Scale model testing of the Ampelmann

Safe and easy access to Offshore Wind Turbines

----- Patent Pending -----

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Abstract

Offshore wind turbines require maintenance. But to reach the turbine to apply the maintenance is difficult and costly offshore. The main problem is to transfer personnel and equipment from a moving vessel to a fixed turbine. To overcome this problem, this paper explores a new transfer method: the Ampelmann. This system consists of a vessel mounted Stewart platform. By measuring the vessel motions and real-time control of the actuators in the platform, the top deck becomes stationary compared to the fixed world. For this concept a design was made for a typical offshore wind farm and scale model test were conducted to prove the working of the concept.

Accessing offshore wind turbines

Offshore wind energy is a very promising application of wind power, particularly in countries with dense populations. For offshore wind farms, the accessibility for servicing and maintenance is a major concern due to the inability of maintenance personnel to reach a malfunctioning turbine within a short period of time. The main reasons for this are the distance from the shore and adverse weather conditions with accompanying high waves. Given the fact that offshore wind turbines are expected to require maintenance as frequent as onshore turbines, there is a need for a safe and easy way of transferring personnel and/or equipment to and from the turbines.

At present four access methods are used/proposed for servicing and maintenance visits: i) boat-to-ladder transfer, ii) helicopter craning, iii) the use of jack-up vessels and iv) transfer via a flexible gangway. Each method has its own advantages and disadvantages. For example, the boat-to-ladder transfer method is relatively simple and cheap, but only allows for pocket-sized equipment transfer and is limited to mild sea states. Helicopter craning provides fast site access, but is very expensive and again allows for little other than personnel transfer. Moreover, this option requires the installation of a hoist platform on the top of each turbine. The use of a jack-up vessel provides a stable and secure base for the transfer even of large components (*e.g.* rotor blades), albeit at high cost. The jacking operation becomes nearly impossible above 1 m significant wave height. The concept of a flexible gangway is currently being tested. By connecting the gangway to a bar on the Offshore Wind Turbine, relative motions are reduced. The current version only allows personnel and small equipment transfer and requires connection bars on each turbine. The aforementioned access methods require calm seas, adaptations to the offshore wind turbine or expensive equipment. For a typical offshore wind farm in the North Sea, a threshold of 1 m significant wave height limits the accessibility to 50%. When a system can work up to 2.5 m significant wave height, it can be used during more than 90% of the year.

Ampelmann design philosophy

Several research groups at the Delft University of Technology joined forces to analyse and solve this problem. Offshore wind structures, in contrast to offshore oil & gas structures, always appear in numbers, even great numbers. This means that any adaptation required on a turbine needs to be on every turbine. The first requirement was therefore to create a system that can operate without interface on the turbine. In order to create a safe transfer system, it would be ideal to have a platform on top of the vessel cancelling all motions to make it stand still in comparison to the fixed world; the turbine. These systems exist in a reversed form: flight simulators. The moving part of these simulators consists of a contraption of 6 cylinders, known as a Stewart platform. These platforms can move in all six degrees of freedom and are therefore ideally suited to cancel all ship motions.

From these contemplations, the following requirements were established:

- No adaptation requirements on the offshore wind turbines
- Vessel mounted system
- Use a Stewart platform
- Safe
- Easy
- Fast
- High workability: > 90%.

Introducing the Ampelmann

The concept was first envisaged during the 2002 World Wind Energy Conference in Berlin. After an intensive day of listening to scientific palaver, German beer and open minded brainstorming lead to the accidental birth of idea to put a Stewart platform on a ship. The concept should be so reliable that the maintenance engineer only needed to watch the pedestrian traffic light change to green to signal him that he could safely transfer. As the concept needed a codename, the solution was quickly found: "Der Ampelmann". Ampel is traffic light in German and at the time East Berlin could only be recognised by the fact that the figure in the pedestrian lights is wearing a hat, as opposed to his hatless colleague applied in West-Berlin (and the rest of the world). Ampelmann has since become the trading name of both the concept of Stewart platform on ship and of the Stewart platform itself. Figure 1 shows the "Mann mit Hut geht's gut", the Ampelmann.

Figure 1: *Der Ampelmann, name giver and mascot to the concept*

Conceptual design

The first step in the development was to make a conceptual design of the Ampelmann system for an actual offshore wind farm. The Near Shore Wind farm (NSW) off the Dutch coast was selected as reference site. This wind farm has relatively deep water, up to 20 m, and lies highly exposed to the westerly winds dominating the North Sea. By analysing the wave scatter diagram for this site, it was found that the Ampelmann system needs to be able to operate safely up to a sea state with a significant wave height of 2.5 m (with maximum wave heights of 4.6 m).

