

Execution and evaluation of cyclic tests at constant load amplitudes – DIN 50100:2016

Dedicated to Professor Dr.-Ing. Harald Zenner on the occasion of his eightieth birthday

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Article Information

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Tests with constant load amplitudes are used to characterize the fatigue strength behavior of material specimens and components. The S-N curve derived from these test results describes the relationship between the load amplitude and the corresponding cycles to failure. Different concepts for carrying out and evaluating fatigue tests make it difficult to compare the results from different research institutes. The aim of the new version of the German standard DIN 50100:2016 is to define a procedure for determining an S-N curve for metallic alloys that does not allow any scope for interpretation. It is assumed that the test results are subject to logarithmic normal distributions in both load and cycle direction. It is further assumed that the S-N curve in the high-cycle fatigue regime and the long-life fatigue regime can be approximated by a bilinear function. For the determination of the straight line of finite life, the pearl string method and the load level method are available for determining the position parameter and the slope of the power function according to Basquin. Long-life fatigue strength is determined using the staircase method and forms the knee point of the S-N curve on average with the straight line of finite life. For the long-life fatigue regime, a horizontal course or a decrease with low inclination, depending on the material group examined, is assumed. In addition, DIN 50100:2016 contains information on the accuracy of the estimation of the mean values and the scatter of the characteristic values according to the sample size. The goal of achieving comparability of S-N curves is supported by extensive examples. An English translation of DIN 50100:2016 is available also.

Since the 1930s, intense efforts have been made to standardize the vocabulary of fatigue tests; these efforts have led to the development of test guideline DVM 4001 – fatigue testing by the German Association for Materials Testing in Engineering (DVM) [1].

This test guideline was extended and published in 1942 as pre-standard DIN 50100, [2]. In the further course of development of DIN 50100 standards, various methods for

describing mean stress were added and published, with a supplement in German, English, French and Russian provided in 1953 [3]. In 1978, the changeover to SI units occurred [4]. DIN 50100 remained unchanged and essentially contained the definition of terms until 2016.

Notes on the execution and evaluation of fatigue tests were not included. The lack of a method for evaluating the results

of fatigue tests causes the same test results to be interpreted differently by individual experts (see Figure 1) [5]. For the computational lifetime estimation, the relationship between the cycles to failure and the numerous influencing variables is usually empirically derived from the test results of many research institutes; however, this procedure is unreliable without knowledge of the test conditions and the

procedure for the test evaluation, and it contributes to the scatter of the estimated S-N curve. A working group founded by the fatigue standards committee in 2012 has revised DIN 50100 for metallic alloys, with the goal of comparing the test results of various research institutes easily in the future [6]. An English translation of DIN 50100 will be available soon. In conclusion, the evaluation of fatigue tests with constant load amplitude can also be standardized internationally [7].

S-N curve – Wöhler curve

August Wöhler (1819-1914) derived from his test results the phenomenon of fatigue. Under cyclic loading, material strength is significantly lower than tensile strength [8]. He developed testing machines for components for various load types and methods that are used to observe the deformations under normal operation. Due to the pioneering achievements accomplished using this test in the field of fatigue strength, a test with constant load amplitudes is also called a Wöhler test, and the resulting characteristic S-N curve is also called a Wöhler curve.

Characteristics of S-N curves

In the fatigue test, a specimen or a component is stressed with a periodically changing load. The load amplitude L_a and the mean load L_m are constant during a Wöhler test. Depending on the magnitude of the load amplitude L_a , it can be applied variously, often until a failure criterion, e.g., crack initiation or rupture, has been achieved. At small load amplitudes L_a ,

there is the possibility that no failure of the specimen will occur until a predefined number of cycles N_G is reached. In this case, the test result is evaluated as a runout [6]. The number of cycles N_G is also called the ultimate number of cycles.

Graphically, the results of several tests are plotted in a diagram of load amplitude L_a against the number of cycles to failure N . Both axes of the diagram are logarithmically scaled, as shown in Figure 2 with data from Maennig [9]. The curve can be divided into three regimes:

- Low-cycle fatigue regime (LCF) is characterized by up to approximately 10^4 cycles. In the LCF regime, the slope of the S-N curve is significantly smaller than that in the high cycle fatigue regime. The high plastic strain amplitude in this regime usually requires a strain-controlled test procedure. LCF tests are not part of DIN 50100:2016.
- High-cycle fatigue regime (HCF) is characterized by approximately 10^4 cycles up to the cycle number at the knee point N_K . Depending on the given load amplitude L_a , the specimen will fail after N cycles. The S-N curve can be approximated by a straight line of finite life plotted within a double logarithmic scale.
- Long-life fatigue strength (LLF) is characterized by the number of cycles $N >$ the cycle number at the knee point N_K . Depending on the given load amplitude L_a , both failures and runouts will occur.

