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Methodology for the Selection of Winches and Ropes for Assist and Escort Tugs in Dynamic Seas

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SYNOPSIS: A methodology is presented to guide the selection of winch and rope systems for use on tugs performing vessel assist and escort operations in dynamic sea conditions. The methodology provides the means to achieve the hawser safety and reliability necessary for conducting long term operation of offshore and exposed oil and gas terminals.

Introduction

The effort to extend ship assist operations into increasingly dynamic sea conditions is currently being driven by several LNG terminals now under construction. In order to be profitable these sites will require assist tugs to routinely operate in fully exposed and open sea conditions. Although we have made great strides toward this end with winch and rope systems on Crowley's *Response* [4], Moran's *Edward Moran,* and Crescent's *Bulldog,* it was nonetheless felt that the overall tug-winch-rope technology to date would be inadequate for these upcoming applications.

To this end Griffin Associates participated in model tests in August of 2004 to determine the tug motions and hawser tensions one would expect in seas to three meters with the short wave periods associated with shallow terminals facing open roadsteads. The test protocol is illustrated in Figure 1 and Photo 1. The results of these tests and others show that extremely high tensions occur at a level well beyond the capacity of typical tug equipment and hardware, particularly when the hawser upward lead angle from tug to ship is greater than fifteen degrees.

The following paper discusses the role we believe the winch and rope system plays in these operations, and proposes a logical methodology to be used in specifying the winch and rope performance, associated marine engineering, and downstream monitoring and maintenance procedures. And finally, the following methodology benefits from important advances and understanding of the construction and behavior of high performance HMPE fiber hawsers when applied to dynamic and energetic seas where cyclic fatigue plays an important role.

Our partners in this effort include Markey Machinery Company, Inc. and Puget Sound Ropes and of course our valued customers and colleagues.

Background

When asked to provide a tug winch recommendation for exposed LNG terminals we are often

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4 "Ship Assist and Escort Winches for Dynamic Seas" Barry Griffin, BA Griffin Associates, Inc. , ITS 2004, Miami

presented with a tug design, proposed winch, line size, and associated fittings that appear adequate for initial contracting but possibly inadequate for the actual operations.

But how inadequate?

As winch and rope engineers with some experience in this application we felt that a job specific analysis would be required to finalize the tug design for each specific terminal, at least until a handful of applications were in service and a more or less standard winch and rope solution could be provided. It never seemed to fail that despite the challenges and uncertainties, we were asked to provide a specification and even a price for a totally new site and tug in less than a week. On reflection we realized this condition is understandable given the way assist and escort tugs are often specified - tug first everything else second. Previously, the "everything else" was easier to specify owing to an extensive body of knowledge based on many decades of using wire rope and first generation synthetic hawsers.

This all changed with the advent of lightweight and high strength High Molecular Weight Polyethylene (HMPE) hawsers capable of handling large ships where wire or medium strength synthetics are completely inadequate. HMPE fiber technology is now entering its 17^{th} year of routine service on the US West Coast and predominates in ship assist applications in North American tug fleets. It is sometimes forgotten that as recently as 1997 we were not entirely convinced that HMPE technology was completely viable.

Fortunately, our ability to gather and analyze real time, historical and forensic information on these ropes using monitoring and data logging built into the winch system has steadily grown and is now improving the entire ship assist operation.

The following methodology for dynamic sea operation is primarily dependent on our knowledge of the behavior of synthetic fiber and hawsers. Therefore, the limitations in the analysis, and areas of most interest in future study are with the nature of HMPE ropes.

Commercial and customer considerations

Our winch and rope customers expect us to provide at least the following in addition to any mission specific performance:

- Lowest risk to all parties
- Shortest time to project commissioning
- Flexibility in tug usage
- Competitive advantage
- Lowest long term operational cost
- Technical leadership

These requirements are of critical importance in the LNG market in North America, where the emerging industry is acutely aware of the downside of accidents and operational failures.

