THE SERIAL PRODUCTION APPROACH FOR JACK-UP ACTIVITIES IN THE RENEWABLE ENERGY SECTOR: CHALLENGES TO INTERFACE DETAIL AND SAFETY MANAGEMENT.

Ekkehard Stade, MSc
Managing Director, Global Maritime Germany
Hamburg, Germany

ABSTRACT

Historically, Jack-up units have been utilized in Energy Projects that would support and require careful preparations before each individual location. Over the last years, jack-ups have been increasingly used in the construction of offshore windfarms. The diverse range of operations include foundation installation, transitions pieces and turbines as well as cable jointing of export cables in landfall locations. In addition, the value of self-propelled jack-ups has been discovered by the OWF operators for the operations and maintenance phase as they combine flexibility in movements with a stable platform for maintenance operations.
As a result, particularly in the construction phase, location specific approvals have been done in series, frequent jacking operations at the same location (not same footprint) by different leg geometries have become the norm. This not only applies to the work site but also to the marshalling yard's jetties.

This situation was not accounted for in existing guidance and regulations documents and therefore some significant lessons were to be learnt. The main areas the paper focusses on are:

- Extremely shallow water location approval
- Port facilities suitability
- Interface DP/ Jacking

The different stakeholders are identified for each of the areas and their status quo with regards to regulation and guidance is examined. (Class/ Flag States, IMO, Coastal states, Port authorities, industry associations)

For example, operations in extremely shallow water were considered to be non-critical, sometimes considered without location approval. Some ports were planning subsequent jacking locations after each jack-up call, others did significant preparatory works and others again did not do anything at all.

In addition, there is still a gap to be filled that exists in the interaction of the jacking system and the propulsion (Dynamic Positioning). Class Societies still do not require the jacking system to be considered in DP FMEAs, thus turning a blind eye to one of the more critical operations of the vessel, the transition from DP to load bearing jacked-up.

This level of uncertainty combined with lack of development of guidance on interfaces between propulsion and jacking, in particular between DP and jacking has caused incidents and accidents.

The paper examines the variety of causes for those issues and tries to categorize them to follow the traditional approach of operations Assurance: technical suitability, operational documentation/ instruction, maintenance (regular verification) and competence.

Based on the conclusions the paper also aims at providing recommendations for all levels of non-government stakeholders (Owners/ Operators/ End clients/ port facilities/ Industry associations).

KEY WORDS: Jack-up, Dynamic Positioning, Safety, Offshore Construction, Renewable Energy

GLOSSARY

CAR	Construction All Risk (insurance policy)
DGPS	Differential Global Positioning System
DP	Dynamic Positioning
DPO	Dynamic Positioning Operator
GNSS	Global Navigation Satellite Systems
IMCA	International Marine Contractors Association
IMO	International Maritime Organisation
JRC	Joint Rig Committee
MWS	Marine Warranty Surveyor
NI	Nautical Institute
SSA	Site Specific Assessment
SOLAS	Safety Of Life At Sea (IMO Convention)
STCW	Standards of Training, Certification and Watch keeping

INTRODUCTION

In recent years the offshore industry was transformed by the introduction of new activities such as renewable energy and the related utilities. This has driven demand for construction units and for stable platforms for highly sensitive construction activities. To facilitate the demand, the use of jack up technologies in the widest sense has been found to be the ideal method. Based on experiences from oil and gas exploration activities it seemed logical to use this technology for other offshore activities as well.

Traditional designs used in the oil and gas industry were used initially and it was quickly realized that although developed over decades for hydrocarbon exploration/ offshore construction, they do not necessarily satisfy all the requirements of the offshore renewable industry. This applies to the design requirements for jacking systems to allow for more frequent jacking operations as well as to crane applications in combination with the ability to transit to and from the worksite with reliable speed and schedule.

In addition, a serial production approach including the sophisticated logistics has to be taken in order to achieve a better cost to benefit ratio and to gain higher levels of acceptance for the public funding.
This paper tries to identify some of the critical issues relating to the challenges involved and how they affect the safety and efficiency of the operations. This will cover in particular the interface to Dynamic Positioning, the frequency of jacking operations and relevant issues at the worksite and in port.
At the end of the discussion the paper tries to show measures to improve on the identified areas.

