Massachusetts Institute of Technology

Sea Grant College Program

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Active Heave Compensator Winch Report

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1 Introduction

One of the missions of the REX-4 is the deployment of probes and a Remote Operated Vehicle (ROV) down to 100 meters under the sea. Since the REX-4 is a very small boat, its response in the sea will be great in comparison with its own size. Because of this, it is crucial to find a good lightweight winch with an Active Heave Compensator system that isolates the motion of the probe from the surface vehicle motion. An Active Heave Compensator winch usually has the following components, Figure 1:

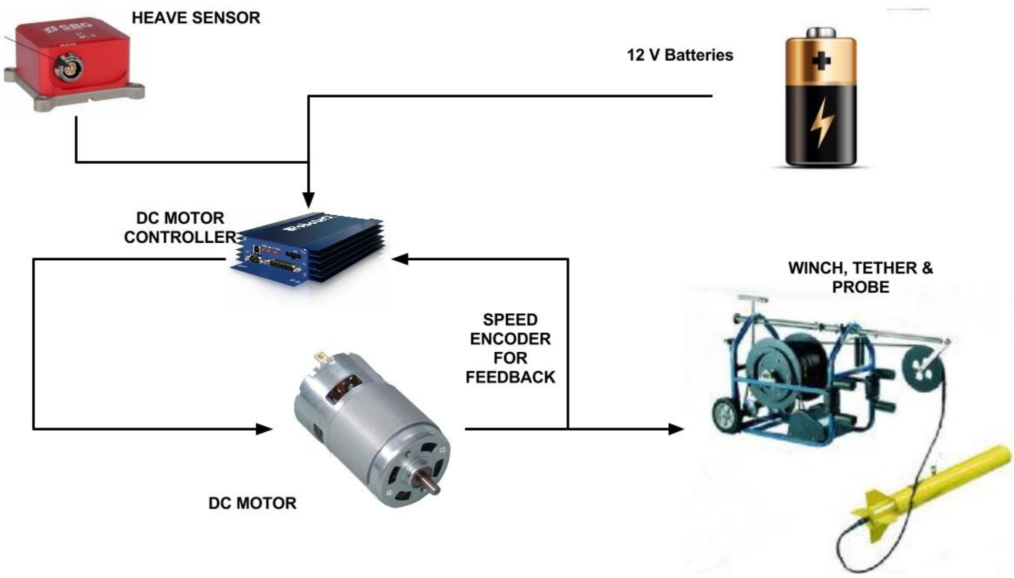

Figure 1: AHC Parts

On the following lines, I will describe all these parts needed to complete the active heave compensator winch.

2 Devices to deploy

The probes and the ROV that the REX-4 will deploy have the following characteristics:

Characteristics	EX01	EX02	Manta2 Sub 3	BlueROV 1
Weight [kg]	1.42	3.6	3.2	3.73
Wet weight [kg]	0.268	0.277	0.22	0 (without electronics)
Diameter [cm]	4.7	7.62	7.49	48.3x33.0
Length [cm]	64.77	71.1	66.04	26.7

3 Tether characteristics

Although some of the probes can work without any kind of connection with the surface vessel, the ROV needs this connection to operate. Due to this, the tether needs to be an electro-mechanical (EM) tether with an Ethernet connection. This has a clear disadvantage: a higher diameter. This higher diameter results in a higher drag force on the tether due to the current. In any case, the place where the REX-4 will operate should not have problems with the current and adding a clump weight should solve partially this problem. It is something that needs to be taken into account.

MIT Sea Grant has already a tether suitable for our purpose and with the following characteristics:

Tether Characteristics	
Braid strength	2000 lbs (907 kg)
Wet weight	0 (neutrally buoyant)
Diameter	9.72 mm
Length	120 m
Approximated total air weight	10 kg

4 Winch

In this step, we need to consider some of the main characteristics that the winch should have:

Winch Specification
Lightweight
Level wind or fair lead (Spooling device)
100-120 meters tether capacity (10 mm diameter preferably)
Electrically driven (12V DC Motor with speed controller)
Slip rings for Ethernet connection
Payload: 5 kg + tether weight

Finding a winch with these characteristics and with an integrated AHC was not an easy task. The offshore industry do has these products but they are designed for depths around the 1000 meters and with a higher payload. At this moment, the companies that have deployed similar probes with small autonomous surface vehicles (ASV) have only done it in lakes where there are not waves.

