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Analytical performance assessment of a novel active mooring system for load reduction in marine energy converters

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ABSTRACT

Reliability and storm survival of Marine Energy Converters are critical to their commercial development and deployment. The Intelligent Active Mooring System (IAMS) is a novel device intended to minimise extreme and fatigue loading in mooring lines through a non-linear load–extension curve that is variable in operation to adjust to the prevailing metocean conditions. An analytical model of IAMS, validated by physical model tests at the Dynamic Marine Component test facility at the University of Exeter, is used in a numerical simulation of the performance of IAMS as part of the mooring system of the South West Mooring Test Facility buoy. A 10 m length of IAMS can reduce the rms line tension in normal operating conditions by up to 21% and the peak line tension in storm conditions by up to 21% when compared to braided nylon mooring lines. Peak line tension reductions of over 50% can be achieved if a longer IAMS unit is used. The resulting mooring system can be optimised to give load reductions in a wide range of metocean conditions; while variable pre-tension could be used for tidal range compensation or to ease access for installation and maintenance.

1. Introduction

Reliability and storm survival of Marine Energy Converters (MECs) are critical to their commercial development and deployment (Thies et al., 2011). Mooring systems can significantly alter both extreme and fatigue loading in moored wave and tidal stream energy converters and so drive both reliability and device survival. Mooring systems can also affect the wave energy extraction efficiency of Wave Energy Converters (WEC) (Zanuttigh et al., 2013; Johanning et al., 2007).

The requirements for a floating MEC mooring system are to provide high minimum breaking load (MBL) and good reliability and position keeping in extreme conditions while still having sufficient compliance to reduce the peak and operating loads on the device (Gordelier et al., 2014). The usual solution is to employ fibre ropes, but a small number of alternative designs have been proposed recently which offer significant advantages over fibre ropes, primarily through having a stiffness which increases with increasing line extension. For example the TfI Mooring Tether (Thies et al., 2014) has an elastomeric element which gives a soft response in normal operation and a separate stiff compressive element to withstand storm loads. The Seaflex system (Bengtsson and Ekström, 2010) uses elastomeric elements with a rope as backup in the event of over-elongation. The Exeter Tether (Gordelier et al., 2014) is a hollow braided fibre rope with an elastomeric core – the tension load is carried by the rope while the core controls the extension by resisting the reduction in diameter as the rope extends.

The performance assessment presented here is based on a novel mooring system referred to as the Intelligent Active Mooring System (IAMS) which combines user controlled axial stiffness and damping with a high MBL. The IAMS device has a load–extension curve such that the stiffness increases with increasing axial extension. The shape and steepness of the load–extension curve are variable *in operation* to adjust to the prevailing metocean conditions. This allows a much wider range of response characteristics than would otherwise be available. The initial aim of the novel mooring system is to minimise fatigue loading on the device and mooring system in normal operating conditions, while still providing adequate position keeping and reduced device and mooring loads in storm conditions. The MBL of the device is independent of the operating axial stiffness curve chosen.

The technology is designed to significantly reduce the cost of mooring wave, tidal and floating wind installations through mooring load control and the subsequent reduction of structural loads on the floating device and the mooring system components.

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In the special case of a Wave Energy Converter (WEC), the stiffness and damping could potentially be tuned to enhance the motion of the device, thus increasing the yield. The ability to reduce the pre-tension (by reducing the accumulator pressure) could be used to allow easy access to a MEC for servicing and installation. The variable pre-tension could also be used for tidal range compensation or even to artificially submerge a device for storm survival.

This paper describes the physical scale model and the accompanying analytical model of IAMS as they relate to the performance assessment. A case study is then presented for model validation and the remaining sections comprise the numerical performance model design and results, followed by a discussion and concluding remarks.

2. IAMS model and test approach

The IAMS design is based around a hollow braided rope which supports all the lengthwise loads and a flexible water filled bladder inside the hollow braid which resists reductions in the braid diameter through hydraulic pressure. As the rope extends, the diameter of the hollow braid decreases until the rope strands finally lock together at around 17° braid angle; any further extension beyond this point is due to the extension of the rope strands. Braid angle is defined as half the included angle between two crossing strands. A detailed view of the braid fibres is shown in Fig. 1. An accumulator is attached by hydraulic pipe to the bladder outlet so the load–extension properties of the whole system can be varied by changing the accumulator air volume and pressure.

