A PURPOSE-DESIGNED VESSEL FOR THE INSTALLATION OF WAVE POWER DEVICES

Stephen Salter
S.Salter@ed.ac.uk

Engineering and Electronics, University of Edinburgh EH9 3JL Scotland

This paper extends some thoughts first given to the WATT conference in Aberdeen May 2005.

ABSTRACT

The cost of installing marine renewable energy devices can be a large fraction of the initial capital cost and may have to be paid several times over, especially in the early days. While we must take all the useful information we can from the marine engineering industry there may be flows of information in the reverse direction. One such has been the development of wave tanks and wave-maker technology. A second might involve the way in which offshore objects are moved. We have to find a means of installing and removing equipment at short notice that is cheap enough to be used frequently, perhaps initially every day.

INTRODUCTION

The ideas for this project began after the loss of the oil-tanker Braer on 5 January 1993. The author set out to design equipment to tow large, crewless, burning ships loaded with oil, chemicals or explosives in extreme weather conditions, a subject which attracted little interest a few days after the event.

Conventional technology uses tugs and cables. An inelastic cable connecting two objects which are far enough apart to be in waves of opposite phase can experience a tension which is the relative separating acceleration (possibly twice the acceleration of the water in a wave) times the mass and added hydrodynamic mass of the lighter object. Even higher tensions can result if a cable is allowed to go slack and then retighten after the build-up of kinetic energy. Model tests on solo duck models show that this will happen in quite small but steep waves.

An elastic cable can store energy which will be half the square of the peak tension times the spring rate of the rope. If the cable should ever part it will release this stored energy in a frighteningly short space of time.

Cables can apply only tension and in only one direction. They are slow to make changes in that direction. To connect or disconnect heavy cables at sea requires the intelligent communication and control of large forces and heavy objects at both ends of the cable, but vessels in distress often have no power to move heavy objects or even a crew. The only attractive things about a cable are that the tug can be a safe distance from a dangerous client vessel and the cable can be coiled for compact stowage. **Everything** else about cables is very bad.

WHAT WE DO NOT NEED

Conventional tugs must be able to make trans-ocean crossings lasting many days in any weather and must provide acceptable living conditions for quite large crews. This makes hire expensive, typically tens of thousands of pounds a day. Furthermore availability and hire costs vary widely and unpredictably depending on weather and demands of other work. The vessels have to be paid for as they move between jobs and when they have no work. Until the oil has gone, the wet renewables cannot compete with the charter prices of oil firms.

WHAT WE DO NEED

A better system would place the tug and wave energy device close enough to be in the same wave phase and arrange that their phase and amplitude responses to wave spectra were similar. This would produce a large reduction in the force between them.

The driver vessel should be able to apply force of either polarity in any direction through a short connecting link and change it in a short time. The system should allow instant connection and disconnection with intelligence at only one point and no need for large handling forces.

For the installation of renewable energy plant a vessel need have an endurance of only a few hours and those in daylight and selected weather. It need not have more than three people aboard. It should be cheap enough to be owned by the operators of the devices. It seems that the universal method of moving objects at sea has many undesirable and unnecessary features. So much for making use of existing marine technology.

MAGNETICS

The key idea is to use magnetic force. Let us recall some school physics (McCaig 1977). The magnetic permeability of free space, μo is $4\pi \times 10^{-7}$ Henrys per metre. For a pole area A and flux density B Tesla, the attractive force between opposite poles is

$$F = \frac{B^2 \cdot A}{2 \cdot \mu o}$$

The properties of mild steel limit practical flux densities to about 1.3 Tesla. This would give a ‘pressure of attraction’ of about 670 kiloPascal. With a coefficient of friction of wet steel on steel of say 0.3 we can develop around 200 kiloNewtons of shear force per square metre of area.

Tug owners traditionally quote bollard pull in tons, with many tugs delivering tens of tons and the very biggest ocean-going ones perhaps 200 tons equivalent to 2 megaNewtons. This means that the pole area to transmit the bollard pull of a very large ocean-going tug is only 10 square metres. Magnet friction offers the further advantage that the system could be designed to slide without losing grip at a tension safely below the limit of the attachment mechanism. This slide could take place over many metres with no loss of towing force so that the whiplash hazard is removed.

