SafeWinch tackles slack wires and peak loads

For practical use in harbour towage and escorting

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SYNOPSIS: The tug market focuses more on safety in tug operations, aiming at two focal points: a) Prevention of slack wires and b) Prevention of overloading. The new SafeWinch offers a simple and robust solution to tackle both points by adding a ratchet to the winch: This patented ratchet automatically separates the torque in the hold direction to the brake side and in the pull direction to the drive side. The winch is further composed of proven components manufactured and tested by Kraaijeveld Winches. Also the operational handling and controls have been improved for limited human action and safe operation during towage.

1. Introduction

This paper describes the development of a new winch type to improve the safety of tug operations, with specific attention to preventing both slack wires and overload.
The development of this new SafeWinch involved the following steps: Analysis of present towing winches, development of a new ratchet based on risk analysis, prototype testing and the final SafeWinch.

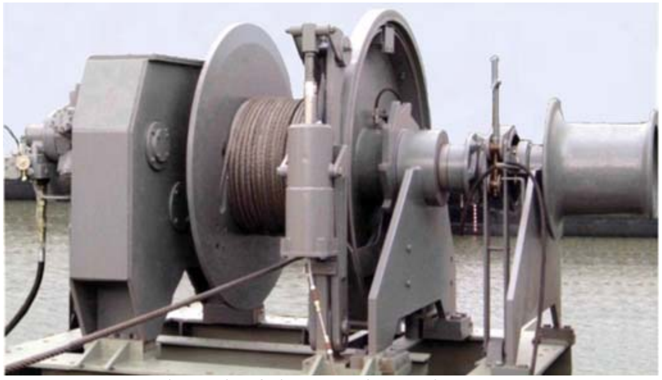

Fig. 1 : The first SafeWinch in factory of Kraaijeveld

2. Present Towing Winches

Present towing winches can be divided into three categories, will be briefly discussed as reference for the new design:

2.1 Conventional Winch

A conventional winch consists of a brake arrangement and a drive arrangement. During operation, the winch can be used in either the brake or the drive mode. Pull is performed by connecting the drive and pay out is performed by disconnecting the drive and varying the brake force.
In pull mode the speed and pull force are directly related to the applied motor power and gear ratio. In release mode, the speed and brake force are directly related to the brake type and optional cooling, see e.g. in Fig. 2.
Limitations: Changes from brake to drive and vice versa are limited by manual control / start up time and may involve operational errors.

2.2 Constant Tensioning Winch (CT)

In contrast to the conventional winch, the self-tensioning (also called constant tensioning) winch is continuously operated in the drive mode. Both pull and pay out is done with connected drive side. Speed and force are directly related to the applied motor power and gear ratio. During pay out the energy is dissipated through cooling of motor and fluids. Maximum pull and release speed is limited by the maximum speed of the motor, see e.g. Fig. 2. (e.g. 75 m/min equals only a speed difference of 2.5 kn).
Limitations: Due to connected drive relative large components are needed to achieve the full pull and the maximum speed is limited.

2.3 Render-recovery winches (RR)

In the recent years there has been an ongoing research on escort tug operation, especially in exposed condition, e.g. the MARIN SafeTug project [1].
Simultaneously, there has been a development for a winch type with two specific requirements:

- Higher pay out speed (also called render)
- Higher pull speed (also called recovery)

This type automatically connects either the drive side during recovery or the brake during rendering. In some cases during rendering both the drive and brake are connected. A typical graph can be seen in Fig. 2. This winch type is subject to ongoing research and development. An example can be found in [2].
Limitations: Complexity of (dis)connecting drive and brake and reliability.

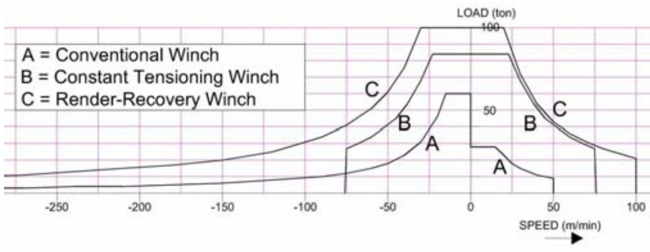

Fig. 2 : Graph of typical parameters of above winches

3. Development of the concept

3.1 Background

In order to investigate the safety of a winch during assistance and escorting, the well-known Fault Tree Analysis approach is used. In this approach, the risk is described in all contributing events and sub events, see Fig. 3. The combined risk is defined as a combination of the failure of the tug side and of the ship side.
All sub events related to the winch have a double line box and will be the subject of further investigation.

