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Cranes — Safe use of high-performance fibre ropes in crane applications

Appareils de levage a charge suspendue — Utilisation en sécurité des câbles synthétiques haute performance pour les applications sur les appareils de levage à charge suspendue

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ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Email: copyright@iso.org
Website: www.iso.org

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Contents

Page

Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 96, *Cranes*, Subcommittee SC 3, *Selection of ropes.*

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Recent developments of high-performance fibre ropes (HPFR) made from synthetic fibre have led to comparable strength with regard to steel wire ropes. The main advantages of using HPFR on cranes are:

a) light weight (significant weight reduction);

b) no environment pollution by grease (no re-lubrication);

c) easy handling (faster and easier assembly/disassembly);

d) robust spooling (increased tolerance for spooling failures).

The use of HPFR on cranes has already started, however, there is limited experience with HPFR in comparison to the long-term application of steel wire ropes.

For steel wire ropes, substantial experience over many decades covering both rope selection and discard criteria exists, which can be found in International Standards (e.g. ISO 16625 and ISO 4309). Currently, there is no standard available that deals with design and discard criteria for the use of HPFR on cranes. Therefore, this document has been developed based on the content of the FEM 5.024 guideline.

The FEM 5.024 guideline was developed by the Fédération Européenne de la Manutention (FEM) as a joint project with various stakeholders in the industry. It is based on first experiences with mobile cranes and the requirements/limits in some cases can be specific to mobile cranes only.

This document includes additional input from tower crane and electric overhead traveling crane manufacturers. Adaptation to other crane types or applications can be necessary.

This document reflects the current knowledge about the use of HPFR on cranes.

Cranes — Safe use of high-performance fibre ropes in crane applications

1 Scope

This document gives guidance for the safe use of high-performance fibre ropes (HPFR) in crane applications.

This document also covers winch applications. The mention of crane applications implicitly includes winch applications.

This document covers performance criteria and the necessary evaluation to enable selection of HPFR as well as best practice guidelines on procedures, testing and maintenance to safely operate HPFR in crane applications including provisions for assembly/disassembly.

The performance criteria are related to tasks performed when using cranes as intended, including assembly/disassembly, operation and required checks and maintenance.

This document does not deal with so-called hybrid ropes which are a combination of steel wire and high-performance fibres, where the load bearing capability is shared between steel wires and the high-performance fibre. This document does not deal with HPFR used for high risk applications (e.g. transport of hot molten metal).

2 Normative references

The following documents are referred to in the text in such a way that some or all their content constitutes requirements 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 2307:2019, *Fibre ropes — Determination of certain physical and mechanical properties*

ISO 4309:2017, *Cranes — Wire ropes — Care and maintenance, inspection and discard*

ISO 9554:2019, *Fibre ropes — General specifications*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
assembly/disassembly
operations needed to set up/down a crane in a specific configuration or change the configuration

3.2
competent person
designated person, suitably qualified by knowledge and experience, and with the necessary instruction to ensure that the required operations are carried out correctly

3.3
cyclic bending over sheave
CBOS
condition where a section of rope experiences a repeated straight-bent-straight change of curvature onto and off a sheave or roller

Note 1 to entry: In a CBOS test, the fibre rope runs around at least one test sheave. A rope pulling force is applied via an appropriate system. During the test, the rope is running in a constant manner on and off the sheave, taking the condition straight–bent–straight. A movement straight–bent–straight over a test sheave counts as one bending cycle for the rope.

3.4
efficiency factor
loss of rope force of a *high-performance fibre rope* (3.5) when bent over sheaves, resulting in rope pull differences

3.5
high-performance fibre rope
HPFR
rope based on high-performance fibres, with a high tensile strength, high modulus and low elongation at break

Note 1 to entry: These fibre ropes have mechanical characteristics in the range of steel wire with regard to strength per area, axial stiffness and elongation at break [e.g. aromatic polyamide (aramid), high modulus polyethylene (HMPE), liquid crystal polymer (LCP), see 4.3.1].

3.6
maximum rope pull
MRP
maximum force applied to the rope during design [of the *rope drive* (3.13)], taking into account dynamic effects, efficiency of the rope drive, reeving, spread, etc., during operation

3.7
minimum breaking strength
MBS
minimum force achieved by a new rope when tested in accordance with a recognized procedure/test method

3.8
point of discard
point where the tested failure or wear criterion is achieved considering the *residual lifetime* (3.10)

3.9
residual breaking strength
RBS
force a used fibre rope achieves at a point in time when tested according to a recognized procedure/test method

3.10
residual lifetime
remaining lifetime at a point in time, where the attested failure criterion is not yet fully achieved

3.11
actual rope diameter
d_{act}
diameter of the circle circumscribed about the cross-section of the rope, usually measured under a given tension and method

[SOURCE: ISO 1968:2004, 5.1.10]

3.12
nominal rope diameter
d
reference value for the diameter of a given *high-performance fibre rope* (3.5)

[SOURCE: ISO 1968:2004, 5.1.11]

3.13
rope drive
reeving system according to ISO 4306-1, including the drum (actuator) or other actuators, e.g. cylinders or traction systems

3.14
rope safety factor
n
ratio between breaking strength of the rope and the *maximum rope pull* (3.6)

3.15
termination
means of connecting the *high-performance fibre rope* (3.5) to load bearing parts (e.g. crane, winch, hook)

3.16
torsional stiffness
ability of the *high-performance fibre rope* (3.5) to resist externally induced twist

4 HPFR performance considerations

4.1 Responsibilities

Where a HPFR is installed in a new crane, the crane manufacturer is responsible for the rope drive design, selection of the rope and instructions for use and maintenance.

The rope manufacturer is responsible for providing correct and complete information regarding the rope characteristics and providing information regarding maintenance and inspection of the rope in use.

When a steel wire rope originally installed in a crane is intended to be replaced by a HPFR, an evaluation of the crane design in general and the rope drive components shall be performed by the crane user, with the support and approval of the crane manufacturer, to ensure that all the provisions given by the HPFR manufacturer and this document are fulfilled. The same principle applies when an existing HPFR is replaced by another type of HPFR. The crane user is responsible for ensuring that the crane is used and maintained as instructed.

4.2 Risk assessment

Prior to approval for use of HPFR on a crane application, a risk assessment considering the intended use and any reasonably foreseeable misuse shall be carried out by the manufacturer of the crane application, identifying potential risks that can impact the safety of the rope in operation (see ISO 12100:2010).

The risk assessment should cover the entire life cycle of the rope including installation, maintenance, storage and disposal, rope drive, potential environmental conditions and specifics of the application, including all reasonably expected risks of contact with objects external to the crane. This document shall be reviewed jointly by both the rope manufacturer and the crane application manufacturer (or other applicants), in order to identify potential operational and system risks that can affect the safety of operation. Critical interactions during operation between the rope drive system and HPFR identified in this analysis shall be documented in the technical files to ensure they are in line with the requirements of this document and provide suitable safety as determined for mitigation in the risk assessment process.

Qualification testing of the HPFR shall cover identified critical wear modes to validate that discard criteria provide the required safety factor. The safety factor shall take into account residual breaking strength (RBS) in relation to maximum rope pull (MRP) and residual lifetime required at discard condition of the HPFR.

Where either the HPFR or the rope drive system is intended to change, the risk assessment shall be reviewed to ensure that critical safety considerations are not changed.

The limits of the machinery and the remaining residual risks, which can result from the risk assessment analysis, shall be added in the crane's manual.

