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Fatigue test method for transmission precision roller chains

Méthode d'essai de fatigue pour chaînes de transmission de précision à rouleaux

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PDF disclaimer

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Foreword

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The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

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ISO 15654 was prepared by Technical Committee ISO/TC 100, *Chains and chain wheels for power transmission and conveyors*.

Fatigue test method for transmission precision roller chains

1 Scope

This International Standard specifies an axial force fatigue test method for transmission roller chains, the tests being of the fluctuating tension type, carried out at room temperature in air, with the force applied along the longitudinal axis of the chain. It also specifies procedures for statistically analyzing the test results and gives formats and elements for presenting the results of fatigue tests and analyses.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 606, *Short-pitch transmission precision roller and bush chains, attachments and associated chain sprockets*

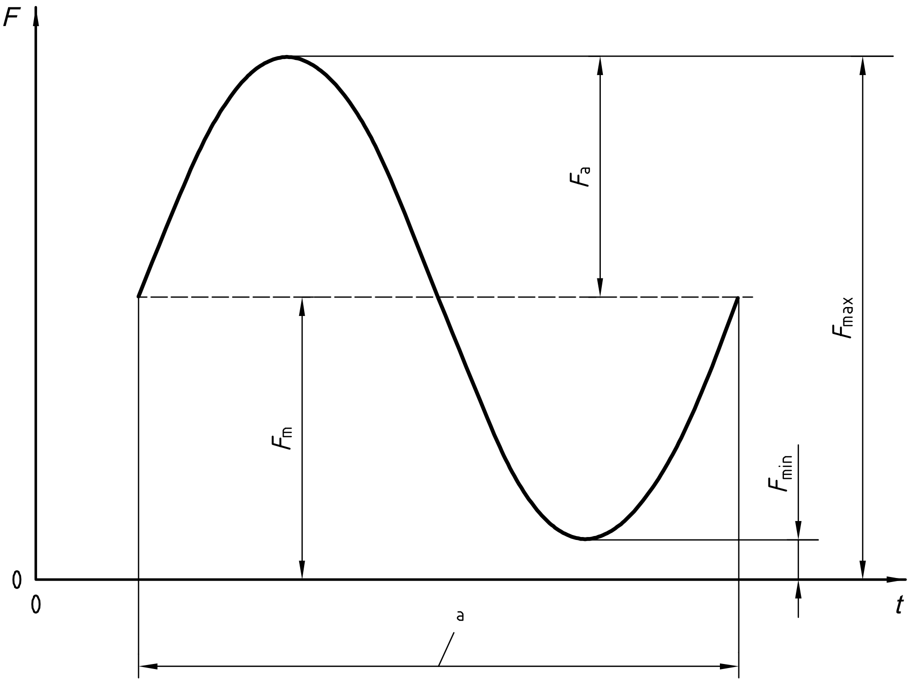
ISO 10190, *Motor cycle chains — Characteristics and test methods*

3 Symbols

See Table 1 and Figure 1.

Table 1 — Symbols

Symbol	Description	Unit
d	Step size — interval between adjacent force levels in a staircase test [see Equation (5)]	N
F_{max}	Maximum force — maximum value of force in the cycle	N
F_{min}	Minimum force — minimum value of force in the cycle	N
F_m	Mean force — half the sum of the maximum and minimum forces in the force cycle [see Equation (1)]	N
F_a	Force amplitude — half the difference between the maximum force and minimum force [see Equation (2)]	N
F_b	Mean fatigue strength — test force, corrected to zero minimum force, at which there is a 50 % probability of failure at endurance [see Equation (6)]	N
F_d	Fatigue limit — test force, corrected to zero minimum force, at which there is a calculated 0,135 % probability of failure at 10^7 force cycles — approximates the force below which a chain may endure an indefinite number of force cycles [see Equation (8)]	N
F_t	Test force — maximum force, corrected to zero minimum force, at which a test is run [see Equation (3)]	N
F_u	Minimum UTS — minimum tensile strength of chain as specified in ISO 606 or ISO 10190	N
N	Number of cycles, at a given alternating force, applied to a specimen chain at a particular time in the test	—
N_e	Endurance — predetermined number of cycles at which a test will be discontinued without failure of the specimen chain	—
n	Number of test data points included in the analysis	—
p	Chain pitch	mm
S	Standard deviation of the staircase test data [see Equation (7)]	N



$$F_m = \left(\frac{F_{max} + F_{min}}{2} \right) \quad (1)$$

$$F_a = \left(\frac{F_{max} - F_{min}}{2} \right) \quad (2)$$

Key

F force

t time

a 1 cycle.

Figure 1 — Typical force cycle

4 Principle

Tests are made on transmission chains to determine fatigue properties of chain plates such as those shown on a *F*–*N* diagram or to verify conformance to dynamic strength requirements in ISO 606 and ISO 10190.

5 Apparatus

5.1 Testing machine

The size of the testing machine shall be selected so that the maximum force on the test specimen is $\geqslant$ 10 % of the maximum capacity of the machine. Tests shall be conducted on a machine capable of applying a sinusoidal fluctuating force to the test specimen in axial tension.

The test frequency shall be chosen so as not to induce a damaging temperature increase in the test specimen.

The machine shall be calibrated periodically in order to maintain suitable accuracy and should be calibrated to within $\pm$ 2 % of its maximum capacity. A force-monitoring system could be mounted in series with the test specimen to ensure that the force cycle is maintained throughout the test.

The testing machine shall also have

a) a counter to record the number of force cycles,

b) a device to stop the machine when the chain fails, and

c) a device to prevent the machine from restarting after an emergency stop due to power failure, etc.

5.2 Test fixtures

The test fixtures shall be capable of transmitting an axial force to the test piece without inducing a subsidiary force caused by the fixtures. Universal type fixtures shall be used for fatigue testing of transmission chains.

The universal fixtures shall be designed according to the chain dimensions specified in the separate standards. Examples of the structure of the fixtures are shown in Figure 2.

Universal fixtures shall permit free movement on both sides of the chain centreline in both the normal plane of articulation and in the transverse plane. The hole in the fixture shall be a size equal to the bush hole diameter of the chain under test.

NOTE The test specimens all illustrate five free pitches.

When testing chain on sheaves, the chain shall be restrained from moving around the sheaves to ensure that only specific pitches of the chain are tested.

6 Test specimens

6.1 At least five free pitches of chain shall be used as a fatigue test specimen, except for chain pitch over 50,8 mm where a minimum of three free pitches are acceptable.

Free pitches are those chain pitches that do not contact the fixtures.

6.2 The test specimens shall be unused, undamaged chains on which all phases of manufacture have been completed. The final lubricant type is discretionary.

7 Test procedure

7.1 Test forces

7.1.1 Minimum force

The minimum force for the test shall be at least 1 % but not more than 5 % of the minimum tensile strength given for the subject chain in ISO 606 or ISO 10190.

7.1.2 Maximum force

The maximum force for the test shall be determined in accordance with 7.2 for a conformity test or in accordance with 7.3 for a staircase test.

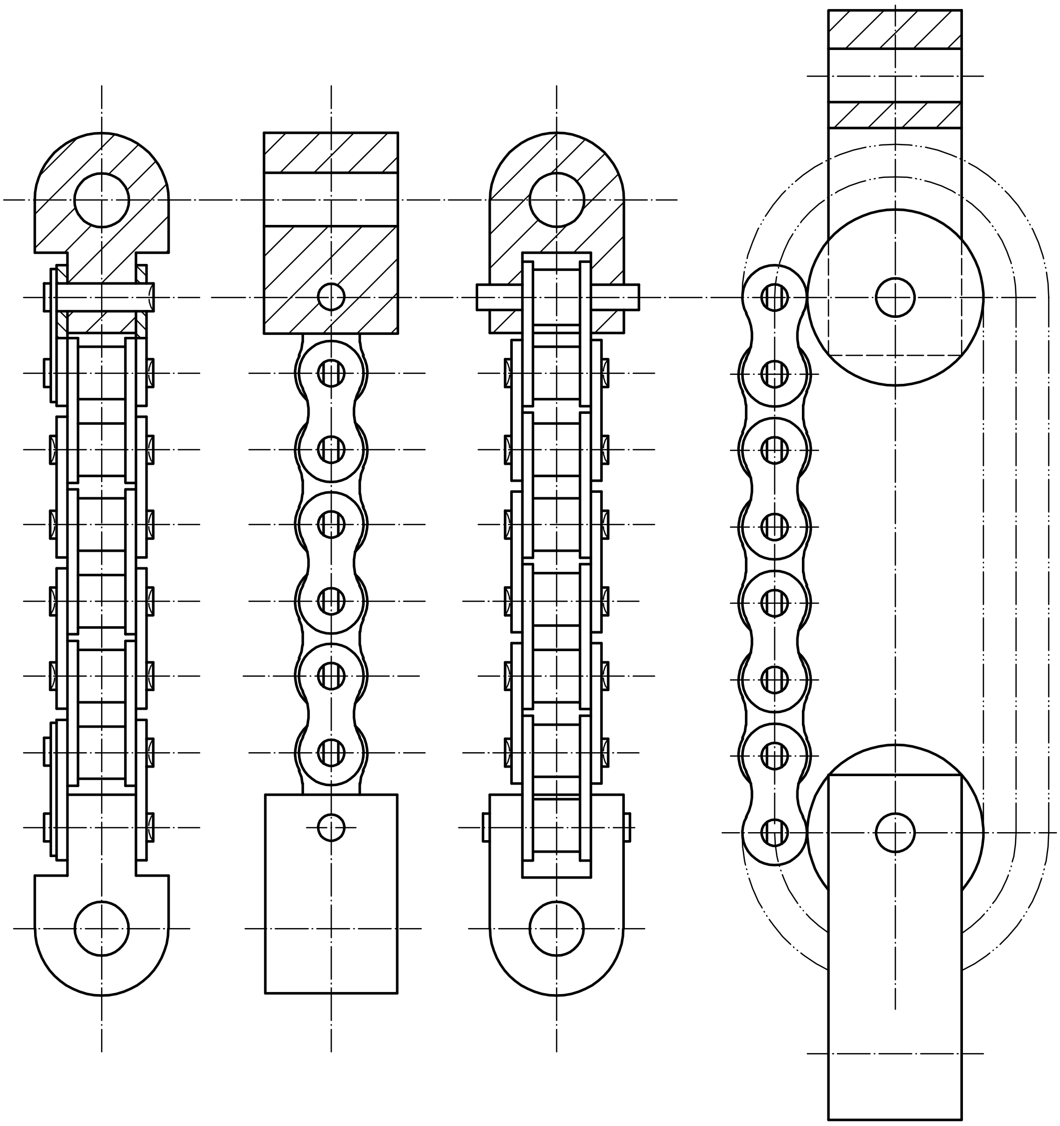
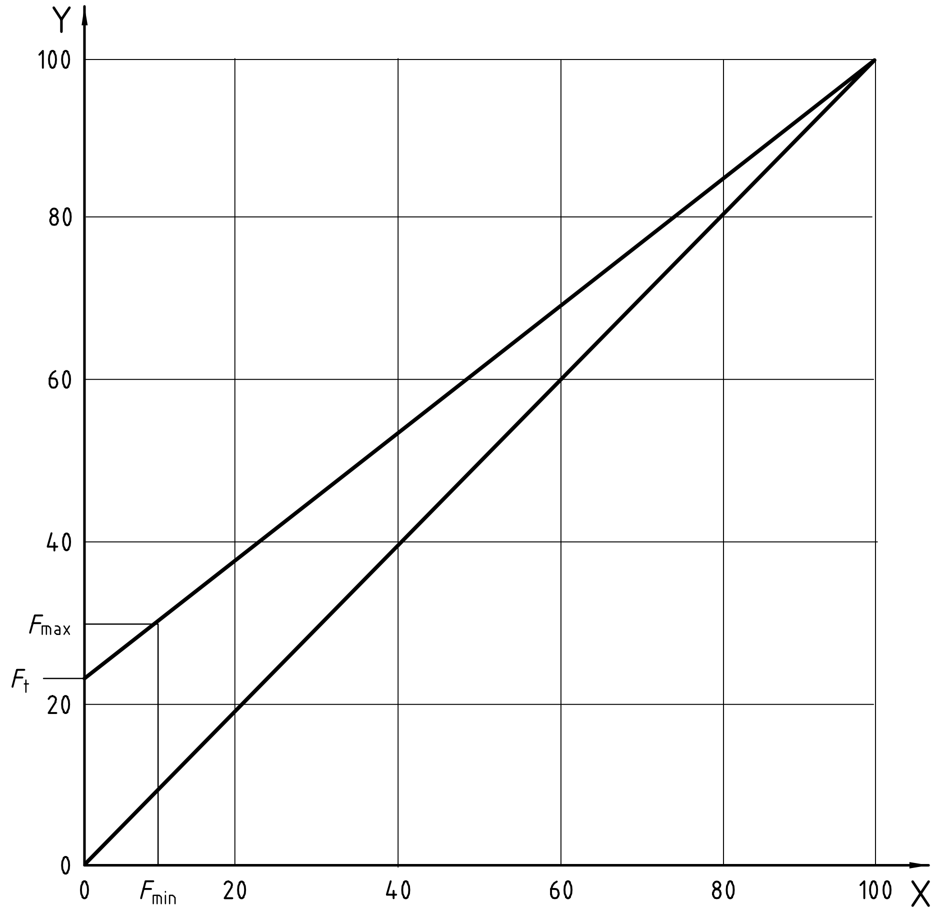