Figure 2 presents the results of a very large number of tests. The test results can be used to create an s-shaped curve fit. Usually, significantly smaller sample sizes are available. In this case, the parameters of an s-shaped curve fit cannot be esti-

mated. For this reason, DIN 50100:2016 uses the Basquin [10] approach to approximate the curve in the HCF regime by a straight line of finite life; see Equation (1). This approach includes two parameters, position C and slope k , to describe the relationship between the load amplitude L_a and the number of cycles N to failure

$$N = C \cdot L_a^{-k} \tag{1}$$

By taking the logarithm of both sides of Equation (1), a straight-line equation is obtained (Equation (2)). It can be concluded that the function can only be displayed as a straight line if both axes of the diagram are scaled logarithmically.

$$\log N = C - k \cdot \log L_a \tag{2}$$

The position parameter C describes the intercept of the cycle axis for a load amplitude of $L_a = 1$. In contrast to the usual mathematical representation, the independent variable L_a is plotted on the vertical diagram axis and the dependent variable N on the horizontal diagram axis in the S-N curve. This must be taken into account when evaluating test results, for example, with spreadsheet programs.

The term “LLF strength” is introduced in DIN 50100:2016 to replace terms such as “fatigue limit” and “endurance limit”. These terms always assume a horizontal course of the S-N curve beyond the knee point N_K . Several tests have shown that cracks can also occur in axially stressed, unnotched steel specimens at cycles $N > 10^7$. These crack initiations are usually caused by nonmetallic inclusions within the volume of the material [11].

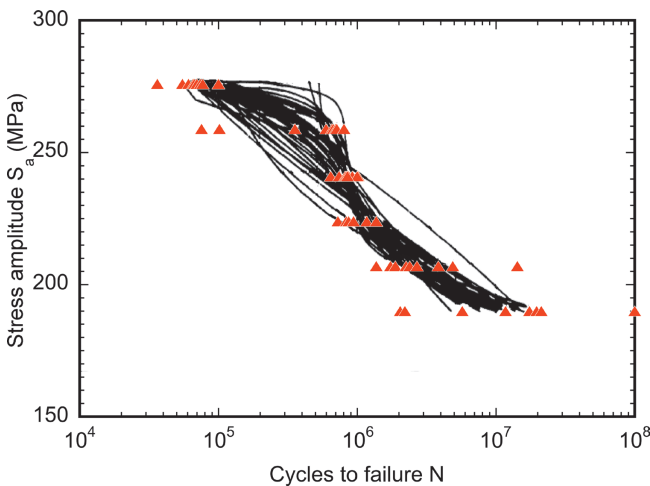


Figure 1: S-N curves after evaluation of the same dataset by different research institutes; data from [5]

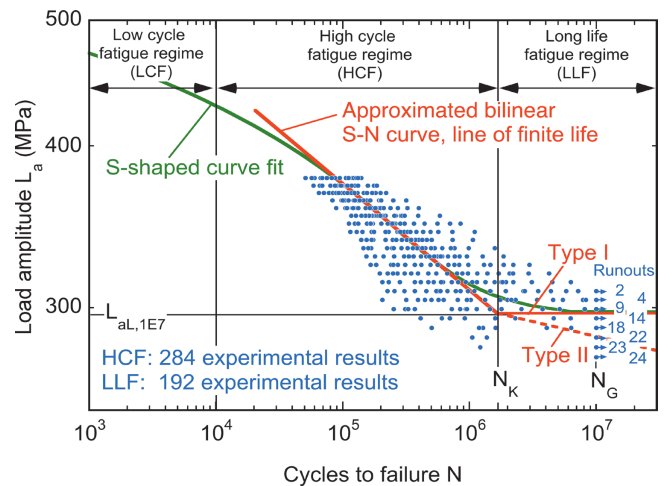


Figure 2: Fit to the s-shape of test results using a bilinear equation; data from [9]

In the regime of LLF, the course of the S-N curve is divided into two types:

- Type I: The horizontal course of the S-N curve, called “LLF strength” (formerly referred to as “fatigue limit” or “endurance limit”), which is frequently observed in cubic-space-centered materials, e. g., ferritic steels.
- Type II: Further decrease of the S-N curve beyond the knee point following an assumed straight line with a smaller inclination k_2 compared to the HCF regime is frequently observed in face-centered or hexagonally packed materials, e. g., austenitic steel, aluminum, magnesium, or titanium.