Pole width should not exceed hull thickness. For the Braer project the magnet poles would have consisted of 16 rows of 25 mm wide poles arranged like beads on a necklace of towing cable needing only about 15 metres on either side of the stricken vessel − a very small fraction of the water line length of the Braer. Short bead segments allow the line to make contact with a curved hull. Magnet friction that can tow the largest ships in the worst weather is more than enough to move wave energy plant in any sea state suitable for installation and recovery. For installing wave power devices, one tenth of the area of the Braer, shared between two tugs, would be sufficient.

One square metre of pole area might be 8 rows of 12.5 mm poles 10 metres long and could pass the full thrust of a pair of 300 kW (or 400 HP) outboard motors at 3 metres per second, nearly six knots, well above the speed limit of most harbours.

The very cheapest (and now slightly old-fashioned) magnets are made of sintered ferrite with rather low remnant flux densities, perhaps only 0.35 Tesla even in a circuit with no air gaps. This is called the remnant flux density. It can be increased to values close to the saturation limit of mild steel by the use of pole pieces which concentrate the flux from a large area of magnet into a smaller area in contact with the target.

The largest ferrite magnets available are 150mm by 100 mm by 25 mm thick. Some weight could be saved by tapering the mild steel pole pieces as shown in figure 1. This also reduces the amount of flux which could leak backwards. A bead using six ferrite magnets was tested against 25 mm steel plate. It took 16 students acting with a synchronized jerk to make it slip.

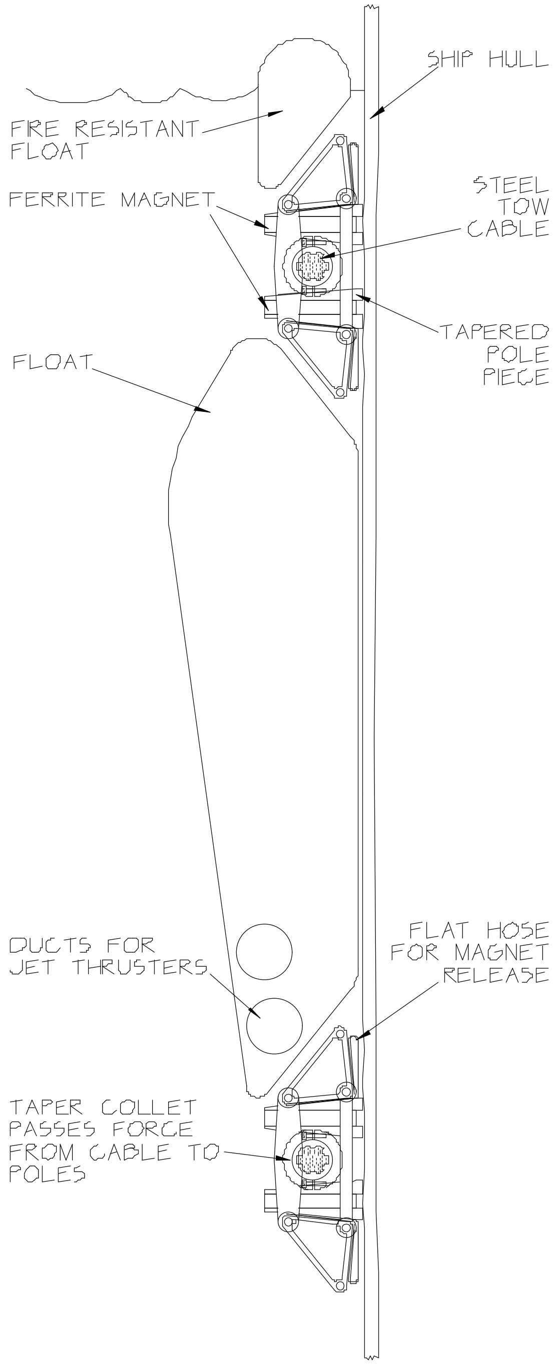


Figure 1. A section through ferrite magnets, cables, floats and water ducts of a pair of tow beads which could capture and move the largest ships.

Magnet designers like very short air gaps. For ship towing applications 'air' is deemed to mean water, rust, paint and marine fouling. Ship hulls are not flat or smooth and there will be further increase due to the imperfect curve matching of pole segments. However slippage between poles and hull will saw through surface coverings and so reduce the air gap.

The length of a magnet driving flux round a magnetic circuit is analogous to the voltage of a battery driving current round an electrical one. Ignoring flux concentration by pole pieces and saturation in the iron path, the flux density in a gap is the remnant flux density of the magnet material times the ratio of magnet length to the sum of magnet and gap lengths.