The Ampelmann system can be mounted on any ship. But ship dimensions heavily influence its response to wave action so for every individual ship, the Ampelmann system will be different. A number of ship types and sizes were therefore selected to come to the most economical solution. The types analysed comprised tugs, fishing vessels, twin-hull vessels and offshore supply vessels. The ships were modelled in the strip-theory program SeaWay. By calculating the vessel motions, velocities and accelerations during the maximum sea states, the required envelope for the Ampelmann could be established. The method simulated each sea state long enough to make sure the theoretically most probable maximum wave height would occur. The requirement for the Ampelmann system is that it should reach all these motions perfectly.

Based on the motion envelope, the cylinder lengths were determined and the requirements for velocity and acceleration could be summarized. A first check revealed that the required velocity and acceleration of the system lie well within the capabilities of normal cylinders: no special features are needed in that area.

After several design optimisations, the offshore supplier with a length of around 50 m turned out to be the best Ampelmann carrier for this particular site with these workability requirements. Smaller vessels will respond more significantly to higher waves, requiring very long legs to counteract these movements. The Ampelmann dimensions will have 4 m stroke cylinders. This will mean that the platform will have a neutral position of 6 m above the deck. With a typical height of the deck above the waterline of 2.5 m, this cylinder length will bring the transfer deck near the level of the work platform of the offshore wind turbine.

Safety checks for sea states above the design state revealed that the Ampelmann system will only move occasionally a few centimetres when the significant wave height is increased to 2.75 m. A 3 m significant wave height (maximum wave: 5.6 m) the system will move in the order of 10 centimetre occasionally. Should these motions be acceptable for transfer, workability would be increased from 93% to 97% for this particular site.

Further, a design study was devoted to the access from the vessel deck to the Ampelmann transfer deck and from the Ampelmann to the wind turbine. For ship access, a scissor elevator will be most ideal. This system can use the Ampelmann hydraulic power to be operated when the Ampelmann is in settled position. The system will fold away completely from the motion envelope. The scissor elevator can further be optimised to match the load carrying capacity of the Ampelmann. The gangway for transfer to the Ampelmann will require an electrically or hydraulically driven draw-bridge like structure. The requirements of this system are highly influenced by the estimated accuracy of the Ampelmann system: will it stand still completely, move only a few centimetres or

even several tens of centimetres? Several designs were made, comprising both full actively compensated motions (actually creating a second Ampelmann compensation system) or passively compensated systems. Further detailed safety analyses will be required to find the most optimal solution. The design process described in this section is depicted in the flowchart in figure 2, the detail of the required motion envelop is shown in figure 3.

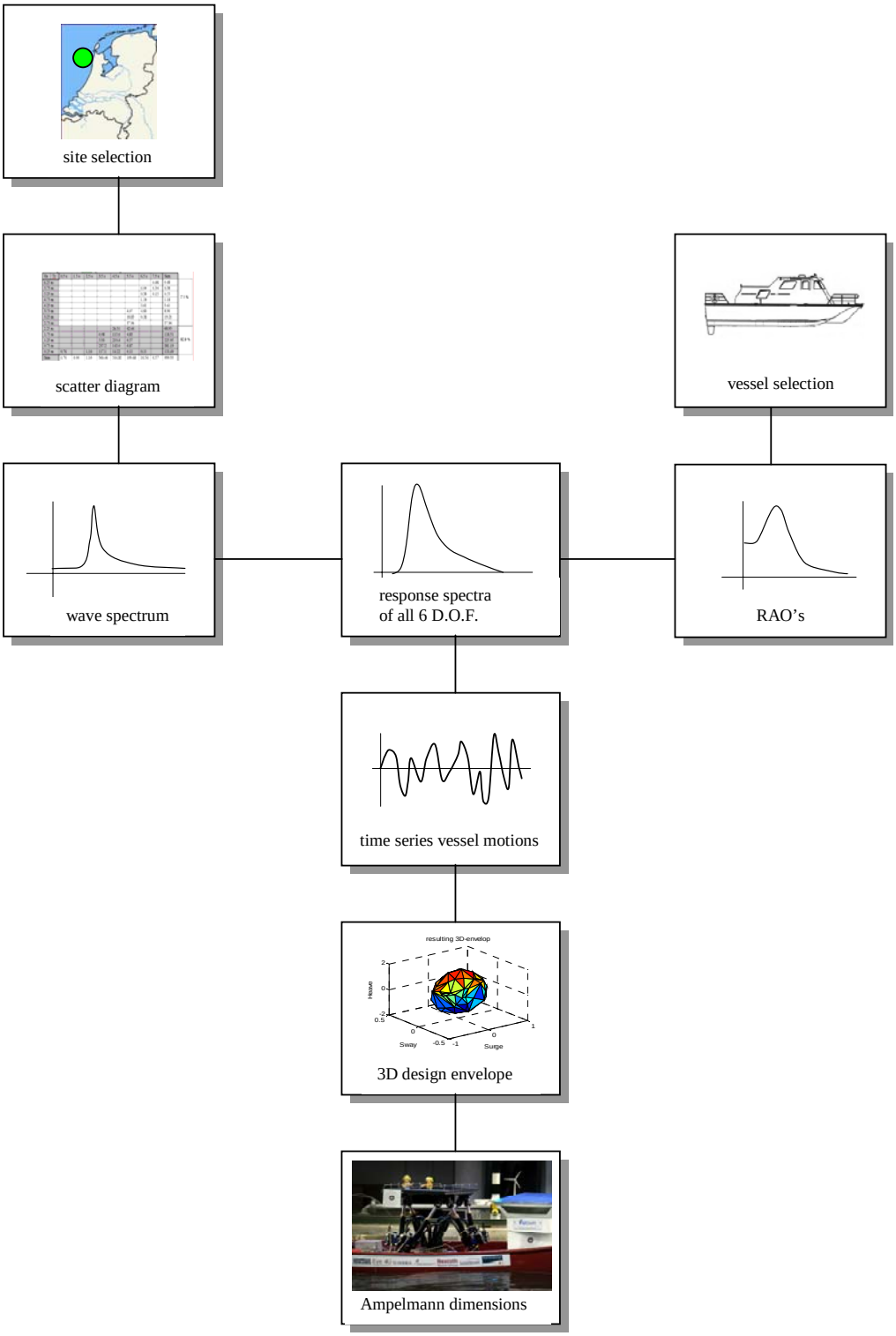

Figure 2: *Flowchart of Ampelmann conceptual design process*

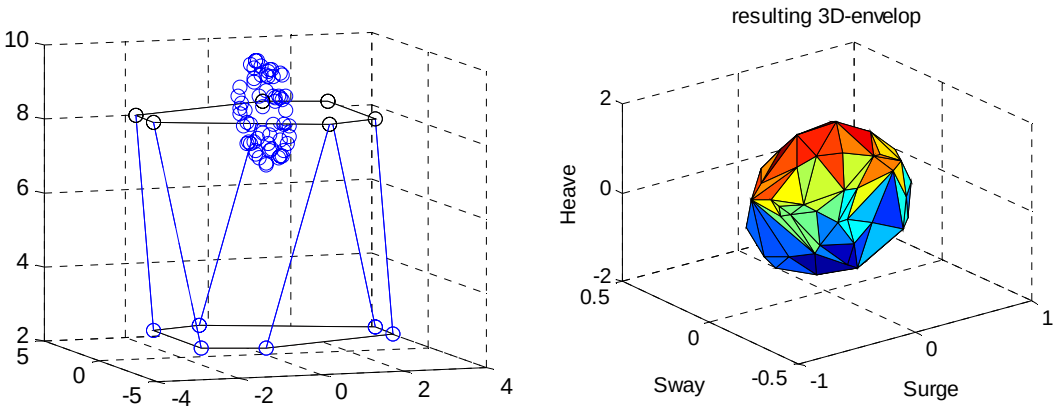

Figure 3: *Design envelope for the centre of the Stewart platform top plate*

Conceptual design conclusions

The main conclusion of the conceptual design is that an Ampelmann can be constructed to meet the requirements. The structure will be larger than typical flight simulators but can be constructed with off-the-shelf components. The biggest issue still to explore is the connection between a real measurement system and a real Stewart platform. Although computer programs can simulate all sub-components of the systems, the connection between real measurement and control mechanisms can only be solved in the real world. It was therefore decided to start a testing program of a scale model Ampelmann.

Scale model testing

The goal of the scale model testing in threefold:

1. Acquire experience in connecting measurement system and Stewart platform
2. Demonstrate the working of the Ampelmann
3. Create promotion material: pictures and video.

Although the university comprises all required fields of science to approach this problem, contact was sought and found with commercial companies for back-up, experience and equipment. This resulted in the consent to participate of Rexroth Hydraudyne, a company specializing in the construction of Stewart platforms. Their Micro Motion System has been made available for these tests for 3 months. Boskalis, the world's largest dredging company with a fleet of over 300 specialized vessels and extensive knowledge of ship movement measurement systems donated two measurement systems: the MRU and the newer and more accurate Octans. As the project progressed, also the manufacturer of the Octans, IXSea became involved. Finally, Shell Wind B.V., as developer of several offshore wind farms, provided financial sponsoring to cover transport and insurance costs for the borrowed equipment.

