Wave basin tests with Joltech's GyroPTO completed in March 2016

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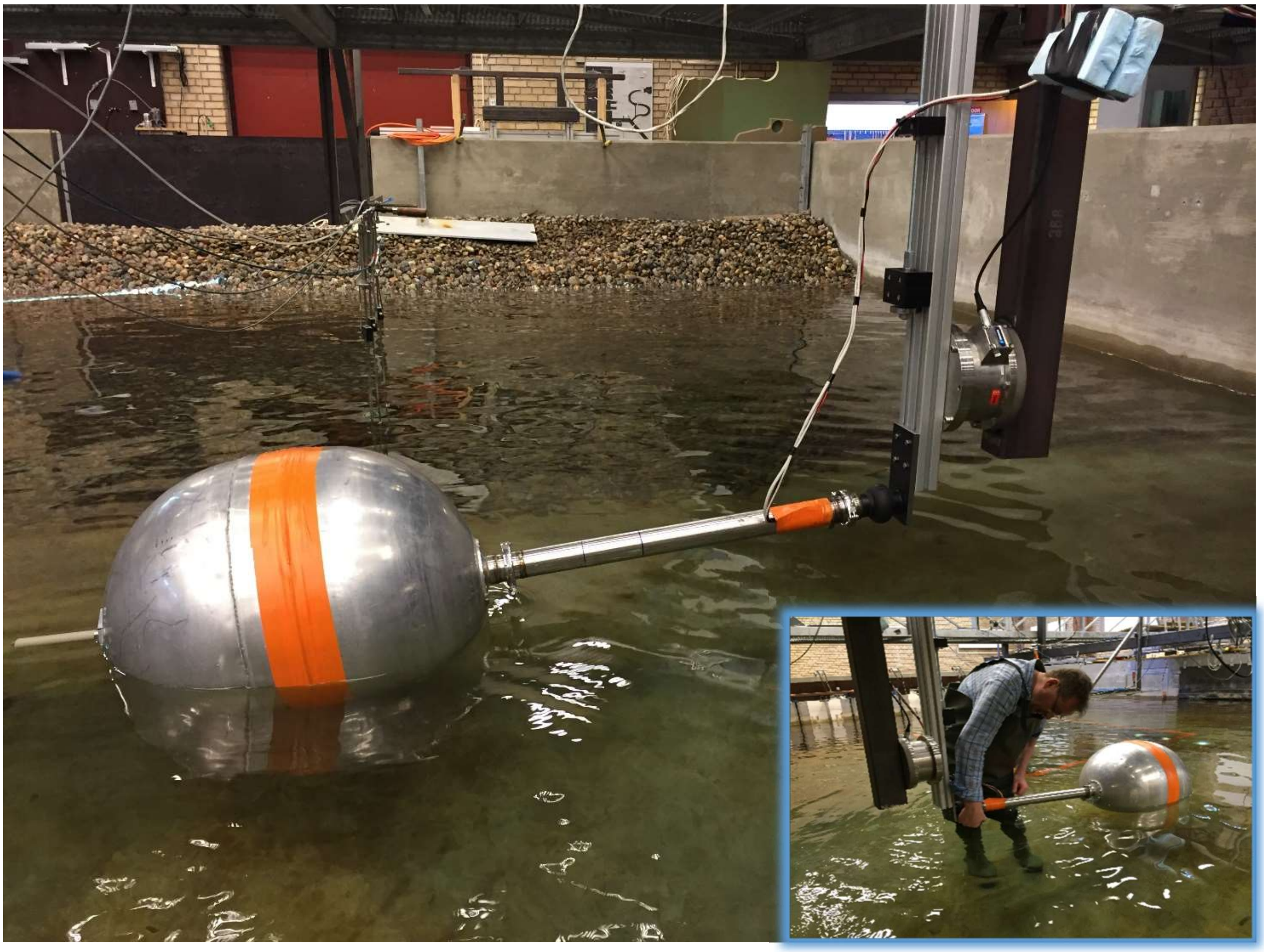

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1 Preface

The work presented in this report was completed under the support from the Danish Energy Technological Development and Demonstration Program (EUDP), project no. 64015-0007 "Gyro electric energy converter theory and analysis"[1].

Testing took place in the wave basin at the Department of Civil Engineering at Aalborg University in two periods; 16-17 March and 30-31 March 2016. The laboratory activities were carried out by Morten Kramer, Jan Olsen, and Nikolaj Holk.

