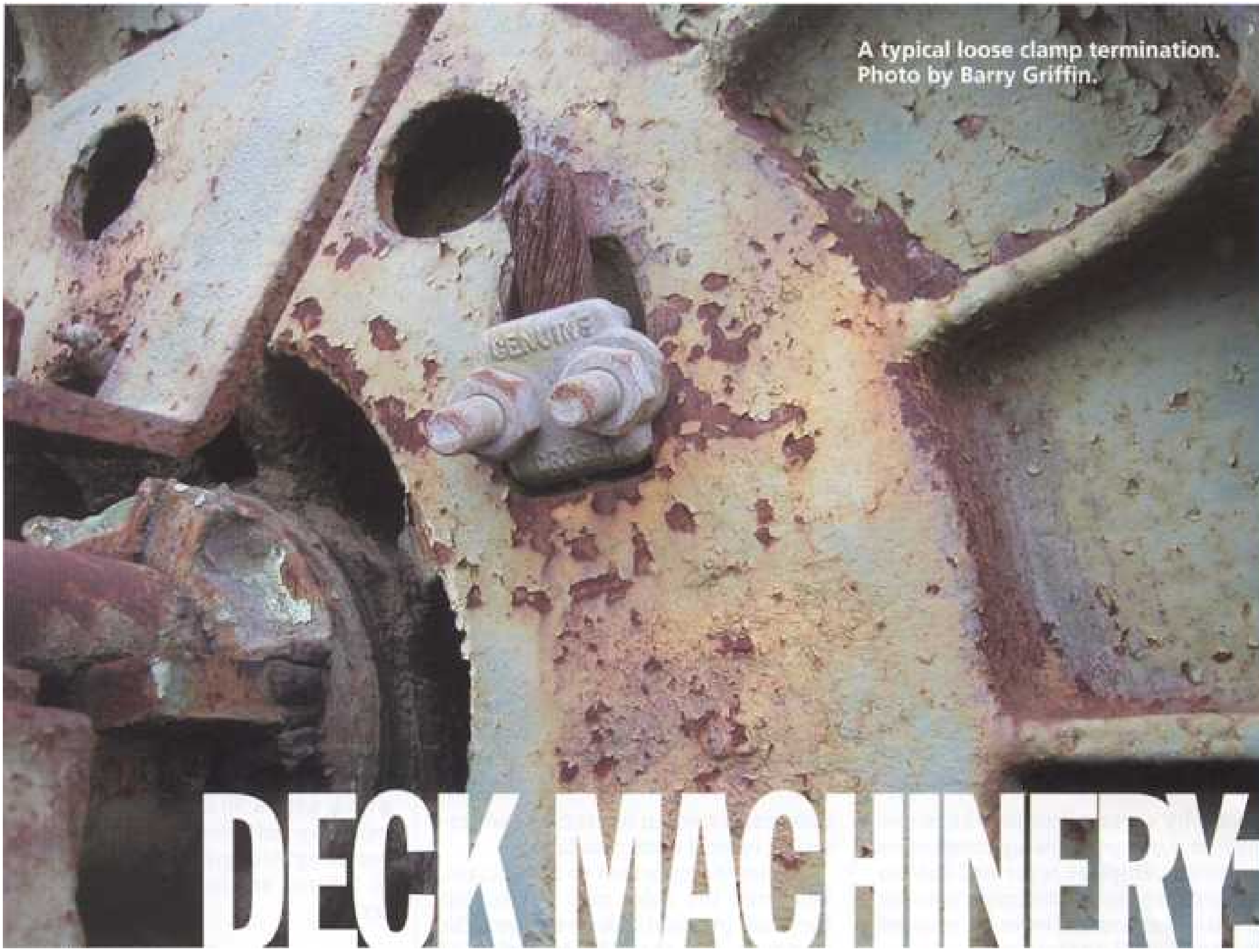


A typical loose clamp termination. Photo by Barry Griffin.

DECK MACHINERY: MOORING ISSUES

By Barry Griffin

A young man was fatally injured last year while assisting a commercial barge mooring operation. He lived a few days, long enough for his family to be with him for his final moments. He left family and friends to grieve, and stunned co-workers and industry participants to wonder and discover what went wrong. After the initial legal and regulatory investigation, teams were assembled to survey and test the mooring machinery and operation. I was involved in the winch and wire analysis. The ensuing legal case has been settled, and I have received permission and encouragement from the legal and insurance community to discuss what I believe are important lessons to be learned.

The tragic results of a mooring accident. Photo by Barry Griffin.

As best as can be determined, the worker was struck in the head by tail hold (winch) end of a 2" wire mooring line as it pulled free of the winch drum during payout of the mooring line. It is generally agreed that the wire was on the barrel layer at the time. There is no way to determine with certainty the force levels that were present, and therefore no way to point to one aspect of the winch, wire condition, number of wraps, dead end clamp, or operational protocol or training to affix responsibility. All that can be said is that a tragic accident occurred to someone who was too close to a winch with the wire on the barrel layer in a dynamic situation.