4.3 Rope

4.3.1 Types of ropes

The base element of a HPFR is the load bearing fibre. There is a variety of high-performance fibres available to rope manufacturers, each with different attributes that affect characteristics of the final rope. Typical materials utilized in HPFR design include amongst others:

a) aromatic polyamide (aramid);

b) high modulus polyethylene (HMPE);

c) polyarylate (liquid crystal polymer, LCP);

d) polybenzoxazole (PBO).

The high-performance fibre is selected by the rope manufacturer based on specific characteristics inherent to the material including:

a) tensile strength;

b) modulus (axial stiffness);

c) elongation at break;

d) creep characteristics (if applicable);

e) fatigue resistance (bending and tension);

f) coefficient of friction;

g) linear density;

h) environmental resistances [for details see 4.3.2.2 j)].

For further information, see ISO 9554:2019, Table A.1.

The high-performance fibres are combined into larger structures through a process such as twisting, braiding, winding or a combination of these or other methods. The design of HPFR construction has a significant impact on the performance of the rope.

Traditional fibres such as polyester, polyamide or polypropylene may be utilized in non-load bearing structures [e.g. protective covers (jackets), stabilizing cores].

Coatings and other non-fibrous materials may be incorporated into the construction of a HPFR in order to achieve various performance characteristics.

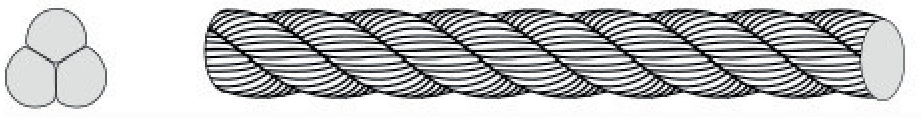
Various rope constructions can be utilized in the design of a rope. Several common examples are shown in Figure 1:

— laid in Figure 1 a);

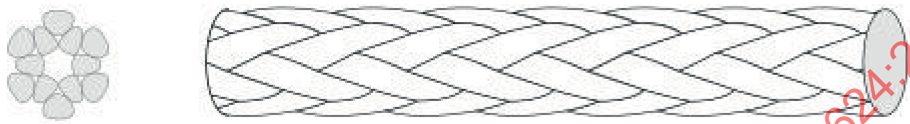
— braided in Figure 1 b);

— cover (jacket over braided rope) in Figure 1 c);

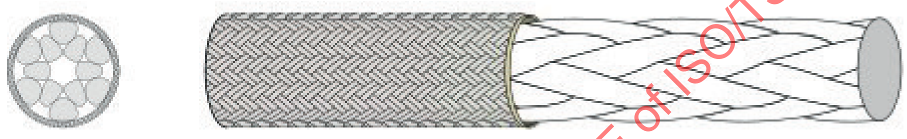
— cover (jacket over parallel fibre) in Figure 1 d).



a) Laid



b) Braided



c) Cover (jacket over braided rope)

d) Cover (jacket over parallel fibre)

Figure 1 — Common rope construction examples

4.3.2 Selection of ropes

4.3.2.1 General

Hoist ropes shall be selected individually for each particular application and shall be made of suitable materials so that they withstand the intended use. They shall be designed for a period of use, which shall be at least twice the inspection interval, as specified by the crane manufacturer.

The fibre, rope construction and coatings utilized in the design of a HPFR, as well as the design of the rope drive, impact the performance of the HPFR in a given application. Selection of a suitable HPFR shall be the responsibility of the crane manufacturer supported by the rope manufacturer, taking into consideration the potential operational and system risks of the particular crane application including the items listed in 4.3.2.2 and 4.3.2.3.

The HPFR discard criteria as per examples shown in Annex D shall be provided by the rope manufacturer and shall be provided in the manual of the crane.

Where HPFR is used in static (e.g. pendants) or semi-static applications, the rope manufacturer and crane manufacturer shall agree on designed lifetime and discard criteria, specifically in consideration of creep elongation, creep rupture, tension-fatigue and dampening.

The list of items given in 4.3.2.2 and 4.3.2.3 is not exhaustive. Additional items given in Annex A shall be fulfilled.

NOTE Many of the properties listed do not have standard test methods available. The rope manufacturer needs to show how these properties were determined.

4.3.2.2 Rope characteristics

The rope characteristics shall be provided by the rope manufacturer. The rope characteristics shall include the standard or test method used to determine each characteristic.

a) Rope basic characteristics:
   - nominal rope diameter
   - actual rope diameter (initial and in service including tolerances and measurement method);
   - length (initial and in service including tolerances);
   - rope weight (per metre);

b) efficiency factor;

c) abrasion resistance;

d) resistance to particle ingress;

e) cut resistance;

f) coefficient of friction;

g) fatigue characteristics:
   - bending fatigue;
   - tension-tension fatigue;

h) load elongation characteristics:
   - elongation;
   - stiffness (axial, transverse);
   - creep;

i) terminations (see 5.1 and 5.2):
   - installation methods;
   - fatigue characteristics;

j) environmental resistance:
   - temperature;
   - chemical;
   - ultraviolet radiation (UV);
   - weathering;

k) discard criteria;

l) rope minimum breaking strength (MBS);

m) twist performance:

— tension-torsion coupling;

— torsional stiffness.

4.3.2.3 Rope drive characteristics

The rope drive characteristics are the responsibility of the crane application manufacturer.

a) Maximum rope pull (MRP);

b) fleet angles;

c) in-service, out of service and storage temperatures;

d) service intervals;

e) efficiency of the rope drive system;

f) sheave, block and drum design:

— roughness;

— corrosion resistance,

— diameter ratio;

— groove profile and system;

— spooling performance (including pre-tensioning, rope pull etc.);

— material;

g) classification (according to ISO 4301-1):

— U-class (total numbers of working cycles),

— Q-class (load spectrum);

— D-class (average displacement of load);

h) average load movements (displacements).

4.4 Proof of competence

The rope drive design shall assure sufficient safety margins on strength and service life until discard for a given application of a crane. This shall be achieved by the following requirements:

a) the HPFR shall be selected according to the criteria given in 4.3.2; and

b) the competence of the rope drive design shall be determined by a proof of competence, including proof of static strength and proof of fatigue strength of the HPFR.

This is achieved by a qualification test (see 6.3).

4.5 Safety factor at discard for HPFR

Selection of an appropriate HPFR for specific applications shall take into account a rope safety factor at discard when assessing suitability for the required lifetime (design lifetime) and specified inspection frequency.

The safety factor at discard for HPFR shall be determined by the crane manufacturer, considering performance data from the rope manufacturer and the results of the risk assessment, to ensure a sufficient safety margin for residual breaking strength and a sufficient residual lifetime at discard. Inspection intervals of the HPFR drive and in particular of the HPFR shall be determined with regard to the degradation of the rope during use.

The minimum safety factor at discard, expressed as the ratio of RBS at discard and MRP, and the ratio of residual lifetime and total lifetime shall be taken from Table 1 and Table 2 for various crane types (see also 6.3 and 7.5).

Table 1 — Minimum HPFR safety factors for running ropes at discard for various crane types

Crane types	Safety factor at discard *n*	Residual lifetime at discard %
Winches for pulling purpose only	2,4	60
Hoists (including winches for lifting)	3,0	60
Mobile cranes	3,0	60
Tower cranes	3,0	60
Bridge and gantry cranes	3,0	60

Table 2 — min. HPFR safety factors for stationary ropes at discard for various crane types

Crane types	Safety factor at discard *n*	Residual lifetime at discard %
Mobile cranes	2,5	60
Tower cranes	2,5	60
Bridge and gantry cranes	2,5	60

NOTE 1 The safety factor at discard differs from the normally used safety factor related to the beginning of the service-life.