While looking for this winch, I found different possibilities. Some of them with the whole package (winch + AHC) and some others including only the electrically driven winch. On the following lines you can find all these different options:

4.1 HydroBios

This German company has a hand winch with some characteristics very useful for the REX-4. I asked for prices for this winch, but the company **did not want to give the price** information because they said it could be useless for our mission. Since this winch **does not have a level wind**, we could have some problems spooling the tether remotely. It is a good option for manned vehicles, not for unmanned ones.

HydroBios Winch Specification
Lightweight: Hand Winch 15 kg and Electric motor 7 kg
Shift gearbox 1:1 and 1:3
Drum capacity: 300 m fiber rope (3 mm dia.)/150 m multi conductor cable (4.8 mm dia.)
Electrically driven (12V/260W DC Motor with speed controller)
5 pin slip ring
Payload: 30 kg
Breaking strength: 950 daN / 500 daN

Website: HydroBios Hand Winch
Customer Request **#6477** Contact: **André Reuter - A.Reuter@hydrobios.de**

HydroBios suggested, instead of their product, the product of a different German company that could be suitable for us. This company is ecoTech.

Figure 2: HydroBios Hand Winch

4.2 ecoTech

This winch is called 'ecoTech Profiler'. It has a level wind and it is good for unmanned vehicles. This company is also the YSI dealer in Germany and they have developed this winch specifically for the EX0 sondes, but it accepts other probes also. The winch has good characteristics, but a high price ($25k). It does not have an AHC and it seems it would be difficult to integrate it to the winch.

HydroBios Winch Specification
Level wind Weight: Approx. 40 kg (depending on tether) Drum capacity: 100 m (Optional 200 m) Electrically driven (12V)

Website: ecoTech Profiler
Contact: **Timo Wolf - ecotech@ecotech-bonn.de**

4.3 Marine Sonic Technology

I found this company by the end of August. At this moment I do not have more information than the one that appears on the website. The ER200 would be a nice option for the REX-4

Website: Marine Sonic Technology Easy Reel

4.4 SeaRobotics

I contacted this company in order to obtain some information about where did they get a similar winch for their vehicles. They told me that there was the possibility to build a new winch specifically designed for our mission. After asking many times for an approximated price and answering many question about the characteristics of the winch we were looking for, they finally gave me three options for our mission:

Lightweight wire line winch: It uses a mechanical tether (simple wire, no EM). It does not have AHC. **$21k**

Programmable Parameters	Line Pay-out (meters) Pay-in/Pay-out Speed (m/s) Dwell Time at depth (seconds) Offset altitude from depth reading (meters)
Line Capacity Delivered on Drum	125 meters (410 feet)
Winch line material	40.8 kg (90 lb) Stainless Steel braid
Resolution of pay-out distance	+/- .15meters (.5 ft)
Recommended Instrument Payload Air Weight	Min: 2.3 kg (5 lb) Max: 6.8 kg (15 lb)
Maximum Line Pull	11 kg (24.3 lb)
Pay-in / Pay-out Speed Min.	0.1 m/s (20 ft/min)
Pay-in / Pay-out Speed Max.	1.0 m/s (200 ft/min)
Supply Voltage	12V/24V
Weight (with line, battery not included)	12 kg (26.5 lb)

Figure 3: Searobotics Winch Specification

Figure 4: SeaRobotics lightweight wire line winch

Lightweight EM cable winch for small cable: Cable diameter: 2-6 mm. The unit has rudimentary heave motion mitigation, which has not yet been quantified.**$49k**

Light weight EM winch for ROV cable: Cable diameter: 8-10 mm. The unit has rudimentary heave motion mitigation, which has not yet been quantified.**$74k**

Website: SeaRobotics
Contact: **Don Darling - ddarling@searobotics.com**

4.5 Seatools

This company has given the possibility of obtaining the winch and the integrated heave compensator for an amount of **$100k**. They were really concerned about the problem of the current we may have. Having a tether with such diameter will produce a huge drag force on the tether, making the deployment of the probe really difficult.