The Physics of the "Safety Layer"

There are a variety of "standards" and folklore regarding the minimum number of turns or wraps that should always be present on the 1st layer, or core (barrel) layer of a winch. This is sometimes referred to as the safety layer. As few as three wraps are men-

A typical single or double clamp installation to winch side flange. Photo by Barry Griffin.

tioned by certain handbooks, some say five, and some towing companies require a complete layer and half on the next layer as the minimum amount of wire that must always be present during normal operations.

These safety rules are the result of field testing and industrial testing in specific industries and applications. Specific machinery components and systems have also evolved to allow reasonable safety factors to be achieved by the average skilled worker and seaman when operating and servicing typical deck machinery.

What is important to appreciate, whatever the rules may be, is that they all probably derive from the common fact that the behavior of wire or softline on the barrel layer of a winch is highly non-linear, counter-intuitive, and unpredictable. This behavior is largely due to the laws governing how frictional forces multiply when two materials are wound in radial contact. These same laws also govern the behavior of winch band brakes and the grip of rope on capstans and bitts.

This behavior is illustrated in ***Figure 1***, in which the calculated holding power of the first few wraps on a winch drum is shown. In this example it is assumed that the winch brake is set and 2 wire rope "Dead End" clamps are well tightened to their design torque. The controlling equation has exponential terms, which include the coefficient of friction, or sliding grip, between the rope and drum surface, and the number of degrees of contact. The force builds like the well-known "pennies on a chess board" game, in which repeated doubling of an initial penny quickly builds to millions of dollars.

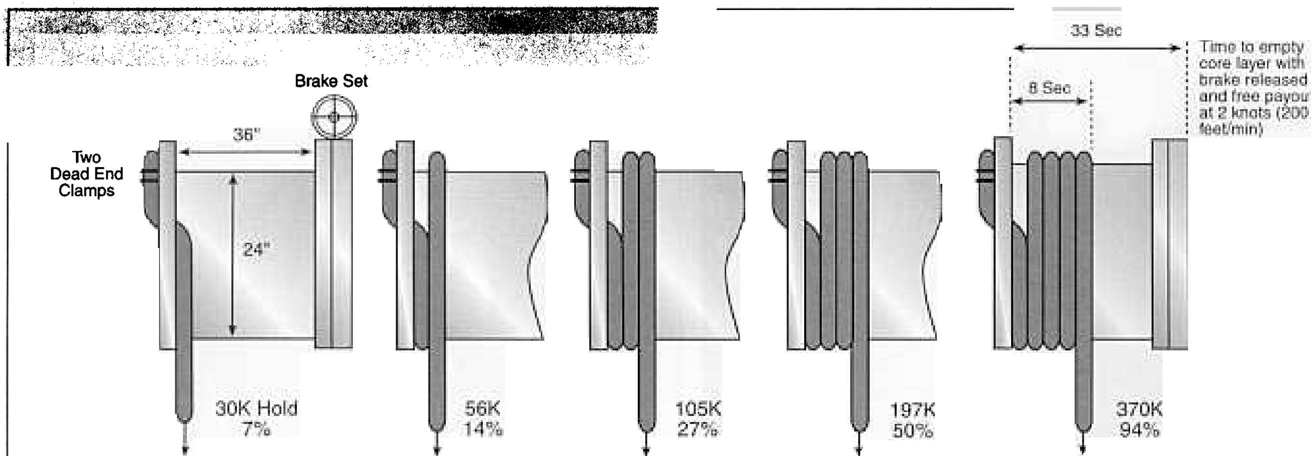
Holding power builds in a similar way. Unfortunately it decays just as quickly in the reverse direction. It is not intuitive that reducing the wraps from 4 to 2 results in much less than half the holding power. As shown, a winch with a 30,000 pound tail hold will have sufficient grip to resist the breaking strength of the wire after 4 to 5 turns are in place on the core layer.

mu

The coefficient of friction, or mu, is also a key player, or disrupter, of nearly every aspect of winches, from brakes to capstans, to drum dimensions and surface finish. This is especially true with the increased use of polyethylene "high performance" UHMW-PE softlines such as Spectra, PLASMA and Amsteel-Blue as a winch mooring line or hawser. The rope is slippery, and increasingly so as the typical urethane coating wears off to expose the even-more slippery native fiber. With an mu much less than steel or polyester, the rope requires many more turns to achieve identical holding power. We typically require 8-10 turns of UHMW-PE line to achieve the same grip as 3-4 turns of polyester. However, from a practical standpoint, the drum width remains about the same because UHMW-PE lines are approximately half the diameter of an equal strength polyester line.