NOTE 2 The various factors consider the risk assessment for different applications and current experience.

NOTE 3 HPFR safety factors and residual lifetimes can be reviewed after gaining future experience.

5 Crane design considerations

5.1 Termination on the drum

The termination on the drum consists of:

a) the drum attachment; and

b) a requisite number of safety wraps.

This termination a) and b) shall be capable of holding at least a rope force equivalent to 80 % of the safety factor at discard, n, multiplied by the maximum rope pull, F_{MRP}.

To calculate the required drum attachment strength, Formula (1) shall be used:

$$T_{drum} \geq 0{,}8 \times n \times \frac{F_{MRP}}{e^{\mu\alpha}} \quad (1)$$

where

F_{MRP} is the maximum rope pull;

T_{drum} is the required drum attachment strength;

n is the required minimum safety factor at discard (see Table 1 and Table 2);

μ is the coefficient of friction for HPFR to drum;

α is the angle of wrap in radians, equivalent to 2π times the number of wraps on the drum.

The coefficient of friction varies with service conditions. Accordingly, testing shall be performed under the worst (slippery) service conditions (e.g. wet, oily, ice, temperature).

NOTE 1 Current experience indicates a minimum value of friction μ = 0,04.

The HPFR drum attachment a) shall be capable of holding at least 1,2-times the maximum rope pull in the rope drive. The HPFR fastening, e.g. wedge and socket, shall not become detached even when the rope pull is zero.

The termination of the HPFR shall be selected taking into account the rope and drum contours. The drum attachment a) shall be easily accessible for maintenance and replacement of the HPFR.

NOTE 2 Over time the efficiency of the termination can decrease, for example in a clamp. In such cases re-application of a tightening force is necessary.

5.2 Termination at load side

The end termination at the load side shall be capable of holding at least a rope force equivalent to 80 % of the safety factor at discard, n, multiplied by the maximum rope pull, F_{MRP}, as given in Formula (2).

$$T_{load} \geq 0,8 \times n \times F_{MRP} \quad (2)$$

where

T_{load} is the required load side strength;

F_{MRP} is the maximum rope pull;

n is the required minimum safety factor at discard (see Table 1 and Table 2).

5.3 Drum

5.3.1 Lowering limiter

The hoisting system shall be fitted with a lowering limiter. The lowering limiter shall ensure that the minimum engagement (requisite safety wraps) of the HPFR with the drum is maintained at all times during operation.

5.3.2 Forces on flange and tube (Multilayer drum)

HPFR behave differently than steel wire ropes whilst spooling on a multilayer drum and can cause significantly increased forces acting on drum flange and tube. These forces shall be taken into account where multilayer drums are equipped with HPFR. The calculation should be verified by practical testing.

NOTE A HPFR is more compressed during work than a steel wire rope, flattening the rope and causing increased lateral forces acting on the flange. The difference in axial stiffness can also increase the forces acting on the drum tube.

5.3.3 Shape of grooves on drums

Drum grooves surfaces shall be smooth and free of surface irregularities that can damage the HPFR. Peaks and edges shall be rounded to reduce damage of the HPFR due to cutting. System grooving, helical grooving or flat patterns may be used depending on the design of the HPFR and drum.

As HPFR tend to flatten when compressed on the drum, the cross-section for rope stored on a drum is typically not circular. This effect shall be taken into account.

The groove pitch shall provide sufficient clearance between adjacent HPFR turns on the drum, taking into account the HPFR diameter tolerance.

The groove of grooved drums shall fit to the type of HPFR as given by the HPFR manufacturer.

The rope manufacturer shall be consulted regarding the anticipated changes in width of the rope under the compressive loading specific to a given application prior to optimizing the groove profile for a given HPFR. The amount of rope ovalization depends on many factors including high-performance synthetic fibres used, rope construction and tension profile common in the application.

NOTE The minimum groove diameter to be chosen in relation to the nominal rope diameter strongly depends on the effects of bedding-in a new rope.

5.3.4 Clearance between rope and diameter of drum flange

Where HPFR is used in hoisting mechanism, measures on drums shall be provided, e.g. flanged drum end plates, frame/housing and rope guides, which prevent the ropes from running off the ends of the rope drums.

Flanged drum end plates shall protrude beyond the rope wound on the drum at the top layer by at least 1,5 times the bedded-in HPFR diameter with the rope spooled on the drum with minimum (functional) rope pull.

5.3.5 Temperature limits

HPFR acts as a thermal insulation when compared with steel wire ropes spooled on a drum with internal gearbox. This effect shall be taken into account when designing the drum system. Peak temperatures shall not exceed the allowable temperature limits for the HPFR used, taking into account the maximum permitted environmental temperatures.

5.4 Sheaves

5.4.1 Shape of grooves

Sheave grooves shall be rounded to form a close-fitting saddle as recommended by the rope manufacturer, based on the design of the HPFR. The opening of the sheave should be wide enough to easily allow rope entry at any anticipated fleet angle with an opening angle between 45° and 60°.

Grooves of sheaves shall be smooth and free from surface defects liable to damage the HPFR. The peaks/edges shall be rounded to reduce damage of the HPFR due to cutting.

5.4.2 Material of sheave

Sheaves for use with HPFR may be made of either metallic or polymer materials. Consult the rope manufacturer on recommended materials and surface requirements.

5.4.3 Minimum D/d ratio

The minimum D/d ratio chosen shall be at least as large as the ratio proven in qualification CBOS testing, where D is the sheave pitch diameter and d is the nominal rope diameter.

Reliability of discard criteria shall be explicitly proven for D/d ratios used in the application (see rope qualification testing in Annex B).

NOTE Current experience indicates a typical D/d value of 20. A lower value can reduce the lifetime.

5.5 Crane

5.5.1 Contact surfaces

All surfaces where contact between HPFR and structural parts is foreseen shall be free from sharp edges, defects and corrosion. Surface roughness values shall be maintained as specified by crane and/or rope manufacturer.

Surface roughness should not exceed ISO 1302:2002 roughness class N9 (equivalent R_a 6,3 µm). Greater classes significantly accelerate the rate of abrasion in HPFR and reduce service lifetime.

NOTE All surfaces need to be checked for potential contact with the loaded or unloaded HPFR for in- and out-of-service and transport/travel and during assembly.

5.5.2 Fleet angles

The maximum fleet angle of running ropes shall be kept under 2,5°, unless the risk assessment allows small deviations to higher values.

Any fleet angle influences the lifetime of the rope. The lifetime of a HPFR is significantly decreased if the fleet angle of 2,5° is exceeded.

Potential influence of fleet angle on twist (rotation) of the HPFR shall be checked during qualification testing (see Annex B).

5.5.3 Substitution on existing design and optimization on new designs

When intended to fit HPFR on new cranes designed originally for use with steel wire rope, an evaluation of the crane design shall be performed by the crane manufacturer to ensure all instructions given by the HPFR manufacturer and this document are fulfilled.

In addition, the crane manufacturer shall review other criteria relevant for safety, e.g. rigid body stability of the crane, which can be related to the weights of the installed rope.

Optimization of the mechanical systems specifically for use with HPFR is preferable whenever feasible. Following a process of designing the crane systems specifically for use with HPFR allows for full realization of the benefits provided by the technology.

5.5.4 Substitution on used cranes

When a steel wire rope originally installed in a crane is intended to be replaced by a HPFR, an evaluation of the crane design and the rope drive components shall be performed by the crane user with the support and approval of the crane manufacturer to ensure all instructions given by the HPFR manufacturer and this document are fulfilled. Critical and worn out parts need to be repaired or exchanged prior to the use of HPFR on the crane.

