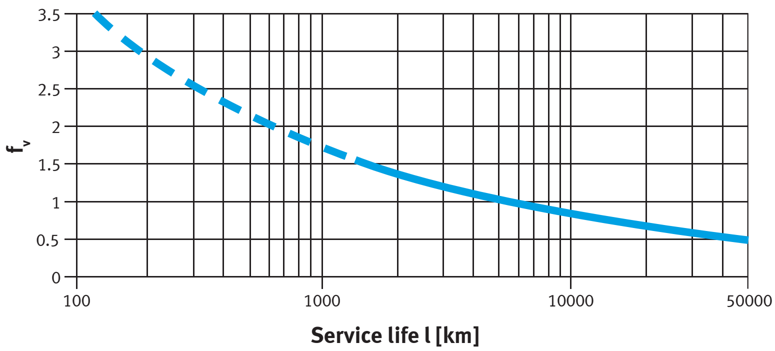
Pneumatic mini-slide with ball bearing cage guide



Electromechanical toothed belt axis with ball-bearing guide

Electromechanical axis with rail guidance and recirculating ball spindle

Relationship between load and service life
As described above, the service life of a roller bearing depends on the specific load.
To provide a rough statement on the service life of the guide, the diagram below shows the load comparison factor f_v as a characteristic in relation to the service life.
The factor f_v is the result of the ratio between the nominal load of a roller bearing and its actual load.



Load comparison factor f_v as a function of the service life

Calculation example
A user wants to move an X kg load with a pneumatic gantry axis.
The formula for the load comparison factor f_v for roller guides gives a value of 1.5 for f_v.

According to the diagram, the guide has a service life of approx. 1,500 km.

Formula for the load comparison factor f_v for roller guides

$$f_v = \frac{|F_{y,dyn}|}{F_{y,max}} + \frac{|F_{z,dyn}|}{F_{z,max}} + \frac{|M_{x,dyn}|}{M_{x,max}} + \frac{|M_{y,dyn}|}{M_{y,max}} + \frac{|M_{z,dyn}|}{M_{z,max}}$$

Formula for the load comparison factor f_v for roller guides

Piston Ø	8	12	18	25	32	40	50	63
$F_{y,max}$	300	650	1 850	3 050	3 310	6 890	6 890	15 200
$F_{z,max}$	300	650	1 850	3 050	3 310	6 890	6 890	15 200
$M_{x,max}$	1.7	3.5	16	36	54	144	144	529
$M_{y,max}$	4.5	10	51	97	150	380	634	1 157
$M_{z,max}$	4.5	10	51	97	150	380	634	1 157

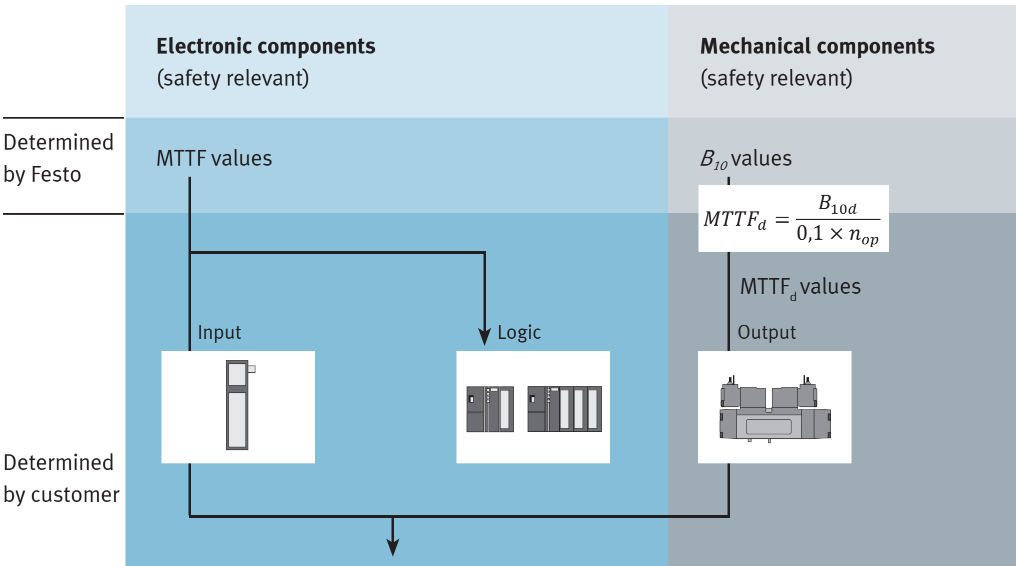
Note
The nominal load specifications for roller bearings are determined by Festo usually for a service life of 5,000 km (running performance).
The running performance of 5,000 km does not represent a B_{10} value with the corresponding probability of survival, but must fully meet the test criterion in the long-term function test.
The B_{10} values of the roller bearings at nominal loads are considerably higher than the nominal running performance of 5,000 km.