Magnets made from materials like Alnico (from the 1940's) had high remnance values but rather low 'voltage' capability, which magnet people call coercivity. They often had to be about 25 times longer than the gaps they were driving. Despite lower remnant flux densities the later ferrite materials had better coercivity and the magnet-to-air gap length was closer to unity. Ferrites are brittle but have a high resistance to seawater.

Much higher flux densities can be achieved by the more modern neodymium-boron materials. The best ones have remnant flux densities approaching the saturation of mild steel and so need little or no flux concentration. Now that the original patents have expired, the cost of these has fallen dramatically. However they are very easily corroded. Without very good protection, such as nickel plating, they will behave like sugar lumps in tea.

CONNECTION and DISCONNECTION

The method proposed for catching the Braer may also be useful for stray wave plant. Water from the tug's fire pumps would go along the towline to a pair of backward-facing nozzles fixed at an angle of about 20 degrees either side of the line. If the flow to the nozzles was the same, then the large jet force would pull the cable along a straight course from tug to target. But flow variation allows the tow cable to be steered. The distant end would be forked like a snake's tongue and one line of beads would be directed along each side of the bow. The sequence is shown in figure 2.

Very large forces of attraction raise the difficulty of how the tug owner could ever get the magnets back after a successful tow. The magnet system is mounted on a glass-reinforced plastic backing which can support a pair of flat tubes like fire hoses. If these are not inflated, the magnetic poles can make contact with the hull. But if they are inflated with either air or water, then they will develop a release force equal to contact area times pressure. Fire hoses work at pressures of 10 bar so a 75 mm diameter hose flattened to 118 mm will produce a separation force of over 100 kiloNewtons per metre length of hose. They also have outer casings which allow them to be dragged over gravel when full of water.

A VESSEL FOR WAVE DEVICES

For wave energy installations the magnetic beads complete with flattened release hoses would be attached to the sides of an inflatable vessel which would have only to nudge up against the target vessel to make the attachment. Figure 3 shows what such a vessel might look like.

It would have its heave response tuned to the response of the object to be towed by the addition of gravel ballast in sets of bags along the underside. This reduces relative motion.

At the centre of the vessel is a hard rectangular box-structure with circular grooves for one air tube on each side, a small moon pool and 'pulpits' at each end with attachments for outboard motors. The box can also be fitted with pumps for water and air compressors needed for disconnection and trimming. An overhead gantry, not shown, could lift objects with cables through the moon pool. With all its inflatable tubes removed the box should be a safe, sea-going vessel in its own right.

On each side will be a further pair of oversize side-tubes with axial connections. These can allow a considerable amount of mismatch in pitch, heave and roll. The large tubes allow damage-free nudging contacts with the object being towed.

The maximum tow force will be set by the need to keep a positive tension in all directions in the skin of the side tubes. The inflation pressure of a tube induces a hoop tension of one-half the pressure times the diameter times the length of tube. If the tube material has reinforcement inclined by angle of 45 degrees to the tube axis, the hoop tension can be resolved along the directions of the reinforcement to give two forces of .707 times the hoop force. The shearing force due to the tow will increase one and reduce the other. The bag will remain in the proper shape provided that the tensile forces are always positive.

Suitable reinforced fabric is available in 1.5 metre wide rolls with the main reinforcement along the roll direction (Banks 2005). Using two layers of opposite-handed helical windings with three starts will give the reinforcement in the oblique direction we choose. It may be possible to reduce tooling costs by wrapping them round a tube made from layflat polythene and filled with air.