Performing tests in the LLF regime, an ultimate number of cycles N_G must be predefined, from which point a test is evaluated as a runout. Only up to this ultimate number of cycles N_G is the course of the S-N curve experimentally proven. Extrapolation of the S-N curve beyond the ultimate number of cycles N_G is prohibited within the scope of DIN 50100:2016. DIN 50100:2016 recommends including the number of cycles N_G in the index of the characteristic value for LLF strength, e. g., or $L_{aL,10^7}$ or $L_{aL,1E7}$.

If no better values from experience exist, then the following values for the ultimate number of cycles N_G are recommended:

$N_G = 5 \cdot 10^6$: for cubic-space-centered materials, e. g., ferritic steels or cast iron

$N_G = 10^7$: for cubic face-centered or hexagonally packed materials, e. g., austenitic steel, aluminum, magnesium, or titanium

Distribution functions for S-N curves

Due to the varied test procedures, test evaluation for fatigue test results differs between the HCF and LLF ranges. In the HCF regime, scatter is observed in the direction of the number of cycles. In the LLF regime, the likelihood of fractures and runouts with respect to an ultimate number of cycles N_G is observed in the load direction. In fatigue tests, the mean and the scatter of the population are typically derived from small sample sizes. For an evaluation of the test results, a distribution function must be chosen that is regarded as applicable for the population, e. g., the log-normal distribution. When evaluating of fatigue tests, the following distribution functions are often used:

- Normal distribution
- Log-normal distribution (normal distribution with logarithmic input data)
- Weibull distribution

Using small sample sizes, only quantiles close to the mean are observed in the experiment, for example an interval of 10 % to 90 %. Within this small interval, it is impossible to identify strong differences between various probability distribution functions. Only when extrapolating to a small or high probability of survival P are there significant differences; (see Figure 3). An investigation of a large database with test series of sample sizes $n \gg 10$ using modern statistical test methods has shown that log-normal distribution usually better approximates the test results than does two-parametric Weibull distribution [12]. Hence, statistical evaluation according to DIN 50100:2016 is based on logarithmic normal distribution, which is completely described by its mean and its standard deviation.

Different kinds of loads

Fatigue tests can be carried out on the basis of different kinds of loads L . DIN 50100:2016 uses the general term load L for loading a specimen or component. Loads can include the following:

- Forces
- Bending moments
- Torsional moments
- Displacements
- Angle of torsions

If a cross section or a section modulus can be defined for the specimen, then the nominal stress, such as the kinds listed below, can also be used as load variables L

- Nominal tensile/compressive stress

- Nominal bending stress
- Nominal torsional stress
- Nominal shear force stress

If the relationship between external loads and local stress or strains is known for specimens with stress concentrations caused by notches, according to elasticity theory, local stress or strains, such as those kinds listed below, can also be used as load variables L .

- Normal stress
- Shear stress
- Normal strains
- Shear strains

Note that strain-controlled tests with significant plastic strains cannot be evaluated using DIN 50100:2016.

A static mean load L_m can be superimposed on load amplitude L_a . Load ratio R_L describes the ratio between a minimum load L_{min} and a maximum load L_{max} ; Equation (3).

$$R_L = \frac{L_{min}}{L_{max}} \tag{3}$$

For the determination of an S-N curve, all tests are carried out using the same load ratio R_L or the same mean load L_m .

Specimen design and specimen manufacturing

A prerequisite for the determination of a valid S-N curve is the use of specimens of the same quality within a test series with regard to material, heat treatment, manufacturing technology, geometry and surface roughness.

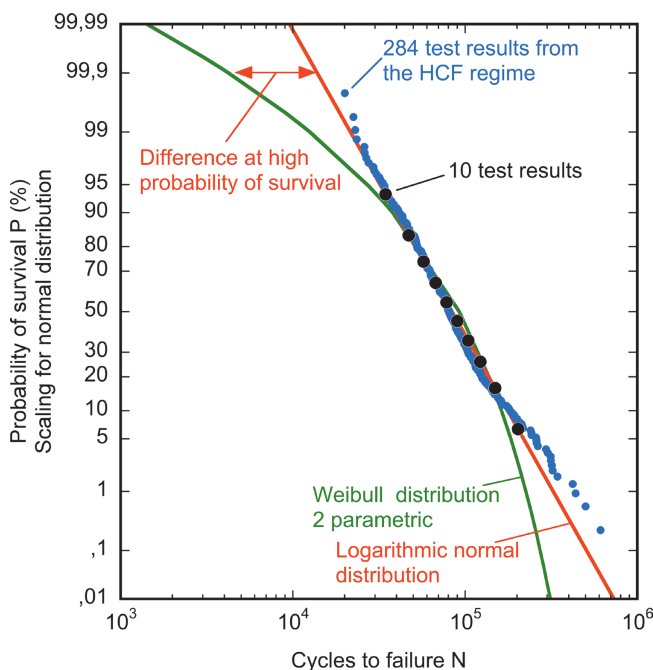


Figure 3: Comparison of a normal distribution and a Weibull distribution in a probability plot