Machine safety and determination of the MTTF value for safety functions

Machines have to be designed in a way that protects people, animals, property and the environment from harm. When using products in safety circuits, the risk reduction must be determined.

The risk reduction level through the use of a safety function is evaluated by the standard EN ISO 13849-1. This evaluation requires qualitative information on the components used, such as the MTTF value for electronic components and the B_{10} value for mechanical components.

When considering safety aspects, it must be noted that, in contrast to the total productive maintenance calculation, only the safety-relevant components are included.



For one channel

$$\frac{1}{MTTF_d} = \sum_{i=1}^{N} \frac{1}{MTTF_{di}}$$

or

For two redundant channels

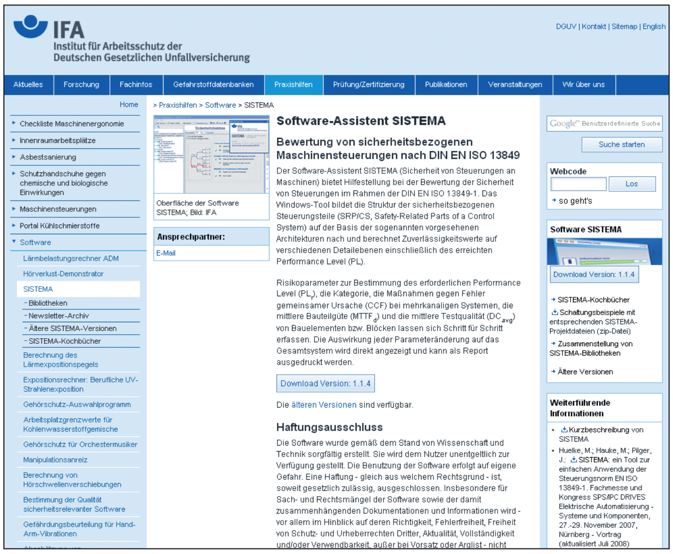
$$MTTF_d = \frac{2}{3}\left[MTTF_{dC1} + MTTF_{dC2} - \frac{1}{\frac{1}{MTTF_{dC1}} + \frac{1}{MTTF_{dC2}}}\right]$$

The mean time to failure dangerous ($MTTF_d$) for the entire safety function is first calculated individually for each redundant channel. A total $MTTF_d$ value is then determined using the values from both channels. This value is specified in years and is a qualitative value of the safety function. The MTTF value for the technical protective measures according to the standard DIN EN 13849-1 is divided into three areas: low, medium and high.