The Delft University of Technology has a history with constructing Stewart platforms. To create a flight simulator, the mechanical engineering and aerospace engineering faculties co-operated to create the "Simona" flight simulator. As the project neared completion, the platform was transferred for the mechanical the aerospace department. The platform was so dearly missed that a smaller version was created not long after: the "Simonita". The platform is used as a research tools and is also available for Ampelmann testing.

The Ampelmann concept was proven in two different stages: the "Dry Testing" and the "Wet Testing". In preparation of these two phases, the available measuring equipment was tested leading to a sound selection of the device to use in the proof-of-concept. Purpose-built control software for the Ampelmann system was also written and tested in advance.

Testing measuring devices
The two measuring devices made available by Boskalis during the preparation phase were tested on top of the Simonita (figure 4) in order to choose the most apt device for the wet and dry tests. This testing was of great importance, since IRS systems are notorious for their drift problems. Indeed, the drift problems of the Seatex MRU were too big to ignore. The iXSea Octans had negligible drift and small errors and was therefore considered suitable for use in the Ampelmann system. While testing the Octans, contact was made with its manufacturer iXSea, who were prepared to provide an Octans during the other test phases and willing to assist with their expertise.

Figure 4: *Testing measuring devices*

Figure 5: *Testing control software*

Testing control software
New software was written especially for this project. This software, the Ampelmann Converter, enables measurements by the Octans to be transformed instantly to input for the Micro Motion System. Since this software was custom-made, it had to be tested thoroughly before starting the other test phases. This was done by checking the Octans motions with the Octans output, the Octans output with the Converter input and the Converter output with the MMS input. Finally this resulted in visual motion tests, where the Octans was used as a "3-D joystick" to move the MMS, as shown in figure 5, giving us the first satisfying results.

Figure 6: *Dry Testing set-up*

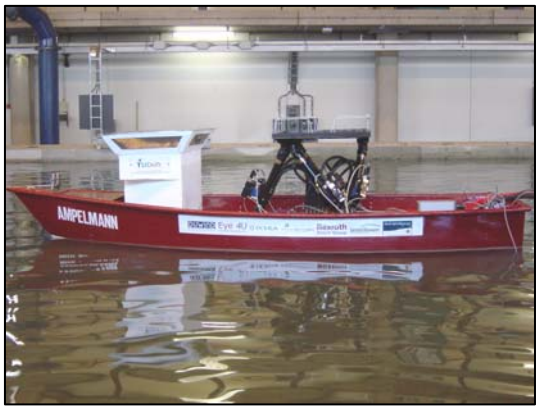

Figure 7: *Wet Testing set-up*

Dry Testing
During the Dry Testing, the small Stewart platform was mounted on top of a larger Stewart platform as shown in figure 6. This larger platform is called the Simonita and is located at the faculty of Mechanical Engineering of the Delft University of Technology. Simonita can simulate the motions of a ship's deck in any sea state, which then has to be compensated by the upper platform. This method allows the Ampelmann system to be tested in various frequency ranges, and makes fine-tuning of the control system possible. The major advantage in this test phase is the fact that the simulated motions are completely controllable and therefore allow thorough testing in a safe fashion.

The Dry Testing phase made it possible to perform tests in each degree of freedom separately, for regular sinusoidal motions at different frequencies. The motions of the upper platform were measured using fixed laser beams pointing on targets on the upper platform. This allowed us to experiment with the low-pass filter in the Converter software in order to get the optimum results. The results are plotted in figures 8 and 9, immediately leading to the conclusion that the system performs very well for frequencies from 0.2 to 0.3 Hertz, coincidentally the frequency range of most waves in the North Sea. However, for the frequencies outside of this range the

motion compensation was poor. When consulting iXSea, the manufacturer of the Octans about this, we learned that this was no coincidence: Octans is programmed to perform optimally in this frequency range simply because it is the most common range for sea waves. Constant speeds are filtered out, therefore omitting the lower frequencies; higher frequencies which can often come from machinery on board of a vessel, are also preferably deleted. Given the expertise of iXSea in the field of measuring devices, we decided to accept these frequency-dependent results. However, these filter properties can be altered by iXSea if this is required for the prototype.