Jan Olsen was representative for the Joltech GyroPTO, and Jens Peter Kofoed was coordinating the work by representing Aalborg University.

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[1] http://energiforskning.dk/node/8613

2 Background & introduction

Extensive testing of the Gyro device has been completed at Aalborg University in 2015 as described in [1]. The testing demonstrated that with properly tuned control gains it was possible to achieve a positive power output as long as the waves were constant and sinusoidal. However, it turned out during the testing that the device was extremely sensitive to changes in the wave shape. In irregular waves a positive power output could not be achieved.

Based on the findings in [1] it was decided to modify the device in order to try to achieve positive power production in irregular waves. The current report describes testing completed in March 2016 on the updated device.

The main purpose of the tests was to investigate the power absorption performance in irregular waves.

Scaling, geometry and laboratory setup was similar to [1], and therefore not repeated in the current report.

3 Laboratory set up

Figure 1 shows the setup in the basin including the mount of the force sensor. Figure 2 shows details of the two types of mounts that were used.

Figure 1: Setup in wave basin. Right photo shows the 6-axis force sensor and the mount.

Figure 2: Two types of mounts. Left: Normal type with motion in two degrees of freedom (pitch and roll), Right: Special mount with only roll motions (vertical motions of float) and restricted for horizontal motions in wave direction.

4 Diary

The list below describes what was done throughout the test campaign:

Week 1, Day 1 Wednesday 16 March 2016

Setup of Wavelab data acquisition

Setup of Awasys trigger (logging in WaveLab & Jans system)

Mounting of model in basin

Test of force sensor (first two tests with WaveLab)

Test of control in calm water

Week 1, Day 2 Thursday 17 March 2016

Calibration of wave gauges

Step up of Gyro generator in calm water

Tests in regular waves

Tests in irregular waves, change of control setting

Changes in between the weeks with tests:

Change of the rollers in the float to conical ones

Added three channels with arm translational accelerations in PTO logging

Week 2, day 1 Wednesday 30 March 2016

Meeting with Søren, Zili, Jens Peter, Jan, Morten

Friction dry tests

Waves only tests

Tests with free float in waves, PTO not running (wave type reg1 and irregular1)

Eigen frequency tests

Tests with float in waves (yaw stiffness as original, and afterwards with changed setting)

Week 2, day 2 Thursday 31 March 2016

Tests with changed stiffness settings

Tests with changed control parameters

5 Waves

The sea states used in the tests are given in Table 1.

Table 1. Sea states given as targets.

Regular

Name	H (m)	T (s)
Reg 1	0.0848	2
Reg 2	0.2	1.8

Irregular

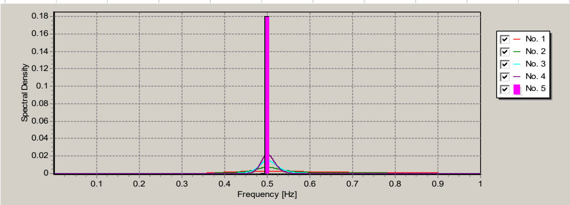
Name	H_{m0} (m)	T_P (s)	gamma (-)	Length (s)
Irregular1	0.12	2	1	1000
Irregular2	0.12	2	5	1000
Irregular3	0.12	2	50	1000

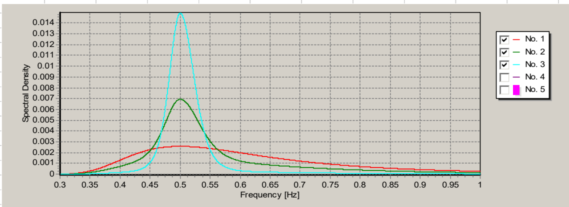
Generated using random phase (seed =1) method.