6 Qualification testing of HPFR

6.1 General

The qualification testing shall demonstrate fitness for purpose for a HPFR drive design for the considered application and validate the discard criteria of the HPFR.

To approve a HPFR for use in a specific application, the rope manufacturer and/or the crane manufacturer shall determine at least the data of 6.2 to 6.4. They shall also ensure safe use and fitness for purpose of the HPFR as identified in the risk assessment.

6.2 Basic data of HPFR

6.2.1 General

For a HPFR in a specific application, the following basic data at least shall be determined by testing:

a) minimum breaking strength, MBS;

b) residual breaking strength, RBS at discard;

c) residual lifetime at discard.

6.2.2 Minimum breaking strength, MBS

The minimum breaking strength shall be stated by the HPFR manufacturer. The MBS shall be verified through testing in accordance with ISO 2307:2019.

6.2.3 Residual breaking strength, RBS

The most damaged section of the rope shall be the area of interest for this testing. Therefore, it shall be placed at the centre of the free rope length of the test specimen. The rope residual breaking strength shall be verified through testing in accordance with ISO 2307:2019, but changing the pre-tensioning force during bedding-in procedure from 50 % MBS to 20 % MBS.

6.2.4 Residual lifetime

The most damaged section of the rope shall be the area of interest for this testing. Therefore, it shall be placed at the location showing the most degradation during continued testing of the test specimen. The rope residual lifetime shall be verified through continued testing of the sample in a manner that simulates the same wear pattern which resulted in the observed discard criteria being achieved (e.g. cyclic bend over sheave, abrasion with a substrate, etc.) (see also 6.3).

6.3 Qualification testing

6.3.1 General

Testing included during qualification of the HPFR shall be determined based on the application specific considerations identified during the risk assessment. These tests shall simulate the rope damaging wear modes that occur through use in the designated operation. Qualification testing shall be designed to identify the discard criteria and ensure that they are observable while the required safety margin remains.

The combined effect of the factors identified under 4.3.2 has a significant impact on the HPFR lifetime. Therefore, qualification testing of the rope drive is required taking into account these factors and a combination of these factors. The requirements and test scope of this program shall be established between crane and rope manufacturer. A recommended practice is given in Annex B.

The samples for qualification testing shall be chosen to give sufficient statistical evidence (at least 3 samples, except if the deviation in the first two test results is less than 25 % of the higher lifetime, then two tests are sufficient).

NOTE 1 For guidance, see Annex B.

Where applicable, test samples for evaluation of the safety factors should be taken from both the area of discard as well as from other critical areas. The following tests shall be included in the qualification testing for applications that are identified as having the corresponding wear modes.

NOTE 2 For an example report of results, see Annex C.

6.3.2 Bending fatigue performance

It shall be proven experimentally with a full-scale rope diameter that the discard criteria for bending fatigue reliably shows the point of discard:

a) in intended use as defined by the crane manufacturer (e.g. rope pull regime, *D*/*d* ratio, etc.);

b) in the most relevant combination, e.g. bending counts, identified in the risk assessment for the discard criterion to show up.

It shall be demonstrated that for the above combinations of lifetime determining factors the tested HPFR section meets the required minimum safety factors at discard as given in Table 1 (see 4.5).

CBOS testing is not a requirement for stationary ropes that are not subjected to any bending.

NOTE For guidance on CBOS testing, see B.3.

6.3.3 Multilayer spooling performance

It shall be proven experimentally on a full-scale basis (e.g. rope diameter, number of layers) that the discard criteria for multilayer spooling reliably show the point of discard:

a) in intended use as defined by the crane manufacturer (e.g. rope pull regime, *D*/*d* ratio, etc.);

b) in the most relevant combination, e.g. bending counts, identified in the risk assessment for the discard criterion to show up.

The multilayer spooling performance testing should preferably be performed as a full-scale test run to breakage to establish the residual multilayer spooling lifetime at the point of discard.

Alternatively, if the full-scale test cannot be carried out until breakage on the testing equipment, a combination of multilayer spooling test, CBOS testing and/or other comparable wear testing shall be performed.

It shall be demonstrated that for the above combinations of lifetime determining factors the tested HPFR section meets the required minimum safety factors as given in Table 1 (see 4.5).

NOTE 1 Sections other than the one which shows the discard criterion can have been stressed equally or even higher.

NOTE 2 For guidance on multilayer spooling testing, see B4.

6.3.4 Tension fatigue performance (rope and termination)

It shall be proven experimentally with a full-scale rope diameter that the discard criteria for tension fatigue reliably shows the point of discard:

a) in normal use operation (e.g. rope pull regime, *D*/*d* ratio etc.);

b) in the most relevant combination identified in the risk assessment for the discard criterion to show up.

It shall be demonstrated that, for the above combinations of lifetime determining factors, the tested HPFR section meets the required minimum safety factors at discard as given in Table 1 (see 4.5).

6.3.5 Termination performance (Static)

It shall be proven experimentally with a full-scale rope diameter that the performance of the terminations meets the requirements of 5.1 and 5.2 at point of discard of the HPFR.

NOTE For guidance on termination testing, see B.5.

6.4 Interpolation of test results

If the tests of the HPFR demonstrate consistency of the HPFR design across the size range, interpolation of sizes between two tested sizes can be utilized for a given rope drive design (number of layers, wraps, etc.). Interpolated HPFR sizes should have cross-sectional areas under unstressed condition not differing by more than 50 % as compared to the closest size previously tested.

7 Information to be provided regarding care, maintenance and inspection

7.1 General

General information regarding installation and maintenance are given in ISO 9554:2019.

Both the HPFR manufacturer and the crane manufacturer shall provide general information regarding installation and maintenance in accordance with ISO 9554:2019. The crane manufacturer shall provide all as part of, or as a supplement to, the manual of the crane.

7.2 Installation of HPFR

7.2.1 Stationary ropes

Instructions regarding HPFR installation in static or semi-static applications shall be provided by the crane manufacturer in accordance with 7.1. In addition:

a) HPFR shall be installed without twist;

b) HPFR should not be connected to steel wire ropes. If not specifically addressed, the consequence of not following this rule is the possibility of torsion/twist being introduced into the HPFR.

7.2.2 Running ropes

The crane manufacturer shall provide information for running rope applications according to 7.1.

The crane shall be inspected by a competent person to ensure the suitability for continued use of HPFR, taking into account the requirements listed in 5.3, 5.4 and 5.5 prior to first installation of a HPFR.

Any deficiencies discovered shall be resolved prior to the installation.

Due to the multitude of fibre elements in the structure of a HPFR and the inherent void space that is maintained between them, the new rope diameter is often much larger at the installation stage than when in the operating stage. Adequate tension, as defined by the rope manufacturer, shall be applied to the entire length of the rope in order to bed-in the rope diameter prior to use and allow for appropriate spooling performance in operation.

7.3 Maintenance

7.3.1 Maintenance of the rope

HPFR not in regular use (e.g. transport, storage, prior to installation, during extended downtime) shall be stored in environments that provide protection from damaging elements as required by the rope manufacturer including:

a) maintained below the specified critical temperature;

b) protected by covering from UV radiation;

c) covered against particulate ingress:

— between rope wraps;

— within the structure of the non-tensioned rope;

d) away from non-approved chemicals.

The provided maintenance instructions shall be followed. This can include re-termination, re-application of coatings, removal of damaged sections, etc. In the case of significant particle ingress within the rope structure, the foreign material shall be removed as this can cause an accelerated rate of internal wear. The HPFR manufacturer should be contacted for recommended methods of cleaning.