2.1. Physical scale model

A physical model was constructed by Teqniqa Systems Ltd. at reduced scale (or for smaller applications) and was tested by the University of Exeter at the Dynamic Marine Component (DMaC) test facility in Falmouth docks. A full dynamic performance assessment was carried out and will be reported in future publications. The results presented in this paper concern only the semi-static tests carried out to calibrate the numerical and analytical models. Tension and position are recorded through the DMaC control system (NI Compact RIO) at 250 kHz and 120 kHz respectively (for full details of DMaC capabilities see Johanning et al., 2011). Fig. 2 shows the IAMS physical model installed in DMaC.

The pressure supply system used in the physical model tests is not representative of the proposed final design, rather it was designed for ease of installation in the test rig. A schematic of the pressure supply system is shown in Fig. 3. The braid outlet USB pressure transducer records at 10 Hz, while the USB pressure and temperature transducers on the accumulator record at 2.5 Hz. Emergency pressure relief valves were in place as shown. The main constriction in the pipework was a globe valve which caused significant pressure drop, but the results presented here concern only semi-static tests (period >300 s) and so are unaffected by the pressure drop. Water temperature varied by less than 1°C during the tests.

2.2. Analytical model

The performance of IAMS can be approximated using a simplified analytical model of the load–extension relationship based on the internal pressure and the accumulator gas volume. The braid angle α can be calculated as:

$$\alpha = \arccos\left(\frac{L_0 + z}{L_F}\right) \quad (1)$$

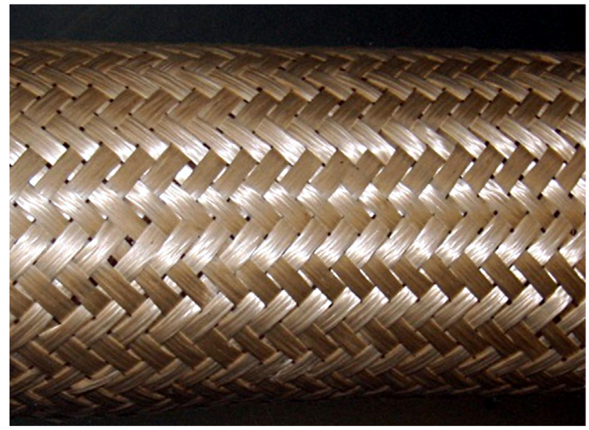

Fig. 1. Detailed view of the 32 strand hollow braided Vectran rope. The individual strands are arranged so they lie nearly flat around the circumference of the water filled bladder.

Fig. 2. IAMS installed in DMaC.

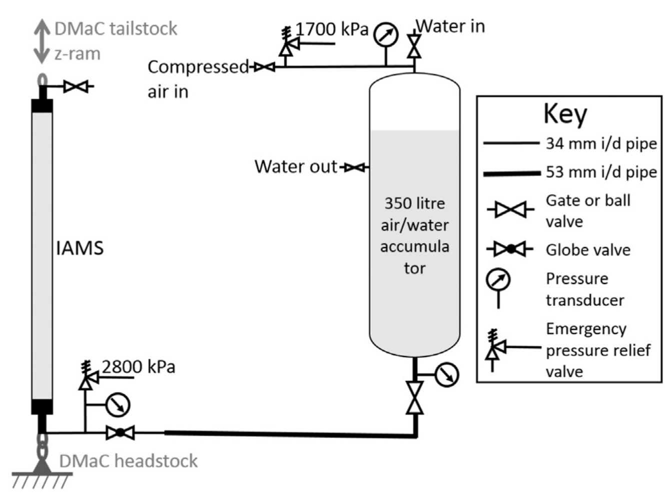

Fig. 3. Pressure supply system for physical model test at DMaC.

where z is the elongation of IAMS, L_0 is the hollow braid length at 0% extension and L_F is the helical length of the braid fibres (equal to the theoretical braid length at $\alpha = 0$). The cross-sectional area A of the hollow braided rope section is then: