International Journal of Fluid Power, 2015
Vol. 16, No. 2, 75–82, http://dx.doi.org/10.1080/14399776.2015.1055990

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Wavepod a transmission for wave energy converters – set-up and testing

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(*Received 12 January 2015; accepted 26 May 2015*)

Marine wave energy is expected to play a significant role in future energy production. A range of converter types has been proposed, some of which have been tested, but none have achieved economic feasibility yet. Partly this is due to transmissions, which are too expensive, not reliable enough or too poor in terms of efficiency. A new system has been developed by a consortium consisting of Bosch Rexroth, Aquamarine Power and the Institute for Fluid Power Drives and Controls (IFAS) of RWTH Aachen University. The consortium aims to solve these problems by developing an off-the-shelf standardised hydraulic transmission or power-take-off. It is called WavePOD. WavePOD provides improved flexibility for adjusting to different wave conditions without requiring customised components or fast control response times. An 8% scaled power test rig was built and commissioned for operation at IFAS in November 2014. In the first step multiple tests will be carried out to show proof of concept, efficiency and reliability until end of March 2015. In this paper basic criteria for the design of WavePOD will be explained, leading to an explanation of the system. The test rig will then be presented together with intended tests and first results.

Keywords: WavePOD; wave energy; power take off (PTO); hydraulic transmission; test-rig; wave energy converter (WEC); concept study

1. Introduction

Marine waves contain energy stored in the velocity and the height differences of the water particles. This energy is exploitable and can play a role for future energy production. Several types of wave energy converter (WEC), acting to transform the energy of the waves into mechanical energy of moving bodies, have been presented and some of them have been built as prototypes or scale models. Nevertheless, since none of the concepts are commercially available on the market yet, it is apparent that they have not yet achieved economic viability.

A new approach to improve the economic feasibility of various WEC concepts is to develop an industry standard power-take-off (PTO), a transmission transforming the mechanical energy of the moving body into electric power, to improve reliability, costs and power output. This PTO is called WavePOD and has been in development since 2011.

For developing a PTO for WECs it is necessary to understand the boundary conditions it needs to deal with. These are the incoming wave power and the specific needs of WECs, the electric power output and the environment where it is installed in.

Marine waves are created by winds accelerating the top layer of the water. Since this is a turbulent process some water particles get faster than others leading to the first ripples on the surface. Over time these get bigger and form waves. Accordingly the water particles move in an orbit with a velocity in direction of the wind speed on the crest of the wave and a reverse velocity in the wave surge, see Graw (1995). Since the orbital motion of the water particles changes over water depth, see Figure 1, various concepts for different water depths have been proposed. They all have in common, that specific motions relative to the water particles are best to extract the energy from the waves. The WEC motion depends on the waves and the damping force or torque of the PTO resulting in the PTO damping being crucial for extracting power. It neither should be too highly damped preventing motion of the WEC, nor have too low damping extracting no power. As energy in the waves change with time due to effects such as the weather, previous research has shown that damping should be varied to suit the predominant wave conditions. This leads to more optimal power captured, see Kamizuru (2014).

Marine waves provide highest average power in the range of 1–30 s wave period, compare Graw (1995). The majority of WECs have been designed to convert the wave power into reciprocating motion, because the orbital motion of the waves directly relates to an oscillation at a fixed position. The reciprocating motion from the WEC is taken as an input into the PTO, indicated by the dashed lines in Figure 1. The PTO converts the reciprocating motion to electrical energy to feed into the electric grid. Thereby the proposed PTO is intended to suit a wide variety of different types of WECs.

The electric energy produced is exported to the grid. However, the quality of power that can be accepted onto

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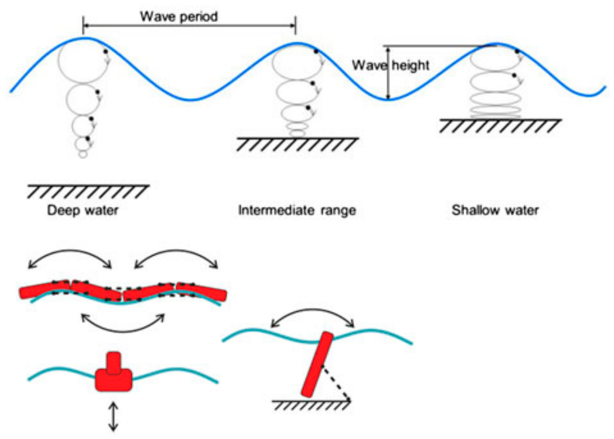

Figure 1. Wave particle motion at different water depth and according WECs, Murrenhoff *et al*. (2013), compare Graw (1995).

the grid is tightly controlled in accordance to the grid codes, compare Berndt *et al*. (2007). The grid codes state requirements for the generating system in terms of controllability of the power output to maintain a stable grid. Better control of the PTO electric connection will improve grid stability.