Figure 2 — Examples of test specimens mounted in universal fixtures

7.1.3 Test force

For analyses of fatigue test data, maximum forces shall be corrected to zero minimum force. A test force is obtained by correcting the maximum force to zero minimum force by means of the Johnson–Goodman method [Equation (3)]. The Johnson–Goodman relationship is illustrated by Figure 3, where F_{min} is 0,05 × F_u, and F_{max} is 0,3 × F_u, and the resulting F_t is 0,263 2 × F_u.

$$F_t = \frac{F_u(F_{max} - F_{min})}{F_u - F_{min}} \tag{3}$$



Key

X minimum force, % of F_u

Y maximum force, % of F_u

Figure 3 — Johnson–Goodman diagram

7.1.4 Force application

A longitudinal tensile force shall be applied, sinusoidally varying between the minimum test force determined according to 7.1.1 and the maximum test force determined according to 7.1.2. The test shall continue to endurance or until the specimen fails, whichever is sooner.

7.2 Conformity test

7.2.1 Purpose

The purpose of this test is to determine whether or not a chain meets the dynamic strength requirements given for it in ISO 606 or ISO 10190.

7.2.2 Endurance

Endurance shall be 3×10^6 cycles.

7.2.3 Minimum test force

The minimum force for the test shall be set in accordance with 7.1.1.

7.2.4 Maximum test force

The maximum test force shall be determined using Equation (4):

$$F_{max} = \frac{F_t F_u + \left[F_{min}\left(F_u - F_t\right)\right]}{F_u} \quad (4)$$

7.2.5 Number of tests

Three specimens shall be tested.

7.2.6 Acceptance

All specimens shall survive to endurance without failure.

7.3 Staircase test

7.3.1 Purpose

The purpose of this test is to determine the fatigue limit of the subject chain.

7.3.2 Description

For the purposes of this International Standard, a staircase test is one in which specimens are tested sequentially at predetermined, equally spaced, force levels. The first specimen is tested at a force level slightly greater than the estimated mean fatigue strength of the chain. If the first specimen runs to endurance (runs-out), the next specimen is tested at the next higher predetermined force level. If the first specimen fails before endurance, the next specimen is tested at the next lower predetermined force level. Force levels for subsequent tests are determined in a like manner, and the testing continues until the required number of tests are completed.

7.3.3 Endurance

Endurance shall be 10^7 cycles when testing for fatigue limit.

7.3.4 Rules for conducting a staircase test

The test shall begin with a response reversal, then a run-out followed by a failure, or a failure followed by a run-out.

The test shall have at least ten data points to determine the mean with 95 % confidence and six data points to determine the mean with 90 % confidence. It shall have the minimum number of data points in accordance with Table 2 to detect a difference in the mean of approximately one-half step size.

Table 2 — Required sample sizes

Confidence	3-step staircase	4-step staircase	5-step staircase
90 %	6	11	16
95 %	10	15	20

The highest force level in a staircase shall contain only failures.

The lowest force level in a staircase shall contain only run-outs.

Intermediate force levels in a staircase shall contain both failures and run-outs.

7.3.5 Determining step size

7.3.5.1 Using survival test with Probit analysis

See Annex A. The step size shall be determined in accordance with A.5.

7.3.5.2 Using combined test method (CTM)

See Annex B. The step size shall be determined in accordance with B.3.4.3 [see Equation (B.10)].

7.3.5.3 Using empirical method

Extensive testing has shown that reliable results can be obtained when the step size, expressed in newtons (N), is set according to Equation (5):

$$d \approx 14 p^{1,5} \tag{5}$$

8 Staircase test data analysis

8.1 Data

The data for a staircase test analysis shall be gathered in accordance with 7.3.

An additional test point at the end of a staircase test can be determined by the rules for conducting a staircase test (see 7.3). This additional test point, sometimes called a “phantom” point, shall be included in the analysis.

8.2 Plotting staircase data

It is customary to tabulate and plot the data as a staircase test progresses to ensure that the rules for constructing a staircase are followed. An example of such a data plot (3 levels and 95 % confidence level) is shown in Table 3.

Table 3 — Staircase data plot — Example

Test force	Invalid tests		Valid tests									
$F_t + 2d$	x											
$F_t + d$		x						x		x		#
F_t			x		x		o		o		o	
$F_t - d$				o		o						

o run-out

x failure

phantom point

8.3 Statistical calculations

8.3.1 Mean fatigue strength: 0,50 probability of survival

The mean fatigue strength shall be calculated using Equation (6).

$$F_{\text{b}} = \frac{\sum_{i=1}^{n} F_{\text{t}i}}{n} \tag{6}$$

where n is the total number of valid tests in the staircase calculations.

8.3.2 Standard deviations

The standard deviations of the staircase data shall be calculated using Equation (7).

$$S = \left[\frac{\sum_{i=1}^{n} F_{\text{t}i}^{2}}{n} - F_{\text{b}}^{2} \right]^{0,5} \tag{7}$$

8.3.3 Fatigue limit: 0,99865 probability of survival

The fatigue limit shall be calculated using Equation (8).

$$F_{\text{d}} = F_{\text{b}} - 3S + d \tag{8}$$

9 Report of test results

9.1 Test chain information

The originator shall provide to the user

a) the brand name or other identifying name or mark of the test chain,

b) the ISO number or manufacturer's number and the pitch of the test chain, and

c) the length in free pitches of the test specimens.

9.2 Test equipment and procedures

9.2.1 Test equipment

The originator shall provide to the user

a) the brand name and type of testing machine,

b) the maximum rated capacity of the test machine,

c) the number of machines used if more than one,

d) the method of dynamic force verification and monitoring, and

e) the method of calibration and the most recent date calibrated.

9.2.2 Test procedures

The originator shall provide to the user

a) the type of test; conformity or staircase,

b) the number of cycles to endurance, and

c) any ambient conditions that could affect the test results.

9.3 Test results for conformity and staircase tests

The originator shall provide a table of test results to the user, which shall include

a) identification of the test specimen,

b) the test sequence, the order in which the specimens were run,

c) the maximum and minimum force for each test,

d) the test force, corrected to zero minimum force, for each test,

e) the force cycling frequency,

f) the number of cycles at which each test was terminated,

g) the reason each test was terminated and, if a failure, the component of the chain that failed,

h) a brief summary of the post-test examination, if any, and

i) the machine used for each test, if more than one machine was used.

For a staircase test, the originator shall also provide the user with

— the mean fatigue strength, F_b, and

— the minimum fatigue strength, or fatigue limit.

Annex A
(informative)

Survival test with abridged Probit analysis

A.1 Principle

The purpose of this test is determine the mean fatigue limit and its standard deviation. A survival test with abridged Probit analysis may also be used to determine the step size for future staircase testing of the subject chain model.

A.2 Description

The survival test is a procedure in which groups of chain specimens are tested at different force levels such that the central force level contains approximately 50 % failures, the highest force level contains 90 % to 95 % failures, and the lowest force level contains 5 % to 10 % failures.

The Probit analysis is used to estimate the mean fatigue limit and standard deviation of the tested population. The step size is then set equal to between 67 % and 150 % of the standard deviation for future staircase testing of the subject chain model.

A.3 Test procedure

A.3.1 Test specimens

Prepare at least fifty, and preferably a hundred, test specimens in accordance with Clause 6, with all test specimens from the same production batch.

Provide additional test specimens for preliminary or invalid tests.

A.3.2 Endurance

Set endurance at 10^7 cycles.

A.3.3 Force levels

Use five force levels in the survival test; one giving approximately 50 % failures before endurance (very close to the mean), two force levels above that, and two below. There may be only four force levels if the mean falls approximately midway between two force levels.

Ensure that the interval between adjacent force levels is uniform.

The central force level may be selected by means of a brief (five or six tests) staircase test.

A.3.4 Testing

Allocate test specimens to each level according to Table A.1 or Table A.2 in order to make the precision at each force level comparable. At least five specimens at each level, and fifty specimens in total, are required for acceptable accuracy.

Table A.1 — Allocation of test specimens for five force levels

Expected run-out %	Relative group size
25 to 75	1,0
15 to 20 or 80 to 85	1,5
10 or 90	2,0
5 or 95	3,0
2 or 98	5,0

Table A.2 — Allocation of test specimens for four force levels

Expected run-out %	Relative group size
20 to 80	1,0
5 to 10 or 90 to 95	2,5

Test each specimen until it fails or reaches endurance.

— Central force level: approximately 50 % failures.

— Highest force level: at least one run-out.

— Lowest force level: at least one failure.

A.4 Analysis procedure

A.4.1 General

A Probit analysis is a complex technique for calculating an optimum line through the survival data points using a least-squares analysis to weight each data point according to its distance from the optimum line. This abridged method calculates a regression line through a single survival point on each force level. The abridged method has proven to be quite adequate for the purposes of this International Standard.

A.4.2 Distributions

Visually check the distributions of survival (cycles to failure) and force by means of a probability plot and confirm that the distribution of cycles to failure at the central and each higher force level is log-normal and that of survival across the force levels is normal.

As the Probit analysis assumes normal distributions, if either distribution is obviously not normal (or log-normal), do not attempt the analysis.

A.4.3 Standard deviation

Estimate the standard deviation of the survival test data, S, which is also the slope of the regression line, using Equation (A.1).

$$S = \left| \frac{n_{\mathrm{L}} \Sigma XY - \Sigma X \Sigma Y}{n_{\mathrm{L}} \Sigma X^2 - \left(\Sigma X \right)^2} \right| \tag{A.1}$$

where

n_L is the number of force levels in the test;

X is survival, in standard normal transform units, Z;

Y is the test force, in newtons (N).

A.4.4 Mean fatigue limit

Estimate the mean fatigue limit of the survival test data, Y_0, which is also the Y-intercept (of force with 50 % survival), using Equation (A.2).

$$Y_0 = \frac{\Sigma Y + S \Sigma X}{n_L} \qquad \text{(A.2)}$$

A.5 Step size

Set the step size for subsequent staircase testing at 67 % to 150 % of the standard deviation. The step size should be set nearly equal to 100 % of the standard deviation.

A.6 Example

A survival test was conducted with specimens of 16A chain tested at six force levels. All failures were obtained at the highest force level and all run-outs were obtained at the lowest force level. Survival data from the remaining four force levels are shown in Table A.3.

Table A.3 — Test results

Force level kN	n_L	Failures	Run-outs
19,45	25	23	2
17,60	10	6	4
15,75	10	4	6
13,90	25	1	24

A table usually is created for the survival test data and preliminary calculations. Table A.4 was created for this example.

