Experimental evaluation of bending hysteresis loop of different submarine power cables by comparing 4-point & 3-point bending methods

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ABSTRACT

In the present work four different types of submarine power cables are examined by applying four-point and three-point bending methods. Array (static and dynamic) and export cables were evaluated. Considering as benchmark the four-point bending method the results between the two methods are evaluated and presented. The comparison focuses on the Friction Moment and Stick-Slip behavior of the cable. According to the outcomes of this research, three-point bending method results in similar bending hysteresis loop compared to the four-point bending method. Furthermore it has been found that the total length of the cable may result in an increased friction moment.

KEYWORDS

Submarine power cables, bend stiffness, 4-point bend, 3-point bend, full scale tests

INTRODUCTION

During the installation or the load-out procedure of a submarine power cable or even during the operation of a dynamic submarine power cable the behavior of the cable is affected by its mechanical properties. The most crucial parameter is the bending stiffness, EI (kNm^2) since it is related to significant deformations that results in radii down to the Minimum Bending Radius, MBR. An overestimation of EI may lead to over bending and thus a potential damage, while an underestimation may result in handling problems due to its rigidity. It is well known that the EI of a submarine power cable is armor dominated and greatly affected by the bitumen applied between the armor wires. Although there are available analytical and numerical models, an actual experiment is mandatory to validate the theoretical models. Furthermore, due to the complexity of the cable bending stiffness, it is common practice to experimentally derive the bending hysteresis loop. The most widely known methods to measure the bending hysteresis loop is the four-point and three-point bending methods. In theory, the four-point method results in a constant bending moment in the middle section and thus constant radius. In contrast according to the Timoshenko beam theory that refers to beams, three-point method does not lead to constant bending radius.

Previous work [1] performs 3-point bending hysteresis loop on a HV submarine power cable for different temperatures. The work plots the hysteresis loop as Force versus Displacement. On the other hand, [2] indicates that a flexible cross section such as a submarine power cable can be assumed to be constant when a 3-point bending is performed. Furthermore, the 3-point method has benefits such as simplicity of the test rig. In contrast, [3] performs bending test on HVDC and HVAC submarine power cables according to 4-point bending method for different cable temperatures.

BENDING METHODS

While there are plenty ways to bend a body, 3-Point and 4-Point bending methods are good alternatives in order to bend it. More precisely both methods are followed as a common practice for small scale experiments of samples with constant cross section for laboratory testing. Considering that the deformations are small and thus the sample behavior is linear the Timoshenko theory is applicable without considerations in order to derive the bending stiffness of the sample cross section.

In contrast, when an actual submarine power cable is bent in large curvatures the result is a non-linear bending behavior well kown as bending hysteresis loop. The bending forces exerted in the inner helically applied layers such as the power cores and the armoring wires overcome the frictional forces and thus there is a transition from the stick to slip behavior. Previous theoretical works had studied this transition such as [4] and [5].

For the 3-point method the maximum applied bending moment (M_{max}) can be described by eq. [1].

$$M_{max,3p} = \frac{P}{2} \cdot \frac{l}{2} \qquad [1]$$

where, P is the applied force and $\frac{l}{2}$ (m) is the half distance between the two outer supports. The bending moment M is proportional to the distance from the joint position. Thus M as function of distance x can be described by eq. [2]. A detailed sketch showing the distribution of the bending moment for the 3-point method can be seen in Fig. 1

$$M_{(x)} = \frac{P}{2} \cdot x \qquad [2]$$

The assumption of constant curvature will result in constant bending moment. For this reason eq. [1] over-estimates the actual bending moment that is assumed to be constant along the cable length. As already has been mention by [2], EI is estimated as a fuction of deflection h (m) in the middle point of the sample as per eq. [3].

$$EI = \frac{P \cdot l^3}{48 \cdot h} \qquad [3]$$

Since the curvature is assumed to be constant in the context of the present study, eq. [4] is used to calculate the desired bending radius R (m) when the deflection of the middle point, h (m) and the span between joints, l (m), are known.