General operational guidelines

The winch and rope guidelines common to many of the proposed terminals are as follows:

- **Maximize tug performance.**

The winch and rope system must allow the tug and crew to readily achieve the commanded position and line pull, up to the tug's rated bollard pull in modest seas and to a lesser pull in the worst case seas. The degradation in tug pull is dependent on both the tug and winch design and can be visualized in a "tug effectiveness curve". The system performance is also dependent on the mission specific positions the tug must maintain in addition to the related upward hawser lead angles, ship chock heights above the water, and other factors.

- **Maintain connection and prevent damage to the assisted vessel.**

There is ample evidence from model tests, tug Masters, and other analysis that the hawser shock loads that can occur in ship assist operations at the proposed terminals would eventually, if not immediately, lead to the failure of the hawser and the associated ship and tug fittings. It is therefore of primary and greatest concern that the tug stay connected to the ship with positive tension in the hawser in all sea conditions where operations are required (typically on the order of a maximum of three meter seas (significant) with eight to ten second periods) while at the same time limiting the hawser tensions to no more than the Safe Working Load of the chocks and fittings of the LNG tankers (generally between 50 and 120 tonnes).

This would also need to include the following contingencies:

- **Rogue seas**

  Unexpected seas outside the design window could occur during normal operations. In these circumstances very high tensions could occur. If so, the winch must always render at a safe setting, regardless of the level of sea energy or snap loads that result from the tug surging into a slack hawser.

- **Loss of tug power**

  Loss of main engine, propulsion, and generator power are realities in normal ship work, with the result that the winch will be unable to recover line when tug motions create slack line conditions. The displacement of the tug is sufficient to create high and possibly dangerous tensions if the tug fetches up on a slack hawser. In this instance the winch system must be able to render line at a safe level using a control system independent of the tug's other systems..

- **Provide reliable and long service.**

The machinery design, marine engineering, crew training, routine maintenance, and on-site service and support must take into account the need to achieve full utilization of the terminal, including multiple dockings and sailings per week, for a period in excess of 20 years.

Winch and Rope System Methodology

To achieve these goals we are developing a comprehensive design strategy for winch and rope systems for dynamic seas on behalf of Markey Machinery Company and Puget Sound Ropes. The design approach includes scale model testing and numerical analysis of tug motion, winch model evaluation, tug to vessel interaction simulation, and the further study of the interaction of hawsers with ship fittings on both a short term and long term basis. The result will be an analysis package capable of quick and accurate prediction of winch and rope system performance.

This process requires input from each participant group including shipper, pilot, towing provider, naval architect, shipyard, and winch and rope supplier. The steps we have identified in the design process are as follows.

- **Preliminary Design Sequence**

  - **Define vessels and terminal**
    1 Type, DWT, chock and bitt heights, positions, and strength ratings for the range of vessels expected at the terminal.
    2 Physical and Environmental data: Measure actual local sea state and wave spectra.
    3 Other operational considerations, such as shipping schedule.

  - **Develop zero sea state maneuvers.**
    1. Identify through simulation or other methods the tug positions and forces required, as well as their duration to effect each required ship maneuver.

    2. The forces required for our analysis are the actual horizontal component of the raw forces placed on the ship, unaltered by any other assumption or formula in the simulator or analysis, while in a zero sea state condition, with other environmental forces active, such as wind and current.

  - **Size hawser.**
    1. Select preliminary hawser size and type using initial safety factor
    1 Include cyclic fatigue life for docking duration and sea state, contact issues, etc.
    2 Set initial safety factor for the greater of 6 times maximum maneuvering force in sea state zero or 6 times the tug bollard pull.

  - **Size staple and other fittings**
    Initially to 8 times the hawser diameter.

  - **Size Winch(es) capacity for**:
    1 <u>Tug to Ship Pennant</u> : Minimum length of maximum chock height above the water times two depending

on the closest operational position.