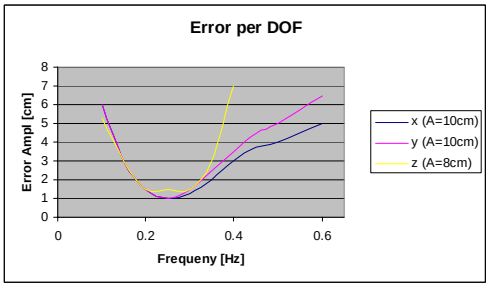

Figure 8: *Errors in translational motions*

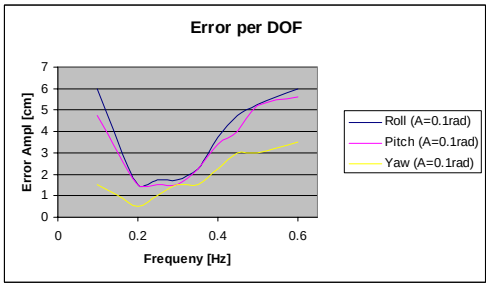

Figure 9: *Errors in rotational motions*

When testing all motions combined, with amplitudes of 7 cm and 3 degrees, the deflections of the upper platform stayed well within 2 cm as long as the motions of the lower platform stayed in the mentioned frequency region of 0.2 - 0.3 Hz.

Wet Testing

For the Wet Testing, the small Stewart platform will be fixed on a scale model vessel (see figure 7). The vessel will be excited by waves in the large wave basin of the faculty of Civil Engineering at the Delft University of Technology. This basin can create both regular and irregular waves at different frequencies and with different amplitudes, which makes it the ideal testing facility. Again, the system can be tested in various frequency ranges, and further fine-tuning of the control system is possible. Moreover, the wet tests will prove the system's seaworthiness and the set-up is perfect for a public demonstration once the concept works.

The Wet Testing phase was not without problems. The very first problem appeared immediately when the system was engaged: resonance occurred in the roll direction. When preparing the boat, its keels were removed to prevent damage to the bottom of the basin; the wave basin was shallow compared to the draught of the vessel. Unfortunately this caused the boat to be less stable around its length axis, allowing the MMS to cause the resonance. Since the MMS has about the same weight as the boat, the cylinders of the MMS could easily push the boat too far during motion compensation. This problem was solved by welding roll-dampers on each side of the boat. This solution proved to be simple but perfect.

Figure 10: *Wet testing*

Once the rolling problem was solved, the second problem was faced: the performance in the basin was poor. The waves in the frequency range of 0.2 to 0.3 Hertz were exactly the waves that did not cause much excitation to the boat. Waves with a higher frequency did cause the vessel to move nicely, but the motions were badly compensated by the Ampelmann system. So to improve our system, a high-pass filter was added to our Converter software and the parameters in the software were adjusted. This led to a much better performance: the deflections of the upper platform were reduced to less than 1 cm for waves with a frequency up to 0.55 Hertz. This was a significant improvement to the Ampelmann system, now enabling it to compensate waves in a wide range of frequencies. Waves with periods between 1.8 and 5 seconds could now be compensated. This covers about 90 % of all sea states in the Dutch North Sea. Waves with lower frequencies hardly occur, and only in combination with very low significant wave heights (up to 0.25 m). Waves with higher periods could not be examined, because they caused negligible motions to the ship in this test set-up.

Discussion

This project has been completed successfully: the proof-of-concept was delivered. But along the project, we became more and more acquainted with the Ampelmann system, the new software and how to improve its performance. This resulted in a system that functions in a wide frequency range. Moreover, we became very familiar with the measuring equipment, the Stewart platform and our software, giving us the right knowledge for building a prototype in the near future.

The Octans measures with an accuracy of approximately 1 cm and this accuracy is maintained when located on a moving full size vessel. Therefore, the relative errors will only decrease when building a larger Ampelmann. Larger Stewart platforms are commonly used for flight simulators and thus form a proven technology. These platforms are known to reach high accelerations, making it no problem for the ship motions to be compensated even in heavy conditions. In conclusion, it can be stated that the scale model Ampelmann has proven that this concept can definitely be used on offshore supply vessels to enhance offshore access, making it as easy as crossing the street.

Conclusions

With respect to the tests performed on the scale model Ampelmann, the following conclusions can be drawn:

- The Octans is accurate and fast enough to function within the Ampelmann system
- The MMS Stewart platform is accurate and fast enough to function within the Ampelmann system
- The Converter software works perfectly and includes filters that enable proper functioning at wave frequencies from 0.2 to 0.55 Hertz, equal to periods from 1.8 to 5 seconds.
- Waves with periods shorter than 1.8 second barely occur and when they do it is in combination with significant wave heights no higher than 0.25 meters.
- Waves with longer periods than the 5 seconds mentioned caused insignificant vessel motions in this particular test set-up and scale; they could therefore not be examined.

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