No generally valid specimen geometry can be specified in DIN 50100:2016 because the geometry of specimens depends on various conditions, e. g., the geometry of the semi-finished product, the testing machine, or the type of stress. When choosing specimen geometry, it must be ensured that no cracks occur in the area of the specimen clamping and in the transition zone between the clamping head and the test cross section. Specimens with cracks outside of the test cross-section are rejected as invalid. If an S-N curve has to be determined for a component, e. g., a crankshaft, a conrod, or a rotor shaft, then the load must be applied according to the requirements of operation. The conditions mentioned above concerning the position of cracks, etc. can become invalid for components. For example, when testing a threaded connection, the crack usually appears next to the bolt head. This crack is often next to the clamping head; however, it is also a desired behavior.

Execution and evaluation of tests

When carrying out fatigue tests, a distinction must be made between the HCF and

the LLF regimes. In the HCF regime, a failure criterion is always achieved, e. g., crack initiation or rupture. The result of a test in the HCF regime is the number of cycles N at load amplitude L_a . DIN 50100:2016 recommends the pearl string method and the load level method for the execution and evaluation of HCF tests. In the LLF regime, an ultimate number of cycles N_G is specified beyond which a test is evaluated as a runout. The results of tests in the LLF regime are samples of “failures” and “runouts”. In DIN 50100:2016 tests in the LLF regime are carried out and evaluated using the staircase method.

High cycle fatigue – Pearl string method. The tests are carried out on different load levels in the HCF regime; (see Figure 4). The advantage of the pearl string method is its ability to conduct a test according to information on previous specimens. This allows the option to approach the transition areas to the LCF and LLF regimes by shifting load levels stepwise. As a disadvantage, the test results for the middle of the HCF regime only offer a small contribution to the estimation of the slope k of the straight line of finite life, at least from the point of view of reliability. Slope k and position C of the finite life line, Equation (2),

are evaluated by a linear regression using the least number of squares for all n value pairs of load amplitude $L_{a,i}$ and the number of cycles N_i of a test series. It is important to choose the number of cycles as the dependent variable in the regression algorithm (Equations (4) and (5)).

see Equation 4 (4)

$$C = 10^{\frac{1}{n} \left(\sum_{i=1}^n (\log N_i) + k \cdot \sum_{i=1}^n (\log L_{a,i}) \right)} \tag{5}$$

Using the pearl string method, it is assumed that the standard deviation does not vary between the load levels. Therefore, test results can be shifted parallel to the finite life line to a fictitiously load level $L_{a,fict}$ with the number of cycles $N_{i,fict}$ to calculate standard deviation (Equation (6)).

$$N_{i,fict} = N_i \cdot \left(\frac{L_{a,fict}}{L_{a,i}} \right)^{-k} \tag{6}$$

The mean of the number of cycles $N_{50\%,fict}$ on the fictitious load level $L_{a,fict}$ and on standard deviation $\tilde{s}_{\log N}$ are calculated by Equations (7) and (8).

see Equation 7 (7)

see Equation 8 (8)

$$\text{Equation 4 } k = - \frac{n \cdot \sum_{i=1}^n (\log L_{a,i} \cdot \log N_i) - \sum_{i=1}^n (\log L_{a,i}) \cdot \sum_{i=1}^n (\log N_i)}{n \cdot \sum_{i=1}^n (\log L_{a,i})^2 - \left(\sum_{i=1}^n (\log L_{a,i}) \right)^2}$$

$$\text{Equation 7 } \log N_{50\%,fict} = \frac{1}{n} \sum_{i=1}^n \log N_{i,fict} \rightarrow N_{50\%,fict} = 10^{\log N_{50\%,fict}}$$

$$\text{Equation 8 } \tilde{s}_{\log N} = \sqrt{\frac{1}{n-2} \cdot \sum_{i=1}^n (\log N_{i,fict} \cdot \log N_{50\%,fict})^2}$$

Note the number of degrees of freedom of $n - 2$ in the denominator of Equation (8). Position C and slope k (two parameters) have to be estimated by the test results. Therefore, the number of degrees of freedom has to be set to $n - 2$. The empirical standard deviation is underestimated for small sample sizes and is corrected by Equation (9) [13].

$$\tilde{s}_{\log N, \text{korr}} = \tilde{s}_{\log N} \cdot \frac{n-1.74}{n-2} \tag{9}$$

High cycle fatigue – Load level method.