2 Adjust pennant length during service so that pennant to main hawser splice is beyond staple in clear span during closest normal operation. This allows the main hawser eye to be quickly sent back up to the ship if a pennant fails, without requiring the crew to manhandle the splice through the staple or other fittings; or engage and deploy a second drum if so fitted.

3 <u>Tug Main Hawser</u> : Working length of a minimum of ten times the maximum vessel chock height above the water.

4 <u>Tug Stretcher Segment</u> : If required , a minimum length of 30 meters or 1 times tug length, or some multiple of the winch drum capacity per layer.

5 <u>Tug Reserve Hawser</u> : A minimum of two layers of main hawser diameter tightly spooled on first two layers of winch.

6

- **Model and Size winch performance.**

1 Find winch hp to give the zero Sea State line pull required at the maximum operational Sea State and closest operational position (highest hawser uplead angle).

2 This analysis will determine the auxiliary hp the tug must provide for the winch alone and also the related winch systems for cooling, control and other items.

- **Design Tug**

1 Design the tug working deck; below deck, and auxiliary spaces, including the marine and structural engineering required to accommodate winch and rope system.

2 Refine the winch and rope system to accommodate the realities of tug size and mission if necessary.

3 Design the remainder of tug.

<u>Winch Operation and Marine Engineering Issues</u>

The following discusses the general nature of the power and control of the latest series of Markey winches when in their Asymmetric Render Recovery (ARR) mode of operation in dynamic seas, including a review of horsepower flow through a winch system.

- **Control of Hawser Tension in Dynamic Seas**

Under dynamic sea conditions the ability of a winch to compensate for the tug's surge, heave, and pitch is nearly impossible for a man to achieve using lever controls, and is therefore best achieved using automatic controls which operate within operator selected limits. In these seas the tug cyclical motions determine the winch action, the first being the motions which accelerate the tug forward toward the tanker, and the second being the sea motion forcing the tug away.

Each motion requires a different action on the part of the winch, with the forward motion requiring a line recovery action and the away motion requiring a line render action. The winch response in these conditions is somewhat similar to deep sea rod and reel fishing in which the star drag pays out or renders line when tension is exceeded, and with the fisherman recovering line quickly when slack line is inadvertently or intentionally created. The tension that the fish feels varies from a high “drag” level to near zero, with the average tension being somewhere in the middle. The faster and stronger the fisherman, the closer the line tension would be to the drag tension level and the higher the average tension would be.

It can be appreciated that very high horsepower might be required when attempting to maintain 75 tonnes bollard pull when the tug motions are very fast, such as the brief periods during the tug motion cycles one sees in the associated model testing. It should be noted however that the tug motions are somewhat sinusoidal and therefore the speed at which the winch must react varies from fast to slow depending on whether the tug is in the trough, the peak, or on the side of the swell. These variations in speed are estimated from the model tests. These motions are used in making the horsepower (hp) calculations necessary to apply as high an average bollard pull as possible, while at the same time providing enough speed to prevent slack and subsequent shock to the tug hawser and ship fittings.

For example, the current proposed design of the Markey Type DESDF-48 Hawser Winch provides average or effective pulls of 75 tonnes in 1 meter seas and 70 tonnes in 3 meter seas with a 10 second period. These are the maximum forces that the pilot can command with the given machinery and power configuration. This performance is achieved by using the water-cooled retarding brakes to render line during any part of the heave and surge cycle where tensions are above the winch motor horsepower limits. Below this level the motor renders and recovers line continuously. Energy that the winch motors produce when retarding the tug is dissipated into air or water-cooled electrical resistors, also called Dynamic Braking Resistors (DBR's).