The PTO needs to be connected to the WEC and therefore it must be capable of operating in a marine environment. Since the WEC will be installed in a location with energetic waves, consideration must be given to ease of maintenance, because high waves could limit access to all components in the sea. Additionally, the PTO is affected by the salty environment and wave forces, as well as biological growth, depending on whether it is installed subsea or above sea level. Due to vibrations by wave action the PTO requires components that are vibration tolerant.

Summarising the aim of a PTO, its investment needs to be competitive in comparison to the power output, reliable and robust bearing the load cycles and vibrations without frequent maintenance and adaptable to various wave conditions to improve power input and output. Whilst the aim is for a reliable system, it must be designed to facilitate maintenance when required. Additionally, it might require energy storage to enable electric power output control, compare Dießel *et al*. (2014). WECs interact with waves differently and have differing damping requirements on the WEC movement. The PTO must be capable of providing these.

2. Concept analysis

The PTO can be based on an electrical, a hydraulical or a mechanical system to transform an oscillating motion into electric power. Possible components are discussed in literature, compare Plummer *et al*. (2012), O`Sullivan *et al*. (2009) or Dießel *et al*. (2014).

Directly generating electric power from the oscillation with a linear generator has here been assumed as too expensive and not robust enough for the environment. This assumption leads to a system transforming the oscillating motion into a unidirectional rotational speed suited to run a standard generator. This speed can either be constant or variable. In both cases either synchronous or asynchronous units are assumed to be most cost effective and reliable, because they are used commonly in industry.

A second assumption is that a system will be cheaper when transforming the wave power into electric power directly at the WEC and transmitting the electric power to shore. Additionally, when installed in a farm cables can be shared if used for several WECs. Therefore the power needs to have the same frequency and voltage at all devices requiring frequency converters at the sea when having a variable speed for alternating current devices. Frequency converters are perceived to be prone to a relatively high failure rate, particularly when subjected to vibrations. Since maintenance offshore is costly, there is a preference to exclude frequency converters from the system where possible. A variable speed DC generator was also discounted, because multiple transformation steps would be required to enable different speeds of generators in various PTOs and grid connection and also due to technology infancy. Therefore, the system presented here has been based around maintaining a grid connected fixed speed at the generator shaft.

The wave power input varies over time and so will the output power. At a constant speed this means that a variable torque needs to be applied to the generator. This can be done in a continuous or stepwise manner, making use of a mechanical or a hydraulical system. Mechanically a continuously variable transmission or a gear box with a clutch are possible, while hydraulically a variable displacement motor provides a continuous transformation and multiple constant displacement motors a stepwise transformation.

After reducing the possibilities for single components four basic systems result which can be used separately or combined, see Figure 2. Adding extra functions to them then leads to complete systems proposed in literature, compare Kamizuru (2014). The first basic system uses a crank-shaft attached to a fly wheel. Since this provides variable speeds depending on the wave period a mechanical transmission is needed to convert the speed. The second basic concept uses either a winch or a rack and pinion to transform the linear motion into a rotation, which then needs rectification utilizing a free wheel. As for the first concept then a mechanical transmission is used to convert the speeds. When using two winches with different directions of motion or a rack and pinion a second free wheel included by gears can be used to gain power from both directions of motion.

The third basic concept contains a hydraulic cylinder being connected to a high and low pressure line by check valves rectifying the volume flow of the cylinder. Accumulators in both lines smooth the power and a variable displacement motor takes the flow from the high