Target wave spectra

No	Type	Hm0	Hs	Tp	Ts	T-1,0	T0,1	T0,2	eps4 (Broa	eps2 (Narr	Wave pow	m-2	m-1	m0	m1	m2	m3	m4	m2	m3	m4
1	Jonswap parameterised (gamma=1)	0.1199	-	2	-	1.7158	1.5513	1.4456	0.73495	0.38931	13.335	2.31E-07	0.001542	0.000899	5.79E-04	0.00043	0.000388	0.000447	0.00043	0.000388	0.000447
2	Jonswap parameterised (gamma=5)	0.11995	-	2	-	1.8392	1.7219	1.63	0.72539	0.34052	14.389	2.48E-07	0.001654	0.000899	5.22E-04	0.000338	0.000264	0.000269	0.000338	0.000264	0.000269
3	Jonswap parameterised (gamma=50)	0.11994	-	2	-	1.9548	1.9199	1.886	0.56344	0.19028	15.37	2.64E-07	0.001758	0.000899	4.68E-04	0.000253	0.000148	0.000104	0.000253	0.000148	0.000104
4	Jonswap parameterised (gamma=1000)	0.11991	-	2	-	1.9867	1.9819	1.9779	0.21153	0.063312	15.636	2.68E-07	0.001785	0.000899	4.53E-04	0.00023	0.000117	6.15E-05	0.00023	0.000117	6.15E-05
5	Monocromatic waves	0.11993	0.0848	2	2	2	2	2	0	0	15.733	0.003596	0.001798	0.000899	0.000449	0.000225	0.000112	5.62E-05	0.000225	0.000112	5.62E-05
6	Monocromatic waves	0.28284	0.2	1.8	1.8	1.8	1.8	1.8	0	0	81.295	0.0162	0.009	0.005	0.002778	0.001543	0.000857	0.000476			

Notes:
* Spectrum no 3 (gamma = 50) is generated with spectrum formula input Hm0 = 0.1261 m (which gives an actual theoretical Hm0 = 0.12 m)
* Spectrum No 4 is just for info (not used).





6 Channel setup

The setup of the channels used in the acquisition is given below.

WaveLab

Channel	Description	Unit
1	Wave gauge 1	m
2	Wave gauge 2	m
3	Wave gauge 3	m
4	Wave gauge 4	m
5	Wave gauge 5	m
6	Wave gauge 6	m
7	Wave gauge 7	m
8	FT6 SG0	V
9	FT6 SG1	V
10	FT6 SG2	V
11	FT6 SG3	V
12	FT6 SG4	V
13	FT6 SG5	V
14	Awasys trigger	V

PTO ver 1 (week 1)

Channel	Description	Unit
1	Time	s
2	Time IMU1	s
3	Angle flywheel	degrees
4	Ctrl quality 1	
5	Ctrl quality 2	
6	Motor rev actual	rev/min
7	Mech Power	W
8	Motor rev target input	rev/min
9	Time IMU2	s
10	Arm angle 1	degrees
11	Arm angle 2	degrees
12	Arm angle 3	degrees
13	Status Acc	
14	Status gyro	
15	Status magnet sensor	
16	Status Kalman system	
17	Sync signal	

PTO ver 2 (week 2)

Channel	Description	Unit	
1	Time	s	
2	Time IMU1	s	
3	Angle flywheel	degrees	
4	Ctrl quality 1		
5	Ctrl quality 2		
6	Motor rev actual	rev/min	
7	Mech Power	W	
8	Motor rev target input	rev/min	
9	Time IMU2	s	
10	Arm angle 1 (horizontal)	degrees	positive towards beach
11	Arm angle 2	degrees	
12	Arm angle 3 (vertical)	degrees	positive downward
13	Status Acc		
14	Status gyro		
15	Status magnet sensor		
16	Status Kalman system		
17	Acceleration arm x	m/s^2	Sensor mounted 50 cm from bearing
18	Acceleration arm y	m/s^2	-
19	Acceleration arm z	m/s^2	-
20	Sync signal		

7 Test schedule and power performance results

The test schedule and the measured power performance is given in Table 2. The power performance was generally unstable and in average about zero in irregular waves. In regular waves positive and stable power absorption could be achieved. The production is in-line with the findings in [1].

Table 2: Test schedule and power performance results.

