UK Magnetics Society

Grove Business Centre Grove Technology Park Wantage Oxfordshire OX12 9FA UK
tel: +44 (0) 1235 770652 fax: +44 (0) 1235 772295 email: mswadling@ukmagsoc.co.uk
www.ukmagsoc.org

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"Snapper" Wave Energy Capture – The Mechanical Challenge

Paul McKeever, Narec, UK, paul.mckeever@narec.co.uk; Dr. Chong Ng, Narec, UK, chong.ng@narec.co.uk; Mark Taylor, Narec, UK, mark.taylor@narec.co.uk; Prof. Ed Spooner, EM Renewables, UK, ed.fieldstile@googlemail.com; Dr. Markus Mueller, University of Edinburgh, UK, markus.mueller@ed.ac.uk; Richard Crozier, University of Edinburgh, UK, r.c.crozier@sms.ed.ac.uk

***Abstract*—This paper presents the development of a novel rare-earth magnet based wave power conversion system called Snapper. The Snapper concept is designed to increase relative velocities within its generator, thus creating the potential to reduce the size, weight and cost of the energy conversion system. This paper focuses on the generator, discusses the Snapper concept and also discusses the development of a prototype machine. In particular, attention is paid to the use of rare-earth magnets and some of the major mechanical challenges faced during design development.**

I. Introduction

Of the many renewable energy converters, wind, tidal and wave power devices share a common theme. A mechanical system couples to a moving fluid and drives an electrical generator. However, the resources differ in the motion of the fluid. Wind turbines are generally rated for wind speeds of 10 to 15m/s, tidal-stream devices are rated for flow velocities of up to 4m/s, but wave power devices must operate with reciprocating motion with velocities of less than 1m/s. The generally unidirectional flow of winds and tides allow turbines to rotate with tip speeds several times greater than the fluid velocity and so it is possible to drive the electrical generators with velocities of typically 10m/s. Wave power devices typically deliver power in the form of a very large force driving at a very low velocity. This introduces one of the major challenges of converting ocean energy into useable electricity, i.e. the necessity to work with the very low velocities associated with wave motion. When explored further, this has an impact on both the size and weight of the energy conversion system, whether or not intermediate stages, such as a gearbox are utilised.

Sadly, electrical generators work most effectively when driven at high speed with low force. Therefore, it is essential to include some form of velocity amplification within a wave-power device if it is to be cost effective. Velocity amplification can be achieved in many different ways including: gears; levers; hydraulic transmission; and magnetic vernier effects.

These are all sound concepts, but pose practical difficulties such as: the desire to avoid using oil-based products in the ocean; the need to keep dimensions within practical limits; and the need to operate electrical machinery at a reasonably high power factor.

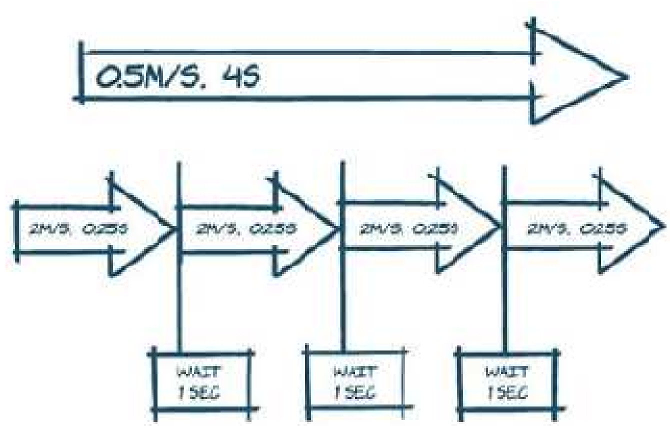

Figure 1. The Snapper Movement Principle

II. THE SNAPPER CONCEPT

The Snapper concept is another approach to amplifying velocity. The principle loosely resembles the switch-mode converter used in electronic power supplies. In the latter, an output voltage of, for example, 24Vdc is achieved by chopping a continuous incoming 240V into 1ms pulses of 240V separated by 9ms periods of 0V. Likewise, the output from a continuous drive of 0.5m/s for 4s might otherwise be achieved by 250ms pulses of 2m/s interspersed with 1s periods of rest as demonstrated in Figure 1.

The Snapper device accomplishes this feat by including a magnetic coupling and a spring in the drive train. Magnetic couplings have well defined maximum force transmission capability and if that is exceeded, they may slip poles, or snap, allowing the two parts to move separately until the forces are suitable for a new stable coupled alignment to form.

A primitive form of Snapper is shown in Figure 2. The upper part of the linear magnetic coupling, the translator is drawn to the right with a continuous slow velocity. The lower part, the oscillator, being coupled magnetically, is also pulled to the right. As the spring is extended, its tension increases until it reaches the maximum value that the magnetic coupling can transmit.