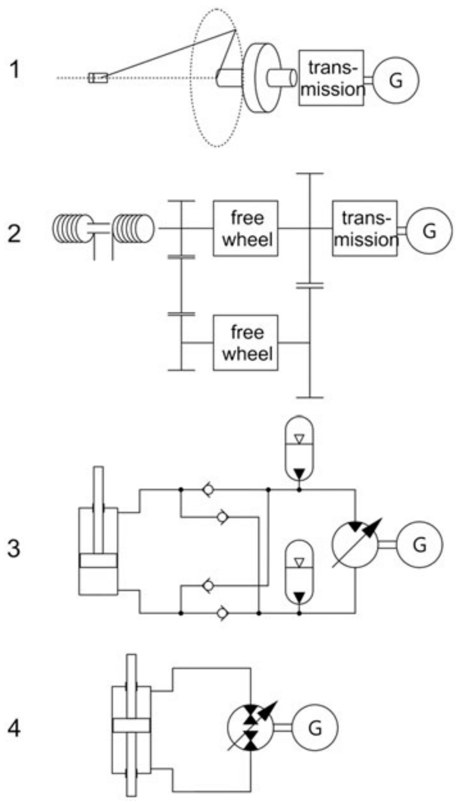

Figure 2. Basic concepts, compare Hansen *et al.* (2013), or Plummer *et al.* (2012).

pressure accumulator to drive the generator. For this concept either a variable displacement motor or a switchable motor set can be used. The fourth basic system also includes a hydraulic cylinder, but this time its flow is directly taken by a variable displacement motor driving the generator.

To evaluate which basic concept is best suited for WavePOD, the main aims of being a reliable, cheap and efficient system need to be considered. A simple set of criteria can then be set against which the design can be assessed. To meet the aim of designing a reliable system it is assumed that closed loop controls with high dynamics or fast switching are detrimental due to high complexity, while standard components and constant operation points are beneficial for a robust operation. Additionally, a simple system will be used initially and after subsequent testing of this system it can be further developed. In terms of designing a suitable cost effective system standard components with a low rated power are preferred. Since the input power varies with each wave, the rated power can be smaller whenever the power has been smoothed with help of energy storage. Finally, adaptability is responsible for two criteria. With a precise control of the damping force more power can be extracted from the WEC leading to a higher total efficiency, while a system that can be damaged by a wrong set value in a control is assumed not to be reliable.

In Table 1 the evaluation of the four basic PTO concepts can be seen using the criteria. It can be seen, that

Table 1. Evaluating basic concepts.

Concept criterion	1	2	3	4
High dynamic required	−	−	+	0
Standard	+	+	+	0
Components at full power	−	−	0	−
Efficiency	−	0	0	+
Robustness	−	−	+	0

basic concept three has advantages in terms of low dynamic controls necessary, use of standard components and robust controls being possible. Due to this and despite possible disadvantages regarding efficiency basic concept three has been selected for further development.

3. System architecture of transmission

The selected PTO is contained within a waterproof subsea nacelle which is connected to two cylinders connected to the WEC, see Figure 3. These cylinders react against the two relatively moving parts of a WEC, while being suitable for a variety of different WEC types. In the nacelle the PTO includes check valves rectifying the flow of each cylinder, high and low pressure accumulators, a pressure relief valve (PRV) and three motor generator sets. The output power is exported to shore with a power cable. Not shown in the picture are the device`s ancillary components comprising the tank, feed pumps, environmental control systems and filters. Mineral oil has been selected as the hydraulic fluid.

Concept three is a simple and robust system. However, the configuration as drawn compromises on efficiency because it is unable to rapidly adjust the damping force applied to the WEC. To increase efficiency of the concept it is altered in a way that multiple components

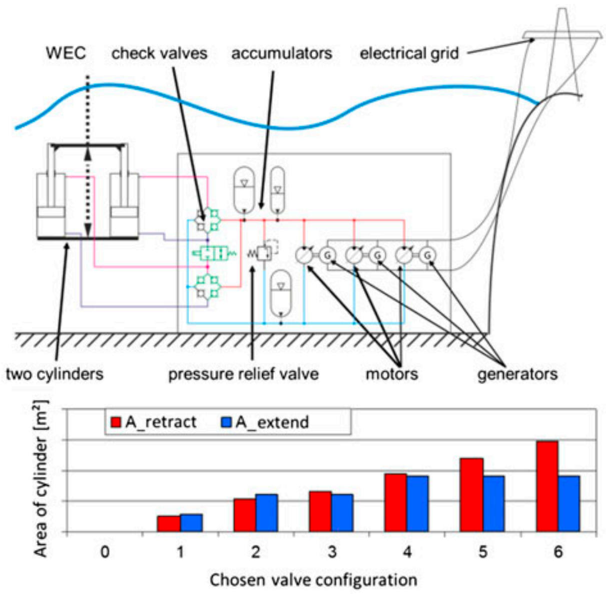

Figure 3. Selected system for WavePOD.