Table A.4 — Survival test data and Probit analysis

n_L	X	Survival %	Z	Force, F kN	X	Y	X^2	Y^2	(XY)
25	1	96,00	1,751	13,90	1,751	13,90	3,0660	193,2	24,34
10	4	60,00	0,253	15,75	0,253	15,75	0,0640	248,1	3,98
10	6	40,00	−0,253	17,60	−0,253	17,60	0,0640	309,8	−4,45
25	23	8,00	−1,405	19,45	−1,405	19,45	1,9740	378,3	−27,33
				Total	0,346	66,70	5,168	1129,3	−3,46

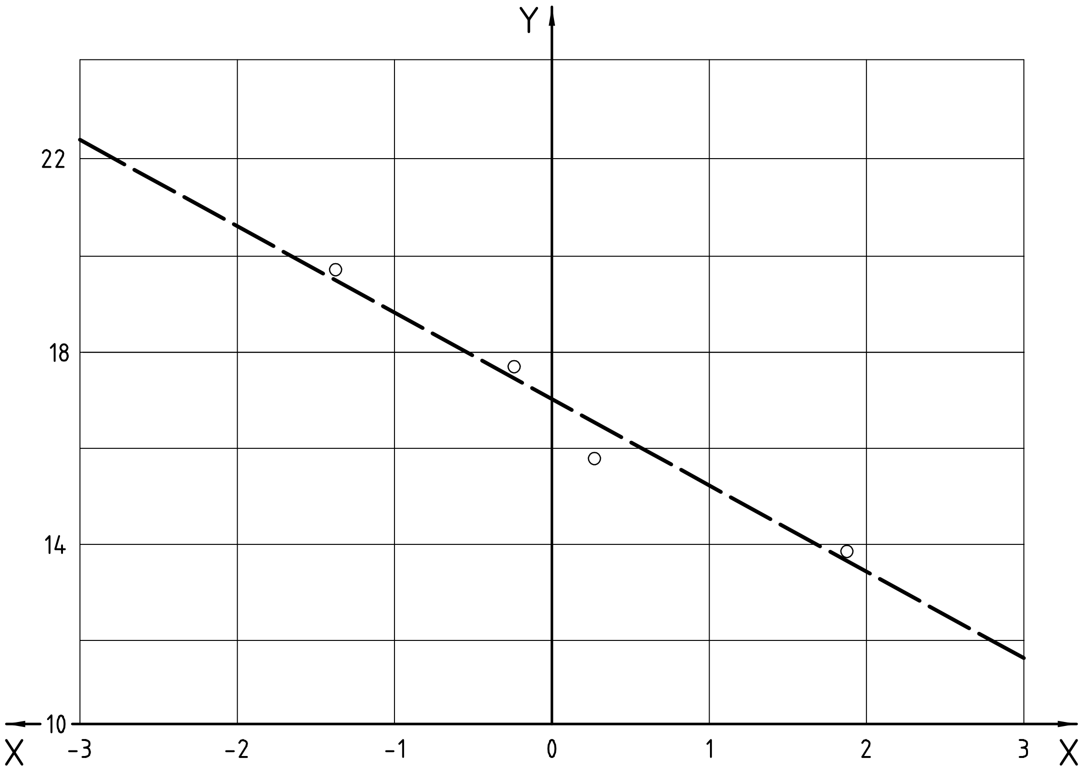
From this data, the calculated standard deviation was

$$S = \left| \frac{4(-3{,}46) - (0{,}346 \times 66{,}70)}{4 \times 5{,}168 - 0{,}346^2} \right| = 1{,}796 \text{ kN}$$

and the mean fatigue limit

$$Y_0 = \left| \frac{66{,}70 + (1{,}796 \times 0{,}346)}{4} \right| = 16{,}83 \text{ kN}$$

The results of this analysis are plotted in Figure A.1.



Key

X survival probability, standard normal transform units, Z

Y force, F, kN

Figure A.1 — Probit analysis

Annex B
(informative)

Combined test method

B.1 Purpose

The purpose of this test is to determine the slope of the F–N line and the fatigue limit of a particular chain in a single test series. The CTM also may be used to determine the step size for future staircase testing of the subject chain model.

B.2 Description

Numbers of test specimens in the CTM are determined by the different probabilities of survival, R, of the mean F–N line. The 14 F–N test method for determining R = 90 %, and the 24 F–N test method for determining R = 95 %, are described here. The 14 F–N test method is a procedure in which eight chain specimens are tested at four force levels in the finite life range, and five specimens plus one phantom data are tested in a staircase. The 24 F–N test method is a procedure in which fourteen chain specimens are tested at four force levels in the finite life range, and nine specimens plus one phantom data are tested in a staircase. The mean F–N line and the standard deviation of fatigue life are determined by statistical calculation. The standard deviation of force in a staircase is derived from the standard deviation of fatigue life in a finite life range, and is the step size for the staircase test.

B.3 Test procedure

B.3.1 Test specimens

Prepare at least 13 test specimens for the 14 F–N test method, or 23 test specimens for the 24 F–N test method, in accordance with Clause 6, with all test specimens from the same production batch. Provide additional test specimens for preliminary or invalid tests.

B.3.2 Endurance

For the staircase portion of the test, set endurance at 10^7 cycles. If endurance is set between 3×10^6 and 10^7 cycles, extrapolate the results to 10^7 cycles by the method given in Annex G.

B.3.3 Force levels

For the finite life portion of the test, establish four test force levels (F_A, F_B, F_C, and F_D) in accordance with B.3.4.1.

For the staircase portion of the test, an initial test force level, F_1, may be set at the force of two steps plus the force where the mean F–N line intersects 10^6 cycles, with additional test force levels in increments of the step size.

B.3.4 Testing

B.3.4.1 Preliminary tests

Test one specimen at the lowest force level (F_D) in the finite life portion. If the measured fatigue life departs significantly from the 5×10^5 cycles, test an additional specimen at an adjusted force level. When the resulting fatigue life is near 5×10^5 cycles, use that force level as (F_D). Then test one specimen at the highest force level (F_A) in the finite life portion, with this highest force level set at no more than 60 % of the minimum tensile strength in ISO 606 or ISO 10190. Calculate the other test force values using Equations (B.1) to (B.3).

$$\Delta = \frac{F_A - F_D}{3} \tag{B.1}$$

$$F_B = F_A - \Delta \tag{B.2}$$

$$F_C = F_A - 2\Delta \tag{B.3}$$

B.3.4.2 Finite life tests

For the 14 F–N test method, complete the finite life portion of the test by testing a total of two specimens at each force levels. For the 24 F–N test method, complete the finite life portion of the test by testing a total of four specimens at force levels F_A and F_B, and three specimens at force levels F_C and F_D. Determine the equation for the F–N line using Equations (B.4) to (B.8). Calculate the standard deviation of logarithmic life using Equation (B.9). Derive the standard deviation of force using Equation (B.10).

B.3.4.3 Staircase tests

The step size for the staircase test should be equal to the calculated standard deviation of force determined by Equation (B.10). Conduct a six-test staircase test (five valid test points plus one phantom point) for the 14 F–N test method, or a ten-test staircase test (nine valid test points plus one phantom point) for the 24 F–N test method, in accordance with 7.3.

B.4 Analysis procedure

B.4.1 Finite life portion

In the CTM, fatigue life is plotted on a logarithmic scale and force is plotted on a linear scale. The F–N line, standard deviation of logarithmic life, and standard deviation of force are determined from Equations (B.4) to (B.10).

The regression equations for the F–N line are

$$\lg N = \hat{\alpha} + \hat{\beta} F_t \tag{B.4}$$

$$\hat{\alpha} = \overline{\lg N} - \hat{\beta} \overline{F}_t \tag{B.5}$$

$$\hat{\beta} = \frac{\sum_{i=1}^{n_f} \left(F_{ti} - \overline{F}_t\right)\left(\lg N_i - \overline{\lg N}\right)}{\sum_{i=1}^{n_f} \left(F_{ti} - \overline{F}_t\right)^2} \tag{B.6}$$

$$\overline{\lg N} = \frac{1}{n_\mathrm{f}} \sum_{i=1}^{n_\mathrm{f}} \lg N_i \qquad \text{(B.7)}$$

$$\bar{F}_\mathrm{t} = \frac{1}{n_\mathrm{f}} \sum_{i=1}^{n_\mathrm{f}} F_{\mathrm{t}i} \qquad \text{(B.8)}$$

where the number of tests, n_f, are 8 for the 14 F–N test method, and 14 for the 24 F–N test method.

The estimated standard deviation of logarithmic life is

$$\hat{\sigma}_{\lg N} = \sqrt{\frac{1}{n_\mathrm{f} - 2} \sum_{i=1}^{n_\mathrm{f}} \left[\lg N_i - \left(\hat{\alpha} + \hat{\beta} F_{\mathrm{t}i} \right) \right]^2} \qquad \text{(B.9)}$$

B.4.2 Staircase portion

The estimated standard deviation of force is

$$\hat{\sigma}_\mathrm{F} = \frac{1}{\left| \hat{\beta} \right|} \hat{\sigma}_{\lg N} \qquad \text{(B.10)}$$

The estimated mean fatigue strength, F_b, is

$$F_\mathrm{b} = \frac{1}{n_\mathrm{s}} \sum_{j=1}^{n_\mathrm{s}} F_{\mathrm{t}j} \qquad \text{(B.11)}$$

where the number of tests, n_s, are 6 for the 14 F–N method, and 10 for the 24 F–N method.

B.5 R–F–N curve

The mean R–F–N curve, at R = 50 % probability of survival, is defined by Equation (B.4) for the finite life area, and by Equation (B.11) for endurance at the staircase test area.

Using data collected by the 14 F–N test method, the R–F–N curve, at R = 90 % probability of survival, is defined by Equation (B.12) for the finite life area, and Equation (B.13) for endurance at the staircase test area. The value of q is 1,28.

Using data collected by the 24 F–N test method, the R–F–N curve, at R = 95 % probability of survival, is defined by Equation (B.12) for the finite life area, and Equation (B.13) for endurance at the staircase test area. The value of q is 1,64.

For either case, extrapolate the fatigue limit to 10^7 cycles using the method given in Annex G, link this point with the point at endurance, and extend that line to connect to a line at the finite life area.

$$\lg N = \hat{\alpha} + \hat{\beta} F_\mathrm{t} - q \hat{\sigma}_{\lg N} \qquad \text{(B.12)}$$

$$F_{0,90} \text{ or }_{0,95} = F_\mathrm{b} - \frac{q}{\left| \hat{\beta} \right|} \hat{\sigma}_{\lg N} \qquad \text{(B.13)}$$

B.6 Sample test report and graph

Fatigue test report

Report No.: 1001 Page 1 of 2 Report date: 2003-07-31

Chain:

Brand:	Number:	Pitch:	Specimen length:	Other:
ABC Chain	16A	25,4 mm	5P,ILEE	

Mechanical properties:

Not taken

Test:

Type:	Endurance:	Temperature:	Other:
Combined (24 F–N)	3×10^6 cycles	Approx. 20°C	Moderate humidity

Machine:

Brand:	Type:	No. used:	Calibration date:	Force verification and monitoring:
XYZ	Servo-hydraulic	1	2000-07-12	Periodic, strain-gauge bar

Date	**Test No.**	**Frequency** Hz	F_{max} kN	F_{min} kN	F_t kN	**Cycles, N**	**Failure**	**Remarks**
03-06-05	001	13	33,3	1,80	32,55	7,055E4	IP	
03-06-05	002	13	24,9	1,80	23,87	2,381E5	IP	
03-06-05	003	13	30,5	1,80	29,66	1,104E5	IP	
03-06-06	004	13	30,5	1,80	29,66	8,980E4	IP	
03-06-06	005	13	24,9	1,80	23,87	2,510E5	IP	
03-06-06	006	13	27,7	1,80	26,77	2,236E5	IP	
03-06-07	007	13	33,3	1,80	32,55	9,895E4	IP	
03-06-07	008	13	24,9	1,80	23,87	2,885E5	IP	
03-06-08	009	13	33,3	1,80	32,55	6,891E4	IP	
03-06-08	010	13	33,3	1,80	32,55	6,036E4	IP	
03-06-08	011	13	30,5	1,80	29,66	9,309E4	IP	
03-06-08	012	13	30,5	1,80	29,66	1,242E5	IP	
03-06-09	013	13	27,7	1,80	26,77	1,905E5	IP	
03-06-09	014	13	27,7	1,80	26,77	2,379E5	IP	

Results and conclusions:

α = 7,07

β = −0,07

$\sigma_{\lg N}$ = 0,081

σ_F (s) = 1,188

The results of the staircase tests are plotted on the attached graph [see Figure B.1].