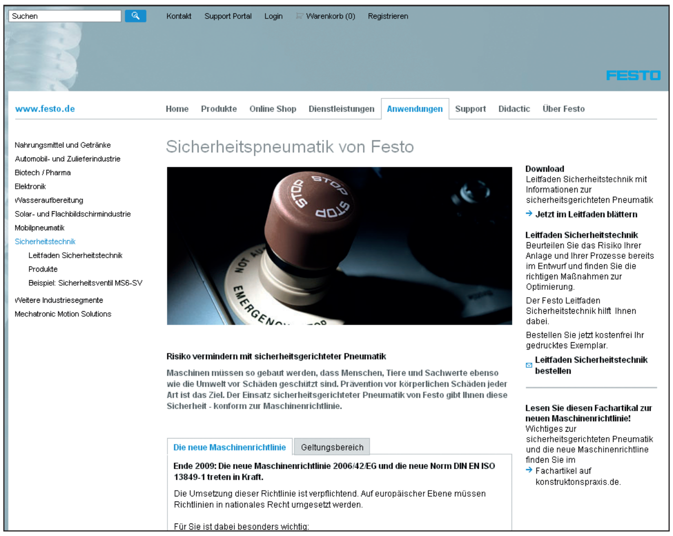
Rating	$MTTF_d$
Low	3 years ≤ $MTTF_d$ < 10 years
Medium	10 years ≤ $MTTF_d$ < 30 years
High	30 years ≤ $MTTF_d$ < 100 years

Source: DIN EN ISO 13849-1 Chapter 4.5.2

Safety engineering coefficients – the Sistema library



Sistema software from the Institute for Occupational Health and Safety [Institut für Arbeitsschutz (IFA)]
The SISTEMA software wizard (safety of controllers in machinery) provides support for the evaluation of the safety of controllers as part of DIN EN ISO 13849-1. The Windows tool maps the structure of the safety-related control parts (SRP/CS, Safety-Related Parts of a Control System). The performance level for the safety function can be calculated on different part levels. The software is available as a free download via the following link:
www.dguv.de/ifa/de/pra/softwa/sistema/index.jsp



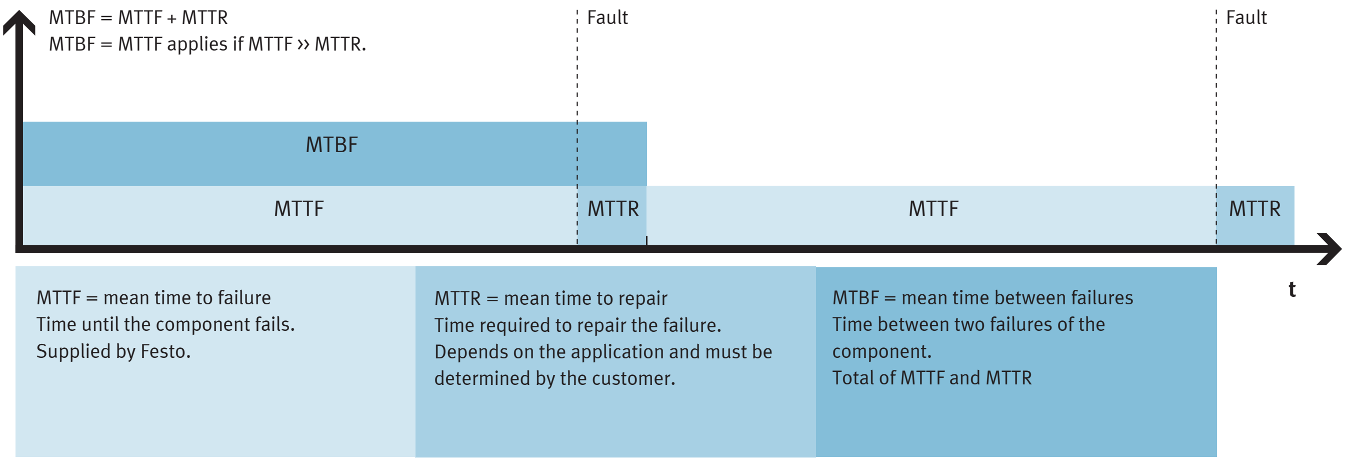
Sistema library from Festo
The Sistema software is only a tool for performing the safety engineering evaluations. To do this, it uses databases with safety-related specifications for products and solutions.
There are numerous links to libraries on the website of the IFA.
The library of Festo's safety engineering coefficients is available as a download on Festo's website:
www.festo.com/sicherheitstechnik
www.festo.com/safety