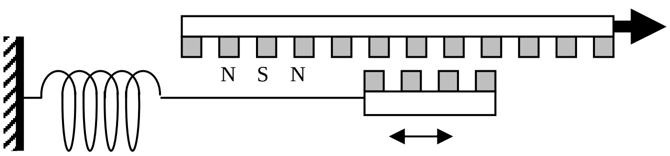

Figure 2. Primitive Form of the Snapper Concept

Further movement of the translator causes the coupling force to reduce. The total force acting on the oscillator then becomes directed to the left. The oscillator then accelerates to the left and the magnetic force to the right reduces, and reverses. The acceleration to the left increases rapidly and the oscillator acquires a high velocity. The oscillator part oscillates in a complex manner. If the oscillator has a small mass, then it can acquire a much higher velocity than the velocity of the drive.

Figure 3 illustrates the behaviour of the two parts of the coupling. In practice, the electrical generator will absorb energy from the mechanical system and therefore, will damp the oscillation. The illustration shows the case where the input drive is slow enough to allow each oscillation to decay completely before the next begins. The behaviour will be much more complex with higher drive speed; each burst has a different starting condition. Analysis of the machine's operation is impractical without the aid of a computer simulation. Further information relating to simulation of the Snapper concept can be found in [1].

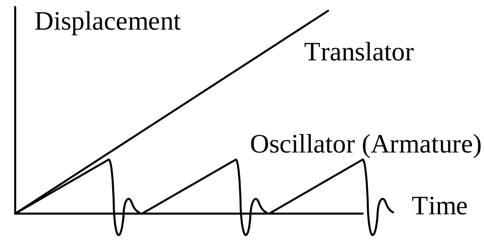

Figure 3. Snapper Armature and Translator Behaviour

In the normal slow drive condition illustrated, each oscillation takes place with the same maximum velocity and so the generator will produce the same emf amplitude. The amplitude of the emf is therefore, independent of the input drive velocity. This is an unusual feature for an electrical machine and one that could be exploited in the design of the subsequent power conversion system.

Returning to the Snapper generator, the key components can be rearranged in alternative ways such as with the spring attached to the input drive and/or the translator to the machine base. In all cases, the spring stores energy during the period between the rapid oscillations and releases the energy during the rapid motion.

III. ELECTRICAL GENERATOR

The oscillator is used to drive a reciprocating generator. One of the more straightforward arrangements is to use a linear permanent magnet generator with its field system (magnets) attached to the oscillating part of the magnetic coupling and the stator attached to the machine base.

A number of alternative configurations can be envisaged such as with the generator using the magnets of the coupling as its field system. Rotary versions of the device are possible also.

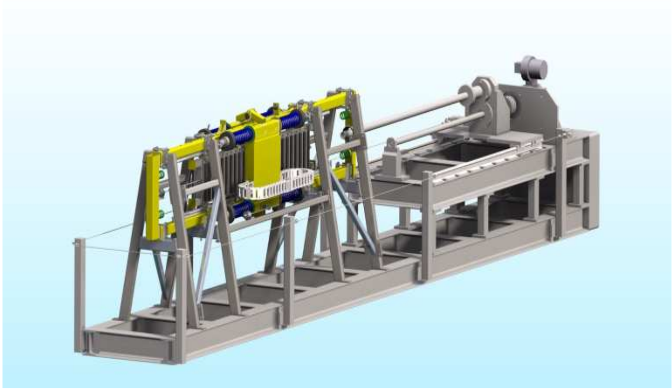

Figure 4. Snapper Electrical Generator on the Narec Linear Test Rig

IV. Experimental Machine

With the support of the European Community's Seventh Framework Programme (FP7), a Snapper Consortium comprising: Narec; EM Renewables; Meccanotecnica Riesi; Technogama; SubseaDesign; Ecotricity; University of Edinburgh; and Ocean Resource is carrying out the development of a scaled demonstration device with a target output power of around 1-2kW for a drive velocity of around 1m/s. The scaled device has now been designed and assembly of the prototype is nearing completion. For the purposes of this project, a configuration was chosen that has the translator attached to the prime mover, with a spring mounted oscillator (armature) surrounding it. Figure 4 illustrates this version of the Snapper device.

The prototype will be tested first in the Narec laboratory on the Narec Linear Test Rig (see Figure 4). Following this, the prototype will be coupled to a large floating buoy deployed in the Narec Wave Tank (see Figure 5) and subjected to waves with amplitude of up to 1m pk-pk and period of around 3s.