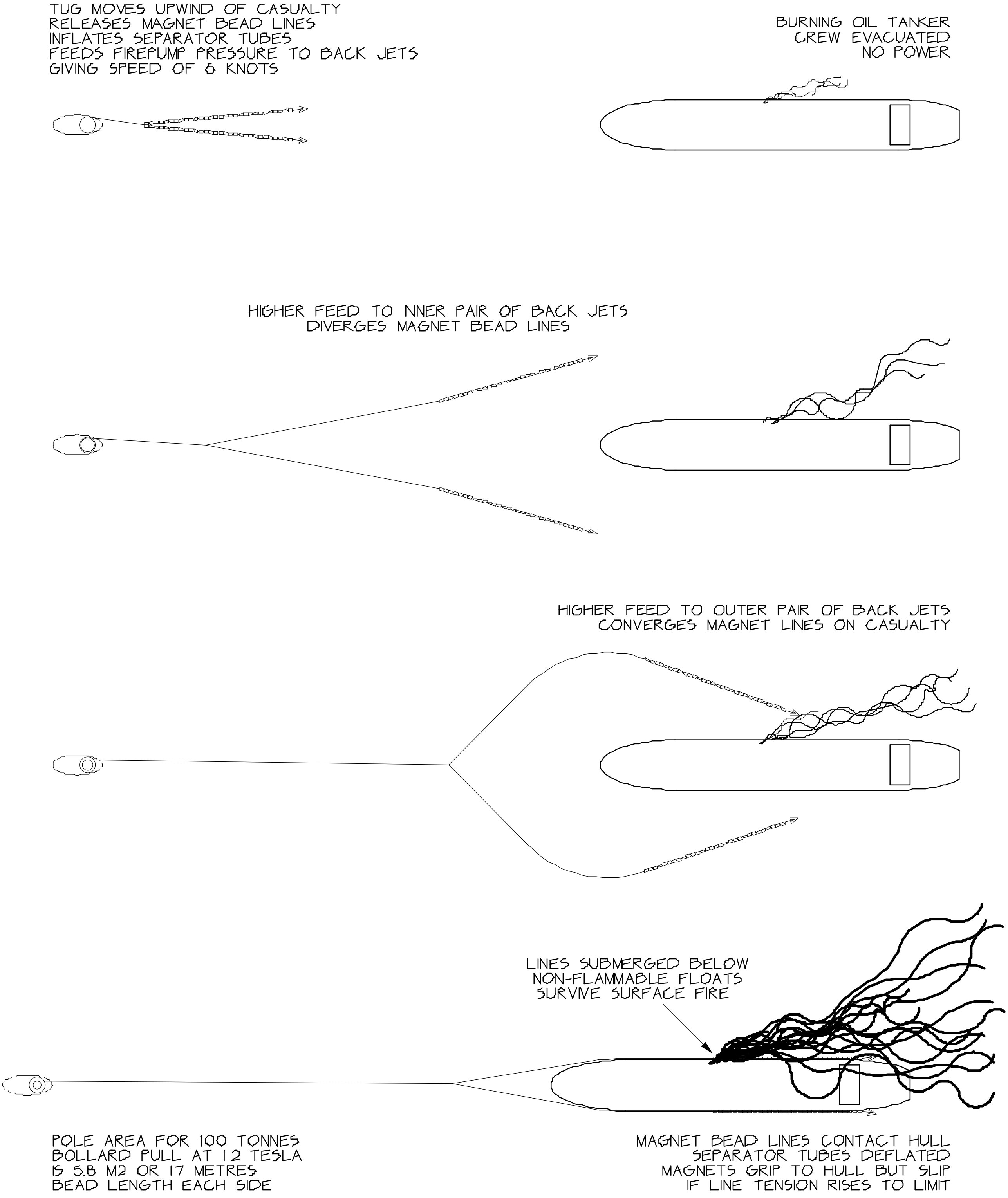
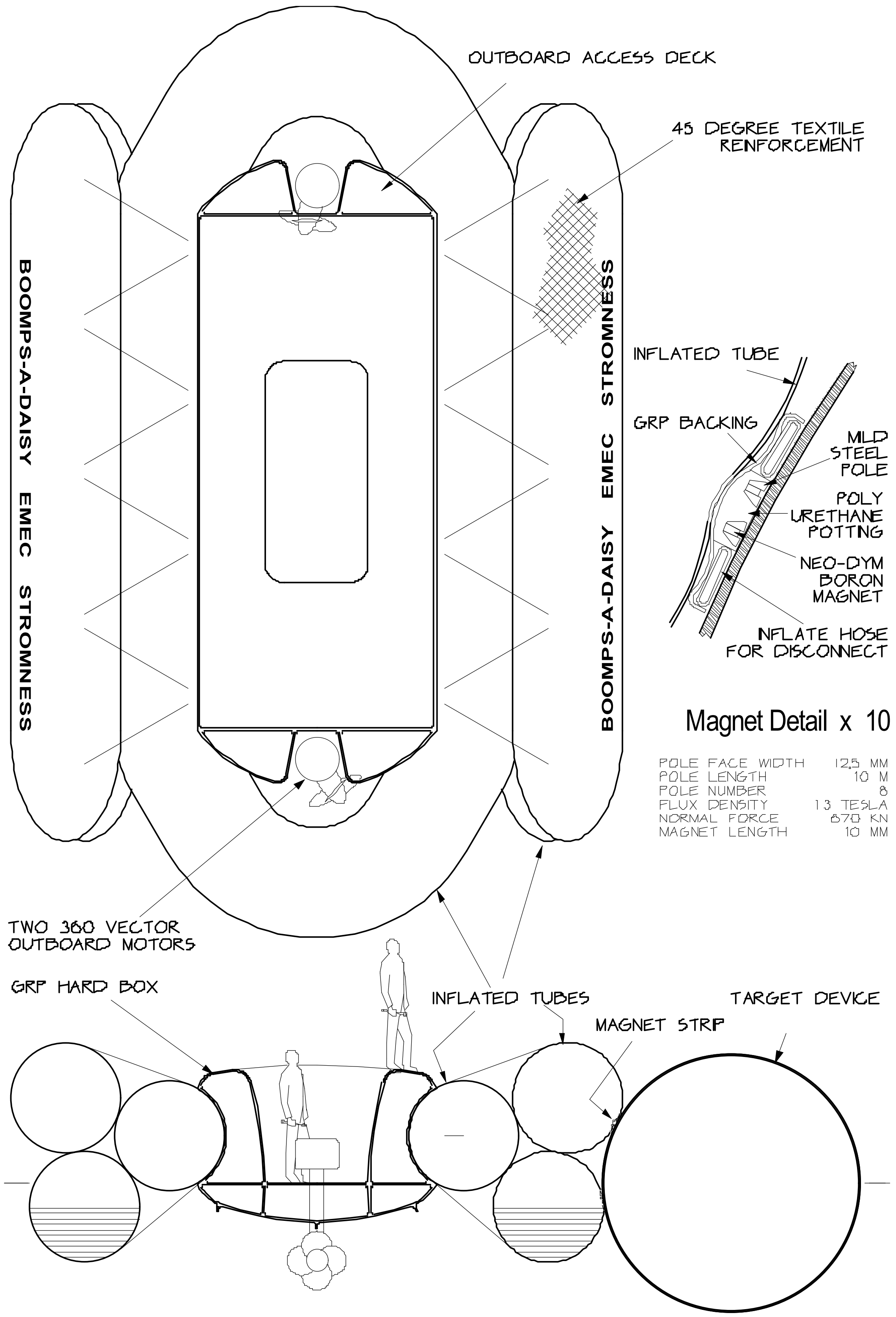


