APPLICATION OF SPACE-STABILISATION TECHNOLOGY

TO OFFSHORE WIND OPERATIONS AND MAINTENANCE

Dr. David W Kirkley B.Sc (Hons), Ph.D (Managing Director)

Mr. Peter G Back B.Eng (Hons) (Technical Director)

Submarine Technology Limited
7 Mariner's Way, Cowes
Isle of Wight, PO31 8PD
United Kingdom

Tel: +44 (0) 1983 201540
E-mail: peter@stlres.co

Summary

Space-stabilisation technology allows a payload to be kept stationary in space regardless of the motion of the device on which it is mounted. A typical application is in compensating for movements of a ship that is subject to wave-induced motion. It has the potential to significantly improve the efficiency and safety of offshore wind operations. A development project code-named Neptune is underway to provide a space-stabilised device that can be used for the transfer of equipment and personnel from a ship to a fixed offshore structure such as a wind turbine or platform. It uses an articulated arm that can accomplish transfers to a height of 28m with a reach of 25m in conditions when there is substantial vessel motion in all six degrees of freedom (heave, roll, pitch, surge, sway, and yaw). The problems of designing a lightweight ultra-stiff arm, accurately sensing ship motion, and providing precise control and actuation are described. Safety and certification issues are mentioned. The Neptune project has proceeded in stages and the stages that involved building a motion simulator and using it for proof of concept with a reduced-scale test and demonstration unit have been successfully completed. Enough confidence has been generated in the concept to justify the design and construction of a prototype that will be used for sea trials in 2014.

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1. Introduction

Operations on a fixed offshore structure that are conducted from a vessel that moves due to wave action are difficult and sometimes dangerous due to relative movement between the two. A vessel can move in six degrees of freedom: three rotational ones (roll, pitch, and yaw) and three linear ones (heave, surge, and sway). Various ways of reducing relative movement have been attempted. For example, heave compensation has been successfully applied to diving operations and offshore drilling. Compensation for vessel roll has also been achieved. For operations on a fixed structure with the vessel in close proximity, however, compensation for vessel movement in only one or two degrees of freedom results in constraints that impair efficiency and safety. Some operations may be seriously affected due to weather and sea state. The risk of damage to equipment deployed, personnel being transferred, the vessel, or the structure may cause delay and increased costs. If equipment can be stabilised in all six degrees of freedom, a significant advantage will result. This process has been called space-stabilisation and a research and development programme to achieve it (code-named Neptune) is described here.

2. Space-stabilisation technology

Space-stabilisation technology allows a payload to be kept stationary in space regardless of the motion of the device on which it is mounted. In the case of an offshore activity, the space is defined with reference to a co-ordinate system fixed relative to the seabed. It does not mean that the payload is fixed in one spot because the set-point for the stabilisation can be moved. For example, a payload being moved by a space-stabilised crane on a ship has the effects of ship motion eliminated but the payload can still be moved from point A on the ship to point B on a targeted fixed structure with no relative movement between payload and target on arrival at point B. In order to achieve this, the following problems need to be solved:

- A device is required to carry the payload that has sufficient articulation capability to change shape to accommodate the movements of the ship beneath it;
- Accurate motion and position sensing is needed at the ship-mounted device so that the required compensation can be computed;
- A control unit needs to take information from the motion and position sensors, compute the required compensating movements, and provide instructions to the actuating devices;
- Actuators must move parts of the device with sufficient force and speed to maintain the payload at the set point in space.

Clearly, there are alternative ways of tackling these problems. In the sections that follow, the approach adopted in the Neptune development project is described.

3. The Neptune concept

The approach adopted in the Neptune development project was chosen following a careful review of requirements for several applications of space-stabilisation technology offshore. Some of these applications are described in Section 7. The geometry of the device selected for handling the payload is a two-component articulated arm. This has the advantage of a large envelope of movements but is simple with only a few actuators needed to enable access to any point within the envelope. This concept is shown in Figure 1.