are used for single functions while decreasing their size enabling switching off components during partial load. This helps to keep the pressure up at part load by using fewer motors or by using fewer cylinders for the same force. Thus all components can be operated in a more efficient operation point, which usually includes a higher system pressure. In order to adapt the force applied to the WEC two cylinders are used, while the check valves can be held open to deactivate single cylinder chambers by connecting them to low pressure, to high pressure or to each other. For the transmission integrated in the test-rig this has been adapted for dampening control using following configurations. However, adaptions can be made relatively easily for use for reactive control, too. The valve configuration 6, as shown in Figure 3, comprises all check valves working as check valves activating all cylinder chambers, then one annulus chamber is connected to high pressure continuously (configuration 5) deactivating the annulus chamber for pumping and later one bore chamber is connected to the low pressure line (configuration 4) deactivating the bore chamber. The other configurations are done similarly in a way by connecting further valves to the low pressure side and by connecting annulus side and bore side directly resulting in approx. same sized steps with the same force in both directions. The valves used for the different configurations are marked in green in Figure 3.

With the approach of switching the check valves between check valve function and continuously open function the cylinder force can be varied without changing the pressure in the accumulators. Depending on the wave excitation and on the current system pressure the most suited active cylinder area can be selected to optimise power input. The valves are only switched when the pressures on both sides of the valves are similar. This is done to maintain the advantage of not needing to control the system with high dynamics and to reduce load on the valves.

The presented concept of switchable valves differs from the active switch valves used by Hansen *et al.* (2013), because check valves which can be held open are used. These open and close passively when acting as check valve and are opened with the control only without pressure difference over the valve reducing the loads on the valve. The amount of switchable check valves furthermore differs from systems presented by Plummer *et al.* (2012) including free-wheeling valves for synchronous cylinders or Schlemmer *et al.* (2012) using check valves only to the low pressure side, because every cylinder chamber can be activated separately and thereby can be connected to high or low pressure, changing the resulting force and leading to better symmetry of the cylinder forces during extension and retraction. Accordingly, the novelty of this transmission in respect to the cylinders and their switching lays in the improved flexibility by connecting chambers to HP, LP or each other while using simple switch valves without fast required response times.

The second aspect that has been changed in respect to the basic concept relates to the accumulation. The basic concept uses one accumulator on the high pressure line to smooth the input power. To avoid cavitation whilst drawing oil into the cylinders, the low pressure line is pre-charged using accumulators to provide the volume flow during fast motion of the cylinders. The accumulator in the high pressure line has been divided into two sets of accumulators at different pre-charge pressures, see Figure 4. The higher pressure accumulators are not providing any benefit during the lowest system operating pressures, when the system pressure is below their set pressure. Nevertheless, their volume is used much better at high system pressures when comparing it to accumulators with lower pre-charge pressure, because now more volume can be stored at highest pressures than an accumulator with a lower pre-charge pressure could store with the same nominal volume at the same pressure. This helps to smooth the pressure fluctuation enabling operation at an average pressure closer to PRV set-pressure without opening the PRV increasing average maximum power output. Nevertheless, since storage is needed at every pressure this is possible with the lower pre-charged pressure accumulators. To prevent the bladders of the accumulators at higher pre-charge pressure to hit the housing a safety valve is included isolating the accumulators from the system at a pressure slightly higher than the pre-charge pressure, see Figure 4. The authors are not aware of any proposal to use accumulators with different pre-charge pressures in the high pressure for PTOs so far, enabling PTOs to improve behaviour without increasing total accumulator volume.

The third aspect that has been adapted is the motor generator set-up. While the basic concept only has one hydraulic motor connected to one electrical generator, the selected system contains three same-sized sets of motors connected to generators. Considering the motor efficiency characteristic, compare Murrenhoff (2012), the efficiency of a motor decreases for little power, i.e. little pressure and swash plate angle. In order to increase efficiency for low power wave conditions only one smaller motor is used at a higher operating point with higher efficiency. Generators used are asynchronous generators to simplify grid connection. They are brought up to speed with the use of the hydraulic motors and connected directly to the grid when synchronized with the grid frequency, significantly reducing the inrush current

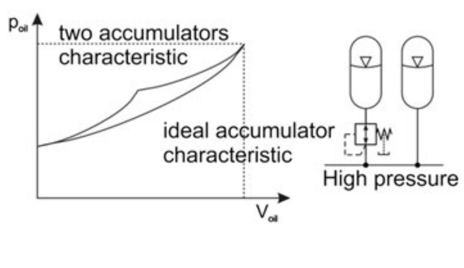

Figure 4. Used accumulator architecture and its characteristic.