Signed: ______________________________

Fatigue test report

Report No.: 1001 Page 2 of 2 Report date: 2003-07-31

Chain:

Brand:	Number:	Pitch:	Specimen length:	Other:
ABC Chain	16A	25,4 mm	5P,ILEE	

Mechanical properties:

Not taken

Test:

Type:	Endurance:	Temperature:	Other:
Combined (24 F–N)	3×10^6 cycles	Approx. 20°C	Moderate humidity

Machine:

Brand:	Type:	No. used:	Calibration date:	Force verification and monitoring:
XYZ	Servo-hydraulic	1	2000-07-12	Periodic, strain-gauge bar

Date	**Test No.**	**Frequency** Hz	F_{max} kN	F_{min} kN	F_t kN	**Cycles, N**	**Failure**	**Remarks**
03-06-12	015	13	19,6	1,80	18,40	8,471E5	IP	
03-06-13	016	13	18,4	1,80	17,16	3,000E6	NF	
03-06-16	017	13	19,6	1,80	18,40	5,581E5	IP	
03-06-19	018	13	18,4	1,80	17,16	1,240E6	IP	
03-06-20	019	13	17,2	1,80	15,92	3,000E6	NF	
03-06-23	020	13	18,4	1,80	17,16	3,000E6	NF	
03-06-26	021	13	19,6	1,80	18,40	8,124E5	IP	
03-06-27	022	13	18,4	1,80	17,16	3,000E6	NF	
03-06-30	023	13	19,6	1,80	18,40	3,000E6	NF	
	024		20,8	1,80	19,64			Phantom point

Results and conclusions:

F_t	Staircase	Histogram
19,64	#	#
18,40	x x x o	xxxo
17,16	o x o o	oxoo
15,92	o	o

F_b = 17,78 kN

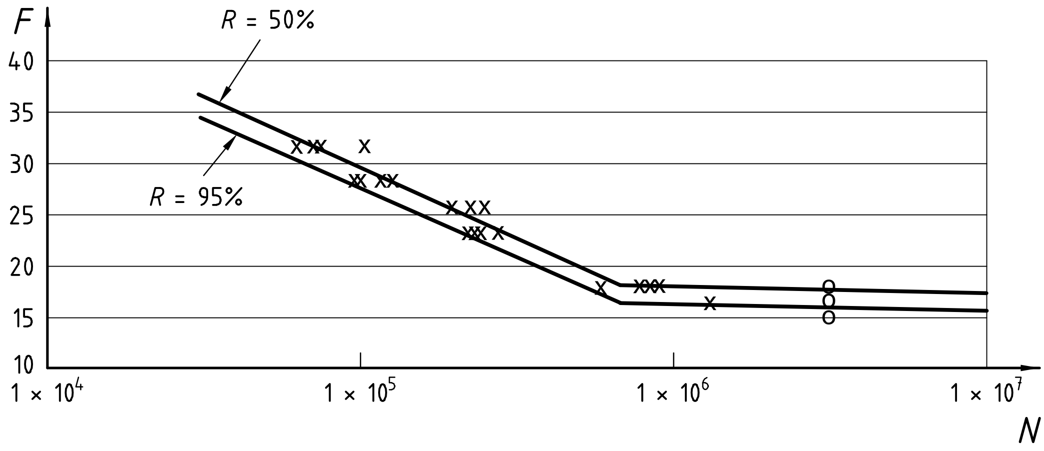
σ_F = 1,188 kN

$F_{0,95}$ = 15,83 kN (at 3×10^6 cycles)

$F_{0,95}$ = 15,16 kN (at 10^7 cycles)

The results of the staircase tests are plotted on the attached graph [see Figure B.1].

Signed: John Smith



Key

F force, kN

N combined cycles to failure

R probability of survival

Figure B.1 — Sample CTM test results

Annex C
(informative)

Justification for adding one step to fatigue limit in staircase analysis

C.1 Introduction

The staircase analyses in this International Standard utilize all test points, both failures and run-outs. The calculated minimum fatigue strength ($F_b - 3S$) is always less than the lowest test force. By definition, all responses at the lowest test force must be run-outs. Consequently, the minimum fatigue strength, with a 0,135 % probability of failure, must be greater than the lowest test force in all cases.

C.2 Analysis

Staircases, having fifty to seventy-five tests, were constructed by combining several staircases with ten tests each. Means and standard deviations were calculated for all tests and failures only in each staircase. Calculations for 10A, 16A, and 24A chains, are presented in Tables C.1 to C.4. A graph of the four-step staircase analysis for 16A chain is shown in Figure C.1.

Table C.1 — Analysis of 10A chain, four-step staircase data

Force (N)	**x**	**o**	n = 75	d = 925		
8 810	7	0		**Analysis of all data points:**		
7 885	21	8		F_b = 7 393	S = 747	$F_b - 3S$ = 5152
6 960	8	23		**Analysis of failures only:**		
6 035	0	8		F_b = 7 860	S = 596	$F_b - 3S$ = 6072
Total	36	39		1,232S = 0,995d = Difference = 920		

Table C.2 — Analysis of 16A chain, four-step staircase data

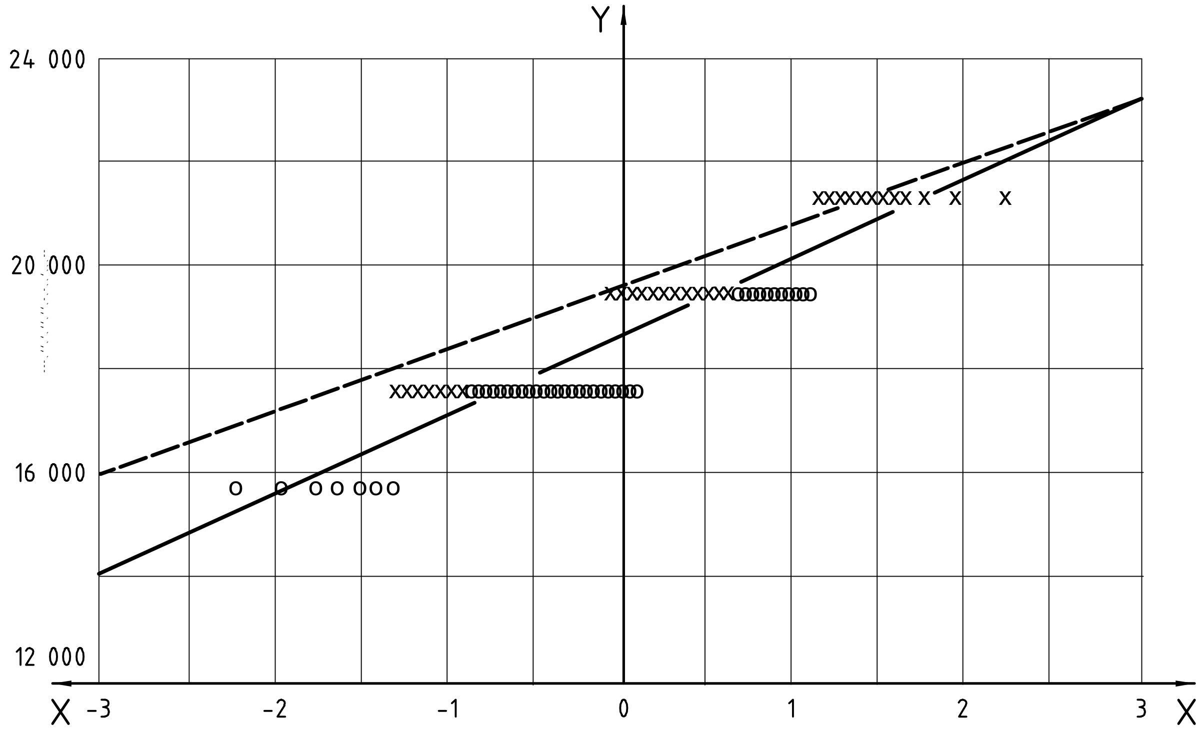
Force (N)	**x**	**o**	n = 75	d = 1 855		
21 315	9	0		**Analysis of all data points:**		
19 460	21	9		F_b = 18 620	S = 1 521	$F_b - 3S$ = 14 057
17 605	7	22		**Analysis of failures only:**		
15 750	0	7		F_b = 19 563	S = 1 214	$F_b - 3S$ = 15 921
Total	37	38		1,226S = 1,005d = Difference = 1 864		

Table C.3 — Analysis of 16A chain, three-step staircase data

Force (N)	**x**	**o**	n = 50	d = 1 855		
21 315	9	0		**Analysis of all data points:**		
19 460	16	9		F_b = 19 203	S = 1 286	$F_b - 3S$ = 15 345
17 605	0	16		**Analysis of failures only:**		
Total	25	25		F_b = 20 128	S = 890	$F_b - 3S$ = 17 458
				1,643S = 1,139d = Difference = 2113		

Table C.4 — Analysis of 24A chain, five-step staircase data

Force (N)	**x**	**o**	n = 75	d = 3 240		
39 350	5	0		**Analysis of all data points:**		
36 110	14	5		F_b = 32 610	S = 3 540	$F_b - 3S$ = 21 990
32 870	11	13		**Analysis of failures only:**		
29 630	9	10		F_b = 34 113	S = 3 167	$F_b - 3S$ = 24 612
26 390	0	8		0,741S = 0,809d = Difference = 2622		
Total	39	36				



Key

X failure probability, standard normal transform units, Z

Y force, F, N

o run-outs

x failures

——— distribution, all data

--------- distribution, failures only

Figure C.1 — 16A chain fatigue analysis

Analysis of 10A and 16A four-step staircases showed the calculated minimums for failures were 0,99 and 1,00 steps and 1,23 and 1,22 standard deviations higher than the calculated minimums for all tests. Analysis of a 16A three-step staircase showed that the calculated minimum for failures was 1,14 steps and 1,64 standard deviations higher than the calculated minimum for all tests. Analysis of the 24A five-step staircase showed that the calculated minimum for failures was 0,81 of a step and 0,74 of a standard deviation higher than the calculated minimum for all tests.

C.3 Conclusions

The following conclusions can be drawn from the foregoing.

a) The fatigue limit, with 99,865 % survival (0,135 % probability of failure), is one step greater than the minimum fatigue strength calculated from all tests.

b) The three-step and four-step staircase analyses support the first conclusion very well.

c) The five-step staircase analysis does not support the first conclusion very well, probably because of the large variance.

d) The fatigue limit, with 99,865 % survival (0,135 % probability of failure), is one standard deviation greater than the minimum fatigue strength calculated from all test points only when the standard deviation is equal to the step size.

Annex D
(informative)

Adding an additional “phantom” point at the end of staircase test

The rules for selecting the third and subsequent test force levels in a staircase dictate that the next test is to be run at a one-step-higher force level if the test just completed was a run-out, and at a one-step-lower force level if the test just completed was a failure. This permits the force level at which a test would be run after the final actual test in a staircase to be determined. Consequently, one data point may be added to the staircase series, after the final test point, even though a test at that point was not actually run.

The procedure is as follows: if the final test was a run-out, add a “phantom” point at one step higher test load; if the final test was a failure, add a phantom point at one step lower test load.

There is no way of knowing if the phantom test would be a failure or a run-out, so only one phantom point after the final test point can be determined.

Annex E
(informative)

Reporting fatigue test results

E.1 General

This annex suggests ways of presenting the results of roller chain fatigue tests, and presents both tabular and graphical methods. Sample fatigue test report forms are presented and explained, and sample graphical methods of presenting fatigue test results are given.

E.2 Tabular presentation of results

This clause presents a format for reporting (see also Annexes B, E and H) the required data from 9.1, 9.2 and 9.3, and gives a brief description of each item of information that may be entered in the appropriate space of this fatigue test report, keyed to the (here) numbered spaces on the form (unnumbered spaces not being in need of explanation).