Using the load level method, two load levels L_{a1} and L_{a2} must be chosen to be as close as possible to the expected transition zone to the LCF and LLF regimes at the start of the experiment; (see Figure 5). The two load levels must not be located in the transition areas to the LCF or LLF regimes. Otherwise, a straight line with underestimated slope will result. The application of the load level method requires knowledge of the approximate position of the finite life line. The advantage of the load level method is the separate evaluation of the mean $N_{50\%}$ and the standard deviation $s_{\log N}$ on each load level (Equa-

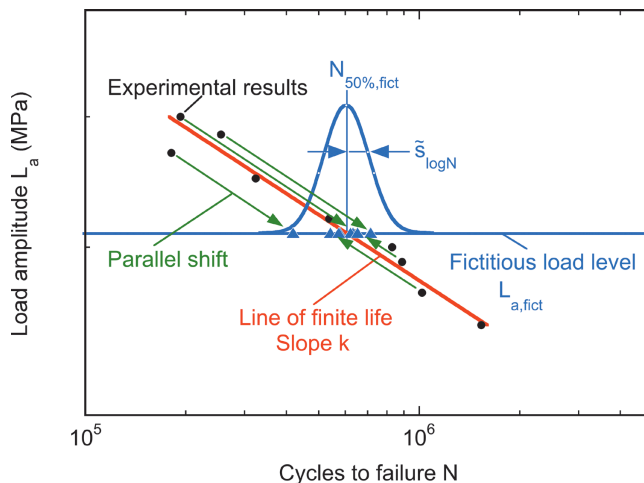


Figure 4: Pearl string method, shifting the test results parallel to the finite life line to a fictitious load level

tions (10) and (11)). In this manner, a load-dependent standard deviation can be evaluated. The disadvantage of the load level method is that it is not possible to detect if a chosen load level is in the transition area to the LCF or HCF regime after the test series has been completed.

see Equation 10 (10)

$$s_{\log N} = \sqrt{\frac{1}{n-1} \cdot \sum_{i=1}^n (\log N_i - \log N_{50\%})^2} \quad (11)$$

In analogy to the pearl string method, standard deviation $s_{\log N}$ is underestimated for small samples sizes n and is corrected by Equation (12) [13].

$$s_{\log N, \text{korrr}} = s_{\log N} \cdot \frac{n-0.74}{n-1} \quad (12)$$

Using the means $N_{50\%}$ of the two load levels L_{a1} and L_{a2} , slope k of the finite life line is calculated (Equation (13)).

$$k = - \frac{\log \left(\frac{N_{50\%, La1}}{N_{50\%, La2}} \right)}{\log \left(\frac{L_{a1}}{L_{a2}} \right)} \quad (13)$$

Parameter C , which describes the position of the line of finite life, Equation (1), corresponds to the intercept of the number of cycles for $L_a = 1$, Equation (14).

$$C = N_{50\%, La1} \cdot L_{a1}^k \quad (14)$$

Long life fatigue – Staircase method. In addition to failures, e.g., a ruptured specimen, at the same load level, runouts can also appear at a predetermined ultimate number of cycles N_G in the LLF regime. Statistical evaluation in the direction of cycles is not possible due to the runouts. Instead, the statistical evaluation is performed in the direction of load amplitude L_a .

Comparing different evaluation techniques for the staircase method [14] reveals that the mean of LLF strength is well estimated using most methods, even for relatively small samples sizes. On the other hand, even for large sample sizes, standard deviation can only be estimated with poor reliability almost independent of the evaluation technique used. Due to its simple applicability, the staircase method modified by IABG is chosen for DIN 50100:2016 [15], and it is described below.

Before starting the tests, the estimated range of LLF strength is divided into

equally spaced load levels L_i . Since normal distribution with logarithmic characteristic is also assumed for LLF strength, a constant factor d_{\log} can be defined between the neighboring load levels. Considering a logarithmic scale, this factor leads to visually equally spaced load levels L_i . To obtain one to three load levels with runouts and failures, the stair case factor d_{\log} is calculated as a function of an estimated standard deviation of the population $s_{\log L, GG}$; Equation (15). Good results are achieved if the stair case factor d_{\log} is approximately the same size as the standard deviation $s_{\log L, GG}$ of the population.

$$d_{\log} = 10^{s_{\log L, GG}} \quad (15)$$

For some materials and components, DIN 50100:2016 contains data for typical standard deviations of the population $s_{\log L, GG}$ to help the test engineer choose the staircase factor d_{\log} . Load levels L_i are calculated on the basis of an estimated LLF strength $L_{a, NG}$ (Equation (16)).

$$L_i = L_{a, NG} \cdot (d_{\log})^i \quad i = \dots, -2, -1, 0, 1, 2 \quad (16)$$

$$\log N_{50\%} = \frac{1}{n} \sum_{i=1}^n \log N_i \rightarrow N_{50\%} = 10^{\log N_{50\%}} \quad \text{Equation 10}$$