Website: Seatools
Customer Request **#16-149** Contact: **Jan Frumau - jfr@seatools.com**

5 DC Motor

In case the options above are not good enough, we can always build the winch ourselves. It is possible to integrate a different DC motor to drive the winch.

5.1 Groschopp

MIT Sea Grant has already one DC Motor integrated into a small winch (20 m tether?). No speed encoder. It has the following characteristics:

GROSCHOPP DC Motor
PM6015-RP7390 12 Volts 3.4 Amps 20 W Reducer output 8.9 rpm 108 in-lbs 90:1

More DC Motors at: Groschopp. You will need to add to these motors the speed encoder

5.2 Power and torque calculation

In order to obtain the power and torque that the DC Motor needs to provide, we will make the following assumptions: The winch will describe the same trajectory as a sinusoidal wave of period T seconds and height H meters.

$$z(t) = \frac{H}{2} sin(\frac{2\pi}{T} t) \tag{1}$$

$$\dot{z}(t) = \frac{H\pi}{T} cos(\frac{2\pi}{T} t) \tag{2}$$

$$\ddot{z}(t) = -\frac{H2\pi^2}{T^2} sin(\frac{2\pi}{T} t) \tag{3}$$

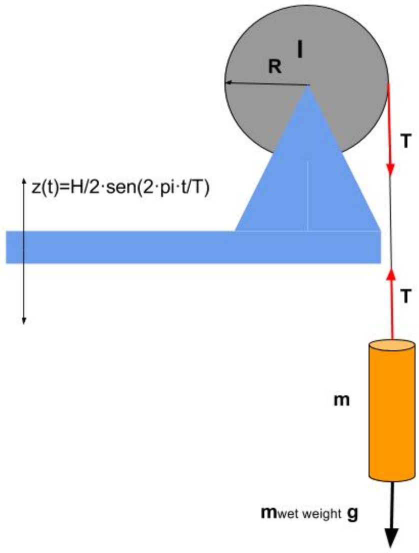

Figure 5: Winch model

Mass system ($m_{wetweight}$ is the wet weight of the probe and the tether, m is the mass of the probe and the tether):

$$T - m_{wetweight}g = ma \tag{4}$$

Winch system:

$$MotorTorque - TR = I\alpha \tag{5}$$

Linear acceleration and angular acceleration:

$$\alpha = \frac{a}{R} \tag{6}$$

We obtain that the Motor torque is:

$$MotorTorque = (\frac{I}{R} + mR)a + Rm_{wetweight}g \tag{7}$$

And the power is:

$$w[rad/s] = \frac{\dot{z}(t)}{R} \tag{8}$$

$$Power[W] = w[rad/s] \cdot MotorTorque[Nm] \tag{9}$$

To isolate the mass motion from the winch motion, we need to apply the heave acceleration to the mass. This way, both motions will cancel each other and the mass will remain stationary relative to the seabed. This means we need to substitute the acceleration from 3 into 7 to obtain the power and the torque needed at each time.

Please, use the EXCEL spreadsheet I wrote for this purpose.