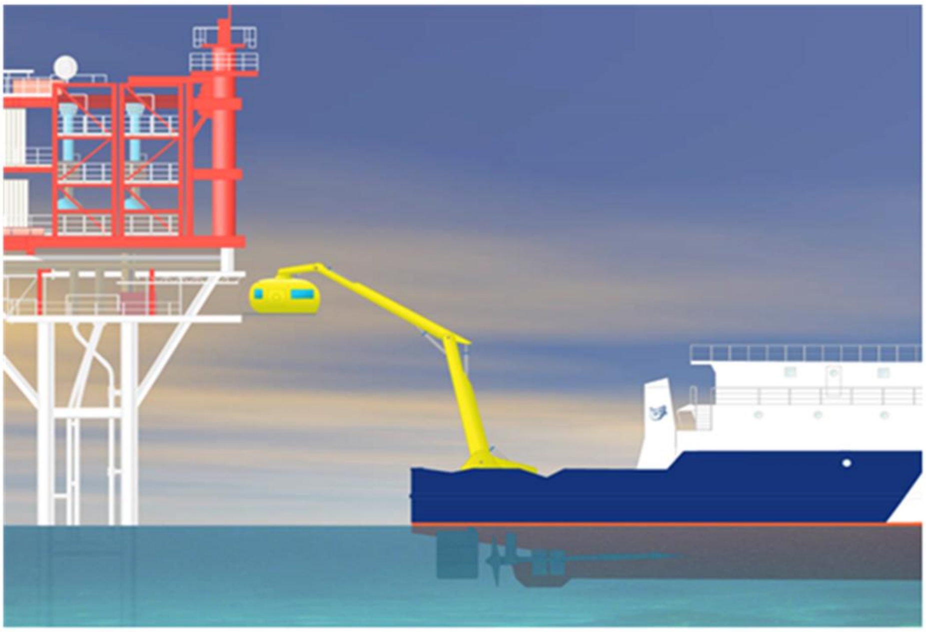

Figure 1: Neptune concept with articulated arm and personnel transfer carrier

The limiting parameters for operation are:

• Height range for access to target:	5m to 28m above sea level
• Vessel stand-off distance:	15m
• Vessel movement footprint:	5m radius from set-point
• Maximum heave:	+/- 2.25m
• Maximum roll:	+/- 10deg
• Maximum pitch:	+/- 5deg
• Maximum yaw:	+/- 5deg

The heave, roll, pitch and yaw figures apply for movements with a five-second cycle period.

4. Technical challenges

The four technical problem areas that need to be resolved have been mentioned in section 2 and are discussed below. It should be realised, however, that perfect space-stabilisation of the payload (i.e. payload motionless) is not possible. The motion induced by vessel movements can be reduced but not eliminated entirely. In the development work described here, the payload movement is targeted to be less than 10 cm from the desired point in any direction.

4.1 Articulated arm

The two-part articulated arm is mounted on a gimballed base that compensates for all three rotational degrees of freedom (roll, pitch, and yaw). The arm itself needs to be lightweight so that inertial forces and resulting stresses are minimised. It also needs to be extremely stiff so that flexing does not add unacceptably to the positioning errors that arise from control system and actuation inaccuracies. It is possible to compensate for flexing using sophisticated control technology but that complication is to be avoided if possible. Two design approaches have been studied: tubular metal trusses and carbon-fibre composite box beams.

Two design criteria have been adopted. Firstly, the arm must be adequately stiff when operating in stabilised mode. Half of the 10cm acceptable movement error is allocated to structural flexing; the other half is allocated to inaccuracies produced by the control system and actuation. Secondly, the arm must be able to survive a worst-case system failure that results in loss of stabilisation so that the arm moves synchronously with the vessel. This is taken to be when the arm is at maximum height and reach and maximum vessel movements are experienced. Flexing under these conditions is not important but containing stresses in the structure within acceptable limits is essential.

4.2 Motion and positioning sensing

Without an accurate knowledge of the motion experienced at the point where the articulated arm is mounted, accurate calculation of the compensation needed is not possible. Many types of motion sensors exist and there are several proprietary IMU's (Inertial Motion Units) available that are in commercial use. Several of these have been tested using STL's six-degree-of-freedom motion simulator with cycle-time periods in the range 3 to 10 seconds (see Section 5). Rotary movements (roll, pitch, and yaw) seem to be accurately measured but heave movement is more difficult. Slow movements in surge and sway directions such as occur due to vessel station-keeping errors are not adequately measured by these IMU's and additional position sensing using GPS, laser ranging, or a similar method is needed.

4.3 Control system

With accurate motion and position data, the necessary compensating movements to achieve space-stabilisation can be calculated and converted into output signals that are fed to the actuator controls. Commercially available PLC devices are adequate for this purpose. It is desirable to use a dual-redundant device with hot standby and seamless changeover to ensure system integrity in the event of a fault or failure.