This paper discusses operational issues during windfarm development. The data upon which the discussion is based stems from experience in the field. No reference can be made to reports, incident investigations etc. due to confidentiality issues. Whilst this is a problem in terms of academic expectations on a conference paper the issues must be discussed and awareness must be raised.

JACK-UP APPLICATIONS IN COMBINATION WITH DYNAMIC POSITIONING

Based on the requirement to relocate with comparable high frequency on the one hand and a capable propulsion system on the other hand, the combination of providing a stable construction platform with dynamic positioning was a logical development. It allowed the realization of very tight logistical concepts inherent to the serial production approach of an offshore windfarm construction project.

Whilst there was traditionally some experience in combining jacking with propulsion systems to introduce higher levels of efficiency into the industry, the introduction of DP represented a paradigm shift for the industry. On many levels this has been digested by the industry very well, others have introduced a number of difficulties. A number of examples are illustrated below.

Competence issues

At the time when the first designs were developed, there was no guidance available how to bridge the gaps of competences between the traditional jack-up competences and the Marine (STCW and others, e.g. IMCA, NI) competences required for the obviously nautical and marine engineering focused operation. Still today, this represents a challenge. Following existing DP Competence schemes, it is almost impossible for a DPO to gain the required hours in DP to be able to keep their license current or worse- to initially acquire a DPO certificate. With the limited number of hours on DP on a DP Jackup another problem aside the certification, is the lack of exposure of operators to abnormal situations e.g. partial blackouts, rogue or tripping thrusters etc. Those types of incidents do not necessarily need to be catastrophic (or non-recoverable) but still introduce a high value learning effect. In other words, only the operators who have been exposed to abnormal (DP related) situations will have the capabilities to efficiently manage one of those situations. The likelihood of experiencing such situations during the very limited time on DP is fairly small. The increase in reliability of DP systems have not helped this situation.

Due to the nature of the operations, the most critical period is the period of transferring the position control from Dynamic Positioning to the load bearing jacking phase.

Competence is split between jacking operators and DP operators. The operational settings of the bridge management team are very diverse. They range from a setting where there are two jacking operators plus two DP operators are present during the above mentioned critical period to only one DPO on the bridge who is also acting a jacking operator.
It has become evident that there were incidents triggered by a lack of competence in this respect. DP systems where used with DGPS input as reference when the legs have been pinned down, no model adjustment applied, (e.g. gain setting changes).

Another issue related to competence is complacency. In particular, when a unit is frequently arriving on site, leaving the work site, transitioning from DP to jacking and vice versa a serial production type operation indicates potential onset of complacency. This is amplified by the fact of only a limited time of critical operations (transition). In previous work, I have discussed the relationship between short, repetitive operations and complacency [3] [5].
There is a robust system in place with most operators to ensure complacency is detected and avoided e.g. for critical DP operations. Similarly, there are systems in place to avoid the same issue with jacking operators. From on board audits it became evident that there are no systems in place to address the potential of complacency at the interface between Dynamic Positioning and Jacking.

Technical issues

In terms of technical suitability of DP systems to be used in combination with jacking operations, some key points need to be mentioned:

The DP uses a vessel model for calculating the thruster response (Thruster allocation logic) to deviations between goal and present (measured). This model uses the vessels hydrodynamics to estimate resistance. During location arrival and preparations for pinning, the vessel is holding position in DP. Lowering the legs significantly alters the hydrodynamics of the vessel. Especially older installations do not allow for a step less variable adjustment of the model as the legs are being lowered. Some newer systems allow for a three step adjustment (fully up, half way down and fully extracted at max water depth). Especially for larger units suitable for greater water depths this might not be appropriate to adjust the thrust allocation logic sufficiently. As a result, there might be position instabilities.

Another key issue is the conflict between a geographically fixed (or semi-fixed) position when pinning, and the control loop of the DP system. In the worst case this conflict can cause a drive off triggered by the external forces introduced to the system as a consequence of the unmeasured resistance of the pinned legs against the thruster activities. Trials with actual systems at sea have shown that only a slight goal position instability can initiate a "fight" of the two systems. It became evident through audits that most operators are aware of this situation and try to mitigate the risk through operational procedures. However, a more solid technical solution would be helping to reduce the risk of this issue dramatically.

Besides those issues there are a number of other technical problems in combining the two systems such as interference of legs and spud cans with hydro acoustic references and survey equipment, documentation challenges to SIMOPS and Management of change. However, those fall outside the scope of this work and should therefore not be discussed further in this paper.

Whereas the above represents a challenge to the arrival at the worksite, there is a more critical issue: when departing. At least during the foundation installation activities of an offshore windfarm there are normally no assets in close proximity to the work location when the installation vessel arrives there initially. When departing, this is different. Not only is there an asset (e.g. a foundation complete with perhaps a monopole and a transition piece) it is also in very close proximity. In addition, the problem described in the previous section is now amplified by the fact that the DP system cannot build a model in the short time available between the spud cans being clear of the seabed and the need for thruster support for maintaining the position until the spuds are clear of the seabed.

This means that there can be no confidence in the accuracy of position keeping, at least not in the required accuracy when an asset is less than 2-3 meters clear of the vessels side. For that reason, operators have reverted to the method of using DP for departure from the worksite only in manual mode (e.g. joystick control of surge and sway, yaw locked to DP.) Although this seems to be an appropriate way of controlling the vessel, it is still prone to issues such as underestimated currents, operator errors etc. Having identified this issue for the particular operation, a risk assessment should be carried out very early in the project to allow for the logistics concept to be adjusted accordingly:

- Where does the unit jack up to allow for the safest departure (blow off situation) also considering currents?
- What is the sequence of installation activities for e.g. foundations? Can it be adjusted to reflect the safest location?

Having discussed those issues, one would come to the conclusion that there is significant scope for improvement. Organizations like IMCA for example have been alerting their members to those risks by issuing notes and guidance. [2][6]

SERIAL APPROACH TO JACKING

With the introduction of multiple jacking operations at or at least near the same location it became necessary to look into the requirements for SSAs from a different angle. An individual location could be frequented by the same unit various times or by different units (e.g. during the construction phase with a different unit than during the Operations and Maintenance phase). Sometimes specific seabed preparations are necessary, for example for heavy lift loading operations of foundations and / or transition pieces. This issue in general applies to two different general locations: in port and at sea/ construction site. How accurate are the previously recorded and documented prints? How accurate is the positioning of the unit following in the footsteps of another? What are the effects of scour since the last recorded footprints? What does the applicable guidance cover and how are those guidelines implemented? In part the answer to those questions could be the objective of further studies, looking at the statistics within the industry, but are likely to be very problematic to research due to confidentiality issues.

The following paragraphs try to discuss some of the challenges involved in the safety of frequent jacking operations in port and at the construction site.

In Port

Port operations play an important part in the offshore renewable industry. Marshalling ports, were windfarm components are either stored or transferred or both, have been increasing in numbers during the last years to accommodate for the significant flow of components from manufacturing to installation. Some projects use those marshalling ports for buffer storage of components (here I specifically would like to refer to components such as foundations, transition pieces, towers and turbines). This means for example that a number of installation cycles are buffered by storing a number of components to be ready for the installation vessel (usually a DP jackup) and to allow for a quick turnaround. Once a project is complete, another might commence with different components to transport and using different jackup units.

In even more complex project logistics, the components may arrive by barge in the marshalling port/ yard, directly loaded onto the installation vessel. They normally carry one more of the components than required for a full loadout of the installation vessel in order to build the buffer mentioned earlier. There have been cases where the barge has been moored to the quay whilst the installation vessel was already located outside. This way the installation vessel's crane can reach the barge, transfer components to the vessel and to the quayside avoiding the need to shift the vessel or the mobilization of a shore side crane. Maneuvering of the barge with a jackup in this close proximity with its legs exposed is a very critical operation but with full approval of MWS and project was done without incident on a number of occasions. The key to a successful operation here lies in the acceptance of similar operational acceptance criteria based on guidance/ requirements being used for offshore operations.