Test description			Results	
Filename WaveLab	**Filename Controller**	**Description**	**Friction power (W)**	**Absorbed power (W)**
160316AA0_Wavelab	-	Offset for FT6 load sensor. Only mounting on bridge (no arm no float), calm water.		
160316AA1_Wavelab	-	No float, no arm. Test of FT6 sensor by pulling in different directions with Newtonmeter (Fx 20 N, Fy 20 N, Fz 20 N, My = 6Nm, Mz = 6 Nm)		
160316A_Wavelab	160316A	Float and arm mounted. Logging on both systems. Test of control in calm water, different periods of ring motion (3-7 seconds).		
160316B_Wavelab	160316B	Repetition of test 160316A		
170316A_Wavelab	170316A	No waves. In water. Step up on generator.		
170316B_Wavelab	170316B	Regular wave 1, PTO target motor RPM to 1470	-3.03	5.19
170316C_Wavelab	170316C	Irregular wave 3 (gamma = 50), PTO target motor RPM to 1450	-4.85	1.74
170316D_Wavelab	170316D	Irregular wave 2 (gamma = 5), PTO target motor RPM to 1450	-5.05	0.44
170316E_Wavelab	170316E	Irregular wave 1 (gamma = 1), PTO target motor RPM to 1450	-4.82	0.18
170316F_Wavelab	170316F	Irregular wave 1 (gamma = 1), change of PTO target motor RPM to 1500	-5.10	-0.06
170316G_Wavelab	170316G	Irregular wave 1 (gamma = 1), change of PTO target motor RPM to 1550	-5.84	0.82
170316H_Wavelab	170316H	Irregular wave 1 (gamma = 1), change of PTO target motor RPM to 1400	-4.00	-0.12
170316I_Wavelab	170316I	Regular wave 2 (T=1.8), PTO target motor RPM to 1600. End with load sensor measurements.	-6.68	22.51
WavesOnly_Reg1		Wave measurements with the float out of the water		
WavesOnly_Reg2		-		
WavesOnly_Irregular1		-		
WavesOnly_Irregular2		-		
WavesOnly_Irregular3		-		
	300316A	Dry friction measurements		
300316B_Wavelab	300316B	Regular wave 1, Freefloat - PTO turned off		
300316C_Wavelab	300316C	Irregular wave 1 (gamma = 1), Freefloat - PTO turned off		
300316D_Wavelab	300316D	Eigen frequency (first vertical with upward lift and release, afterwards horizontal motion with push towards wave generator and release)		
300316E_Wavelab	300316E	Irregular wave 1 (gamma = 1), PTO target motor RPM to 1600, stiffness setting 1	-1.37	-1.13
300316F_Wavelab	300316F	Regular wave 1, change of PTO motor target RPM, stiffness setting 1	-1.65	5.35
310316A_Wavelab	310316A	Stiffness setting 2, Irregular wave 1 (gamma = 1), PTO target motor RPM to 1600	-1.42	-1.26
310316B_Wavelab	310316B	Stiffness setting 2, Irregular wave 1 (gamma = 1), PTO target motor RPM to 1550	-1.25	-0.98
310316C_Wavelab	310316C	Stiffness setting 2, Irregular wave 1 (gamma = 1), PTO target motor RPM to 1525	-1.18	-0.73
310316D_Wavelab	310316D	Stiffness setting 2, Irregular wave 1 (gamma = 1), PTO target motor RPM to 1500	-1.11	-0.49
310316E_Wavelab	310316E	Stiffness setting 2, Irregular wave 1 (gamma = 1), PTO target motor RPM to 1475	-1.03	-0.51
310316F_Wavelab	310316F	Stiffness setting 2, Regular wave 1, PTO target motor RPM varied	-1.58	2.92
310316G_Wavelab	310316G	Stiffness setting 2, eigen frequency tests in calm water (motion against wave generator)	-	-
310316H_Wavelab	310316H	Stiffness setting 2, control gain setting 150 (in all previous tests it was 300), Irregular wave 1 (gamma = 1)	-1.04	-1.39
310316I_Wavelab	310316I	Stiffness setting 2, control gain setting 150, regular wave 1	-1.68	3.12
310316J_Wavelab	310316J	Stiffness type 4, control gain setting 150, Begin with no waves - startup in calm water, later reg wave no 1.	-1.66	1.38
310316K_Wavelab	310316K	Stiffness type 4, control gain setting 150, Irregular wave 1 (gamma = 1).	-1.11	-0.44

8 Mooring restoring stiffness

The yaw stiffness of the normal mount type (ref. Figure 2) was measured in the tests, as given in Figure 3 and Table 3.

Figure 3: Measurement of yaw stiffness.

Table 3: Results of measurements of yaw stiffness.