7.3.2 Maintenance of rope-related parts of the crane

Rotating components (e.g. boom and block sheaves, guide rollers) shall have rotating elements maintained such that they are always free to turn. HPFR can become damaged when operated over stuck sheaves, for example.

All surfaces which come in contact with the rope shall be maintained in a clean condition with surface roughness as recommended by crane and/or rope manufacturer. Metallic crane components should be painted or coated against development of rust in areas which contact the HPFR. Alternatively, the components shall be made from stainless steel/plastics/composites.

7.4 Inspection

Requirements for inspection of HPFR shall be provided by the crane manufacturer. If no instruction from the crane manufacturer is available, the information of the rope manufacturer shall apply in addition to the requirements given in ISO 4309:2017, 5.2 to 5.5, as long as it is applicable to HPFR.

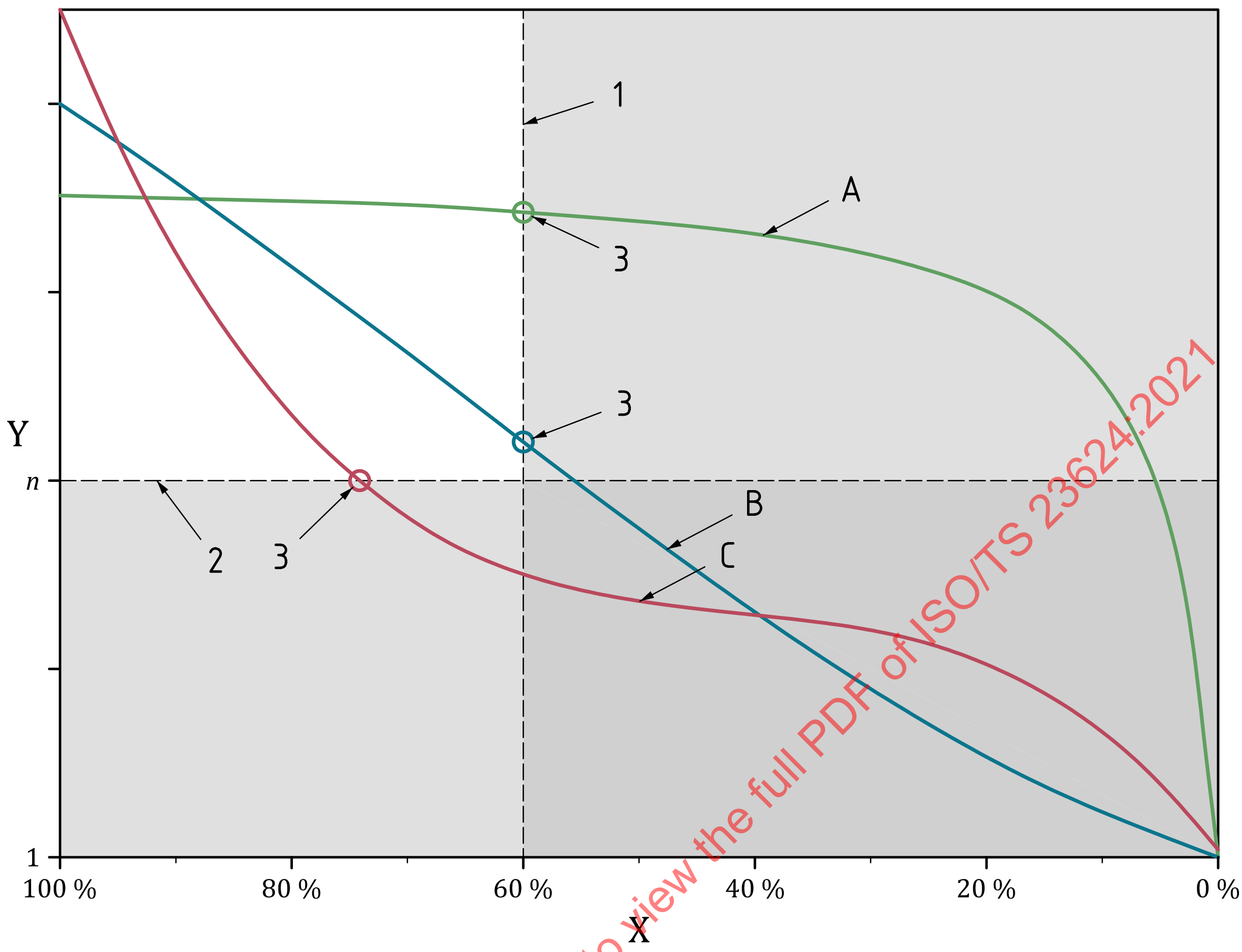
7.5 Discard criteria

A HPFR on a crane is regarded as an expendable component, requiring replacement when the results of inspection indicate that its condition has diminished to the point where further use would lead to an unsafe situation according to this document.

During storage, handling and operation, degradation of the rope's characteristics occurs.

Reliable discard criteria shall be established by the HPFR manufacturer to ensure safe operation over the whole lifetime of the rope, ensuring that the HPFR is discarded with sufficient remaining tensile strength and fatigue life (examples are given in Annex D).

Since there is a variety of HPFR designs, information of discard criteria and inspection method shall be provided in the crane manual to the user. It shall be possible to detect the discard criteria by reliable means selected by the rope manufacturer.



Key

X residual lifetime

Y safety factor as result of residual breaking strength divided by max. rope pull, MRP

n required minimum safety factor (see Table 1 and Table 2)

A development of safety factor, *n* over remaining lifetime of rope type A

B development of safety factor, *n* over remaining lifetime of rope type B

C development of safety factor, *n* over remaining lifetime of rope type C

1 limit for required minimum remaining lifetime at point of discard (see Table 1 and Table 2)

2 limit for required minimum remaining safety factor, *n* at point of discard (see Table 1 and Table 2)

3 points of discard of the rope types A, B and C

Figure 2 — Theorized HPFR performance of various rope types and discard criteria

Discard criteria shall be provided by the HPFR manufacturer that identify whether the rope strength and lifetime at time of measurement are in the acceptable range. Figure 2 shows points of discard for three different types of ropes (A, B and C in Figure 2) either by falling below the required residual lifetime or by falling below the required effective safety factor, *n*. Where the HPFR is found to be outside of the acceptable range, it shall be replaced. Testing of the discard criteria shall be performed for critical life impacting wear effects identified in the risk assessment as required in 4.2 (see Annex B for an example testing procedure).

Specific discard factors that may contribute to a removal of the HPFR from service include:

a) bending fatigue;

b) tension fatigue;

c) static fatigue (creep rupture);

d) axial compression fatigue;

e) overload/shock load;

f) sudden release of the load;

g) abrasion of fibre material – external and/or internal (ingress of particles);

h) environmental degradation (e.g. due to chemical substances, UV radiation);

i) melted/charred fibre;

j) cutting of rope structures (e.g. jacket, strand);

k) damage of termination;

l) deformation of structure (e.g. kink, twist, pulled strand).

NOTE This list is not exhaustive. Depending on the application and environmental conditions, further factors can be considered.

Annex A
(normative)

Selection of ropes

A.1 General

Fibre, rope construction and coating utilized in the design of a HPFR determine the performance in a given application.

Selection of a suitable HPFR shall be the responsibility of the crane manufacturer advised by the rope manufacturer, taking into consideration the requirements of the application including A.2 to A.9.