<table>
<tr><td colspan="10">Fatigue test report
Report No.:   Report date:</td></tr>
<tr><td colspan="10">Chain:</td></tr>
<tr><td colspan="2">Brand:
1</td><td colspan="2">Number:
2</td><td>Pitch:
3</td><td colspan="2">Specimen length:
4</td><td colspan="3">Other:
5</td></tr>
<tr><td colspan="10">Mechanical properties: 6</td></tr>
<tr><td colspan="10">Test:</td></tr>
<tr><td colspan="2">Type:
7</td><td colspan="2">Endurance:
8</td><td colspan="3">Temperature:
9</td><td colspan="3">Other:
10</td></tr>
<tr><td colspan="10">Machine:</td></tr>
<tr><td colspan="2">Brand:
11</td><td colspan="2">Type:
12</td><td>No. used:</td><td colspan="2">Calibration date:
13</td><td colspan="3">Force verification and monitoring:
14</td></tr>
<tr><td>Date</td><td>Test No.</td><td>Frequency
Hz</td><td>F_{max}
kN</td><td>F_{min}
kN</td><td>F_t
kN</td><td>Cycles, N</td><td>Failure</td><td colspan="2">Remarks</td></tr>
<tr><td>15</td><td>16</td><td>17</td><td>18</td><td>19</td><td>20</td><td>21</td><td>22</td><td colspan="2">23</td></tr>
<tr><td colspan="10">Results and conclusions:
24</td></tr>
<tr><td colspan="10">Signed: ______________________________</td></tr>
</table>

Key

1 brand name or other identifying name or mark of the tested chain

2 ISO number or manufacturer's number of the chain

3 nominal pitch of the chain

4 length of test specimens, in free pitches [a]

5 other characteristics of the test chain that might be helpful (production batch identity, experimental chain designation, or non-standard design features)

6 results of tensile tests, or bush and pin press out force tests

7 type of test; conformity, staircase, survival, combined method, or finite life

8 declared endurance, in number of cycles, for a conformity, staircase, survival, or combined method test

9 mean ambient temperature, or range of minimum and maximum temperatures, during test

10 other environmental conditions (high humidity, etc.) that might affect test results

11 brand name or other identifying name or mark of the testing machine

12 type (harmonic spring, servo-hydraulic, electro-magnetic, etc.) of testing machine

13 date on which the machine was last calibrated

14 dynamometer and transducer used to verify and monitor the test force [b]

15 date the individual test was completed

16 sequence number of the test [c]

17 frequency at which the fluctuating force was applied

18 maximum value of the fluctuating force (see Table 1)

19 minimum value of the fluctuating force (see Table 1)

20 test force, corrected to zero minimum force (see Table 1)

21 number of cycles at which the test ended

22 component that failed — inner plate (IP), outer plate (OP), Pin (PIN), or intermediate plate (ITP) [d]

23 any unique notes concerning the test, e.g. if a terminal connector link failed and was replaced during the test, it should be noted.

24 results and conclusions [e]

[a] A note of inner link each end (ILEE) or outer link each end (OLEE) should also be given here.

[b] There also should be a note as to whether the monitoring was periodic or continuous, and whether or not there was feedback control.

[c] This may also be combined with machine reference number, if more than one testing machine was used.

[d] If the test ran-out, “No Failure” (NF) may be entered.

[e] For a conformity test, the information required by 9.3, and a statement of “Accepted” or “Not Accepted”, explaining failure, if possible; for a staircase test, the information required by 9.3, and any supplemental information that might be helpful to the user; for a combined method test, the information required by Annex B, and any supplemental information that might be helpful to the user; for a finite life method test, the information required by Annex H, and any supplemental information that might be helpful to the user.

E.3 Graphical presentation, suggested forms

E.3.1 General

If sufficient data is generated, and the user so requests, the originator should present fatigue test results in a graphical form. Usually, only a combined test, a finite life test, or a finite life test paired with a staircase test on the same batch of chain, generates data suitable for graphical presentation.

E.3.2 Types of graph

The most common graphical methods of presenting fatigue test data are the F-Log N and Log F-Log N plots. The dependent variable (fatigue life in cycles) is plotted on the abscissa, a logarithmic scale. The independent variable (test force in kilonewtons), is plotted on the ordinate, an arithmetic or logarithmic scale.

E.3.3 F-Log N graph

In this presentation, force is assigned an arithmetic scale and life is assigned a logarithmic scale. A typical F-Log N plot for a finite life test is shown in Annex H.

The failures (x) from finite life tests or staircase tests shall be plotted on the test force level at the number of cycles at which failure occurred. The run-outs (o) from staircase tests shall be plotted on the test force level at the predetermined number of cycles for endurance. When there are multiple run-outs at the same force level, the number of run-outs shall be noted just to the right of the symbol.

Transmission chain fatigue test results are acceptably represented by two-segment straight lines. One is a horizontal, or a nearly horizontal, line extending from the fatigue strength at 10^7 cycles to the fatigue strength at 10^6 cycles, at a slope determined by the procedure described in Annex G. The other is a regression line extending from the fatigue strength at 10^6 cycles to the fatigue strength at approximately 10^4 cycles, calculated from finite life test data as described in Annex H.

All test data points shall be plotted on graphs along with calculated or constructed regression lines.

E.3.4 Log F-Log N graph

In this presentation, both force and life are assigned a logarithmic scale. A typical Log F-Log N plot is shown in the sample form presented in E.4.

The failures (x) from finite life tests or staircase tests shall be plotted on the test force level at the number of cycles at which failure occurred. The run-outs (o) from staircase tests shall be plotted on the test force level at the predetermined number of cycles for endurance. When there are multiple run-outs at the same force level, the number of run-outs shall be noted just to the right of the symbol. The failures (x) and run-outs (o) shall be plotted as shown in the graph in Figure E.1.

The slope of the regression line, extending from the fatigue strength at 10^7 cycles to the fatigue strength at 10^6 cycles, is determined by the procedure described in Annex G. The other regression line, extending from the fatigue strength at 10^6 cycles to the fatigue strength at 10^4 cycles, is calculated from finite life test data as described in Annex H.

All test data points shall be plotted on graphs along with calculated regression lines.

E.4 Sample test reports

A staircase test and a finite life test were conducted on one batch of “BCD Chain Company’s” number 16A chain. Results of the staircase test are presented in the following sample test report. Results of the finite life test are given in Annex H. The results of the sample staircase test are shown together with the results of the finite life test from Annex H on the graph of Figure E.1.

NOTE A combined test was conducted on one batch of “ABC Chain” Company’s number 16A chain. The results of that sample test are presented in Annex B.

A conformity test was also conducted on a batch of “BCD Chain Company’s” number 16A chain. The results of that test are given in the sample test report concluding this annex.

Fatigue test report

Report No.: 1002 Page 1 of 1 Report date: 2003-07-20

Chain:

Brand:	Number:	Pitch:	Specimen length:	Other:
BCD Chain	16A	25,4 mm	13P,ILEE	

Mechanical properties:

Not taken

Test:

Type:	Endurance:	Temperature:	Other:
Staircase	10^7 cycles	Approx. 20°C	Moderate humidity

Machine:

Brand:	Type:	No. used:	Calibration date:	Force verification and monitoring:
XYZ	Mech., harmonic spring	1	2000-07-29	Periodic, strain-gauge bar

Date	Test No.	Frequency Hz	F_{max} kN	F_{min} kN	F_t kN	Cycles, N	Failure	Remarks
03-06-12	001	31	17,35	2,224	15,75	4,771E6	IP	
03-06-16	002	31	15,57	2,224	13,90	1,000E7	NF	
03-06-20	003	31	17,35	2,224	15,75	1,000E7	NF	
03-06-22	004	31	19,12	2,224	17,60	4,096E6	IP	
03-06-26	005	31	17,35	2,224	15,75	8,480E6	IP	
03-06-30	006	31	15,57	2,224	13,90	1,000E7	NF	
03-07-10	007	31	17,35	2,224	15,75	1,000E7	NF	
03-06-11	008	31	19,12	2,224	17,60	1,463E6	IP	
03-06-17	009	31	17,35	2,224	15,75	1,000E7	NF	
03-06-17	010		19,12	2,224	17,60			Phantom point

Results and conclusions:

F_t	Staircase	Histogram
17,60	x x #	xx#
15,75	x o x o o	xxxo
17,16	o o	oo

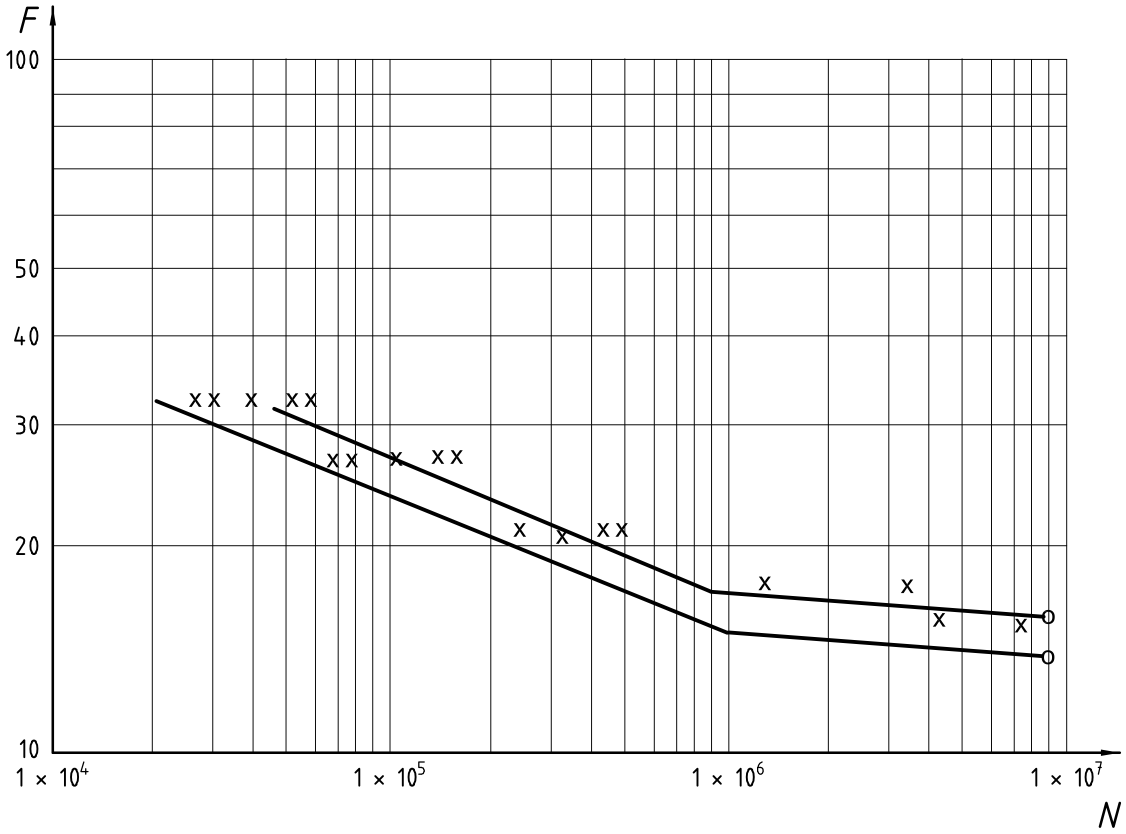
F_b = 17,78 kN

σ_F = 1,188 kN

$F_{d,0,99865}$ = 13,90 kN = $F_b - 3F + d$

The results of the staircase tests are plotted on the attached graph [see Figure E.1].

