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Thermal properties of Fiber ropes

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Abstract

Through mathematical modeling and simulation, it is desirable to obtain more insight into what happens with fiber ropes during use, and identify good methods for determining the remaining useful life using thermography.

Introduction

There is a trend within the oil and gas market to shift from steel wire ropes to fiber ropes for lifting, hoisting and mooring applications. The cost of fiber ropes is about 2-3 times that of steel wire ropes, but the natural buoyancy of fiber ropes reduces the overall weight resulting in smaller cranes and thereby reduces the overall costs. For heave compensation, a rope is typically of 3-4000 meters long, such that one rope costs in the order of 7.5 million dollars. The current practice on when to discard a fiber rope is through visual inspections done manually with large safety factors. This means that the rope is discarded before it is necessary, increasing the overall life-cycle costs. The offshore industry wants a better monitoring system to understand when the fiber rope must be replaced.

Fiber Ropes

Fiber ropes consist of several strands that braided into a rope. Cortland Plasma[1] 12x12 is a rope made of High Modulus Polyethylene (HMPE) and consists of 12 strands that are braided into 12 subropes, which again are braided together into one very strong rope. Figure 1 shows the construction of a Cortland Plasma 12x12 rope and an example of how big such a rope can be made.

Figure 1: Cortland Plasma 12x12 rope (left) and the world's largest 12x12 rope (right).

Internal abrasion is the main factor that governs the lifetime of a fiber rope. This means that as strands move against each other, heat is generated, melting the fibers together and thereby reducing the overall strength of the rope. This

[1] http://www.cortlandcompany.com/sites/default/files/downloads/media/product-data-sheets-plasma-12x12.pdf

will continue until the rope is discarded or become severed when the load exceeds its load-bearing capabilities (which are reduced due to melted fibers). One of the most important parameters to monitor for fiber ropes is the temperature, suggesting that a thermographic camera might be a good tool for condition monitoring. Experimental results suggest that there is a relation between the temperature of a fiber rope and its remaining useful life (RUL), something that is illustrated in Figure 2.

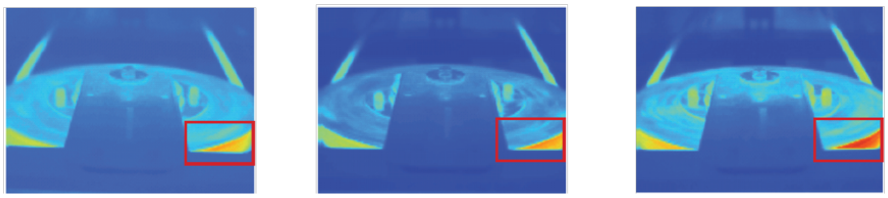


Figure 2: Infrared images of a rope bent over a sheave [2]. The remaining useful life is the largest to the left and decreases towards the right. Notice how the temperature increases as the RUL decreases.

The internal structure of the fiber rope becomes changed over time as the rope is heated and cooled in a cyclic manner. Figure 3 shows the internal structure of a braided rope before and after use. It is obvious that the structure is changed as the fibers melt together, thereby changing the thermal properties of the rope itself, something that can be detected using thermography.

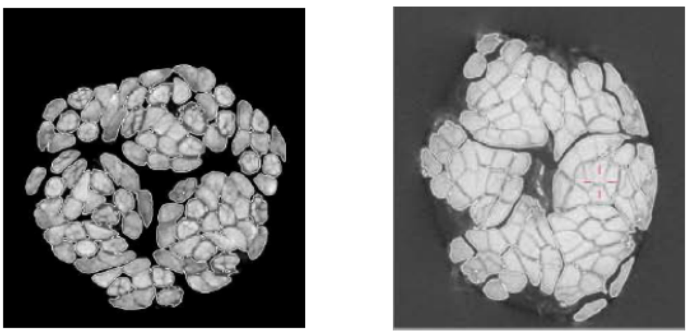


Figure 3: X-ray of a braided rope before (left) and after testing (right) [1]. Notice how the fibers have been fused together changing the structure and making a more dense rope. The figures are not to scale.

A crane contains many sheaves to control the rope, something that is shown in Figure 4. During heave compensation, the rope is moved back and forth over these sheaves, generating much heat, and this is the main cause of deterioration for the rope. Figure 5 shows how the temperature increases as the rope is bent over a sheave, making monitoring of the sheaves on a crane the most critical points when doing condition monitoring. Figure 5 also shows that it is not the friction towards the sheave that generates the heat, but it is the internal abrasion between the strands in the rope that generates the heat, which melts and deteriorates the rope.

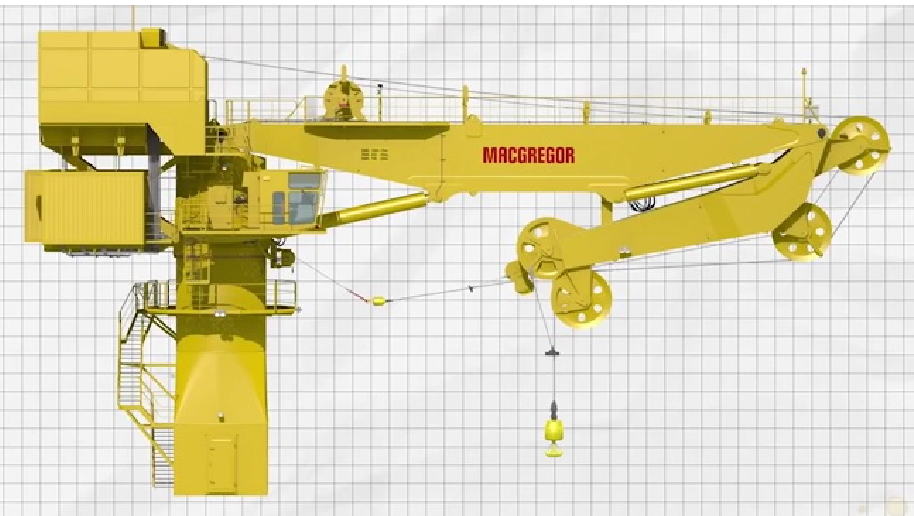


Figure 4: On a crane used for heave compensation, it is the sheaves that have the most impact on the remaining useful life of the fiber ropes.

Questions

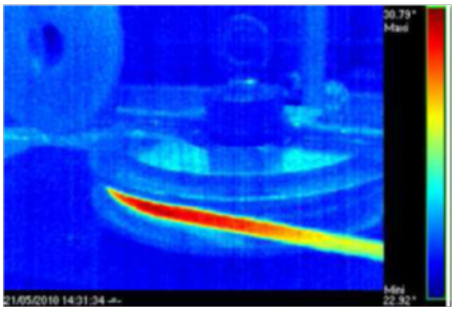
The temperature profile of a rope bent over a sheave is a function of ambient temperature, diameter of sheave, number of strands, braiding pattern, coating of the rope, number of cycles, cycle speed, load on the rope, and load history. It therefore represents a very complex problem, with many unanswered questions. For the following, consider a Cortland Plasma 12x12 rope with 100mm diameter as a case.

1. It is desirable to use thermography for monitoring the temperature inside the rope. Figure 2 shows the surface temperature, while measurement of the internal temperature requires embedded sensors. From a modeling perspective, how is the temperature inside the rope relative to what you obtain from the thermographic image, and can this be used to create a simple tomographic model? (Mapping from surface to internal)

2. How is the *change* in temperature as a point on the rope moves away from the sheave? Due to structural changes (*cf.* Figure 3), the heat dissipation is expected to be different between a new rope and an old rope. Can this be used to better describe the condition of the rope than static images?

3. The temperature is very high at the end of the lifetime. Is this due to an accumulation of heat (the fact that it has cycled *e.g.* 10 000 times), or is it due to the changed structural properties of the rope?

4. Based on the degeneration properties of the rope (fusion of fibers), what model is best to describe the deterioration of the rope? Typical for crack propagation is the use of Paris' Law; the question is if there is an equivalent model that can be used for fiber ropes?



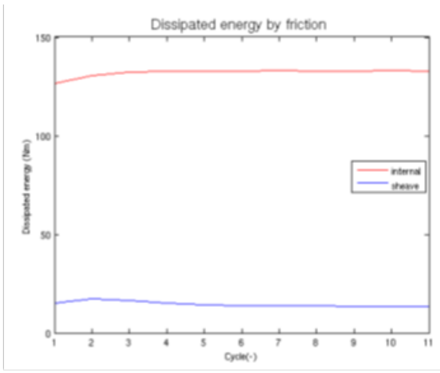


Figure 5: Thermal image during cyclic bend over sheave (left) and the dissipated energy during cycling (right) [1]. The external friction coefficient (towards the sheave) is 0.1, while the internal friction coefficient (between strands) is 0.03. Notice that it is the internal friction (red line) that generates most of the heat.

References

[1] Davies, P. et al., *Bend over sheave durability of fibre ropes for deep sea handling operations*, In proceedings of the ASME 2013 32nd International Conference on Ocean, Offshore and Arctic Engineering, Nantes, France, 2013.

[2] Gilmore, J. and R. Thomas, *Deepwater synthetic lowering and lifting with enhanced cyclic bend fatigue resistance*, Technical paper, Samson, 2009.