As main subevents appear clearly:

- Prevent slack wire : Risk for Crew / Propulsion Loss
- Prevent overload : Break of wire / Risk for Crew / Damage

3.2 Risk of slack wires

Slack wires occur in principle due to large dynamic motions or due to manouvring (errors). During dynamic motions, the tug and ship

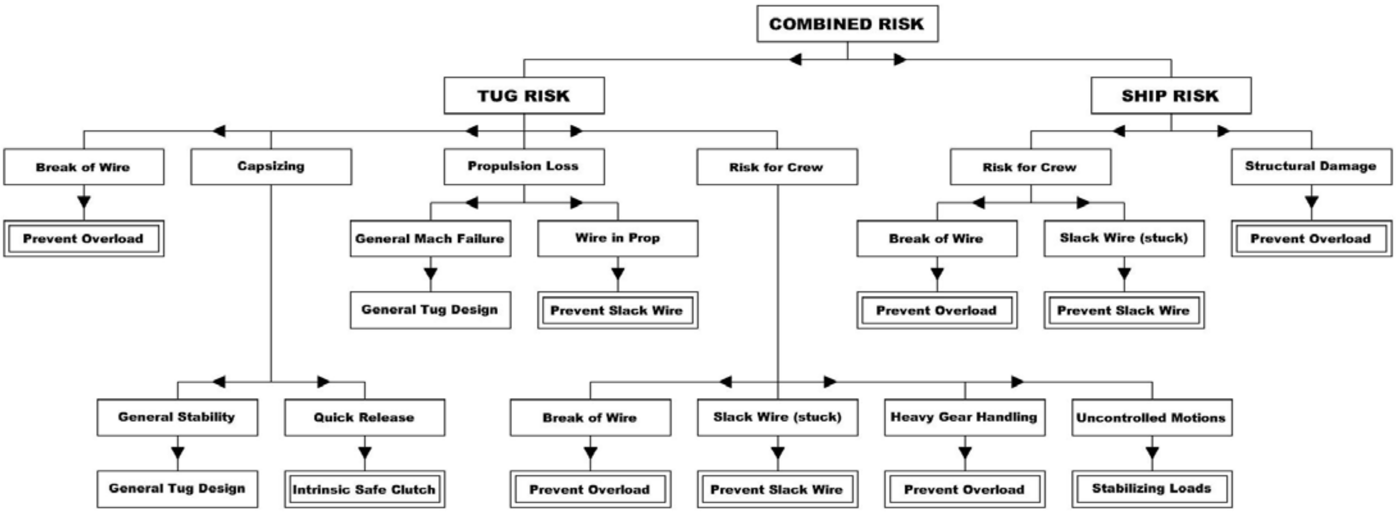

Fig. 3 : Fault Tree Analysis (winch related)

move towards each other and the line slacks, followed by opposite motions and a large peak load.
When this mechanical system is modeled, the following graph is created, showing the relative short slack period followed by extreme peak loads, see Fig. 4. When the parameters are varied, the following relation is determined:

$$\delta s^2 \approx F_{snap}$$

Or in practical terms: ➔ 2x as large slack distance equals 4x as large snap load.

Therefore, reduction of slack wire (distance) is crucial in limiting the peak loadings, since the force increases with the second power of the distance.
Therefore, the winch should recover the line rapidly and interestingly, only “marginal” energy is required to recover the wire (energy equals pull times speed), but significant more energy is needed to counter the inertia force of the winch and wire.

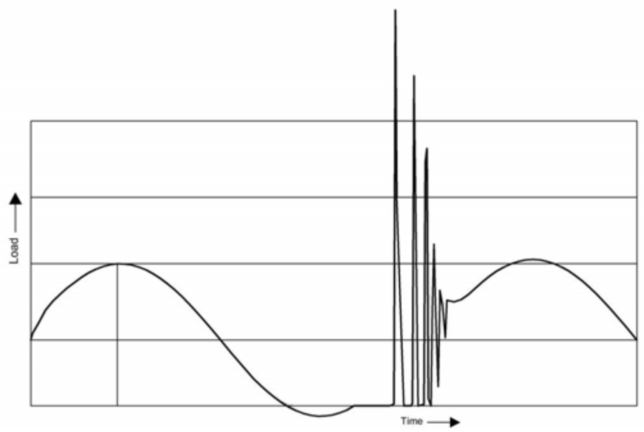

Fig. 4 : Slack wire followed by large peak load (≈ 2.5x Amplitude)