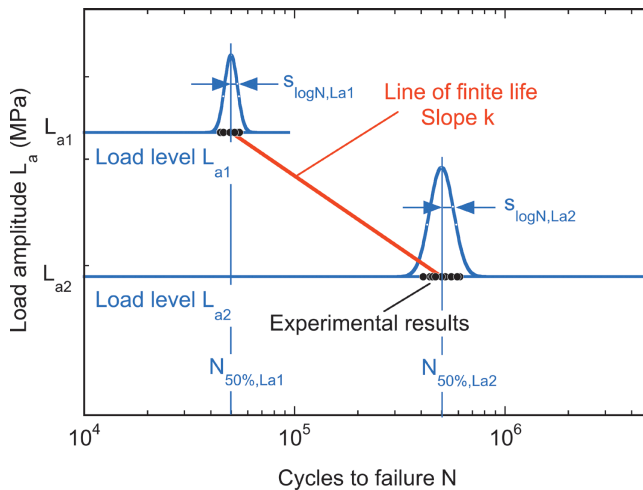


Figure 5: Load level method with a separate evaluation on each load level

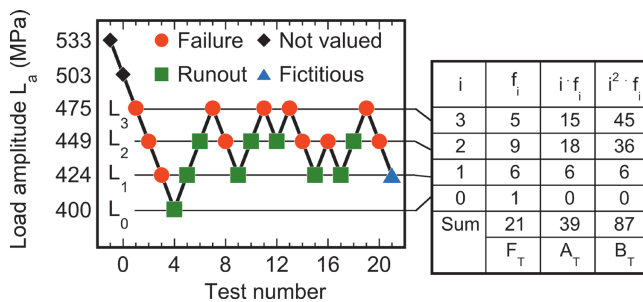


Figure 6: Staircase method and evaluation scheme

be appended, depending on the result of the last physical one. Next, the indicators F_T , A_T , B_T and D_T (Equations (17) to (20)), as auxiliary values for calculating the mean $L_{aL,NG}$ (Equation (21)), and the standard deviation $s_{\log L}$ (Equations (22) or (23)), are evaluated.

$$F_T = \sum f_i \tag{17}$$

$$A_T = \sum i \cdot f_i \tag{18}$$

$$B_T = \sum i^2 \cdot f_i \tag{19}$$

$$D_T = \frac{F_T \cdot B_T - A_T^2}{F_T^2} \tag{20}$$

$$L_{aL,NG} = L_0 \cdot d_{\log}^{\left(\frac{A_T}{F_T}\right)} \tag{21}$$

$$D_T < 0.5; s_{\log L} = 0.5 \cdot \log d_{\log} \tag{22}$$

$$D_T \geq 0.5; s_{\log L} = \log d_{\log} \cdot 10^{4.579\ 494 \cdot (F_T)^{0.889\ 521} \cdot D_T^{7.235\ 548 \cdot (F_T)^{0.405\ 229}} \tag{23}$$

Required sample sizes

Another new feature of DIN 50100:2016 is the specification of the required sample size n . In DIN 50100:2016, the requirement sample size n is chosen with respect to the user's demands for the accuracy of

the estimated mean and standard deviation. To investigate the relationship between the characteristic values of the population and a single test series, extensive Monte Carlo simulations were carried out in [16], and the results were adopted in DIN 50100:2016.

In the HCF regime, the mean $N_{50\%}$, standard deviation $s_{\log N, \text{korr}}$ and slope k of the finite life line are estimated with a single test series, for example the load level method. This estimate is the best guess for the mean $N_{50\%,GG}$, for standard deviation $s_{\log N,GG}$ and the slope k_{GG} of the population. Depending on sample size n , the assumed standard deviation $s_{\log N,GG}$ of the population and the desired range of the finite life line occupied by tests (for example from $N = 2 \times 10^4$ to $N = 5 \times 10^5$), upper permissible errors F_o and lower permissible errors F_u are specified in DIN 50100:2016 for each parameter. With a confidence of 80%, the characteristic value of the population is within the range between upper permissible error F_o and lower permissible error F_u (see Figure 7).