Connecting Wire and Softline to a Winch Drum

There are several means to "dead-end" wire rope into a drum, with the



Some characteristics of a typical 24-inch diameter core by 36-inch wide, two-inch wire mooring/towing drum:
Effect of number of core layer turns on the holding power of wire on a winch drum (approximate typical values)

Rope Type	2" EIPS IWRC
Rope Breaking Strength, LBS	396,000
Winch Dead End Strength, LBS	30,000
Rope to Drum Friction Factor (mu)	0.1

Number of turns around drum on core layer	1	2	3	4	5
LOAD HOLDING CAPACITY, LBS (Brake Set)	56,234	105,408	197,582	370,359	694,221
% of rope breaking strength	4%	27%	50%	94%	175%

Drum holds 17 wraps (turns) of wire on a complete layer

Figure 1

simplest and strongest possibly being the ESCO type "Drum Line Ferrule" that is swaged on to the bitter end and placed in a special cavity, or receiver in the winch drum. However, this termination requires special tooling, certifications, and field expense, and is therefore not practical for commercial vessels that need to change wire themselves, in non-ideal circumstances, or with simple tools.

Of the various ways to connect wire to a winch drum, the most common is the use of new, certified Crosby wire rope clamps, or clips, that are torqued to Crosby's recommendations and fixed to the winch side flange or left free to bear against a hole through the flange. It has been determined by Crosby, and verified by testing for this incident, that each clamp develops approximately 6-10% of the rope breaking strength when properly torqued.

In recent testing, the pullout force for 2 clamps was found to be about 13-18%, or approx. 35,000 LBS for 2" wire. Other combinations and arrangements were tested, such as stacking an equal diameter spacer wire under the clamp. No one of the alternative arrangements was as good as 2 or more wire clamps. In all cases it was imperative to verify that the clamping nuts do not bottom out or run out of threads before the torqueing is complete.

It is sometimes believed that the wire rope clamps are somehow capable of holding much more than they can. Their main requirement is to provide a way to safely spool the core layer at moderate to low tensions. In that way they are usually more than adequate to resist the typical starts, stops, bumps, and ham-

Spooling and tightening the first layer of line on a Markey TES-32, 2-inch wire towing winch. Photo by Barry Griffin.

merings that go on when forcing and praying the safety layer onto the drum. Analysis indicates that two clamps holding 10-15% of wire strength will result in drum holding power equal to the wire breaking strength after 5 wraps, using conservative MU.

Dead End "Fuse"

Many commercial operations desire the wire to let go, or pull out, if necessary to get away from a dangerous situation. This is so because it is difficult or impossible for most commercial vessels to overpower their towing and mooring wires using their own propulsion. The design of winch dead ends must take this into account, so that the wire will pull out.

FOSS Maritime, Puget Sound Ropes, and Markey Machinery Company have developed the fuse concept for attaching synthetic PLASMA hawsers to Assist and Escort tugs. In this method, a carefully selected "leader" with known breaking strength is joined with a proprietary FOSS splice into the main line and threaded into a special receiver tube on the Markey drum. This system provides a very controlled safety breakaway capability.

This is a common dead end method shown to have low holding power. Photo by Barry Griffin.

Rotating Inertia, Drum RPM, and Reaction Time

A final "barrel layer" issue worth mentioning is the complication resulting from the inertia, or rotational energy, and speed of a spinning winch drum operating on the core layer. Using the typical dimensions of a common mooring or towing winch as shown in Figure 1 on page 27, consider a situation in which you begin free spooling or lowering an anchor or setting gear at a modest 2 knots (200 feet per minute), with the drum brake released. Because of the decreasing amount of wire on each layer, the speed of the drum will need to increase as the wire moves to lower layers, in order to maintain the 200 feet per minute. If you began paying out with a full drum, you would start with about 1 minute to pay out 1 layer. When you got to the barrel layer you would pay out that layer in typically half the time, or 33 seconds. If you noticed too late that you were on the barrel layer and approaching the magic 5 safety wraps – you would have only 8 seconds before the rope pulled out. If you attempted to brake or stop the winch suddenly, you would have to overcome the inertia of the drum. The drum is now spinning twice as fast as when you started, and the drum inertia, which is proportional to the square of the rotational speed, would now be 4 times as great! Of course the weight (mass) of the wire is now off the drum, and depending on the depth of water, catenary, or other forces, may or may not be adding or subtracting from the overall system inertia. In any case the wire weight affects the inertia proportionally, not exponentially like the drum speed. Under these conditions, the drum brake or other winch drive component, may break or fail to respond in a known way. Not a good situation to be caught in unaware.

Please mind the safety layer.

I would be happy to discuss these issues and learn from your experiences. Contact me through this magazine at bagriffin@pacmar.com

I would like to thank Alaska National Insurance Company for their help, and permission to discuss this case. PMM

Barry Griffin is a Harvard graduate with more than 20 years of engineering and sales experience in the marine equipment business. Since 1992 he has logged more than 850 ship-days observing winch and vessel operations specializing in high performance winch and rope systems as a manufacturer's representative for Markey Machinery Company, Puget Sound Ropes, Schoellhorn-Albrecht, Ocean Spar Technology, and PERKO Commercial.

This is a custom, triple-plate termination. Photo by Barry Griffin.