A.2 Abrasion resistance

A.2.1 Interaction with external contacts

Abrasion resistance of the HPFR against external contacts is required to withstand contact with surfaces of the rope drive (e.g. sheaves, drums – especially flanges, terminations, the rope itself, parts of the crane structure) or surfaces contacted during operation and assembly (e.g. buildings). All external contacts influence the lifetime of the HPFR. The rope manufacturer shall indicate the maximum roughness of the surfaces in contact with the rope (see also 5.5.1).

A.2.2 Interaction with internal contacts

In every bending and at every load cycle, the fibres and strands of the HPFR move against each other. This relative movement causes internal friction and wear that degrades the rope, and which is not always visible from the outside.

A.2.3 Particle ingress

Particles which penetrate the HPFR increase the rate of internal wear and degradation. Therefore, HPFR shall be kept clean to keep particle ingress at a minimum.

A.3 Cut resistance

HPFR are susceptible to cutting. Damage from contact with sharp edges while the HPFR is under tension shall be avoided.

Where applicable, the user shall ensure during both operation and assembly/disassembly conditions that contact with objects external to the crane system is avoided whilst tension is applied to the rope. For applications where the history record shows damage of the rope by contact with objects external to the crane, the crane manufacturer shall take this risk into consideration during the risk assessment.

Sections of the crane structure that have a reasonable potential to interact with the rope during both operation and assembly/disassembly shall have edges rounded as required by the HPFR manufacturer.

A.4 Coefficient of friction

The coefficient of friction is relevant for the terminations (e.g. when bolted or spliced), in which case a high coefficient is desirable.

For sliding of the rope on itself (e.g. in multilayer drum winding) or across components of the rope drive system, a low coefficient generates less external abrasion.

The coefficient of friction can change during use and depends on various factors, e.g. speed and load.

A.5 Fatigue characteristics

A.5.1 Bending fatigue

In both operation and assembly/disassembly, the rope can be bent, e.g. around drums and/or sheaves. Bending of the rope causes internal wear via fibre-on-fibre movement, compression fatigue and tension-tension fatigue. The number of bends a rope can be subjected to until it breaks is limited and shall be known. Bending fatigue life is a function of many factors including sheave design, D/d-ratio, tension applied, rope design, cycle frequency, temperature and fleet angle.

The number of bending fatigue cycles required for the design life calculation of the crane depends on the designed total lifting cycles of the application and the designed number of rope replacements.

Bending performance should be tested by CBOS testing (see B.3).

A.5.2 Tension — Tension fatigue

In both operation and assembly/disassembly, the HPFR is stressed by different loadings. These changes in tension create internal wear. The number of tension-tension loadings a rope can be subjected to until it breaks is limited.

Tension-tension performance should be validated by testing agreed between the rope and crane manufacturer.

A.6 Load elongation characteristics

A.6.1 Elongation

Under tension, the HPFR elongates. This can be reversible (e.g. elastic elongation) as well as permanent. Permanent elongation can be observed during initial loading of the HPFR as constructional bedding-in and/or during the operating life.

A.6.2 Stiffness (axial; transverse)

Every rope has a certain axial and transverse stiffness. Axial stiffness of the rope exerts an influence on handling characteristics, transverse stiffness on the grade of deformation when the rope is running over sheaves and the spooling performance in multilayer spooling. The elastic behaviour of the HPFR generates forces on the drum tube and the flange which can differ significantly from the forces generated by steel wire ropes.

A.6.3 Creep

All of the fibres used in HPFR creep under the influence of tension, time and temperature.

Creep can result in permanent elongation of the fibre. For applications which subject the HPFR to periods of extended tension (i.e. stationary support ropes), it is critical to ensure that the load bearing fibre has sufficient resistance to irreversible elongation and rupture.

The rope manufacturer shall provide test data and/or modelling for worst-case scenarios, as provided by crane manufacturer, that can be experienced in these static or semi-static rope applications prior to implementation.

A.7 Terminations

Known terminations for HPFR today are different types of splices, mechanical hardware and resin sockets. Unqualified terminations (e.g. knots) shall not be used as terminations or anywhere in the rope drive due to significant loss in breaking strength.

A.7.1 Installation methods

Depending on the application and the rope drive the terminations can face different requirements. Only terminations approved by the crane and rope manufacturer shall be used.

A.7.2 Fatigue characteristics

Terminations can fatigue as well as the HPFR itself. Therefore, the intended terminations shall be tested with regard to tension-tension fatigue before use (see B.5).

A.8 Environmental resistance

A.8.1 Temperature

Temperature influences the performance of the HPFR with regard to breaking strength, bending fatigue, tension-tension fatigue, stiffness, etc. This depends on fibre type, rope design, coating, etc. The rope manufacturer shall specify the critical operating and storage temperature limits for the HPFR. The critical temperature limits shall not be exceeded, taking into account ambient conditions, contact surface temperatures and generation of heat within the rope drive.

Contact with hot metal, grinding and welding slag as well as vicinity to heat sources shall be avoided to prevent melting or charring damage to the HPFR. If welding or grinding takes place within the vicinity, the rope shall be protected accordingly.

A.8.2 Chemicals

HPFR can be adversely affected by chemicals used in cranes or on job sites.

For chemicals commonly used in cranes (e.g. fuel, hydraulic oil, lubricant, diesel exhaust fluid, cleaning agents), the rope manufacturer shall provide guidance regarding the influence on rope properties if contamination occurs to the HPFR.

For chemicals encountered during operation, rigging, transport or storage the rope manufacturer shall be contacted for guidance.

A.8.3 Ultraviolet radiation (UV)

UV degrades the load bearing capacity of HPFR. Therefore, it influences the breaking strength and/or the lifetime.

Exposure of the HPFR to UV shall be minimized, in particular during longer storage periods.

A.8.4 Weathering

Combinations of temperature, UV radiation and other factors such as humidity, rain, snow, etc., can affect HPFR differently. The rope manufacturer shall be contacted for advice.

A.9 Twist performance

A.9.1 General

Depending on the rope design and the design of the rope drive (fleet angles, etc.) the rope can twist in service. Induced twist influences breaking strength, bending fatigue, tension-tension fatigue, stiffness and residual breaking strength of the HPFR. The influence of induced twist on these parameters shall be known and the HPFR manufacturer shall specify the maximum allowed twist. Appropriate countermeasures shall be applied to the rope drive system.

A.9.2 Tension - Torsion coupling

Depending on the rope, twisting of the HPFR can be experienced when tensile load is applied.

Annex B
(informative)

Qualification testing

B.1 General

This annex provides guidance on parameters for qualification testing of HPFR to be used in crane applications. These testing parameters should be considered during design of the testing plan for qualification process, in combination with critical parameters and concerns identified in the risk assessment, performed in accordance with 4.2.

B.2 Recommendations for testing party

Testing party should be an institution that is experienced in fibre ropes and testing. Tests should always be done in a safe and responsible manner, the practice of approaching a rope while under load should be avoided.

B.3 Qualification testing, CBOS

B.3.1 Performance of bending tests

The tests should cover at least the following content:

a) *D*/*d* ratio;

b) test force;

c) rope surface temperature;

d) twist;

e) number of test samples.

An example of a typical bending test program is given in Table B.1.

Table B.1 — CBOS test matrix

Test number	1	2	3	4
D/*d* ratio	20			
Test force	Maximum rope pull in the rope drive			
Target rope surface temperature (toward groove) (°C)	20 ± 5		50 ± 5	
Twist (turns/100*d*)	0	1	0	1
Water cooling/heating	Yes	Yes	No	Yes
Minimum number of test samples	2	1	2	1

NOTE 1 The temperature value can differ depending on the risk assessment and the end user requirements.

NOTE 2 It is not current practice to make UV tests on the entire rope but on the yarns when it is deemed to be necessary.