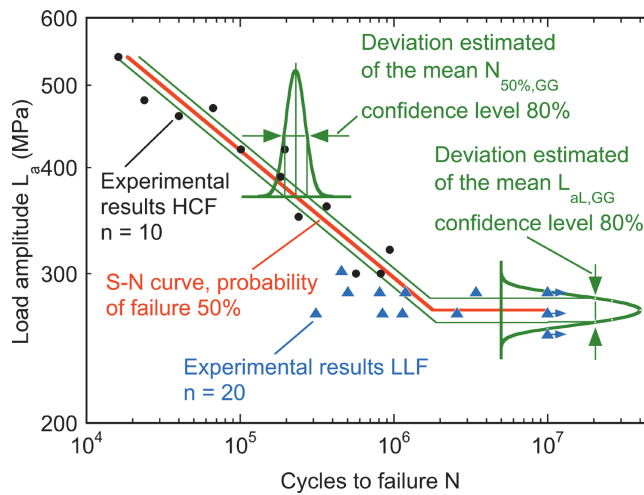
Example pearl string method. For a steel specimen that is forged and machined, according to DIN 50100:2016, a typical standard deviation for the mean value of the population $s_{\log N,GG} = 0.10$ can be taken. For the tests, it is assumed that the results will be between 20 000 and 1 000 000 cycles. Depending on the permissible error demanded, the user can take the required number of specimens n from DIN 50100:2016; Table 1.

Example load level method. The same assumptions apply to the pearl string method, with the exception of the area occupied by test results, because a larger distance to the transition areas of the HCF and LLF regimes must be maintained. For the test series, it is assumed that the results will be between 50 000 and 500 000 cycles. Depending on the permissible error demanded, the user can take the required number of specimen n from DIN 50100:2016 (see Table 2).

Assuming that a larger range of the of finite life line can be covered using the pearl string method than by using the load level method, the accuracy of the estimated mean $N_{50\%}$ and slope k is comparable for both methods.

Example staircase method. In the LLF regime, the scatter of the test results is evaluated in the direction of the load. The required sample size n for the staircase method also depends on the user's accuracy demands. The result of a single series of tests with a confidence of 80% should not deviate from the population by more than the permissible error.

Figure 7: S-N curve from test results for a probability of failure of 50%; scatter band for the estimated mean with a confidence of 80%



	Permissible Error (%)	Required sample size n				
		4	10	20	50	100
Estimated mean $N_{50\%}$	F_o	28.7	18.9	13.7	8.4	5.9
	F_u	-25.8	-15.9	-12.0	-7.8	-5.6
Estimated standard deviation $s_{\log N}$	F_o	116.9	39.9	24.5	14.1	9.6
	F_u	-53.9	-28.5	-19.7	-12.3	-8.8
Estimated slope k	F_o	12.4	8.9	6.5	4.2	2.9
	F_u	-11.0	-8.2	-6.1	-4.0	-2.8

Table 1: Pearl string method, required sample size n for a test series as a function of the required permissible error for a confidence of 80%, standard deviation of the population $s_{\log N,GG} = 0.10$, test results between 20 000 and 1 000 000 cycles

	Permissible Error (%)	Required sample size n				
		4	10	20	50	100
Estimated mean $N_{50\%}$	F_o	28.2	17.3	12.1	7.5	5.2
	F_u	-22.0	-14.7	-10.8	-6.9	-5.0
Estimated standard deviation $s_{\log N}$	F_o	259.5	65.1	36.9	20.9	13.9
	F_u	-72.2	-39.4	-26.9	-17.3	-12.2
Estimated slope k	F_o	13.6	8.4	5.9	3.7	2.6
	F_u	-12.0	-7.8	-5.6	-3.6	-2.6

Table 2: Load level method, required sample size n (sum of both load levels) depending on the required permissible error for a confidence of 80%, standard deviation of the population $s_{\log N,GG} = 0.10$, test results between 50 000 and 500 000 cycles

For a steel specimen that is forged and machined, a standard deviation of the population $s_{\log L,GG} = 0.030$ is estimated for LLF strength $L_{aL,NG,GG}$. Depending on the desired permissible error, the user can choose the required sample size from DIN 50100:2016 (see Table 3).

Considering the examples above with the given assumptions, the parameters of the population, such as the mean and the standard deviation, will appear within a confidence of 80%. The boundaries of the confidence band are equal to the permissible errors given in the Tables 1 to 3.

Tables 1 to 3 state that a mean value can be well estimated even with relatively small sample sizes n . The accuracy of the estimation of the standard deviation, on the other hand, is always poor, even for large sample sizes n . Standard deviation is necessary for calculating values of small probabilities of failure. In these cases, DIN 50100:2016 recommends the use of standard deviations from the literature that result from averaging the standard deviations of a large number of tests. The estimated standard deviations in single tests will lead to inaccurate results. Typical standard deviations are given by Adenstedt [17]. For some material groups and component types, DIN 50100:2016 also contains values for typical standard deviations.

Conclusions

The aim of the new version of DIN 50100:2016 is to standardize the planning, execution and evaluation of fatigue tests with constant load amplitudes to obtain comparable results at different research laboratories.

