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DESIGN VERIFICATION OF WINCH FOR OFFSHORE CRANES

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ABSTRACT
Offshore cranes are designed for advanced installation works and maintenance tasks at offshore. While the failure of the crane and the foundation of the winch is relatively easy to predict due to the existing solid knowledge on the design and performance, how the winch drum performs is often complex. One of the few design criteria that is used in the industry is from DNV Standard for Lifting Appliances. This standard is not designed specifically for offshore winches, but covers several different types of winches that will naturally have different properties and the forces acting on them will be different. The study reported in this article is intended to find out the appropriate safety factor that can be used in offshore winches and how far the design standards can guarantee failure predictions. Both analytical calculations and finite element analysis are performed and compared with practical measurements of the loads on the winch drum using strain gauges.
Keywords: Offshore winch, winch load, strain gauge measurement, finite element analysis

1. INTRODUCTION
Offshore cranes are designed for advanced installation works, off-shore construction, pipe lying, drilling vessels operating in deep water and maintenance tasks at harsh conditions offshore. The experience in using offshore cranes shows that failure of the crane and the winch foundation is relatively easy to predict due to the existing solid knowledge on the design and performance. How the mooring elements such as wires behave under tension-torsion loading has also been studied and reported in the literature [1-4]. How the winch drum performs is however often complex mainly due to improper approximation of the field loading patterns on the winch, inadequate knowledge of actual forces transmitted onto the flange and drum barrel of the winch and/or defects in the structural joints. A study by Chaplin [5] on torsional failure of a wire rope during deep water installations concludes that the twist force in the wire can be transferred from one component to another, including the winch and the barrel, with potentially serious consequences.
An in-depth review of the open literature reveals that several large winches failed in service exposing the owners to millions of dollars in repair or replacement costs on the winches. The probable causes of these failures are the state of the art in design of large winches, in practice, remained more or less empirical and that in some instances, quality control in manufacture was not being taken as seriously as this equipment warrants. In addition, neither the wire rope nor the winch manufacturers have established wire rope characteristics which are necessary for designing winches.
One of the few design criteria that is used in the Norwegian industry is from DNV Standard for Lifting Appliances [6], which is designed not specifically for offshore winches, but covers several different types of winches that will naturally have different properties and the forces acting on them will be different. As a result of frequent offshore winch failure incidences, DNV revised the standard and raised the safety factor requirement significantly from 1.75 to 3.0. This has led to a number of challenges in both design and production of winches. Thus, many companies using/producing offshore winches are interested in reviewing the calculation methods used to determine the required safety factor. The study reported in this article is intended to find out the level of the safety factor and

understand how far the design standards can guarantee failure predictions. Both analytical calculations and finite element analysis are performed and compared with practical measurements of the loads on the winch drum using strain gauges.

2. PROBLEM DESCRIPTION

Offshore winches are equipped with steel wire lengths of several kilometers and this means that the wires must be wrapped on the drum in a large number of layers. This put both the drum and wire for high stresses and introduces a number of challenges to achieve accurate and reliable strength. While in use the constant motion of the steel wire over the drum exposes offshore winches to large stresses. Particularly, spooling of the wire and winch at high speed, pulling over drum discs and exposing the whole system to variations in bending, tension and twist loads leads to great wear of the drum and the outer threads. Design of the surface of both the wire and the drum will have a big effect on the wear resistance where a smoother surface gives less wear and tear while a rough surface provides more wear and tear.

Winding or unwinding error exposes the offshore crane to an uncontrolled movement or shock loads and at the same time a higher wear on the drum and the wire. The possible errors that can take place during operation can be categorized as:

- Sticking of underlying layers while spooling multiple layers (Figure 1(a))
- Winding/unwinding speed (Figure 1(b)).
- The used winding system.

Further, the deformation of the wire/rope under loading and its inhomogeniety makes the exact verification of the design calculation more complex. The load on the drum depends on the weight of the rope remaining on the drum while unwinding.

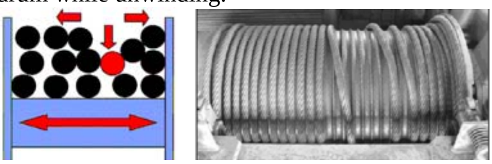

Figure 1 Examples of winding related errors: (a) sticking problem, (b) winding speed

3. MODELING AND EXPERIMENTAL WORK

3.1. Test winch

In order to verify the design calculation methods and assess the results with respect to the real loads and perform stress/strain measurements, a previously produced (in 1999) winch that was no longer in service was used as a test winch. The winch has been modeled in 3D based on earlier design dimensions with minor modifications to facilitates ease of strain gauge measurements. Physical specifications of the test winch are given in Table 1.

Table 1 Specifications of the test winch

Lifting capacity (SWL)	4000 kg (4 ton)
Net weight of drum	1600 kg
Rope length	985 m
Weight of rope	2100 kg
External dimensions	1290 mm x 1480 mm x 1685 mm
Rope diameter	22 mm

3.2. Assumptions and limitations

The calculations and the analysis done in this study are based on the following general assumptions:

- The rope does not significantly deform under load
- The load is static and constant
- Friction between drum surface and rope is neglected
- The flange is always perpendicular to the drum surface

- The rope is tightly wound
- The layer windings are not sticking into each other

Two methods were implemented in order to be able to compare results and verify the solutions with those obtained according to the recommendation given by DNV Standard No. 2.22 [6]. The design methods and requirements according to this standard are not included in this article due to the page limitation of this conference contribution.