NOTE 3 With laid construction ropes, the direction of twist is relevant.

NOTE 4 Water cooling/ heating is allowed for accelerating testing to maintain the surface temperature of the rope with correlation of the test results between wet and dry condition recorded.

If deviation between duplicate test samples is more than 25 % of the higher lifetime, an additional sample should be tested. If the third test sample also does not meet this target deviation, the test procedure and HPFR design should be reviewed and the tests should be repeated.

EXAMPLE

— Sample 1: 30 000 bending cycles; Sample 2: 50 000 bending cycles;

— 25 % of 50 000 cycles is 12 500 cycles;

The difference of 20 000 cycles between Sample 1 and Sample 2 is greater than the allowable deviation of 12 500. Therefore, an additional test needs to be carried out.

B.3.2 Sheaves

The geometry, material and surface of the sheaves used in testing should be optimized for the HPFR construction and the design used should be provided with the test results.

NOTE Typical steel wire rope sheaves designed for cranes have groove R/d ratios greater than 0,525 with opening angles of 45° or greater, where R is the radius of groove in sheave, and d is the nominal rope diameter.

B.3.3 Testing

Testing should be performed for single bending evaluation with a bend length of at least 20d.

B.3.4 Water cooling/heating

The setup for the water should be defined clearly and provided with the test results, for example:

a) either rope running through a water bath (whole rope cross-section should be watered), spraying or flowing water in the groove at a minimum flow rate of 2 l/min;

b) if a water tank is utilized, it should have a capacity big enough to prevent saturation of the water with material removed from the rope;

c) temperature control, especially for 50 °C ± 5 °C;

d) no salt water;

e) water should be changed after every test (because of coating, chemicals, etc.).

NOTE Water acts as lubricant and can have an influence on the rope performance.

B.3.5 Machine parameters

The bending machines should feature the following parameters:

a) load tolerance: ±2 %;

b) minimum distance of the bending zone to the end connection: 10 times nominal HPFR diameter, d;

c) fleet angle of 0°;

d) wrap angle on the test sheave: minimum 60° (usually around 150°);

e) speed and stroke length variability.

B.3.6 Identifying discard criteria

Periodic observation to identify discard criteria should be made and documented with the test results:

a) measurements of sample condition such as diameter, elongation, etc., should be tested at periodic intervals when feasible;

b) stopping the machine can have an influence on the result and should be maintained consistently for all samples to provide equivalent conditions and should be included within the test results.

B.3.7 Test end criteria

The bending test should be ended in the case of:

a) a broken strand;

b) a whole broken rope;

c) if the rope is elongating and the rope force cannot be applied;

d) if 1 000 000 cycles are reached (long runner).

NOTE If a residual breaking strength test is performed, the bending test needs to be stopped when discard criteria is reached.

B.4 Multilayer spooling test

B.4.1 General

Tests are either carried out:

a) on test equipment designed for multi-layer winding; or

b) on a crane that is prepared for the eventuality of a potential rope break.

B.4.2 Setup of the drum test

a) The test can be done either by lifting a load or pulling between two winches and the parameters of the test system should be provided with the test results.

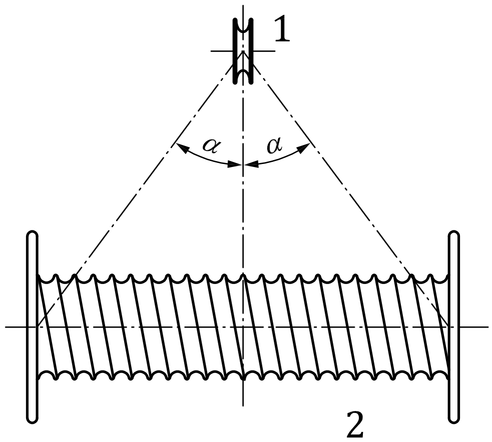
b) The system for applying the load should be sufficient enough for a load corresponding to the rope force used in the application.

c) It should be ensured that the rope force where the rope spools onto the drum remains constant within the tolerances of ±2 % over the entire rope spooling cycle.

d) Drum(s) should be large enough for the number of layers used in the application.

e) Drum(s) width allowing number of wraps should be equivalent to those in the application.

f) The fleet angle between the drum and the first sheave in the test configuration should be 2,0° ± 0,5° when the rope is positioned against each flange, unless the application requires operation at larger or smaller fleet angles (see Figure B.1).



Key

α fleet angle at the sheave (angle is enlarged for better visibility)

1 sheave

2 drum

Figure B.1 — Fleet angle

g) Drum design should be as in the intended application.

h) Number of sheaves that the rope bends around in the test setup should be minimized.

B.4.3 Full load test method

a) An appropriate pre-tensioning procedure should be applied at installation to ensure that the HPFR is not damaged prior to test start.

b) One test cycle is defined as spooling the entire rope length on and off the drum from the minimum wrap limit to the uppermost layer as specified for the application.

Maximum rope pull (MRP) is applied to the rope for the duration of every cycle on and off the drum.

c) Periodic observation to identify discard criteria should be made and documented with the test results.

Measurements of sample condition such as diameter, elongation, etc., should be tested at periodic intervals when feasible.

d) Testing should be performed at ambient temperature with measured temperatures provided with the results.

B.4.4 Alternating load test method

a) An appropriate pre-tensioning procedure should be applied at installation to ensure that the HPFR is not damaged prior to test start.

b) One test cycle is defined as spooling the entire rope length on and off the drum from the requisite number of safety wraps to the uppermost layer.

— Rope is spooled onto the drum with 5 % MRP applied.

— Rope is spooled off the drum with 100 % MRP applied.

c) Periodic observation to identify discard criteria should be made and documented with the test results.

Measurements of sample condition such as diameter, elongation, etc. should be tested at periodic intervals when feasible.

d) Testing should be performed at ambient temperature with measured temperatures provided with the results.

B.4.5 Number of test samples

At least two drum tests should be carried out for each test method on the chosen equipment to provide sufficient comparison between results.

Where deviation between the test samples is more than 25 % of the higher cycle number, an additional sample should be tested. If the third test sample also does not meet this target deviation, the test procedure and rope design should be reviewed, and the tests should be repeated.

EXAMPLE

— Sample 1: 3 000 spooling cycles; Sample 2: 5 000 spooling cycles;

— 25 % of 5 000 cycles is 1 250 cycles.

The difference of 2 000 cycles between Sample 1 and Sample 2 is greater than the 1 250 allowable deviation. Therefore, an additional test needs to be carried out.

B.4.6 Test end criteria

The drum test should be ended in the case of:

a) a broken strand;

b) a whole broken rope;

c) discard criteria being reached, if a residual breaking strength test is performed.

B.5 Termination test

B.5.1 Termination at drum side

The termination used to connect the HPFR to the drum should be evaluated to ensure the following.

a) The rope termination without safety wraps is capable of holding at least 1,2 times the MRP of the HPFR (see 5.1).

This termination strength requirement is intended to provide safety in the event that the wrap limiter fails. The termination should not fail when loaded to this target tension with the rope loaded as under service conditions. Testing results should be provided as evidence along with parameters of the test method used.

b) The rope termination including safety wraps is capable of holding at least (0,8 × n) times the MRP of the HPFR (see 5.1).

Evaluation of strength with minimum required friction wraps can be performed through direct testing on a drum with wraps.

An alternative method is testing a drum attachment without wraps where a calculation for the tension reduction by wraps is determined in accordance with 5.1.

HPFR fastening on to the rope drum should be tested with the rope installed on a test fixture utilizing the minimum friction wraps. The termination should not fail when stressed to the required termination strength (see 5.1) and testing results should be provided as evidence along with parameters of the test method used.