Signed: John Smith



Key

F force, kN

N life, cycles

Figure E.1 — Graph of sample staircase test and finite life test for a 16A chain (Log *F*/Log *N* plot)

Fatigue test report

Report No.: 1003 Page 1 of 1 Report date: 2003-07-20

Chain:

Brand:	Number:	Pitch:	Specimen length:	Other:
BCD Chain	16A	25,4 mm	5P,ILEE	

Mechanical properties:

Not taken

Test:

Type:	Endurance:	Temperature:	Other:
Conformity	3×10^6 cycles	Approx. 20°C	Moderate humidity

Machine:

Brand:	Type:	No. used:	Calibration date:	Force verification and monitoring:
XYZ	Mech., harmonic spring	1	2003-01-29	Periodic, strain-gauge bar

Date	**Test No.**	**Frequency** Hz	F_{max} kN	F_{min} kN	F_t kN	**Cycles, N**	**Failure**	**Remarks**
03-07-18	026	31	11,39	2,224	9,55	3,000E6	NF	
03-07-20	027	31	11,39	2,224	9,55	3,000E6	NF	
03-07-22	028	31	11,39	2,224	9,55	3,000E6	NF	

Results and conclusions:

Accepted

Signed: John Smith

Annex F
(informative)

Establishing chain application fatigue ratings

F.1 Scope and general

This International Standard prescribes procedures for determining the fatigue limit of transmission chains by means of a staircase test under specified laboratory conditions. Some of the conditions are a five-pitch specimen length, all specimens from a single production batch and a ten-test staircase. In actual applications, the chain length usually is between fifty and two-hundred-fifty pitches, the chains used may be from several production batches, and the total production volume greatly exceeds that represented by only six or ten tests. Additional analysis methods clearly are needed to evaluate the differences between specified laboratory conditions and actual applications.

This annex presents possible methods for evaluating some of the differences between a chain's fatigue limit under specific laboratory conditions and that chain's fatigue rating for a variety of applications. Neither it nor this International Standard as a whole prescribes a method for establishing chain application fatigue ratings.

Instead, this annex describes some methods that may be used to evaluate the effects of three specific differences between the fatigue limit obtained from laboratory testing and a fatigue rating suitable for applications. Experience has shown these methods to be reasonably reliable in evaluating the differences between a five-pitch specimen length and a much longer drive chain length, the production quantity represented by a six-test or ten-test sample and a much larger production quantity, and one production batch and many production batches. Some other factors that should be considered are mentioned, but methods to evaluate them are beyond the scope of this annex. There also may be factors that should be considered that are not mentioned in this annex.

F.2 Methods

F.2.1 Chain length

One method for evaluating the effect of difference between test specimen length and drive chain length follows.

It can be shown that, for $F_{\mathrm{b}N}$ to be the median of the least of N values:

$$A^N = 0{,}50 \qquad \text{(F.1)}$$

Similarly, for $F_{\mathrm{b}(-3SN)}$ to be the -3σ of N values:

$$A^N = 0{,}998\,65 \qquad \text{(F.2)}$$

For the purposes of this annex, N is the number of potential failure sites, or the number of inner plate apertures, in the given chain. Thus, $N = 12$ for a five-pitch test chain with an inner link at each end, and $N = 200$ for a one hundred-pitch drive chain. Calculated values of A^N, for selected values of N, are given in Table F.1 and shown in Figure F.1.

Then

$$F_{\mathrm{b}N} = F_{\mathrm{b}1} - Z_{(A,F\mathrm{b})}\, S_{\mathrm{P}} \qquad \text{(F.3)}$$

where

F_{bN} is the median (mean) fatigue strength of a sample of chains, each with N inner link apertures;

F_{b1} is the median (mean) fatigue strength of a sample of chains, each with one inner link aperture;

$Z_{(A,Fb)}$ is the standard normal transform corresponding to A^N and F_{bN};

S_P is the estimated standard deviation of population when $N = 1$.

and

$$F_{b(-3SN)} = F_{b1} - Z_{(A,-3\sigma)} S_P \quad \text{(F.4)}$$

where

$F_{b(-3SN)}$ is the minimum ($-3S$) fatigue strength of a sample of chains, each with N inner link apertures;

F_{b1} is the median (mean) fatigue strength of a sample of chains, each with one inner link aperture;

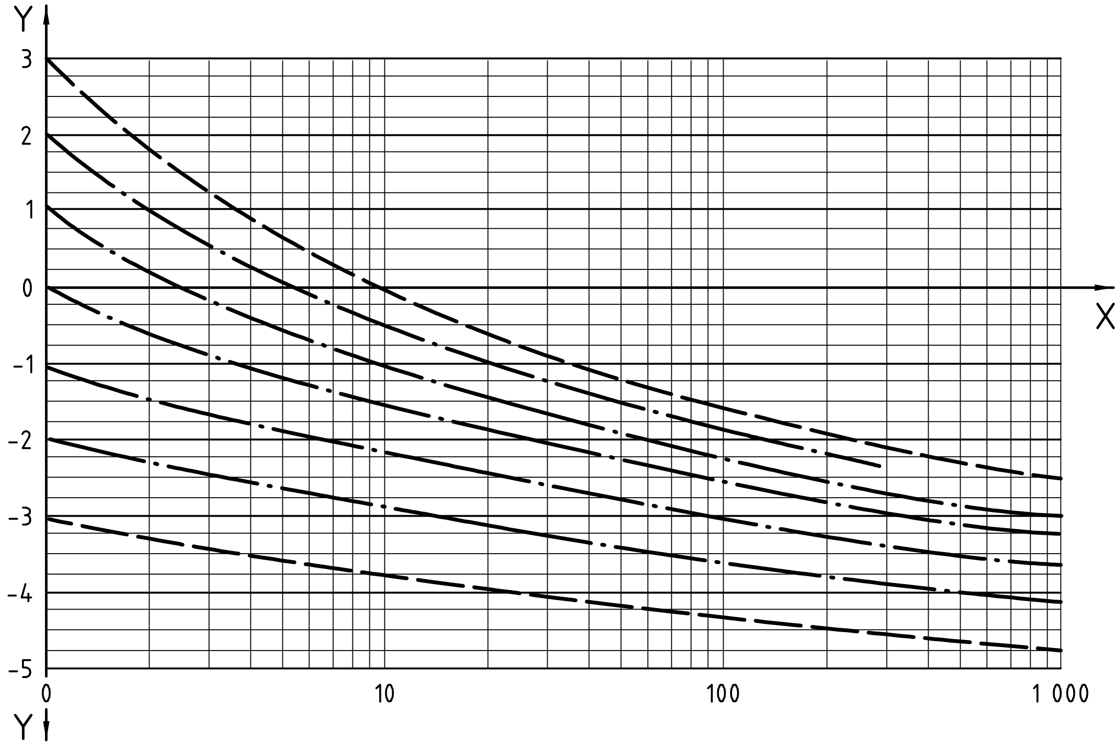
$Z_{(A,-3\sigma)}$ is the standard normal transform corresponding to A^N and $F_{b(-3SN)}$.

The standard deviation of the population (S_P) is estimated by simultaneously solving Equations (F.3) and (F.4). This calculation is an approximation of S_P because the interval between standard deviations is not uniform.

Finally, the mean and minimum fatigue limit of a chain of any length may be estimated by substituting the appropriate values for F_{b1}, S_P, $Z_{(A,Fb)}$, and $Z_{(A,\,-3\sigma)}$.

Table F.1 — Adjusted probabilities (A^N) for specimen size (N)

N	−3σ		−2σ		−1σ		F_b		+3σ		+2σ		+1σ	
	A^N	Z	A^N	Z	A^N	Z	A^N	Z	A^N	Z	A^N	Z	A^N	Z
1	0,998 650	−3,000	0,977 250	−2,000	0,841 345	−1,000	0,500 000	0,000	0,158 655	1,000	0,022 750	2,000	0,001 350	3,000
2	0,999 325	−3,205	0,988 560	−2,275	0,917 248	−1,387	0,707 107	−0,545	0,398 316	0,258	0,150 831	1,033	0,036 742	1,790
4	0,999 662	−3,399	0,994 263	−2,528	0,957 731	−1,725	0,840 896	−0,998	0,631 122	−0,335	0,388 370	0,284	0,191 682	0,872
8	0,999 831	−3,584	0,997 128	−2,762	0,978 637	−2,026	0,917 004	−1,385	0,794 432	−0,822	0,623 193	−0,314	0,437 815	0,157
12	0,999 887	−3,689	0,998 084	−2,892	0,985 707	−2,189	0,943 874	−1,588	0,857 771	−1,070	0,729 595	−0,612	0,576 581	−0,193
16	0,999 916	−3,761	0,998 563	−2,981	0,989 261	−2,299	0,957 603	−1,724	0,891 309	−1,234	0,789 426	−0,804	0,661 676	−0,417
20	0,999 932	−3,816	0,998 850	−3,048	0,991 400	−2,382	0,965 936	−1,824	0,912 059	−1,354	0,827 655	−0,945	0,718 648	−0,579
24	0,999 944	−3,863	0,999 042	−3,103	0,992 828	−2,449	0,971 532	−1,904	0,926 159	−1,448	0,854 163	−1,054	0,759 329	−0,704
28	0,999 952	−3,900	0,999 178	−3,148	0,993 849	−2,503	0,975 549	−1,969	0,936 364	−1,525	0,873 616	−1,144	0,789 790	−0,806
32	0,999 958	−3,930	0,999 281	−3,187	0,994 616	−2,550	0,978 572	−2,025	0,944 092	−1,590	0,888 496	−1,219	0,813 435	−0,891
36	0,999 962	−3,958	0,999 361	−3,221	0,995 213	−2,591	0,980 930	−2,073	0,950 146	−1,646	0,900 245	−1,283	0,832 313	−0,963
40	0,999 966	−3,986	0,999 425	−3,251	0,995 690	−2,627	0,982 821	−2,116	0,955 018	−1,696	0,909 755	−1,339	0,847 731	−1,027
60	0,999 977	−4,079	0,999 617	−3,364	0,997 125	−2,762	0,988 514	−2,274	0,969 782	−1,878	0,938 894	−1,546	0,895 720	−1,258
80	0,999 983	−4,144	0,999 712	−3,443	0,997 843	−2,854	0,991 373	−2,381	0,977 250	−2,000	0,953 811	−1,683	0,920 723	−1,410
100	0,999 986	−4,200	0,999 770	−3,503	0,998 274	−2,924	0,993 092	−2,462	0,981 758	−2,091	0,962 875	−1,785	0,936 059	−1,523
120	0,999 989	−4,238	0,999 808	−3,551	0,998 561	−2,981	0,994 240	−2,527	0,984 775	−2,164	0,968 965	−1,866	0,946 425	−1,611
140	0,999 990	−4,275	0,999 836	−3,591	0,998 767	−3,027	0,995 061	−2,580	0,986 936	−2,224	0,973 339	−1,932	0,953 899	−1,684
160	0,999 992	−4,303	0,999 856	−3,626	0,998 921	−3,068	0,995 677	−2,626	0,988 560	−2,275	0,976 632	−1,989	0,959 543	−1,745
200	0,999 993	−4,359	0,999 885	−3,683	0,999 137	−3,134	0,996 540	−-2,701	0,990 837	−2,359	0,981 262	−2,081	0,967 501	−1,845
240	0,999 994	−4,396	0,999 904	−3,730	0,999 280	−3,187	0,997 116	−2,761	0,992 358	−2,426	0,984 360	−2,154	0,972 844	−1,924
300	0,999 995	−4,433	0,999 923	−3,786	0,999 424	−3,251	0,997 692	−2,833	0,993 882	−2,505	0,987 469	−2,240	0,978 215	−2,018
360	0,999 996	−4,470	0,999 936	−3,830	0,999 520	−3,302	0,998 076	−2,890	0,994 899	−2,569	0,989 546	−2,310	0,981 813	−2,093
400	0,999 997	−4,508	0,999 942	−3,856	0,999 568	−3,332	0,998 269	−2,923	0,995 408	−2,605	0,990 587	−2,349	0,983 617	−2,135
500	0,999 997	−4,545	0,999 954	−3,912	0,999 655	−3,393	0,998 615	−2,992	0,996 325	−2,681	0,992 462	−2,431	0,986 872	−2,222
600	0,999 998	−4,582	0,999 962	−3,953	0,999 712	−3,443	0,998 845	−3,047	0,996 936	−2,741	0,993 715	−2,496	0,989 048	−2,292



Key

X specimen size, N

Y adjusted probability, standard normal transform units, Z

Figure F.1 — Adjusted probabilities (A^N) for specimen size (N)

F.2.2 Sample size

When establishing chain application fatigue ratings, the sample selected for staircase testing should be sufficient to minimize statistical error.

F.2.3 Sample representativeness

When establishing chain application fatigue ratings, the sample selected for staircase testing should be representative of more than one production batch.