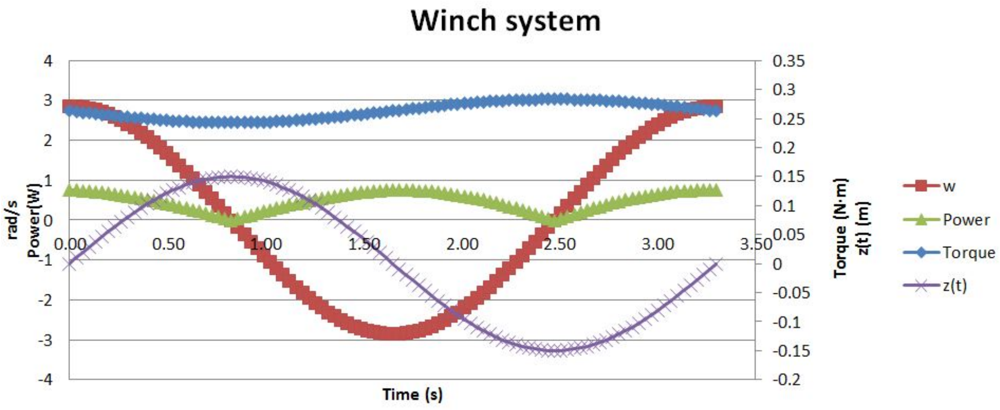

Figure 6: Excel Winch Model

6 AHC Controller

As we have seen on the previous section, getting the winch with the integrated AHC seems to be very expensive. Because of this, I started looking for these controllers separately.
An AHC Controller usually has the following parts: the **heave sensor**, usually a motion reference unit (MRU); and the **winch controller**. Sometimes there is an HMI (Human Interface Operator) for the user.

6.1 Active Heave X-Wave

In this case, the company is from the United Kingdom and they have the AHC system that can be integrated with an existing winch. The price of the product in **pound sterling** is between **30k and 50k**. Includes the motion reference unit, the winch controller, HMI (Human Interface Operator) for operator interaction, datalogging and remote access.

It was a good option although a little bit expensive. It was not possible to obtain a discount. They wanted to use some marketing advantage from being involved with MIT, but MIT does not allow using its name.

Website: Active Heave X-Wave
Contact: **Paul Cairns - paul.cairns@mec-ltd.co.uk**

6.2 Seatools

We have talked about this company before. They also sell the AHC controller separately. Seems to have the same price as the previous one based on the price they gave us for the whole package.

Website: Seatools Heave Mate
Customer Request **#16-149** Contact: **Jan Frumau - jfr@seatools.com**

6.3 Scantrol

This company is from Norway and sells the AHC controller for the big offshore vessels. I have not received any reply from them to my inquiry e-mails. I will keep you updated if I receive something interesting.
Website: Scantrol AHC

7 Winch Controller: Speed controller

Since the Active Heave Controllers are expensive, we will build it from the scratch. As I said before, one of the parts is the winch controller. Basically it is a DC Motor speed controller. It takes the input from the Heave data and outputs the signals to control the speed of the winch. It needs an encoder in the DC Motor to obtain the speed feedback.

7.1 RoboteQ

The basic DC Motor Speed Controller we would need is around the 200$. Luckily, **MIT Sea Grant already has one** and it can be used for this mission. It is designed for controlling two engines at the same time and its price is $645.

Website: RoboteQ HDC2450

Figure 7: DC Motor Speed Controller

8 Heave Sensor

This is the most complex part of the system. The offshore industry usually use a motion reference unit (MRU) to obtain acceleration, velocity and displacement. This units consist of an acceleration, magnetometer and gyroscope sensor and the filters needed to erase the drift generated when double-integrating the data. This drift is generated due to orientation error or sensor bias.

8.1 Kongsberg

I contacted this company twice in order to get a price for an MRU unit specifically designed for an active heave compensator, MRU H. I have received no reply from this company yet. Maybe they are on vacations right now.

Website: Kongsberg MRU

8.2 SBG Systems

This company has many types of MRU units that could be used for the AHC system. Next, the prices and the main characteristics of the products that may work for our mission can be found:

MRU	Ellipse-A	Ekinox-A	Ekinox-M
Price	$2,500	$15,000	$17,000 (Waterproof)
Heave Accuracy	10 cm	5 cm	5 cm
Voltage	5-36V	36V	36V
Overview	Ellipse	Ekinox	Ekinox
Leaflet	Ellipse	Ekinox	Ekinox
User Manual	Ellipse	Ekinox	Ekinox
			

Website: SBG Systems
Contact: **Jack Mawson - jack.mawson@sbg-systems.com**

8.3 Accelerometer and filter

Another option is to build the heave sensor from the scratch. For this purpose, we need an accelerometer, magnetometer and gyroscope sensor and the filter.

MIT Sea Grant has three of these sensors already built. In my summer report, BNO055 Sensor, I will explain I little bit more how they work.

The last step should be building the filter based on the numbers that Brian Gilligan obtained. Since we are controlling the winch speed, the best option is to obtain the heave velocity through acceleration data and a first order filter. This filter should be really cheap. Concerning the accuracy of the system it is difficult to estimate it at this moment. I would recommend trying this option first and if the results are not good enough, then move to a commercial heave sensor.