Some port operators and windfarm project carefully consider the implications of multiple jacking operations at the same location and others are not, as the incident described further below illustrates.

Below incident illustrates the complexity of challenges related to multiple jacking operations in port but also is linked to DP issues as described in section *Technical issues.*

A smaller sized jack-up approached a berth to load windfarm components. The unit stopped at a convenient location in the channel to switch from free navigation mode to DP. The assigned quay was

approached in DP, yaw (heading) locked and surge and sway on joystick control. When the unit was seen to be in the correct location, the DP system was placed in full control of the vessel utilizing DGPS as the sole position reference.

> *Note 1:*
> *It has to be mentioned at this point that, specifically in port this position reference has notable limitations due to shading, multipath issues etc. [6]. Frequent alterations of heading must be expected during maneuvering which may cause antennae being shaded, Differential signal being lost, and computation failure due to too small number of measurements, are representing only a selection of the variety of problems of GNSS in areas with significant surface infrastructure such as ports.*

The legs were lowered and pinned. The seabed was sloped slightly downwards away from the quay wall. The first indication that something was not right was that the distance to the quayside increased. There was no significant increase in thrust levels noted by the crew even when the distance increased further. The unit began to tilt and at some point the sea chest lost suction, the unit blacked out shortly afterwards, drifted across the harbor basin, hit a number of dolphin piles where she came to a standstill. Falling water levels (tide) and still being blacked out caused the legs to make contact with the seabed again. A catastrophic incident was only avoided by the fact that the crew were able to reinstate systems before there were significant load levels on the pins.

The incident investigation revealed issues that are related to more than one topic of this paper:

- The initial move was triggered by an abnormality in the DGPS position reference. (In port this is not too uncommon and can be caused by shading, multi path issues etc.)
- The distance the unit "drifted" before the blackout was in excess of 8 meters. The absence of high levels of thrust only allow the conclusion that the DP system saw the present position as to be correct.
- There was no documentation provided by the port regarding the suitability of the seabed for jacking.
- There were no detailed procedures available to the crew for transfer of control
- The crew was not familiar with reinstating the vessel's critical systems.
- There was no risk assessment available for this type of operations.

As shown above, this incident could have had much worse consequences. It also shows that only a few adjustments would have been required to be implemented to avoid the incident. A large portion of responsibility lies with the operators of the units to ensure that incidents like the one discussed above can be avoided. The important issue which needs to be discussed here is the interface between the port facility's safety systems and the jack-up operators systems. This is not to say that each and every port call should be covered by an appropriate bridging document that covers all engineering and geotechnical issues of the intended port operation. But as a minimum, consideration must be given to the risks involved by both parties. For example it is important for the operator to know exactly the conditions or changes in the conditions at the jacking berth.
Specifically, the following points should be documented:

- Have jacking operations been carried out at the berth in question?
- Is footprint data available?
- Does the port maintain a record of maintenance to berth seabed conditions?
- Is the berth subject to potential scour issues, when was it last surveyed?
- How is the DGPS signal quality at the location? Are there records?

Guidance to the crew must be available, detailing the challenges of the interface in a vessel specific manual. Having a DP operations manual and a jacking operations manual in place does not help the situation if those documents are generic and more importantly, if they are not properly interfaced/

referenced. It must be clear to operators of the respective systems where the interventions on one system have an effect on the other and vice versa. It is further important to test those interfaces on a regular basis, for example during desktop exercises, DP and jacking trials, mobilization trials etc.