3.3 Risk of overloading and breaking wires

Crucial parameters in the case of overloading are both the magnitude of the force itself and the force increase per time unit.

$$\delta F / \delta t$$

Apart from the mechanical model of tug versus ship motion, the load increase should be tackled by the winch and especially when the load increases rapidly, the drum inertia (including wire), the drive and the applied brake force need to be countered. The higher the load increase occurs, the higher the risk of breaking the wire.
Although theoretically, the use of lower inertia drum + wire (synthetic) will provide a larger safety margin, the best solution is clearly to prevent the occurrence to happen at all **…**

… by preventing a slack wire !
Traditionally, peak loads were countered by applying a stretcher, which offers additional elasticity [3]. However, in modern tugs with increasing bollard pull they are used to a lesser extent (risks) and the modern towing gear has a rather high stiffness, especially in case of high performance synthetic fibres.

3.4 Intrinsic safe release device

An essential feature of a winch is a reliable and safe quick release, based on the release of a brake. However, further design details need to be considered to make a proper design choice.
Basically, brakes can be divided into 3 different types:

- Self “loosening” type (A)
- Self “tightening” type (B)
- Load neutral type (C)

Fig. 5 shows that when a certain brake force is set (horz. axis), each type has a completely different brake force function with increasing external load (vert. axis).

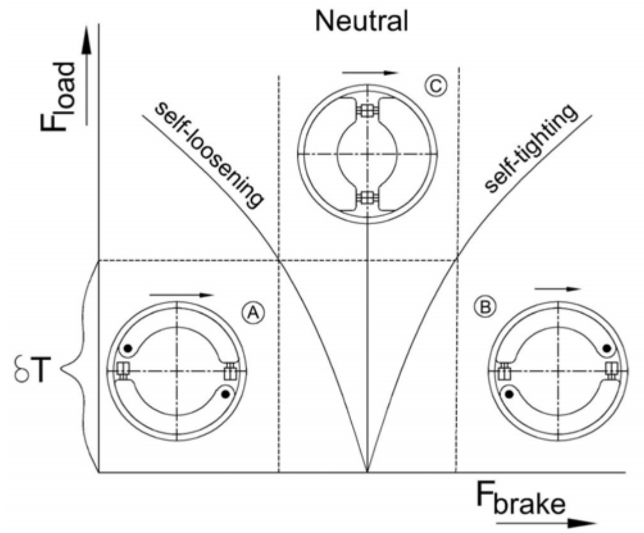

Fig. 5 : Graph of diff clutch types with varying external load

With increasing load the brake force will lower for type A) and in case of extreme overload the brake can still be safely released. However, with increasing load in type B), the brake force will increase and in case of extreme overload the brake cannot be released ! Also rapid increasing (snap) loads (short δT) may prevent safe release. Type C) offers a neutral, load independent brake performance and can be released safely under all conditions. Therefore, only type A) and C) offer an intrinsic safe release device and shall be applied in a new winch.

A band brake, which is widely applied in tug industry, is of a self-tightening type B) and is not intrinsic safe; therefore the brake may not release in case of a (rapid) overload !

3.5 SafeWinch principle
Considering the previous mentioned winch aspects, a new winch is designed, starting from a functional perspective: Pulling is essentially different from paying out and therefore both functions should be split. The heart of the new winch is formed by a patented ratchet free wheel system, which automatically separates the torque depending on the applied direction; see Fig. 6.

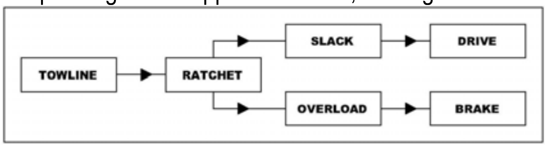

Fig. 6 : Flow diagram of concept I

This concept already incorporates the basic division of overload and slack wire. However, in case of a severe overload the drive side will have to rotate according to the occurring slip in the brake. This disadvantage can be solved by moving the brake (now clutch) between the drum and the ratchet, see Fig. 7.