4.4 Actuation

Hydraulic or electric actuation can be used. Hydraulic units such as rams and power sources are commercially available in a wide range of sizes and they are extensively used and understood offshore. Modern designs have very precise movement and the interfacing of servo valves to the electronic controller using internationally-accepted protocols is well established. Hydraulic actuation is preferred for these reasons though electric actuation is an acceptable alternative. There are advantages to using separate actuators for balancing the static load and for achieving dynamic compensation as described in Reference 1.

5. Neptune project progress

The Neptune project has progressed in three stages:

- Design and build a six-degree-of-freedom motion simulator.
  This was successfully completed in 2010 and the unit is in regular use in the STL Research facility (Figure 2). It can replicate the movement of a ship's deck with cycle times typically in the 3 to 20 second range.

Figure 2: Six degree of motion simulator in use at the STL Research facility

Figure 3: Simplified arm undergoing "proof of concept" testing

- Build a reduced-scale test and demonstration Neptune system.
  A one-eighth scale Neptune system with a simplified arm has been designed, built, and tested on the motion simulator (Figure 3). The main aim was to develop a satisfactory control system and prove that space-stabilisation could be achieved with the necessary accuracy. This was accomplished in 2013. At the same time, a quarter-scale steel-truss arm was built and installed in a test rig to check that the theoretical stresses and deflections matched the values measured in practice, which they did (Figure 4).

Figure 4: Lightweight steel-truss arm sections for validation of stress and deflection predictions

- Design and build a prototype Neptune system and carry out sea trials. This stage is currently underway and trials are scheduled to take place in 2014.

6. Safety and certification

In parallel with technical development, a certification process is underway. It is intended that the system should be fault tolerant and the aim is to achieve a design that can continue to operate safely with any single fault occurring. This has already been mentioned in connection with the control system. Duplication of actuators and tolerance to single-element failures in the structure are other aspects of this approach. In addition, the arm is designed to self-stow back on deck if any fault occurs. Det Norske Veritas is the organisation chosen for certification and their procedure for qualifying new technology is being followed (Reference 2).

7. Applications

Space-stabilisation technology should find numerous applications offshore but only those of particular relevance to the offshore wind industry are mentioned here.

7.1 Crane operations

The movement of tools and equipment from a floating vessel to a wind turbine or distribution platform is an obvious application. At present, the majority of wind farms are near-shore or in semi-sheltered waters and the logistics of transferring equipment are simple using relatively small vessels. As wind farms are built further offshore and are exposed to more difficult weather and sea conditions the problems will increase and small craft based inshore will be inadequate. The advantage of using a space-stabilised crane is that it can be installed on a service vessel and the need for a crane on the offshore structure is eliminated.

7.2 Tool deployment

Specialised tools can be deployed from a vessel that, with space-stabilisation, are less likely to be damaged or fail to operate properly. An example might be a tool used for grouting at the wind-turbine column/foundation transition.

7.3 Personnel transfer

A particularly important application is the transfer of personnel from a vessel to a fixed structure. The need for personnel to gain access to a wind turbine at any time regardless of weather and sea state is important. Far offshore, winter conditions can delay access for long periods with extended downtime and loss of revenue possible. However, transfer of personnel requires a much more stringent approach to risk assessment and safety procedures. Personnel transfer using a space-stabilised personnel access system such as the Neptune device shown in Figure 1 should enable a step-change in access capability to be safely achieved. Personnel enter the carrier on the vessel and are seated with safety belts fastened before being lifted off the deck and transferred to the landing area on the target structure. On arrival there is no relative movement between carrier and structure and personnel can disembark quickly and safely with their tools and equipment.

8. Conclusions

The Neptune space-stabilised system that is under development as described in the previous sections has made good progress and the following conclusions are offered:

- An ability to achieve space-stabilisation of a payload to the required degree using an articulated arm with hydraulic actuation mounted on a motion simulator has been successfully demonstrated.
- A lightweight ultra-stiff metal-truss arm suitable for incorporation in a Neptune system has been designed, fabricated, and tested to successfully validate the stress and deflection predictions obtained using computer-aided design methods.
- Sufficient confidence has been generated in the viability of the concept to justify the design and construction of a prototype that will be tested at sea during 2014.
- There are numerous potential applications for the technology. The transfer of personnel from a ship to a fixed offshore structure is an application for which the Neptune type space-stabilised device is particularly suitable.

9. References

1. Kirkley, D W, "Stabilised ship-borne apparatus", British patent no. GB2336828 London, 3 April 2002

2. "Qualification procedures for new technology" DNV-RP-203, Det Norske Veritas, Oslo, July 2011