3.3. Experimental setup and location of strain gauges

To assess the real tension forces/stresses on the drum, strain gauges were fixed on the surface of barrel and the flange. A strain gauge is used to measure the deformation of the surface of the object and provide an average value of strain over a small area of the surface. A strain gauge senses the change dimension and converts it into an electrical signal. This can be accomplished because a strain gauge changes resistance as it is stretched, or compressed, similar to a wire. For example, when wire is stretched, its cross-sectional area decreases; therefore, its resistance increases. Upon deciding the strain, stresses are then calculated based on Hooke's law.
For this study, the strain measurement was taken in total at 9 points: 4 points on the drum and 5 points on the flange. Eight of the gauges (4 on flange and 4 on drum) were crossing gauges that can measure the strain in two perpendicular directions: radial and tangential on the flange and radial and axial on the drum, while the fifth gauge on the flange is strain rosette type that can measure signals in 3 directions as given in Figure 2.

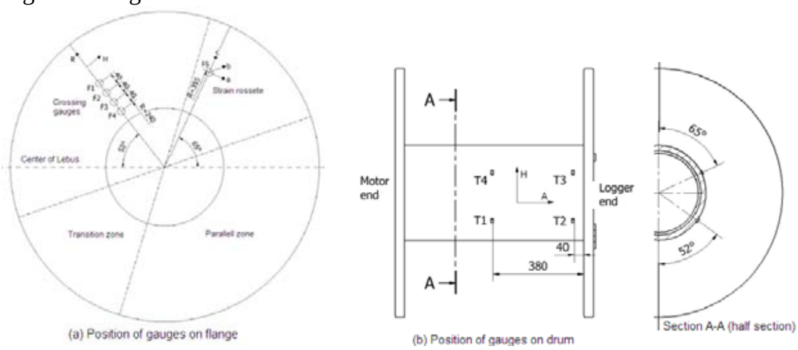

Figure 2 Positioning strain gauges on flange (F1 – F5) and on drum (T1 – T4)

3.4. Modeling and Finite Element Analysis

The finite element analysis (FEA) of the winch was done in ANSYS Workbench by importing the 3D model form Autodesk Inventor. Due to the symmetriy, only 1/8 of the winch was used in the analysis because this saves the processing time. Compressive line forces were then applied at 14 different positions in radial direction of the flange (Figure 3(a)), while the drum is exposed to a surface compression pressure of 7.8 MPa (Figure 3(b)).

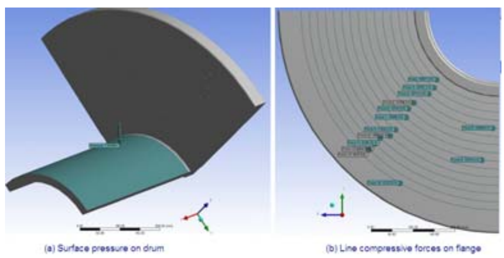

Figure 3 Application of loads on FE model

4. DISCUSSION OF RESULTS

Surprisingly, the axial stress obtained from FEA is exactly the same (25.5 MPa) as that obtained from manual calculation in accordance with the standard. This tress is due to the pressure applied on the flange. On the other hand, the hoop stress due to the line force on the barrel shows certain variation. On the inside of the drum, the stress is higher than values from manual calculations while the values on the inside part are somewhat lower. The manual calculation according to DNV gives a hoop stress of 71.59 MPa.

The strain gauge measurements were registered by CatmanEasyAp tool that also plots the results. Sample plots registered from the drum after winding 14 layers are shown in Figure 4. The strain in general stabilizes after the 6th layer and particularly, the axial strain at all points has a trend of linear variation with the number of layers. The highest axial strain appeared at point 1 ($\epsilon_{T1} = 430 \frac{\mu m}{m}$), which corresponds to a an axial stress of $\sigma_{A1} = 90.3\,MPa$. As expected, the tangential strain (Figure 4(b)) is compressive and shows high gradient at start and stabilizes after a while (after about 5 minutes or the 6th layer). The stress calculated from the measured strain values both on drum and flange in general show some variations with acceptable deviation from manual calculations and FE analysis.

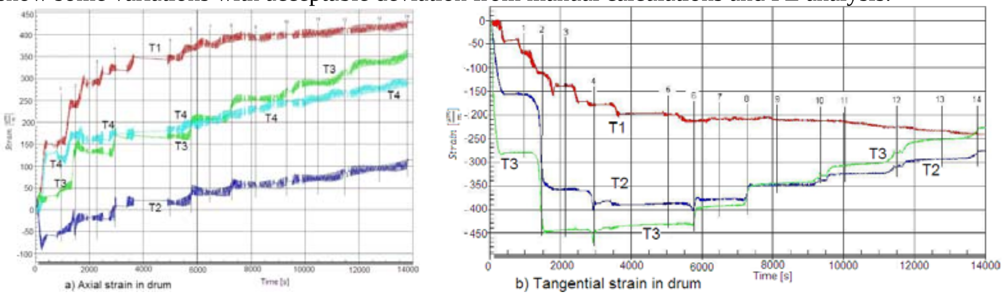

Figure 4 Plot of strain distribution on the winch drum

5. CONCLUSION

This study has investigated the stress level for a test winch that once was in service on offshore cranes. The objective of the study is to find out if the safety factor is within acceptable range in accordance with the recent changes of dimensioning standard for offshore appliances (DNV 2008 no. 2.22). Three approaches, namely manual calculation, finite element analysis and experimental methods using strain gauges are implemented. Though some of the results show certain variations, the deviations as well as the calculated safety factor are within acceptable range.

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