and eliminating the need of frequency converters or soft starters. The use of multiple hydraulic motors has been proposed by Schlemmer *et al*. (2012) and on separate generators Hansen *et al*. (2013). The use of asynchronous generators at constant speed has not been mentioned explicitly by the former and the later uses variable speed generators, requiring converters. Accordingly, novelty of WavePOD regarding the transformation of hydraulic to electrical power includes the use of simple fixed speed asynchronous generators reducing the effort for either frequency converter or grid synchronisation. Furthermore, the good controllability of hydrostatic units is used to switch multiple units to achieve operation in an optimised point.

PTO concepts similar to the selected one have been proposed in literature see Plummer *et al*. (2012), Schlemmer *et al*. (2012) or Hansen *et al*. (2013). Nevertheless, due to the changes optimising the PTO, differences result. Mainly these changes relate to improving efficiency of the hydraulic system and controllability of the WEC while keeping the hydraulic system as simple as possible. This is achieved by using as few components and as simple controls in terms of dynamic as possible.

In summary the system selected is slightly more complex when compared to the basic concept as more components have been added. However, it is more efficient and reliable by its design. In comparison to systems proposed in literature WavePOD combines improvements regarding adaptability to different operation points by switching cylinders and motors without losing the simplicity of switch valves and fixed speed asynchronous generators. All components can be operated without a control with fast response times required.

4. Development of test rig

Installing a PTO subsea requires confidence in its reliability, sound design and precise knowledge about its operation. To establish this confidence a test rig has been developed and installed at Institute for Fluid Power Drives and Controls (IFAS). It is a scaled system designed for a maximum output power of 80 kW and peak input power higher than 1 MW. It contains the complete transmission including cylinders, check valves, accumulators, motor-generator sets, ancillary system components, control cabinet and grid connection equipment, see Figure 5. It is powered by a drive system containing a pump, accumulation for providing peak power, a valve set for powering the drive cylinder and a cylinder frame connecting the drive cylinder with the PTO cylinders by a rocker.

Real life waves can be thought of as superimposed sinusoidal waves of various frequencies. Therefore the size and period of each individual wave is different resulting in an irregular motion of the WEC. The motion of the WEC is a net result of the force applied to it from wave and PTO, respectively. It is therefore important to consider the PTO force as well as the wave force when

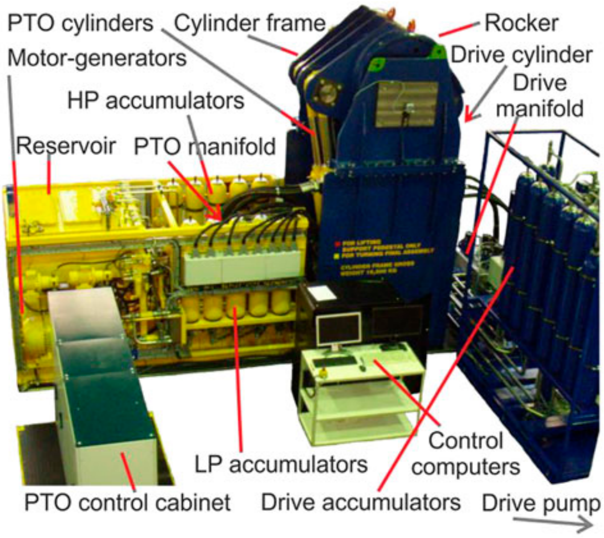

Figure 5. Test rig at IFAS.

estimating the cylinder motion. To enable this within the test-rig the PTO cylinder force is measured and fed into a parallel real-time hydrodynamic simulation of the WEC. The resultant position of the WEC based on the hydrodynamic model is scaled to reflect the test rig size and geometry. The cylinder is instructed to move to this set position using a closed loop control. This provides the ability to reproduce the conditions at sea in a scaled form that reacts correctly to the damping forces applied by the PTO cylinders. Thus different damping strategies can be tested.

The system used for the test-rig is similar to the one above and depicted in Figure 6. Instead of the cylinder force the pressures within the cylinder chambers are measured and the cylinder force derived from these. Additionally, instead of measuring the cylinder position the rocker angle is measured and used for calculating the PTO cylinder position with the help of the geometry.