In DIN 50100:2016, the S-N curve is divided into the areas of high-cycle fatigue (HCF) (each specimen fails) and long-life fatigue (LLF) (at the same load amplitude failures and runouts can occur), which differ in the execution and evaluation of the tests.

Two methods are proposed in DIN 50100:2016 for determining the straight line of finite life in the HCF regime. Using the pearl string method, load levels are chosen with respect to the results of all previously tested specimens within this series. No precise previous knowledge of the position of the finite life line is required.

With the load level method, two load levels at which the tests will be carried out are defined in advance. It is not possible to determine whether the tests are in the transition area to the LCF or LLF regimes and

thus whether the slope of the finite life line will be underestimated. Thus, test results far from the center are favorable for estimating the parameters with a high accuracy. Previous knowledge of the approximate position of the fatigue strength line is required for the successful application of the load level method.

The term “LLF strength” is introduced and replaces the terms “fatigue limit” and “endurance limit”. The goal is to indicate that the S-N curve can continue to decrease even after the ultimate number of cycles at the knee point. LLF strength is determined using a modified staircase method. In this method, the test results concentrate around the mean of LLF strength automatically. No precise prior knowledge of the position of LLF strength is required. Although the mean value of LLF strength can be estimated well by means of just a few specimens ($n \geq 15$), the estimation of the standard deviation is inaccurate even for sample sizes of $n = 100$. If standard deviation has to be used for extrapolation of small probabilities of failure, the use of standard deviations obtained from averaging many test series of comparable materials or components is recommended. The use of standard deviation from a single test series can lead to inaccurate results.

For test evaluation, it is assumed that test results are subject to a logarithmic normal distribution in the direction of the cycles and in the direction of the load.

To limit the scope for interpretation, DIN 50100:2016 contains numerical and graphical examples for the evaluation and representation of fatigue tests with constant amplitudes.

An English translation is available also to allow the procedure for fatigue tests with constant load amplitude to also be standardized internationally.

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	Permissible Error (%)	Required sample size n				
		10	14	20	50	100
Estimated LLF strength $L_{aL,NG}$	F_o	4.7	3.8	3.3	1.9	1.4
	F_u	-4.5	-3.6	-3.2	-1.9	-1.4
Estimated standard deviation $s_{\log L}$	F_o	216.4	173.5	126.8	49.3	30.5
	F_u	-68.4	-63.4	-55.9	-33.0	-23.4

Table 3: Staircase method, required sample size n as a function of the required permissible error for a confidence of 80%, standard deviation of the population $s_{\log L,GG} = 0.030$

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Abstract

Ausführung und Auswertung zyklischer Versuche bei konstanten Amplituden – DIN 50100:2016. Versuche mit konstanter Lastamplitude dienen zur Charakterisierung des Schwingfestigkeitsverhaltens von Werkstoffproben und Bauteilen. Die aus den Versuchsergebnissen abgeleitete Wöhlerlinie beschreibt den Zusammenhang von Lastamplitude und Lebensdauer. Unterschiedliche Konzepte zur Durchführung und Auswertung von Schwingfestigkeitsversuchen erschweren die Vergleichbarkeit von Ergebnissen verschiedener Forschungsstellen. Ziel der Neufassung von DIN 50100:2016 ist die Definition einer Vorgehensweise zur Ermittlung einer Wöhlerlinie, die keinen Interpretationsspielraum zulässt. Dazu wird angenommen, dass die Versuchsergebnisse sowohl in Lastrichtung als auch in Schwingspielzahlrichtung einer logarithmischen Normalverteilung unterliegen und der Verlauf der Wöhlerlinie im Zeit- und Langzeitfestigkeitsbereich durch eine bilineare Funktion angenähert werden kann. Für die Ermittlung der Zeitfestigkeitsgeraden stehen das Perlenschnur- und das Horizontenverfahren zur Verfügung, um Lage und Neigung der Potenzfunktion nach Basquin zu bestimmen. Die Langzeitfestigkeit wird im Treppenstufenverfahren ermittelt und bildet im Schnitt mit der Zeitfestigkeitsgerade den Knickpunkt der Wöhlerlinie. Im Langzeitfestigkeitsbereich wird ein horizontaler Verlauf oder ein Abfall mit geringer Neigung in Abhängigkeit von der untersuchten Werkstoffgruppe angenommen. Zusätzlich enthält DIN 50100:2016 Angaben zur Treffsicherheit der aus den Versuchsergebnissen geschätzten Mittelwerte und Streuungen in Abhängigkeit vom Stichprobenumfang. Durch umfangreiche Beispiele wird das Ziel, die Vergleichbarkeit von Wöhlerlinien zu erreichen, unterstützt. Eine englische Übersetzung von DIN 50100:2016 ist verfügbar.

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