> *Note 2:*
> *Significant gaps in the above discussed assurance process can trigger ship emergencies which may lead to threats such as fire, flooding, capsizing, and sinking. In this context, DP emergencies, jacking emergencies and a combination of both should be seen as equally important as the threats mentioned. To include them into a vessel drill and training program would help to increase awareness amongst operators, reduce complacency and validate procedures [5].*

The local port authority would be required to enforce the applicable guidance by auditing the operators who call their facilities for above described operations. Whilst the consequences of a DP and/ or jacking incident in port are likely to be less severe than at sea, significant delays can be caused by involved unit obstructing the operations of the port.

At the Construction Site

At the work site similar inconsistencies have been noted. Frequent jacking operations in one location or in close proximity to previous locations are required not only during the installation phase of an offshore windfarm but also during the operations and maintenance phase. The reason for the frequent visits of the same location lies not only in regular maintenance activities but also for repairs and troubleshooting.

In the offshore windfarm, we have to differentiate between two phases: the transport and installation phase (T&I) and the operations and maintenance phase (O&M). During the transport and installation phase a CAR insurance covers the damage to assets and requires the inclusion of a Warranty Surveyor. This function allows for a thorough 3rd party check of the proposed methods, limitations and contingencies. This check ensures that the operations are being carried out in line with applicable standards and guidelines. The T&I phase is therefore less prone to problems of poor safety management, procedures and interface management.

During the operations and maintenance phase, this type of activity is less often subject to third party approval. Even if underwriters are involved in specific activities, there may be no independent check on the operations ensuring compliance with applicable standards and guidance. Activities may be regarded to be within the deductibles values for individual policies and therefore not seen to be of risk to the lead underwriters. All of the above combined can lead, and have in the experience of the author led to, poor management of the risk involved in any type of jacking operation. This manifested itself in a lack of risk assessment or at least risk assessments with reduced level of detail, a disregard for requirements of a SSA, the lack of specific instructions to crew for the particular location and the reduced attention to detail of operational procedures and method statements.

The teams involved in the O&M phase are normally concerned only with the efficient operation of the plant. If repair/ trouble shooting activities are required, decisions have to be made quite fast. A thorough marine assurance process is seldom applied. For example, it may be noted that a maintenance jackup is not fully capable of lifting and loading the required loads, but how is it positioned close to an asset such as an Offshore Substation?

> *Note 3:*
> *The consequence of damages as a result of maintenance activities is often underappreciated. Extreme cases can have far reaching commercial consequences. Whilst the damage of foundation during the T&I phase may cause an array of turbines, say 6-8 not being able to be*

commissioned in time, the severity of a damage to an export cable J-Tube of an OSS can cause the entire windfarm to be immobilized for a significant time. Apart from the loss of feed-in revenues, there is added costs involved such as powering the windfarm for control and operation of the turbines (lubrication, weather vane).

During the Operations and Maintenance Phase of an offshore windfarm of approximately 20 to 25 years a number of visits to turbines can be expected in more or less frequent intervals. Especially in the earlier installations, which serve as test cases for structural integrity, component reliability etc., more frequent visits can be expected. The introduction of walk to work type vessels have significantly reduced the required visits by self-propelled DP jack up units. However, for some specific tasks such as component replacement in the nacelle/ blade arrangement, the requirement for stable platform with suitable lifting capacity is still existent.

It has been noted from experience in the UK sector and in some projects in Germany that there is a lack of understanding within operators of the importance of accurate recording of footprints. A minor deviation from the intended footprints is often not recorded. With the number of visits and the congestion on the seabed (assets, obstructions), the probability of incident increases. In addition, almost all maintenance activities are carried out with different units. Only a few operators have a dedicated self-propelled DP jack-up vessel on contract for the operations and maintenance phase of an offshore windfarm. As a result, another challenge to a consistent marine assurance process is added.
The proximity of footprints have been subject to discussion and the consensus seems to be that there can be no advice on acceptable distance between one footprint and the next one. [7] The reasons are listed in the reference and partly also explained in the above.
In an offshore wind logistics concept for the transport and installation activities, repetitive operations are frequently found. For those operations, thorough assessments and preparatory works are normally carried out, not only for the marshalling yard but also for the construction sites. For the O&M phase this is not always the case.