Various sea states will be tested with the test-rig. These differ in required PTO forces and cylinder strokes. Low power sea states include smaller forces and strokes, while high power sea states include larger forces and strokes. Since the drive pump only is capable of providing average power during high power sea states accumulation is needed to provide peak power. The stored oil needs to be available to the system at a pressure not much higher than that required for driving the cylinder, to enable an energy efficient testing operation. Therefore, the accumulator characteristic needs to contain a small pressure gradient over volume. This can be achieved with a fixed volume when increasing the pre-charge pressure. However a low pre-charge is required during small sea-states, whilst a high pre-charge is required during large sea-states. To achieve both, high and low pre-charge, with one set of accumulators, gas bottles with additional nitrogen can be attached at the accumulators with a total pre-charge pressure of 220 bar. When filled

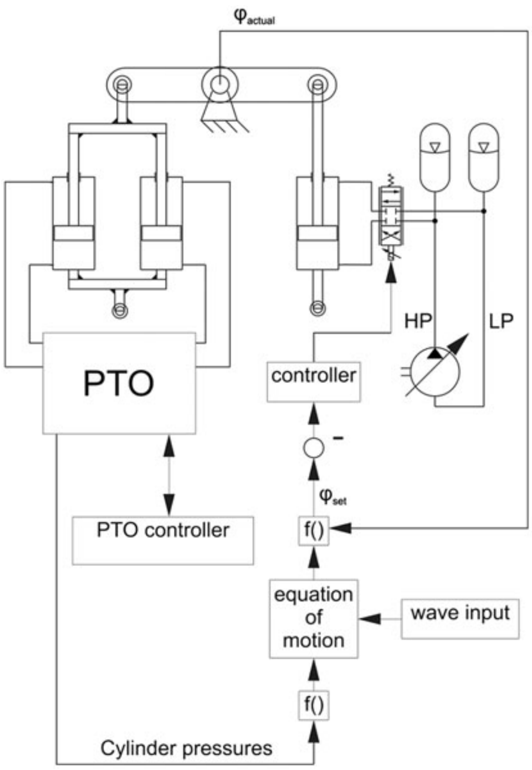

Figure 6. PTO cylinder position control.

completely the pressure in the accumulators and gas bottles rises to 300 bar. With separating the gas bottles now, less gas is available for keeping the pressure high during emptying, resulting in a lower pre-charge pressure of the active configuration. Depending on which gas bottles are attached, the pre-charge pressure of the accumulator can be varied between 100 bar when disconnecting all gas bottles and 220 bar when connecting all gas bottles, see Figure 7. The same system has not been used for the PTO, because switching at maximum pressure requires the system to increase pressure over optimal operating pressure, reducing efficiency during switching operation and increasing complexity to the operation.

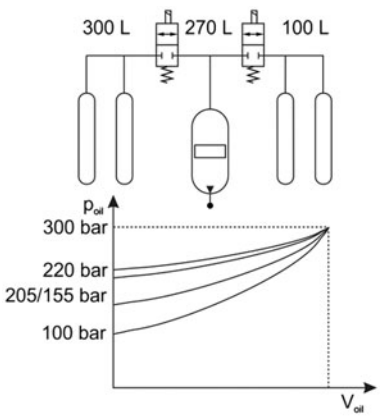

Figure 7. Drive accumulator system.

5. Intended testing

The intended and ongoing tests will be conducted to achieve various aims. Firstly, these are the proof of concept, bug finding and providing feedback for the design, commissioning and operation of a full-scale system. Secondly, single components and the full system needs to be analysed to validate and improve the simulation in terms of dynamic behaviour and efficiency. Thirdly, the reaction of the PTO to failures of single components or the grid needs evaluation for reaching confidence for installation subsea and fourthly learning is required to further improve the system design.

In order to achieve the first aim, initially the test rig is commissioned. This is done stepwise to ensure each component is operating in the desired way. In terms of the test rig this means to pressurise the drive accumulators and actuate the valve controlling the drive cylinder. In parallel the low pressure of the PTO needs pre-charging. Then the cylinders can be moved with all check valves connecting the cylinder chambers to the low pressure constantly open, thus not generating high pressure flow. This procedure is done stepwise at increasing drive pressures. Afterwards single cylinder chambers are activated to pump oil into the high pressure to ensure the functionality of the check valves and high pressure accumulators. In a last step the motors are started, brought to grid frequency, and then the generators are connected to the electric grid. This enables testing of the motors at various swash plate angles and pressures.