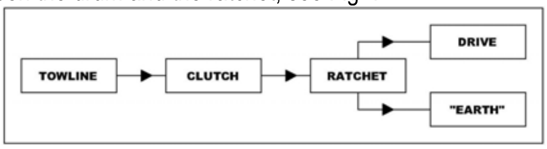

Fig. 7 : Flow diagram of concept II

The towline moment is first guided through a clutch and then through the ratchet, where the torque is divided either into the drive or the "earth" side depending on the direction of rotation:

- Overload: The excess pull force is released by a clutch connected via the ratchet to the earth.
- Slack wire: The wire can be instantaneously retrieved by the drive connected to the ratchet and clutch.

This arrangement fully tackles both the event of a slack wire and an overload event by an intrinsic-safe-design.

The components of the new winch: Drum, clutch, ratchet and drive are shown in a schematic view in Fig. 8.

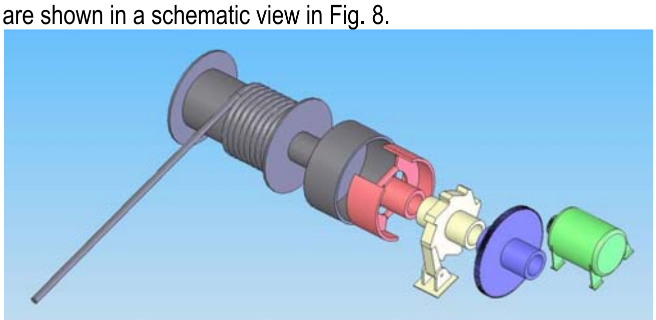

Fig. 8 : Schematic view of components SafeWinch

3.6 Functioning
How does this ratchet function for varying loads?
Fig. 9. shows a typical towline load graph versus time for a tug operating in irregular waves, see e.g. [1] & [4]. The force fluctuates between an overload and a slack 'load' and both will be tackled by the SafeWinch. The upper line represents the load limit of the clutch and higher loads are prevented by the slipping clutch. The lower line represents the limit of the motor (pull) and lower loads are prevented by the pulling of the motor. The final result hereof is a 'load window' between "Clutch" and "Motor". The magnitude of both parameters shall be fixed in the design scope, but can be lowered by the master during the operation.

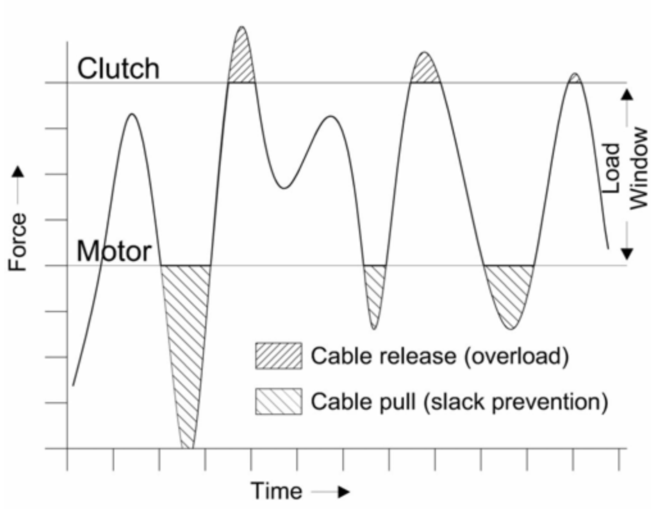

Fig. 9 : Typical towline load variations and SafeWinch behavior

The above diagram simplifies the clutch and motor performance; the clutch has a small difference between static and dynamic friction and the motor has a short inertia delay, which will result is a short 'undershoot.

3.7 Summary
The proposed ratchet arrangement in the SafeWinch offers the following advantages:

- Prevents slack wires
- Lowers peak loads
- Safeguards gear and motor from overload
- Reduces wear of equipment due to limited peak loads

4. Prototype testing

4.1 Introduction
Although the design is composed of many proven components, the winch operation and winch – tug interaction changes and therefore thorough investigation of the new operation is necessary. The investigation started with detailed strength and motion calculations, but continued with real life dynamic testing on a real size winch.

4.2 Prototype
In consultation with Smit Harbour Towage, their ordered winch was upgraded to a SafeWinch in order to test and validate the performance. The installed friction clutch was equipped with a ratchet, see Fig. 10.