A staircase test for establishing chain application fatigue ratings should contain at least thirty specimens, equally representing at least three different production batches.

F.3 Other factors

F.3.1 Statistical limits

The definition of fatigue limit states that there is a 0,135 % probability of failure at 10^7 cycles. The probability of failure is small, but does exist. Either users should be warned of this possibility of fatigue failure, or the chain producer should make additional compensation for it.

F.3.2 Fatigue life

Limited testing shows there are some link plate fatigue failures beyond 10^7 cycles, which indicates that the slope of the F–N line beyond 10^7 cycles may not be quite zero (or ∞). A chain still may fail no matter how carefully selected and maintained. No clear directive can be given on this, but both users and producers should be aware of this possibility of fatigue failure.

F.3.3 Wear

Testing indicates that chain and sprocket wear can reduce the fatigue strength and life of transmission chain. Great variation virtually precludes the prediction of wear effects, but here again, both users and producers should be aware of the possibility of fatigue failure.

F.3.4 Unidentified factors

Many other factors, not listed here, may affect the fatigue life of transmission chain. One common way to treat them is by clearly enumerating the drive conditions under which the ratings apply and exclude everything else.

F.4 Sample calculations

In this example, each of the three production batches had low variation (3-step staircases), but the means differed by about two steps. The constructed thirty-test staircase appears as follows:

Test force N	Staircase																													
19 450					x		x																							
17 600		x		o		o		x		x		x						x												
15 750	o		o						o		o		x		x		o		x		x		x				x			
13 900														o		o				o		o		x		o		x		o
12 050																									o				o	

Basic statistics for this staircase are

— mean fatigue strength, F_b = 15 688;

— standard deviation, S = 1 880;

— minimum fatigue strength, F_{b-3S} = 10 048;

— fatigue limit: $F_{b-3S} + d$ = 11 898.

In this example, test chain length was 13 pitches, with inner link each end (N = 28). Adjustments for chain length are as follows.

15 688 = F_{b1} –1,969S_P a) F_{b1} = 15 688 + 1,969 (1 963)

11 898 = F_{b1} –3,900S_P b) F_{b1} = 19 553

Subtracting b) from a) gives

$3\,790 = 1{,}931 S_{\mathrm{P}}$

$1\,963 = S_{\mathrm{P}}$

So, for a drive chain one hundred pitches long:

— mean fatigue strength, $F_{\mathrm{b200}} = 19\,553 - 2{,}701\ (1\,963) = 19\,553 - 5\,302 = 14\,251$;

— minimum fatigue limit, $F_{\mathrm{b}(-3S200)} = 19\,553 - 4{,}359\ (1\,963) = 19\,553 - 8\,557 = 10\,996$.

And, for a drive chain one hundred twenty pitches long:

— mean fatigue strength, $F_{\mathrm{b240}} = 19\,553 - 2{,}761\ (1\,963) = 19\,553 - 5\,420 = 14\,133$;

— minimum fatigue limit, $F_{\mathrm{b}(-3S240)} = 19\,553 - 4{,}396\ (1\,963) = 19\,553 - 8\,629 = 10\,924$.

Annex G
(informative)

Extrapolating fatigue strength from 3×10^6 cycles to 10^7 cycles

G.1 General

Endurance for the conformity test is 3×10^6 cycles, while endurance for the fatigue limit is 10^7 cycles. It follows then that a method is needed to extrapolate from a conformity test value at 3×10^6 cycles to a corresponding fatigue limit at 10^7 cycles. This annex gives one method of doing that.

G.2 Test data

Several staircase fatigue test series for 16A chain were selected, for nearly identical means and variances. Endurance for all test series was 10^7 cycles. All test chains were thirteen free pitches long with an inner link at each end.

The fatigue tests were run on a Schenck, 10-tonne, mechanical harmonic-spring, axial tensile fatigue testing unit. Minimum force was 2 225 N throughout all test series. Test forces, corrected to zero minimum force, were 13 900 N, 15 750 N, 17 600 N, 19 450 and 21 300 N. Step size was 1 850 N.

G.3 Constructed staircases

G.3.1 Phantom points

All of the test data were from tests run to 10^7 cycles. Staircases, with endurance set at 5×10^6 cycles and 3×10^6 cycles, were synthesized from that original data. When endurance was set at 5×10^6 cycles and 3×10^6 cycles, some of the failures in the tests run to 10^7 cycles became run-outs at the lesser endurance.

There were not enough test points at higher force levels to complete a synthesized staircase, so phantom points were added. All phantom test points were assumed to be failures to make the analysis conservative.

Some data points at lower force levels had to be discarded because there were not sufficient data points at the next higher level to justify their inclusion in the synthesized staircase.

G.3.2 Constructed staircase with endurance at 10^7 cycles

A staircase was constructed from the selected test data with endurance at 10^7 cycles. This constructed staircase contained seventy-six data points on four force levels.

G.3.3 Constructed staircase with endurance at 5×10^6 cycles

Next, endurance was set at 5×10^6 cycles for the staircase data in G.3.2. Two of the failures at the 19 450 N force level became run-outs, six of the failures at the 17 600 N force level became run-outs, and two of the failures at the 15 750 N force level became run-outs. Following the guidelines in G.3.1, two phantom points were added at the 21 300 N force level and eight phantom points were added at the 19 450 N force level. Eight tests were discarded at the 15 750 N force level and two tests were discarded at the 13 900 N force level.

G.3.4 Constructed staircase with endurance at 3×10^6 cycles

Finally, endurance was set at 3×10^6 cycles for the staircase data in G.3.2. Three of the failures at the 19 450 N force level became run-outs, eight of the failures at the 17 600 N force level became run-outs, and two of the failures at the 15 750 N force level became run-outs. Following the guidelines in G.3.1, three phantom points were added at the 21 300 N force level and ten phantom points were added at the 19 450 N force level. Ten tests were discarded at the 15 750 N force level and two tests were discarded at the 13 900 N force level.

G.3.5 Sample staircases and histograms

Sample staircases are shown in Figure G.1. Sample histograms are shown in Figure G.2.

G.4 Staircase analysis

G.4.1 Means

Only the mean fatigue strength was calculated for each constructed staircase. Standard deviations were not calculated because the addition of the phantom points could make them unreliable.

The calculated mean fatigue strengths were 16 724 N for endurance at 10^7 cycles, 17 308 N for endurance at 5×10^6 cycles, and 17 456 N for endurance at 3×10^6 cycles.

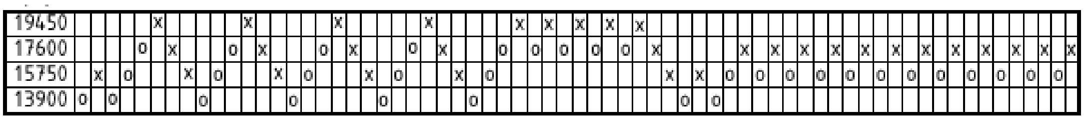
G.4.2 Differences

Mean fatigue strength was 3,5 % higher with endurance at 5×10^6 cycles, and 4,4 % higher with endurance at 3×10^6 cycles. The slope of the Log F-Log N line could have been determined by taking the slope from 3×10^6 to 10^7 cycles, the slope from 5×10^6 to 10^7 cycles, or an average of the two. It was decided to use the slope from 3×10^6 to 10^7 cycles because the dynamic strength requirements in ISO 10190 were set at 3×10^6 cycles, and that slope appeared to best fit the failure data.

G.4.3 Fatigue test staircases for 16A chain

Endurance = 10^7 cycles AVG FS = 16 724

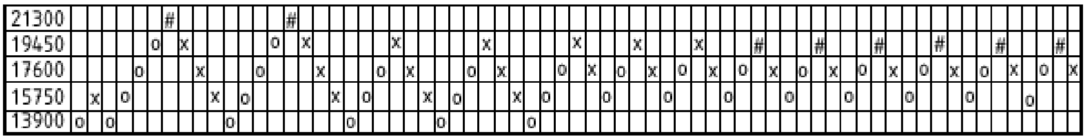
Force **Staircase**
N



a)

Endurance = 5×10^6 cycles AVG FS = 17 308 +3,5%

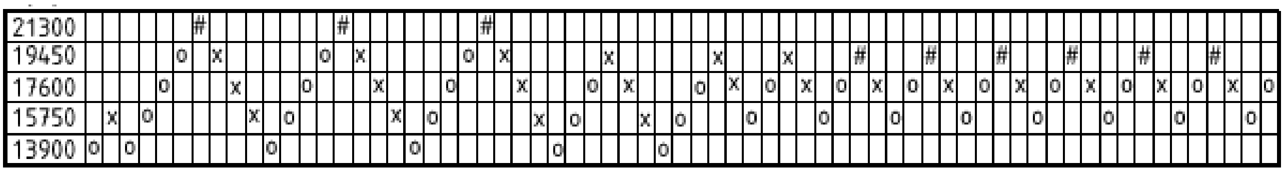
Force **Staircase**
N



b)

Endurance = 3×10^6 cycles AVG FS = 17 456 +4,4%

Force **Staircase**
N



c)

Key

x failure

o run-out

assumed failure

Figure G.1 — Sample staircases

G.4.4 Fatigue test histograms for 16A chain

Endurance = 10^7 cycles AVG FS = 16 724

Force **Histogram**
N

19450	x	x	x	x	x	x	x	x	x																					
17600	o	o	o	o	o	o	o	o	o	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
15750	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	x	x	x	x	x	x	x	
13900	o	o	o	o	o	o	o	o																						
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30

a)

Endurance = 5×10^6 cycles AVG FS = 17 308 +3,5%

Force **Histogram**
N

21300	#	#																												
19450	o	o	x	x	x	x	x	x	x	#	#	#	#	#	#	#	#													
17600	o	o	o	o	o	o	o	o	o	o	o	o	o	o	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
15750	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	x	x	x	x	x	x									
13900	o	o	o	o	o	o																								
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30

b)

Endurance = 3×10^6 cycles AVG FS = 17 456 +4,4%

Force **Histogram**
N

21300	#	#	#																											
19450	o	o	o	x	x	x	x	x	x	#	#	#	#	#	#	#	#	#	#											
17600	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	x	x	x	x	x	x	x	x	x	x	x	x	x
15750	o	o	o	o	o	o	o	o	o	o	o	o	o	o	x	x	x	x	x											
13900	o	o	o	o	o	o																								
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30

c)

Key

x failure

o run-out

assumed failure

Figure G.2 — Sample histograms

Annex H
(informative)

Finite life testing and data analysis

H.1 General

Finite life testing and analysis is used to determine the relationship between force and cycles to failure at numbers of cycles less than the inflection point.

H.2 Test procedure

H.2.1 Test specimens

At least 14 test specimens shall be prepared in accordance with Clause 6. All test specimens shall be from the same production batch.

Additional test specimens should be provided for preliminary or invalid tests.

H.2.2 Inflection point

The inflection point is that point at which the cycles to failure begin to increase rapidly with a small decrease in force. It is near 10^6 cycles for roller chain.

H.2.3 Force levels

H.2.3.1 Number of force levels

There shall be at least two, but not more than four, force levels in a finite life test.

H.2.3.2 Values of force levels

The maximum test force shall not be more than 60 % of the minimum tensile strength listed in ISO 606 or ISO 10190.

The minimum test force shall be sufficient to produce all failures before endurance. The minimum test force should be sufficient to produce all failures before 10^6 cycles.

The interval between neighbouring force levels should be as nearly equal as possible.

H.2.4 Number of tests

A minimum of fourteen specimens shall be tested. As near an equal number of tests as possible shall be tested at each force level. Recommended numbers of tests at each force level are

— seven specimens at each of two force levels,

— five, five and four specimens at each of three force levels, and

— four, four, three and three specimens at each of four force levels.

H.3 Data analysis

H.3.1 Data

The data for a finite life analysis shall be gathered in accordance with H.2.

H.3.2 Statistical distributions

The distribution of fatigue life, at a given force level, is well described by a log-normal distribution. The distribution of force, at a given fatigue life (number of cycles), is adequately described by either a normal or log-normal distribution. Either a normal or log-normal distribution of force may be chosen for analysis.