Measurement results in the commissioning then can be used as first component test results. Nevertheless these need completion by applying various operating points on different components. The focus here will be put on the main components as the cylinders and their friction, the valves and their pressure drop depending on the volume flow as well as their dynamic response, the dynamic behaviour of the accumulators in terms of their reaction time regarding heat dissipation and the efficiency of the motor generator set as well as their dynamic behaviour. Accordingly, different speeds and forces will be applied to the cylinders, volume flows to the valves, pressure traces to the accumulator, pressures and swash plate angles to the motors. The results of these tests than will be used for validating and improving the simulation, as well as for future designs of the system in case single components should not operate as desired.

After testing single components the focus is put on the whole system. In a first step it will be loaded by sinusoidal movements and the total efficiency will be measured. Afterwards various sea states will be applied in connection with specific WECs to analyse the PTO efficiency as well as the power output from the WEC resulting from the PTO cylinder forces. This operation will furthermore be carried out over a longer period of time in the range of multiple weeks, to evaluate running-in effects, analyse long term behaviour regarding temperature and to gain confidence about continuous operation. By the end of this test phase it is intended to have eliminated all initial shortcomings. Accordingly, aims one and two will be achieved.

Consecutively to the above mentioned tests additional tests are required to achieve aims three and four. These will include applying failures artificially induced on the transmission, to prove the effects simulated in advance and to ensure a safe operation and control is possible. These will include disabling the control of various components as actively opening the check valves or starting a motor and controlling its swash plate angle. Furthermore single accumulators will be separated from the system to simulate their inactiveness after gas leak. In all of these cases the PTO control needs to provide a safe operation. Additionally, in case of a grid connection loss the system needs to shut down safely within the specified time. This will be tested by opening the contactors connecting the machine with the grid.

To achieve the fourth aim various function groups within the system will be analysed. Thereby changes at the system are intended to validate the influence of various parameters and to find optimised set-ups. These tests will be developed in future.

6. Preliminary results

Up to the point of creation of this paper only some test have been carried out, the rest will be carried out and analysed in the course of the next few month. Accordingly, only preliminary results showing the test-rig behaviour can be shown within this paper. Complete results are intended to be shown in subsequent papers.

While operating the test rig different effects show whether the desired operation is carried out. Thereby first measurement results show these effects. As power input the PTO cylinders are moved by the drive. This is measured with the rotational sensor at the rocker. While using the check valves the motion leads to a pressure built up in the high pressure line. This can be seen in Figure 8. During excitation by the drive cylinder, the pressure in the various chambers of the PTO cylinders builds up, and falls again according to direction of motion. The check valves open, when the chamber pressure is higher than high pressure. This happens in a way fast enough to prevent pressure peaks at the beginning of pumping mode. Pumping oil into the high pressure line furthermore leads to an increase in pressure within the high pressure accumulator, which can be seen by the rising high pressure.

During longer operation the motors need to be activated, to use the oil in the high pressure accumulators and to prevent too high pressures. A pressure control is used for adjusting the motors swash plate angle leading to oscillations in both high pressure and swash plate angle. This can be seen in Figure 9. Whenever oil is pumped by the cylinders, the pressure in the accumulator rises making the swash plate angle to rise as well. Since a soft PI-control is used so far, the adjustment of the swash plate angle has a delay against pressure rise. Thereby a soft control with small control parameters has been used to prevent extensive swash plate angle motion.

When using real sea states these need to be simulated in real time parallel to operation. The force feedback of the PTO cylinders and excitation forces measured during

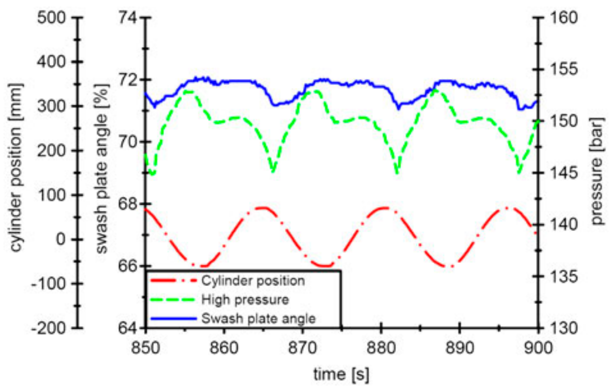

Figure 9. Motor control with pressure dependent swash plate angle.