Fig. 10 : Installed ratchet on SafeWinch

As first functional test, the SafeWinch was connected to another winch and the wire was spooled in various speeds and directions from one to the other. Gradually the speed changes and direction changes were increased in order to simulate real life conditions on a tug and the SafeWinch easily managed to counter the applied variations.
In order to simulate large and rapid variations in towline loads, the previous test was limited by the pulling winch arrangement and therefore a more active pulling object was selected using a large shovel. This large shovel is capable of fast accelerations and change of directions, see Fig. 11.

Fig. 11 : Dry testing of SafeWinch with large shovel

The tests demonstrated clearly the superior functioning of the winch, since both overloads and slack wires were countered effectively. The tests were attended by surveyors from the large classification societies.

For further fine-tuning, the prototype setting will be fitted with a faster variable speed hydromotor and clutch modifications. Video and measurements will be presented at Tugnology.

5. SafeWinch

After the successful testing of the SafeWinch prototype, the well-known winch manufacturer Kraaijeveld Winches offers the new SafeWinch, combined with controls and design sheets for optimal integration.

5.1 SafeWinch series

Based on the different operational tasks of the winches, Kraaijeveld has developed 3 different winch series, see Fig. 12, with either hydraulic or electric drives:

I) Normal Duty SafeWinch (ND)

Arrangement derived from well-proven Kraaijeveld winch with exchangeable components. This type adds the functionality of slack wire prevention and overload prevention, but based on a new developed intrinsic-safe twin shoe clutch.
Application: In sheltered port area where overloading occurs incidental…

II) Heavy Duty SafeWinch (HD)

Heavy-duty winch construction with further improved clutch with forced cooling to allow rapid and controlled rendering above 100 m / min. Pull power can be selected in range and speed, typically near 50% of Hold.
Application: In partly exposed port area with waves, where overloading occurs regularly.

III) Escort SafeWinch

This winch design is based on a different arrangement of the components: The heavy gearbox is fitted between drum and clutch. The winch offers full pull and rendering with Pull power up to Hold level, a multi-disc clutch with forced fluid cooling to allow continuous slipping and rendering at full force.
Application: In fully exposed conditions with large waves and escort operation at higher speeds, where overloading occurs frequently.

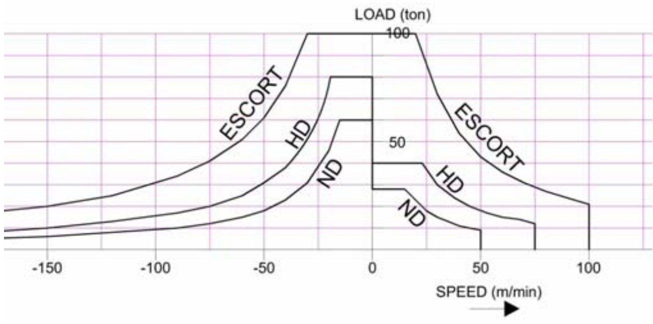

Fig. 12 : Three Winch Series Kraaijeveld

5.2 New console

For easy and safe operation of the SafeWinch, a completely new console was developed ensuring logical operation and minimizing risks of faults / errors, see Fig. 13. The console consists of three elements: A control lever for the winch, a clutch Min/Max setting and a load display.
The central focus was to develop a one hand controlled logical selection lever (1) for full control of the essential functions during towing. This lever ensures that the ratchet can only be changed from open to closed condition and vice versa with zero motor rotation.