The product of the recovery or rendering speed times the corresponding tension level determines the horsepower the winch must provide or absorb. The general equation for horsepower is:

- **Horsepower (hp) = tension or force x speed**

(hp = Newton x meters per second / 746; lbsf x feet per minute / 33000)

It should be noted that horsepower is a general term and can be summed or evaluated at any place in the system. There are 5 power levels in a typical Markey Hawser Winch system. Increasing power is required at each level as losses and other margins are allowed for, as follows:

- **Horsepower flow through the winch**

- **Drum horsepower, or net horsepower** are terms for the actual power delivered by the winch to do its required work beyond the winch and after overcoming the mechanical inefficiencies of the winch itself. For example, to create a hawser tension of 60 tonnes at a speed of 1 meter per second (about 200 feet per minute, or 2 Knots) requires an output of 760 hp.

- **Output horsepower** covers both rendering and recovery functions. It is common to have much higher horsepower ratings required during the render mode of operation. In fact, Markey high performance winch systems often combine regenerative braking through the winch's input drive with the addition of dynamic braking through the multi-disc water-cooled slip brake. In this way, motor horsepower can be kept relatively low compared to the total output horsepower capability of the winch system.

- **Mechanical efficiency horsepower** is the term for that power lost in the winch itself in friction, heat, and noise. These losses vary depending on the type of winch, and add between 15 and 35 percent to the required input horsepower. The latest Markey products for this application are using electric driven winches, which have the highest efficiency available of all drive types. Additional horsepower is required to operate the hawser spooling machinery (fairlead). This is estimated to require an additional 25 hp.

- **Braking (Rendering) power** is that combination of braking resistance and speed that the Slip Brake is capable of absorbing continuously. The slip braking horsepower generally falls between 800 and 1600 hp, as determined by the operational maneuvering and sea state conditions. In previous systems the Slip Brake hp has typically been several times the motor Input Horsepower.

- **Input or Motor Horsepower** is the nameplate or rated horsepower of the motor(s) driving the winch. This motor(s) must be adequate to continuously supply the specified output power plus the winch efficiency losses. In addition the motor is capable of rendering or absorbing energy (regenerating) in order to help control hawser tension, either independently or in combination with the Slip Brake when higher tension rendering is required. The energy produced by the motor is absorbed by water-cooled or air-cooled resistors.

  The electric motor(s) have the added feature of being able to provide intermittent power 28% greater than their nameplate power for short periods if enough electrical or prime mover power is available. Intermittent power adds to the output power with the same proportional reduction for efficiency.

Note:

In Markey hawser winches the motors are normally designed for continuous operation. Electrical motors may also carry a time limit rating of 30 minutes for example. This is adequate for some winch applications with short duration, such as lifting ship's anchors, but not for critical applications or those with an uncertain duration such as operations in and around offshore terminals subject to weather irregularities.

- **The prime or generator set(s) power** determines the maximum power available to the winch system. This maximum may be reduced by hotel and other connected loads, or be totally available to the winch system when using a dedicated generator(s). The generating system for recent winch applications, must provide in excess of 600 hp (448 KW), as high as 760 hp (567 KW) for intermittent use.

