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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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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.

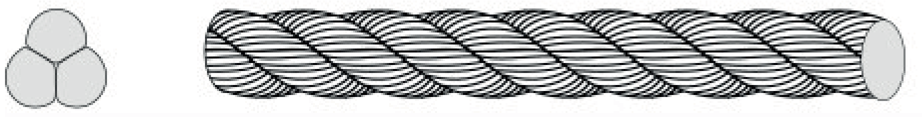
Various rope constructions can be utilized in the design of a rope. Several common examples are shown in Figure 1:

— laid in Figure 1 a);

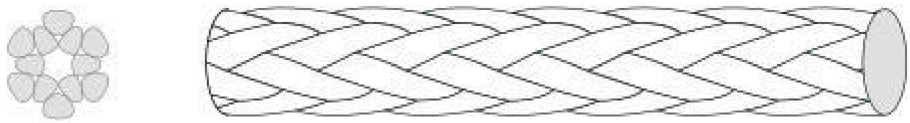
— braided in Figure 1 b);

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

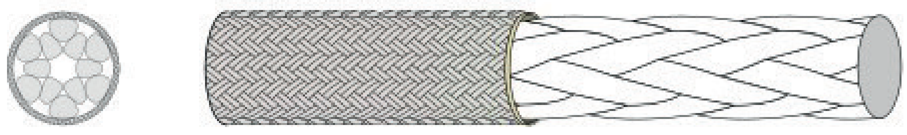
— cover (jacket over parallel fibre) in Figure 1 d).



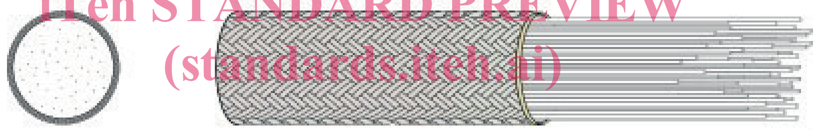
a) Laid



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:

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

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 $\mu = 0{,}04$.

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.