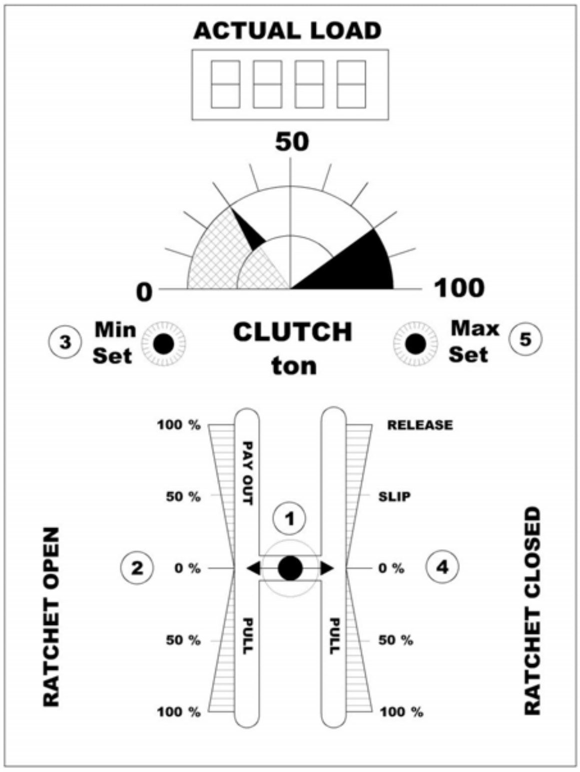

Fig. 13 : Console for easy handling SafeWinch

The left-hand side of the selection lever (2) is used during (dis)connection of the towing wire to the ship for paying out and pulling. In this mode the ratchet is open and the clutch force limited according to Min Set (3) to prevent damage to the gear and motor.

The right hand side of the selection lever (4) is used during towage. In this mode the ratchet is closed and the clutch force is high to enable "full pull" according to Max Set (5).

The second crucial feature is the central clutch setting (4): Before towing, the master will ask the available strength of the bollard on the towed vessel and will limit the clutch setting accordingly by Max Set (5). Hereby damage to either the bollard or the towline during the whole operation is prevented.

5.3 Towing gear implications

The SafeWinch includes a new load-limiting clutch and ensures that loads above the set level will not occur in the towing arrangement.
In towing operations safety margins of 2.5 are widely applied to cover the uncertainty in occurring loads due to additional dynamic loading [5]. Although safety margins remain valid, the SafeWinch offers a sound tool to quantify the required safety margins and reduce the wire thickness. Typically, the following table 1 can be set up for a 60 ton BP ASD harbour tug.

60 t BP tug	Conventional Type	SafeWinch Type
Hold	180 t (band brake)	90 t (new clutch)
Typical peak load	Up to 2x BP = 120 t	Limited by clutch = 90 t
Dia wire	54 mm	48 mm
Wire BL	≈ 190 t	≈ 150 t
Weight/m	1160 kg	917 kg (-20%)

Table 1 : Comparison winch parameters

5.4 Design parameters and performance

Kraaijeveld offers the three winch series, Normal Duty, Heavy Duty and Escort and in close consultation with the customer the following distinct parameters need to be selected for optimal match with the intended operation, see Fig. 14.

- Clutch hold in ton (A)
- Clutch cooling in kW (B)
- Pull force in ton (C)
- Pull power in kW (D)
- Maximum recovery speed (E)

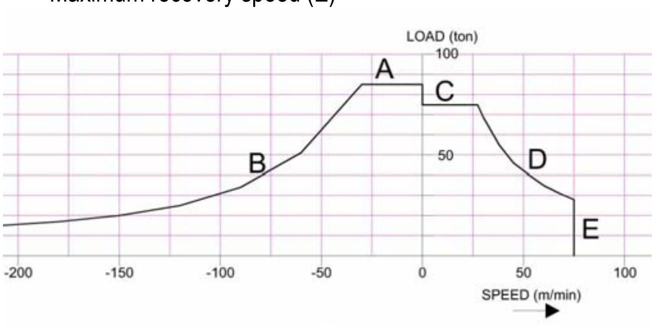

Fig. 14 : Design Parameters SafeWinch Series

The maximum rendering speed is deliberately not included as design parameter, since emergency release should be full release even when a tug is escorting at 10 kn speed (equals 300 m/min) and rapid deck submersion may occur, see e.g. [4] and [6].
Especially, a high recovery speed and the drive power to accelerate the drum shall be closely investigated to achieve the slack wire prevention for the intended tug operation.

The final result hereof is again a custom built winch for the operator, as has been the focus of Kraaijeveld Winches.

6 Conclusions & recommendations

- Analysis of the winch requirements has lead to a new split functionality of pulling and paying out, by means of a ratchet system.
- The result hereof, the SafeWinch tackles effectively both slack wires and overload, thereby improving the operational safety.
- The SafeWinch offers intrinsic-safe design as base for safe operation.
- The SafeWinch design is based on robust proven components and offers therefore a reliable long lasting solution.
- The winch parameters shall match the operational use closely to offer the most effective and cost attractive solution.
- During an assistance the winch requires minimal attention of the master, allowing him to concentrate on his prime tasks.
- The prevention of slack wires already solves the prime part of the problem, since slack wires contribute to a large extent to snap – overloading
- The clear advantages of the SafeWinch offer good perspectives for market wide application.

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More information on new *Safe* Winch : www.safewinch.com