Stiffness against horizontal motion "Yaw"

Stiffness setting 1 (all tests up to test 300316F), length of torsion pin: 55 cm

Moment arm: 148 cm (measured)

Measurements				
Force (N)	Excursion (cm)	Moment (Nm)	Angle (rad)	Stiffness (Nm/rad)
-10	-37	-14.8	-0.253	58.6
10	37	14.8	0.253	58.6
15	60	22.2	0.417	53.2

Stiffness setting 2 (test 310316A - 310316I), length of torsion pin: 18 cm

Moment arm force: 148 cm (measured)
Moment arm position: 162 cm (measured)

Measurements				
Force (N)	Excursion (cm)	Moment (Nm)	Angle (rad)	Stiffness (Nm/rad)
10	20	14.8	0.124	119.6

Stiffness type 3, fixation agains yaw using cardan joint
No measurements of stiffness. First try of complete fixation against yaw.
No measurements from tests.
Only pictures are available

Stiffness type 4, fixation agains yaw using two new bearing and axel
Very stiff (no measurements of stiffness)
Only pictures are available
Last two tests were performed with this configuration.

Notes regarding stiffness setting 1

Hydrostatic stiffness		2925	Nm/rad
Hydronamic added mass:	"Yaw"	28	kgm^2 (approximately, should be checked)
	"Roll"	40	kgm^2 (approximately, should be checked)
Total mass inertia moment		73	kgm^2 (don't know if this is correct)

Estimated eigen frequencies

	omega (rad/s)	T0 (s)
Yaw	0.762	8.251
roll	5.088	1.235

9 Friction measurements

Friction measurements are shown in Figure 4. The absorbed power measurements were compensated for the friction.

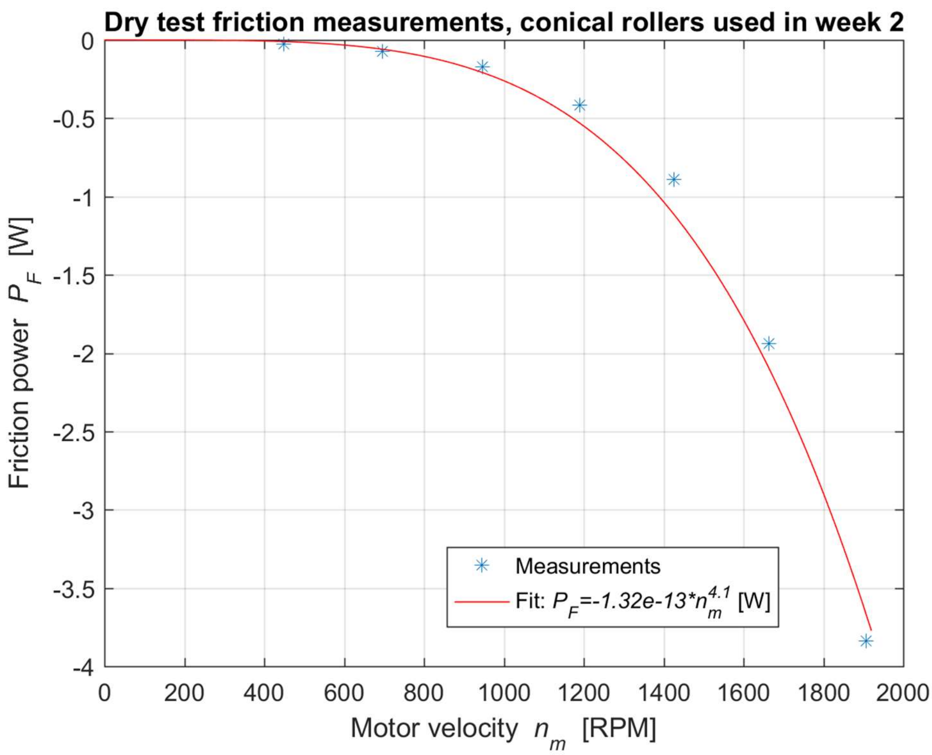


Figure 4. Friction measurements.

11 Conclusions

The conclusion is the same as in [1] and [2]. The testing on the updated device with irregular waves showed that the performance was generally very unstable, and the measured power absorption was negative a large part of the time, with average value about zero.

It appears that to improve the performance of the GyroPTO in irregular sea would require more sophisticated solutions. Some suggestions include properly changing the value of the generator gain in real time using a certain semi-active control law. Improving the performance of the current device is, however, likely to be challenging. Major modifications or completely new inventions integrated in a different setup could possibly be a better path to take.

12 References

[1] Kramer, MM, Pecher, AFS, Guaraldi, I, Andersen, MT & Kofoed, JP 2015, *Hydraulic evaluation of Joltech's GyroPTO for wave energy applications*. Department of Civil Engineering, Aalborg University, Aalborg. DCE Technical Reports, nr. 178.

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