Figure 2. How to capture and tow a large burning ship with an explosive cargo in bad weather. The idea may perhaps be useful for the recovery of offshore wave plant drifting freely toward busy shipping lanes.



POLE FACE WIDTH	12.5 MM
POLE LENGTH	10 M
POLE NUMBER	8
FLUX DENSITY	1 3 TESLA
NORMAL FORCE	670 KN
MAGNET LENGTH	10 MM

Figure 3. A soft tug for installing wave and tidal stream plant. The hazards of long cables and end-connections are avoided by the magnetic coupling. If the heave response of tug and tow are close there will be very little relative movement. The magnet proportions are appropriate for neodymium boron.

PROPULSION

We want rapid changes of force and direction rather than high speed or extremely high fuel efficiency. The vertical axis Voith-Schneider system has the greatest controllability but is meant for larger vessels and would need a special design which is being considered for another project.

We can get nearly as good a flexibility of control by the use of a pair of standard outboard motors, one fore and one aft, with variable-pitch propellers which can go down to zero angle of incidence and be rotated on 360 degree vectoring mountings. This will allow the tugs to turn about their own centre and apply force in any direction with rapid changes.

Off-the-shelf outboard motors are available from several manufacturers with ratings up to 220 kW. Four such motors with a propulsion efficiency of 0.6 could apply 200 kN at a velocity of over 2.5 metres per second. The number of motors could be doubled if necessary. Variable pitch will allow higher velocity at lower thrust. Two such vessels, one at each end of the device being installed, could move it any in any direction and turn it about any centre of rotation. The duration of the installation process should be less than a day so that a hardy crew would need little in the way of home comforts.

The main need for new technology will be to have the controls for propeller pitch-angle and the thrust direction of the outboard motors on *two* tugs available to a single person and linked to a dynamic positioning system.

CONCLUSIONS

Conventional marine technology is not always best for renewable energy, especially for towing.

Magnetic forces can tow the very largest ships.

Short, soft and in-phase is good.

REFERENCES

Banks D. Personal communication 2005.
Flexitec Structures see http://www.flexitec.com/

McCaig, M. Permanent Magnets in Theory and Practice. Pentech Press, London 1977.