Internal systems of operators are not all of the same robustness when it comes to recording accuracy of footprints and associated documentation. This requires the operator who carries field responsibility to check that all information is documented and made available to the vessel operator prior to operations. A field operator might be a utility company, with very limited resources who are technically competent to assess the proposed operation. The required competences an engineering skills are normally provided by 3rd party consultancies as mentioned above e.g. MWS. It is important that each O&M activity is treated with the same attention to detail as the T&I activities.

EXTREMELY SHALLOW WATER

In his function as an auditor and Marine Warranty Surveyor, the author has found a notable lack of consistency in regards to location approval by various operators when the operation at hand was regarded not to be critical to key technical management of the project. In particular, when no heavy lifting was involved (e.g. cable jointing) in very shallow water, the applicable guidance was sometimes ignored. In one case, testing was only carried out to a penetration of 2-3 meters, completely ignoring the fact that there were documented soft pockets of Peat slightly deeper in patches around the location. It has to be mentioned here that the applicable guidance (e.g. JRC 2016) [1] does not differentiate between shallower and deeper water depths. Rightly so as challenging soil conditions may be found in any location where jack up platforms operate. In the above described issue it was argued by the operator that this work location is very shallow and that there is no risk to the work in this location. This was not accepted and the full specification of documentation based on the applicable guidance had to be

delivered, which caused delays and additional cost to the project. The alternative would have been the risk of damaging the cable at or close to the joint with far more adverse effects on the project's progress.

There should be no limitations to the applicability of guidance for this type of operations. The preparation and execution of, for example, a cable joint in shallow water may not be seen as high profile as the installation of a topside of an Offshore substation, but the consequences of damaging the asset involved (e.g. a grid connection) can be even worse than damaging a part of the topside. Furthermore, it can be expected that at the project design/ planning stage, no works for jackup platforms have initially been included as they may be technically avoidable. In those cases, additional pressure on cost and time will be present because of the late involvement of those units means a technical fault earlier in the project. An example of this could be the abandonment of cable installation due to weather and a subsequent jointing requirement in tidal areas or extremely shallow non-tidal areas.

With the number of grid connections on the rise (offshore wind power export) which have to make a beach landing, the level of awareness to those issues must be raised within project owners, unit operators and other stakeholder such as insurances and consultancies. With each landfall there is a risk of cables being damaged or cut for interruption by environmental forces and this leads to an increase in numbers for joints to be installed. The logical choice for selecting the right marine spread falls onto a non-self-propelled, barge type small construction jack- up. Most of those operations are located within the national waters of a coastal state, sometimes subject to tides which make the definition whether this is onshore or offshore somewhat difficult. The task sometimes fall to operators who are well versed in the construction of terminal infrastructure, sometimes within locked port boundaries etc. or very close to existing jetty structures. It is only natural that there is a lack of understanding of offshore standards. However, the risks involved when those units are being used it the interface to offshore infrastructure are equal to regular activities in the offshore industry as the assets, and subsequently the consequences are the same.

It would be the task of the coastal state to draft national requirements containing reference to applicable standards. Those standards and guidelines are provided by all different kinds of stakeholders. The IMO may be an initiator, but many units operating in very shallow water are not subject to the IMO's immediate instrument, SOLAS. Therefore it may only be the industry organizations, insurances and coastal state agencies (e.g. HSE in the UK, BSH in Germany) to force implementation through national requirements.

CONCLUSIONS

The renewable industry has found the jack-up platform a valuable addition to the spread which is required to safely and efficiently execute a serial production type of construction.
As shown above there is sufficient guidance available in the community of stakeholders to jack-up operations. Inherent problem with any guideline is the enforcement. The level of awareness in those involved parts of the industry must be raised. Mechanisms should be developed between industry stakeholders that allow for a consistent application of guidance not only for T&I activities but also for the activities during an O&M phase of an offshore wind farm.
Attention to detail for the use of DP and jacking in combination is required to avoid incidents caused by poor interface management.
Coastal state should implement national legislation reflecting the requirements of appropriate standards and guidelines to cover the gap in regulation for non SOLAS compliant units in shallow water.

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