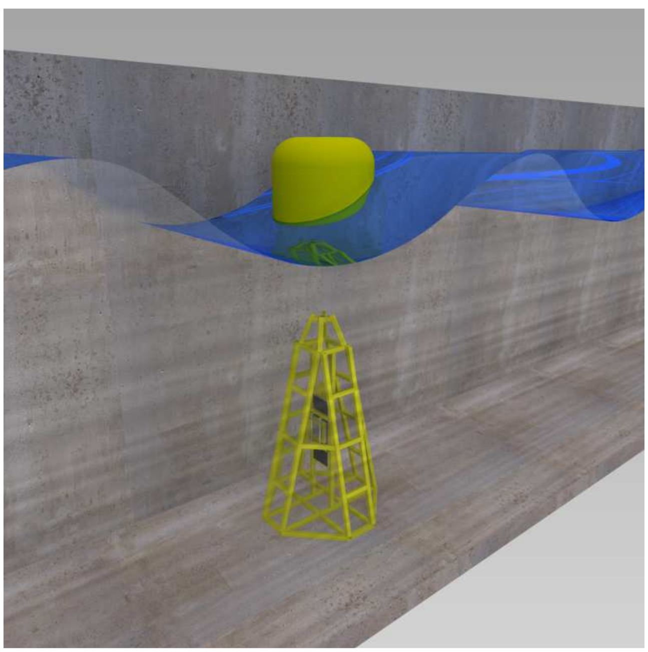

Figure 5. Snapper Device in the Narec Wave Tank

Figure 6 shows the conceptual and the 3D designs of the experimental Snapper generator. In this example, as intimated earlier, the translator, armature and springs are configured according to Figure 2. In other words, the generator employs the translator magnets for its field system with the generator coils embedded in the oscillator's (armature) magnet array. It was found that this configuration could be simulated, designed and built without too much difficulty.

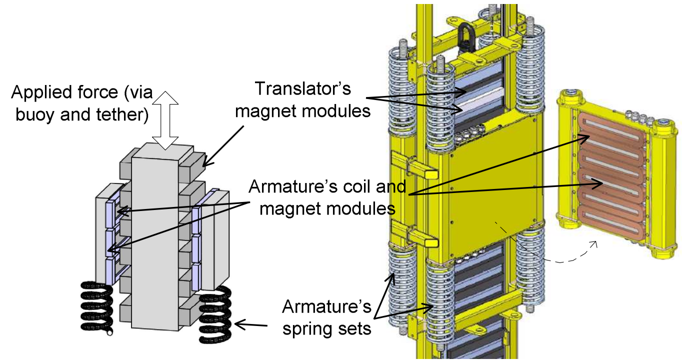

Figure 6. Snapper Generator Conceptual and 3D Designs

V. Mechanical Challenges

This section describes some of the major mechanical challenges that needed addressing during the prototype design phase.

A. Armature Mass

The Snapper device provides velocity amplification related directly to the acceleration of the armature and so it was important to keep the **armature mass** to a minimum during design development.

B. Bearings

Bearing selection was also an important consideration during the design phase; it is important to minimise the coefficient of friction, and thus minimise losses. Figure 7 provides an example of one of the possible Snapper bearing solutions.

Figure 7. Example Linear Bearing Solution for Snapper Armature/Translator

C. High Strength Permanent Magnets

The Snapper design uses **high strength permanent magnets.** This introduces the challenge of high forces between components and demanded that the designed supporting structure be both strong and stiff to maintain the necessary clearances. This directly opposes the need for low mass in the armature. However, the use of double-sided magnet arrangements for both the translator and surrounding armature helps to keep forces in balance and avoid too great a mass penalty. Figure 8 demonstrates some of the FE Analysis performed during the design phase to assess the impact of the predicted magnetically induced forces.

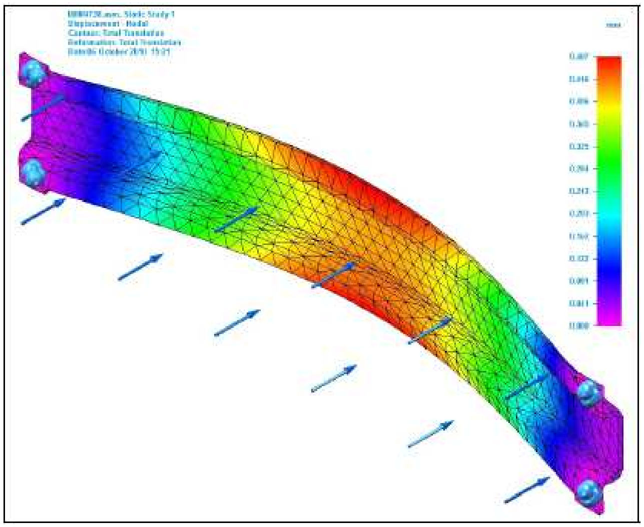

Figure 8. FE Analysis of Armature Magnet Modules

D. Spring Type

The selection of the **spring type** was a significant consideration. It is important to have springs that can store the required amount of energy without fatigue over a large number of cycles, yet they must not contribute too much to the mass of the armature. Furthermore, they must be resilient to the marine environment.

Performance of the springs, as well as additional device characteristics relating to the other mechanical challenges will be monitored during the validation phase of the current FP7 project.

VI. CONCLUSIONS

The experimental machine is intended to demonstrate the Snapper principle and to confirm the performance, design and operation of this novel device. Following the validation phase, test data will be used to inform the design. The data will also help to provide direction towards a more cost-effective and efficient design, ultimately forming the basis for commercial Snapper wave energy farms. Progress of the Snapper FP7 project can be followed via [2].

ACKNOWLEDGEMENTS

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[1] H. Bailey, R. C. Crozier, A. McDonald, M. A. Mueller, E. Spooner, P. McKeever, "Hydrodynamic and Electromechanical Simulation of a Snapper Based Wave Energy Converter", IECON, Phoenix U.S.A., 7-10 November 2010; Annual Conference of the IEEE Industrial Electronics Society

[2] Snapper Project Website http://www.snapperfp7.eu