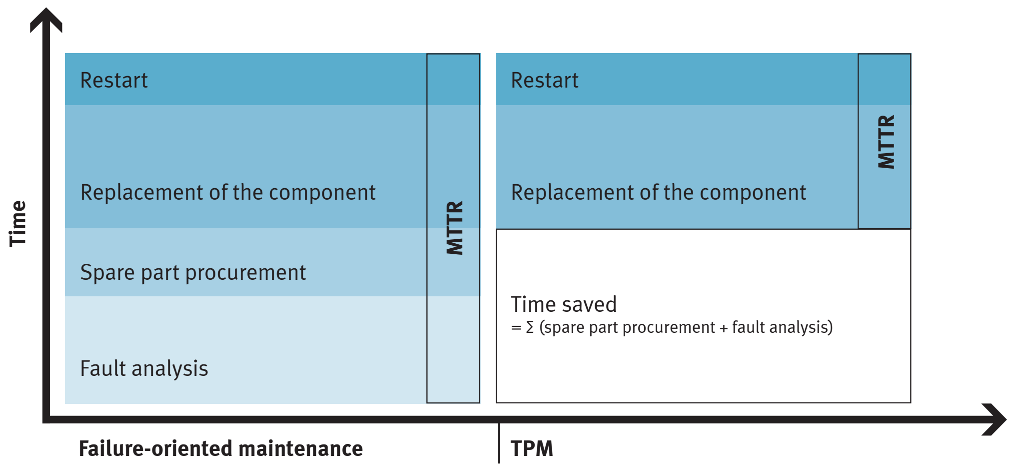
Failure-oriented maintenance versus preventive maintenance (TPM)

TPM saves a considerable amount of time as well as costs in comparison to conventional maintenance methods. In the case of failure-oriented maintenance, only a system failure triggers a reaction.

However, with TPM a replacement is prepared thoroughly and system downtime is included in the production schedule or the replacement is scheduled so that the impact on production is kept to a minimum.

An important difference between safety engineering and TPM is that with TPM all components which can cause system downtime are taken into account. With safety engineering, on the other hand, only those components whose failure poses a risk to people, the machine or the environment are considered.





The time saved may vary. The procurement of spare parts, for example, depends on whether the parts are in stock or have to be ordered.

Any production downtime due to unexpected failures also leads to significant time losses and high costs.

Total productive maintenance TPM

The aim of the TPM concept is to achieve fewer unscheduled system standstills through planned maintenance.

And so the medical proverb "prevention is better (and less expensive) than curing" is transferred to the working world.

The target of this strategy is to systematically increase the availability of machines and systems.

Characteristic values, such as MTTF or B_{10} values for machine functions and components, are required to implement the measures.

Festo supplies this information and these values so that the TPM reference data can be determined.

Total productive maintenance

Elimination of key problems	Autonomous maintenance	Planned maintenance	Preventive maintenance	Training
• Application-specific elimination of the 6 types of loss	• Automatic cleaning, maintenance and small repairs by employees	• Ensuring total availability of systems	• Taking maintenance and accessibility of systems into account as early as the planning and ordering phase	• Demand-based qualification of employees
			• Festo supplies the service life values required	• Training courses from Festo Didactic

Further reading

[1] European Parliament, "Directive 2006/42/EC of the European Parliament and Council from 17th May 2006 on machinery and on the amendment of the directive 95/16/EC (new version)," Official Journal of the European communities, vol. 49, no. 157, pp. 24-81, June 2006.
[2] NFPA 79: Electrical Standard for Industrial Machinery. Quincy, 2012.
[3] Michael Dorra and Dietmar Reinert, "European Project STSARCES. Final Report WP 2.1: Quantitative Analysis of Complex Electronic Systems Using Fault Tree Analysis and Markov Modelling," St. Augustin, 2000.
[4] A. Barner, J. Bredau, and F. Schiller, "Efficient Fault Detection in Safety-Related Pneumatic Control by Conceptual Encapsulation," in 7th IFAC Symposium on Fault Detection, Supervision and Safety of Technical Processes, Barcelona, 2009.
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