Calculated termination efficiency takes into account the results from a linear tension test of the termination without friction wraps; the angle corresponding to the specified minimum friction wraps; the coefficient of static friction between the HPFR and the drum. The coefficient of friction should be taken as 0,04 unless validated through testing by the rope manufacturer with evidence provided in combination with the termination test findings.

c) The rope termination without safety wraps is capable of being cycled under maximum rope pull in the rope drive in a fatigue life test.

This test without safety wraps should ensure that the HPFR is not slipping out of the end termination and the termination is able to hold the rope.

Testing of the termination should be carried out through cycling tension between 50 % and 100 % of the maximum designed rope pull in the rope drive using a new HPFR in the designed termination. The termination should not fail during testing up to 75 000 force cycles. The temperature of HPFRs should be kept at the maximum intended operating temperature. No modification of the termination during the testing should be made. Testing results should be provided as evidence along with parameters of the test method used.

B.5.2 Termination at load side

The termination used to connect the HPFR to the load side should be evaluated in order to ensure the following.

a) Strength exceeds the requirements in 5.2.

Testing should be performed through application of tension up to the maximum rope pull in the rope drive using a new HPFR with the designed termination. The termination should not fail when loaded to this target tension and testing results should be provided as evidence along with parameters of the test method used.

NOTE Terminations for HPFR can necessitate bedding-in (see ISO 2307:2019, 9.5) to be optimally set prior to a breaking strength test.

b) Termination fatigue life allows for repetitive cycling with maximum rope pull in the rope drive.

Testing of the termination should be carried out by cycling tension between 50 % and 100 % of the maximum rope pull in the rope drive using a new HPFR in the designed termination. After performing 75 000 cycles the termination should be loaded to the minimum required termination strength as defined in 5.2. The temperature of the HPFR should be kept at the maximum intended operating temperature. No modification of the termination during the testing should be done. Testing results should be provided as evidence along with parameters of the test method used.

Annex C
(informative)

HPFR test report – Spreadsheet

C.1 General

This annex provides guidance on test reports to demonstrate the performance of the HPFR as required in 4.4 and Clause 6.

C.2 Examples

Examples are given in the Tables C.1 to C8.

Test methods should be provided against the appropriate values in the tables.

Table C.1 — Rope identification and basic specifications

		Remarks
Rope manufacturer	XY	
Rope description	Omni-Optimum-Super	
Date of production	01.01.1911	
Batch number	73,745	
Nominal rope diameter, d [mm]	27,0 mm	
Actual rope diameter, d_{act} [mm]	26,8 mm	
Specific weight total [g/m]	310,0 g/m	
Specific weight of load bearing element [g/m]	260,0 g/m	
Minimum breaking strength (MBS) [kN]	585,0 kN	
Maximum rope pull (MRP) [kN]	120,0 kN	
Safety factor n:	4,88	
Youngs modulus axial [MPa]	40 000 MPa	
Youngs modulus lateral [MPa]	100 MPa	At 20 % MBS
μ coefficient of friction rope on metal	0,05	If not available, take 0,04
Loadbearing material(s):	super fibre	
Non-load–bearing material(s):	super fibre 2	
Termination load side:	splice	
Termination winch side:	socket	

Table C.2 — Limits for the rope use

	Minimum	Maximum
Maximum rope pull (MRP) [kN]	120,0 kN	
D/*d* ratio (*d*: nominal rope diameter)	22,5	No restrictions
Pulley groove radius [mm]	13,5 mm	14,0 mm
Ambient/surface temperature [°C]/[°F]	−20 °C	45 °C
Twist [turns]	0	±1 turns
UV limits		
Chemicals		10 > pH > 2
Any other restriction for use		

Table C.3 — Additional lifetime determining factors according to the risk assessment

	Remarks	
— Tension-tension		
— Open flame		
— Sand		
— Check the complete rope drive		
— Chemicals		
— ...		

Table C.4 — CBOS test

		Remarks
Rope description	Optimum-Super-rope	
Date of production	01.01.1911	
Batch number	73,745	
Actual rope diameter, d_{act} [mm]	26,8 mm	
Actual weight [g/m]	310,0 g/m	
Residual breaking strength (RBS) [kN]	600,0 kN	≥ MBS
Maximum rope pull (MRP) [kN]	120,0 kN	
Test force [kN]	130,0 kN	≥ MRP

Test	1	2	3	4	5	
Conditions	**No twist/ ambient temperature**	**Twist/ ambient temperature**	**No twist/ elevated temperature**	**Twist/ elevated temperature**	**Worst combination according to risk assessment**	**Remarks**
CBOS test setup						
Test force [kN]	130 kN	120 kN	130 kN	130 kN	130 kN	≥ MRP; ± 2%
MBS/Test force	4,50	4,88	4,50	4,50	4,5	≤*n* ; see Table C.1 (rope idenfication and basic specifikations)
Water cooling	yes	yes	no	no	no	
Temperature measured [°C]/[°F]	18 °C	20 °C	52 °C	49 °C	52 °C	20 °C; 50 °C; ≥ maximum allowed temperature; ± 5 °C
Twist applied [turns]	0	1	0	1	2	≥ 1 turn; equal or more than allowed
Additional critical parameters according to risk assessment					x-ray, 10 % HCl	Combination of all lifetime reducing conditions; look risk assessment
Sheave diameter, *D* [mm] *D*/*d*	535 mm 19,8	535 mm 19,8	535 mm 19,8	535 mm 19,8	450 mm 16,7	Measured in pulley valley ≤ min *D*/*d*
Groove radius, *R* [mm] *R*/*d*	14,0 mm 0,52	14,0 mm 0,52	14,0 mm 0,52	14,0 mm 0,52	13,0 mm 0,48	

Table C.4 *(continued)*

Test	**1**	**2**	**3**	**4**	**5**	
Conditions	**No twist/ ambient temperature**	**Twist/ ambient temperature**	**No twist/ elevated temperature**	**Twist/ elevated temperature**	**Worst combination according to risk assessment**	**Remarks**
Bending length, *l* [mm] *l*/*d*	700 mm 25,9	700 mm 25,9	700 mm 25,9	700 mm 25,9	700 mm 25,9	Make sure that there is no unintended double bend.
Machine cycles per minute	6,0	6,0	8,0	8,0	10,0	
CBOS bend-cycles per minute	6,0	6,0	8,0	8,0	10,0	
CBOS TEST RESULTS						
CBOS bend-cycles until 100 % discard criterion reached	70 000	55 000	40 000	23 000	15 000	
CBOS bend-cycles until rope breakage	210 000	170 000	100 000	60 000	42 000	
Residual life time (RLT) in %	67 %	68 %	60 %	62 %	64 %	≥60 % residual lifetime
Residual breaking strength (RBL) at 100 % discard [kN]	365 kN	368 kN	220 kN	250 kN	240 kN	
RBL at 100 % discard [%]	62 %	63 %	38 %	43 %	41 %	
RBL/MRP	3,0	3,1	1,8	2,1	2,0	≥ 3

Table C.5 — Multilayer spooling test

		Remarks	
Rope description	Optimum-Super-rope	Same (same batch number is best)	
Date of production	01.01.1911		
Batch number	73,745		
Actual rope diameter, d_{act} [mm]	26,8 mm		
Actual weight [g/m]	310,0 g/m		
Residual breaking strength (RBS) [kN]	600,0 kN	≥MBS	
Maximum rope pull (MRP) [kN]	120,0 kN		
Test force [kN]	130,0 kN	≥MRP	