H.3.3 Determining force–life (F–N) lines

H.3.3.1 General relationships

The relationship between the force, or the logarithm of force, and the logarithm of fatigue life is essentially linear between 10^4 and 10^6 cycles. The relationship of fatigue life at any applied force within the stated limits may be estimated by a regression analysis.

H.3.3.2 Mean regression line: 0,50 probability of survival

H.3.3.2.1 Normal force distribution

If a normal distribution of force is chosen for analysis, the mean regression line shall be estimated by means of Equations (H.1), (H.2), and (H.3).

The relationship between mean fatigue life N and applied force F_a, between 10^4 and 10^6 cycles, is

$$N = \exp_{10}\left(\lg N_0 + m_\mathrm{F} F_\mathrm{a}\right) \quad \text{(H.1)}$$

The slope of the line is

$$m_\mathrm{F} = \frac{n_\mathrm{f} \Sigma F_{\mathrm{t}i} \lg N_\mathrm{i} - \Sigma F_\mathrm{ti} \Sigma \lg N_i}{n \Sigma \left(F_{\mathrm{t}i}\right)^2 - \left(\Sigma F_{\mathrm{t}i}\right)^2} \quad \text{(H.2)}$$

and the X-intercept, or number of cycles, at zero force is

$$N_0 = \exp_{10}\left(\frac{\Sigma \lg N_i - m_\mathrm{F} \Sigma F_{\mathrm{t}i}}{n_\mathrm{f}}\right) \quad \text{(H.3)}$$

H.3.3.2.2 Log-normal force distribution

If a log-normal distribution of force is chosen for analysis, the mean regression line shall be estimated by means of Equations (H.4), (H.5), and (H.6).

The relationship between mean fatigue life N and applied force F_a, between 10^4 and 10^6 cycles, is

$$N = \exp_{10}\left(\lg N_0 + m_\mathrm{LF} \lg F_\mathrm{a}\right) \quad \text{(H.4)}$$

The slope of the line is

$$m_{\mathrm{LF}} = \frac{n_{\mathrm{f}}\Sigma\left(\lg F_{\mathrm{t}i}\lg N_i\right) - \Sigma\lg F_{\mathrm{t}i}\Sigma\lg N_i}{n_{\mathrm{f}}\Sigma\left(\lg F_{\mathrm{t}i}\right)^2 - \left(\Sigma\lg F_{\mathrm{t}i}\right)^2} \quad \text{(H.5)}$$

and the X-intercept, or number of cycles, at one unit force is

$$N_1 = \exp_{10}\left[\frac{\Sigma\lg N_i - m_{\mathrm{LF}}\Sigma\lg F_{\mathrm{t}i}}{n_{\mathrm{f}}}\right] \quad \text{(H.6)}$$

H.3.3.3 Minimum regression line: 0,97725 (−2σ) probability of survival

H.3.3.3.1 Normal force distribution

If a normal distribution of force is chosen for analysis, the minimum regression line shall be estimated by means of Equations (H.7) and (H.8).

The standard deviation of the logarithm of fatigue life from the mean line, between 10^4 and 10^6 cycles, is

$$S_{\lg N} = \left[\frac{\Sigma\lg N_i{}^2 - \lg N_0\Sigma\lg N_i - m_{\mathrm{F}}\Sigma\left(\lg N_i F_{\mathrm{t}i}\right)}{n_{\mathrm{f}} - 2}\right]^{0,5} \quad \text{(H.7)}$$

and the relationship between minimum fatigue life N_{min} and applied force F_{a}, between 10^4 and 10^6 cycles, with a 0,97725 probability of survival, is

$$N_{\mathrm{min}} = \exp_{10}\left(\lg N_0 - 2S_{\lg N} + m_{\mathrm{F}}F_{\mathrm{a}}\right) \quad \text{(H.8)}$$

H.3.3.3.2 Log-normal force distribution

If a log normal distribution of force is chosen for analysis, the minimum regression line shall be estimated by means of Equations (H.9) and (H.10).

The standard deviation of the logarithm of fatigue life from the mean line, between 10^4 and 10^6 cycles, is

$$S_{\lg N} = \left[\frac{\Sigma\lg N_i{}^2 - \lg N_0\Sigma\lg N_i - m_{\mathrm{LF}}\Sigma\left(\lg N_i \lg F_{\mathrm{t}i}\right)}{n_{\mathrm{f}} - 2}\right]^{0,5} \quad \text{(H.9)}$$

and the relationship between minimum fatigue life $N_{\mathrm{L,min}}$ and applied force F_{a} between 10^4 and 10^6 cycles, with a 0,97725 probability of survival, is

$$N_{\mathrm{L,min}} = \exp_{10}\left(\lg N_0 - 2S_{\lg N} + m_{\mathrm{LF}}\lg F_{\mathrm{a}}\right) \quad \text{(H.10)}$$

H.4 Sample test results

A finite life test was conducted on “BCD Company’s” number 16A chain, consisting of 14 tests run on three force levels. The results are shown on the sample test result form which follows and, graphically, in Figures H.1 and H.2.

Fatigue test report

Report No.: 1002 Page 1 of 1 Report date: 2003-06-9

Chain:				
Brand: BCD Chain	Number: 16A	Pitch: 25,4 mm	Specimen length: 13P,ILEE	Other:
Mechanical properties: Not taken				
Test:				
Type: Finite life	Endurance:	Temperature: Approx. 15°C		Other: Low humidity
Machine:				
Brand: XYZ	Type: Mech., harmonic spring	No. used: 1	Calibration date: 2002-08-26	Force verification and monitoring: Periodic, strain-gauge bar

Date	**Test No.**	**Frequency** Hz	F_{max} kN	F_{min} kN	F_t kN	**Cycles, N**	**Failure**	**Remarks**
03-05-30	001	33	33,36	2,224	32,44	4,500E4	IP	
03-05-30	002	33	33,36	2,224	32,44	6,750E4	IP	
03-05-30	003	33	33,36	2,224	32,44	3,375E4	IP	
03-05-30	004	33	33,36	2,224	32,44	2,925E4	IP	
03-05-31	005	33	33,36	2,224	32,44	5,980E4	IP	
03-05-31	006	33	27,80	2,224	26,64	1,596E5	IP	
03-05-31	007	33	27,80	2,224	26,64	9,000E4	IP	
03-06-01	008	33	27,80	2,224	26,64	7,800E4	IP	
03-06-01	009	33	27,80	2,224	26,64	1,800E5	IP	
03-06-01	010	33	27,80	2,224	26,64	1,200E5	IP	
03-06-05	011	33	22,24	2,224	20,85	3,845E5	IP	
03-06-05	012	33	22,24	2,224	20,85	2,884E5	IP	
03-06-06	013	33	22,24	2,224	20,85	5,770E5	IP	
03-06-07	014	33	22,24	2,224	20,85	5,114E5	IP	

Results and conclusions:

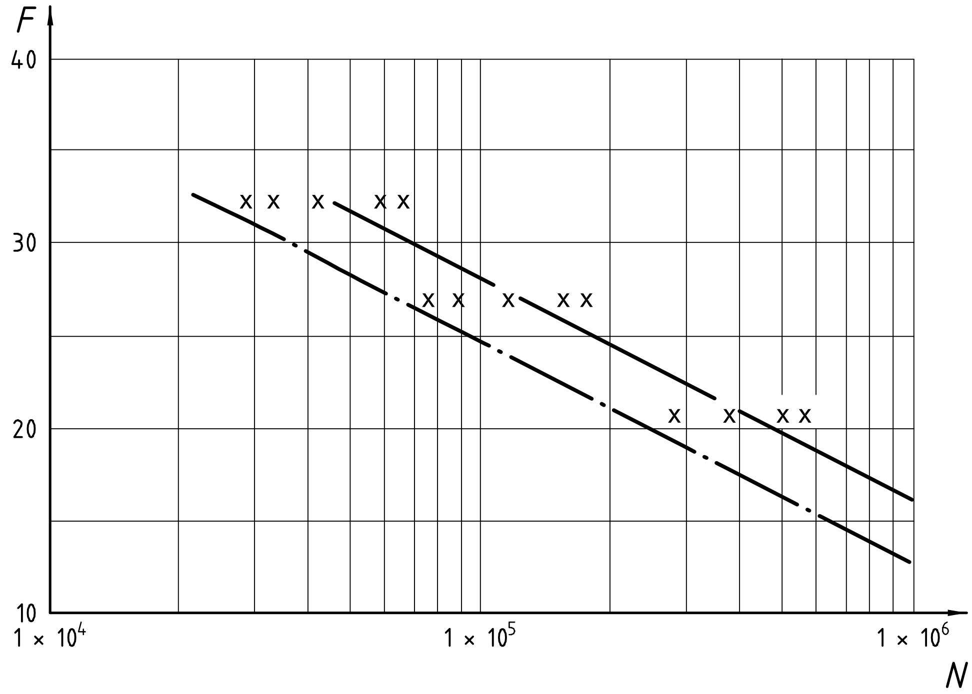
m_F = −0,083 94 m_{LF} = −5,094 25

$\lg N_0$ = 7,353 5 $\lg N_1$ = 12,345 06

$S_{\lg N}$ = 0,143 88 $S_{\lg N}$ = 0,143 88

The results of the finite-life test are plotted on the attached graphs [see Figures H.1 and H.2].

Signed: John Smith

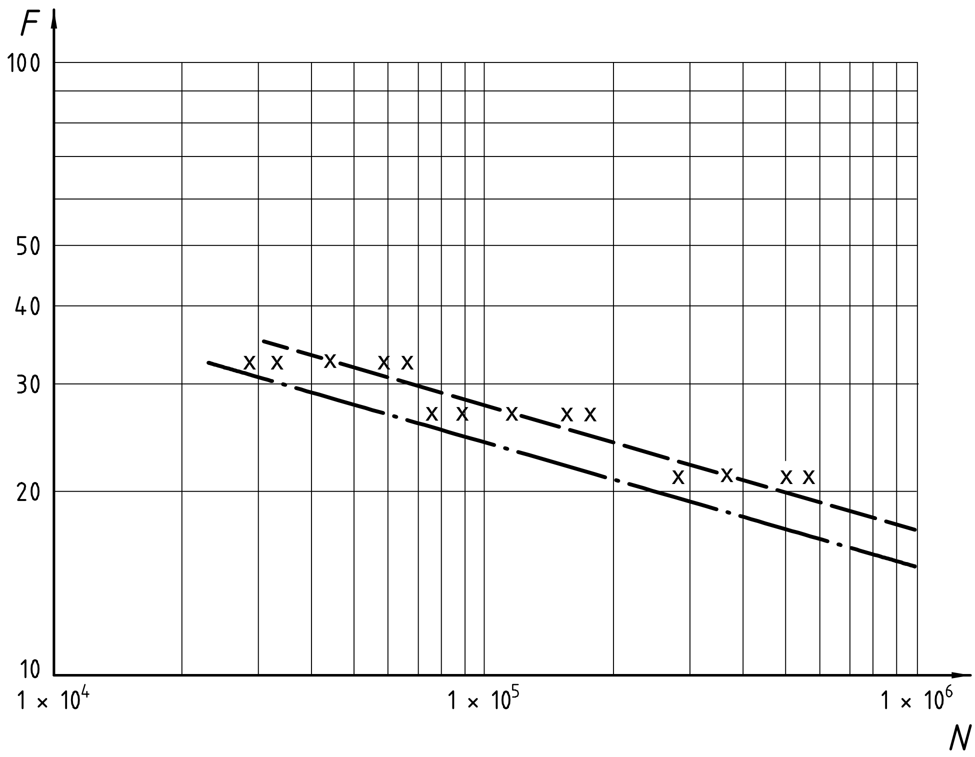


Key

F force, kN

N life, cycles

Figure H.1 — Typical *F*–Log *N* graph for 16A chain



Key

F force, kN

N life, cycles

Figure H.2 — Typical Log *F*–Log *N* graph for 16A chain

Bibliography

[1] ISO 10823, *Guidelines for the selection of roller chain drives* [1)]

[2] ISO 1099, *Metallic materials — Fatigue testing — Axial force controlled method* [2)]

1) To be published. (Revision of ISO 10823:1996)

2) To be published. (Revision of ISO 1099:1975)

ICS 21.220.30

Price based on 47 pages

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