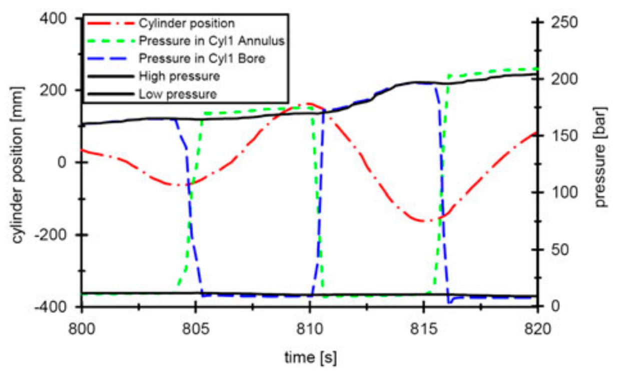

Figure 8. Pressure built up in cylinder chambers due to cylinder motion.

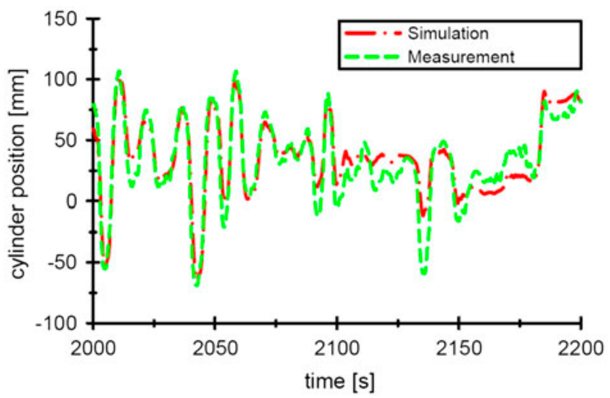

Figure 10. Position control for real wave conditions.

tank tests, which were provided for a specific WEC, are the inputs for the parallel real time simulation. The parallel real time simulation outputs the set position for the PTO cylinder which is transformed to rocker angle set position. This set position is then provided to the drive, where a proportional position control with velocity feed forward is used to actuate the valve at the drive cylinder. The quality of the control is shown in Figure 10. The set motion can be reached with only small errors.

7. Summary and outlook

Marine wave energy has the potential to play a significant role in future energy production, especially when spaces for wind turbines are running out. Various WEC devices have been proposed, some of them have been tested, but none has achieved economic viability yet. Partly this is due to transmissions, which are too expensive, not reliable enough or too poor in terms of efficiency. Accordingly, in this paper the development and the general design of a new system, i.e. WavePOD, were explained with underlying assumptions. It contains two hydraulic cylinders, check valves, which can be held open towards the low pressure side, accumulators in high and low pressure and three motor–generator sets consisting of variable displacement motors and asynchronous generators. Thus a simple, cheap and robust system was created being capable of being attached to various WECs.

Consecutively, a test-rig was presented. As explained it is capable of applying real sea state motion of various WECs to the cylinders with use of a parallel real time simulation. Additionally, it is able to do so in an energy efficient way by using a switchable accumulator set. Finally, intended test have be started.

The test rig has been built, commissioned and operation started in November 2014. The first tests have been conducted and testing is ongoing. Results exceeding the preliminarily results shown here and further learnings will be published in a following paper in the near future.

Disclosure statement

No potential conflict of interest was reported by the authors.

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Dominic Dießel has studied Mechanical Engineering at RWTH Aachen University. Since 2012 he is member of the scientific staff at the Institute for Fluid Power Drives and Controls (IFAS) at RWTH Aachen University.

Garth Bryans has over 10 years experience in the marine renewables sector and has held a number of senior technical roles. He holds a PhD from Queen's University, Belfast and University College Dublin. He also holds an MSc in Applied Physical Oceanography and a BSc in Marine Biology and Oceanography, both from the University of Wales.

Louis Verdegem has over 36 years of Hydraulics Engineering experience. The last 10 years working to supply the Wave and Tidal industry in design and development of Power Take Off Systems globally. He has worked for the previous 16 years on Military Bridging Systems. He has a BSc.(hons) in Aeronautics and Astronautics from Southampton University and is a Fellow of the Institute of Mechanical Engineers.

Hubertus Murrenhoff is director of the Institute for Fluid Power Drives & Controls (IFAS) at RWTH Aachen University. Main research interests cover hydraulics and pneumatics including components, systems, controls, simulation programs and the applications of fluid power in mobile and stationary equipment.

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