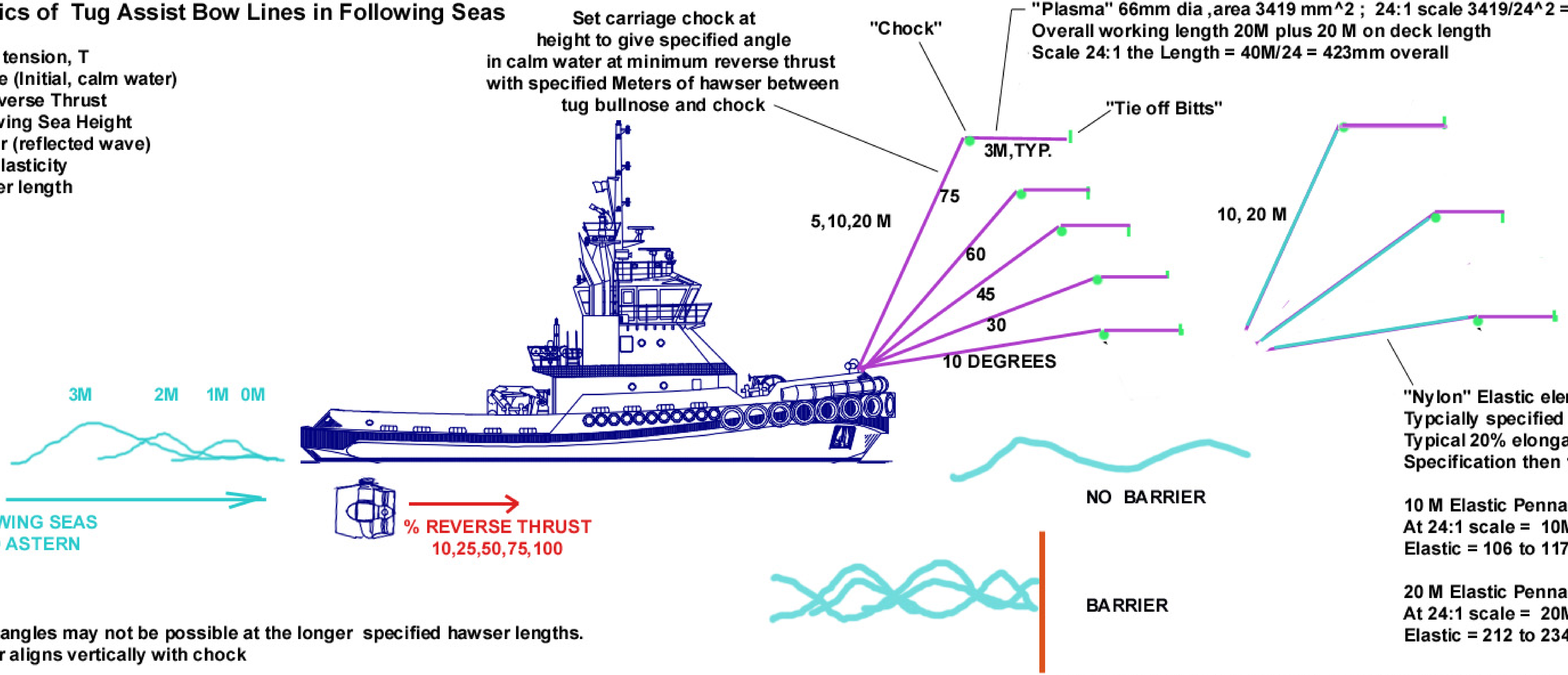
Conclusion and future work

We now have the capability and design tools necessary for advanced system analysis of winch and rope based machinery for offshore tug applications. Numerical analysis will increasingly replace traditional ship model testing and bench and field testing of mechanical models. Advances in machinery and rope monitoring have already added to our knowledge in this area. The results of laboratory and field studies of hawser contact with ship fittings and the long term behavior of HMPE hawsers in actual tractor service should be ready for publication this time next year.

End of Paper - Methodology for the Selection of Winches and Ropes for Assist and Escort Tugs in Dynamic Seas

Dynamics of Tug Assist Bow Lines in Following Seas

Bow line tension, T
vs Angle (Initial, calm water)
vs % Reverse Thrust
vs Following Sea Height
vs Barrier (reflected wave)
vs Line elasticity
vs Hawser length



"Nylon" Elastic element:
Typcially specified at 5:1 over bollard pull
Typical 20% elongation at 40% load or 2xbollard
Specification then 10% at 1 x bollard

10 M Elastic Pennant
At 24:1 scale = 10M / 24 = 106 mm at no load
Elastic = 106 to 117 mm at scale bollard, or 10 Lbs

20 M Elastic Pennant
At 24:1 scale = 20M / 24 = 212 mm at no load
Elastic = 212 to 234 mm at scale bollard, or 10 Lbs

Notes:
1. Some angles may not be possible at the longer specified hawser lengths.
2. Barrier aligns vertically with chock

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