Power producing buoy for strategic applications: Prototype and Testing – Q4 Report

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Summary

The fourth quarter of this project marks the beginning of stage two of the overall effort in which an instrumented proof-of-concept prototype will be built and tested. The intent of this prototype is to validate the numerical model estimates of power production, design and test the power take-off system, and to provide a demonstration of power generation from waves at sea.

Activities

1. Finalized basic size parameters for the instrumented proof-of-concept prototype planned for testing in 2010.
2. Held brief update meeting for DARPA personnel on March 11, 2010.
3. Began systems engineering and design engineering efforts for the prototype stage of the project.
4. Identified technology for the linear power take-off device and established a plan with Levant Power to provide that element.

Technical Status and Results

The prototype being developed and tested in stage two of the project is intended to evaluate how efficiently the mechanical to electrical power conversion can be performed and to demonstrate that the analysis results are useful for predicting the power generation capabilities of a range of system sizes. To meet these goals a buoy size has been selected that has a waterplane area of 5 square meters (nominal diameter = 2.5 m). This size selection is small enough to allow a range of submerged plate sizes to be tested from ships available at a reasonable cost and large enough to capture the physics involved and provide results that can be confidently scaled up to a larger system by using the analysis tools developed in the first stage of the project. The black horizontal bars in Figure 1 show the expected power dissipated in the power take-off system for a range of sea states characterized by significant wave height (Hs). The numbers presented in Figure 1 assume perfect conversion of mechanical damping to electricity in the power take off system. Perfect efficiency is not possible and the development of an efficient power take-off system is of key importance to the success of the project, the ongoing development effort for this is described below.

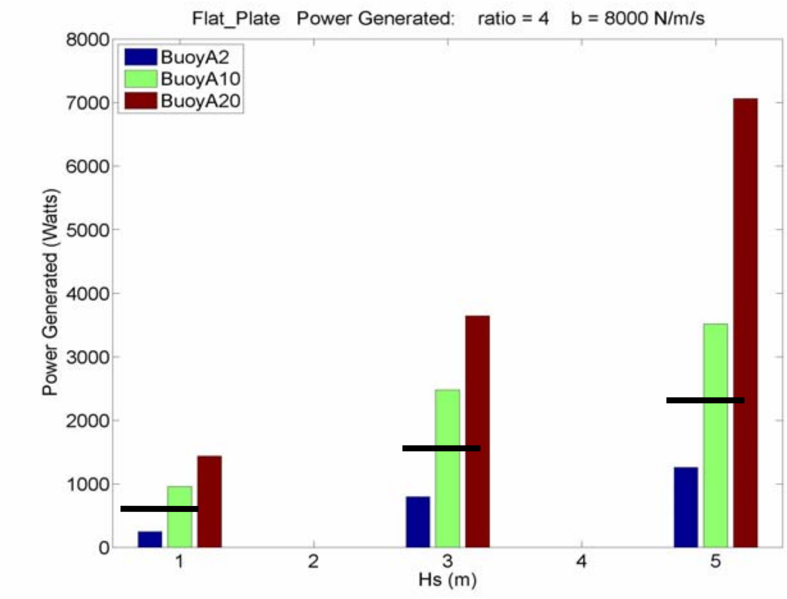

Figure 1: Expected power dissipated by power take-off system for various buoy sizes in a range of significant wave heights. The colored bars indicate three buoy sizes with varying waterplane areas (blue = 2 m^2, green = 10 m^2, red = 20 m^2), the black horizontal bars indicate results for a buoy with a waterplane area of 5 m^2.

In order to develop the needed prototype in an efficient manner, standard system engineering techniques have been adopted to manage this stage of the project. The prototype architecture has been split into a number of sub-systems that can be developed relatively independently and integrated when complete. To do this effectively, requirements and interfaces have been established for each subsystem, allowing engineering efforts to proceed in parallel on several fronts. Figure 2 shows a block diagram of the system architecture and highlights the different types of interfaces between each sub-system. This diagram illustrates a prototype system that does not include flapping foil propulsion and is instead aimed at demonstrating the power generation aspect of the project. This will be the first prototype developed and tested but the system architecture has been selected so that a flapping foil propulsion test can follow the submerged flat-plate without re-designing or significantly changing the system beyond replacing the submerged plate with a flapping foil sub-system.

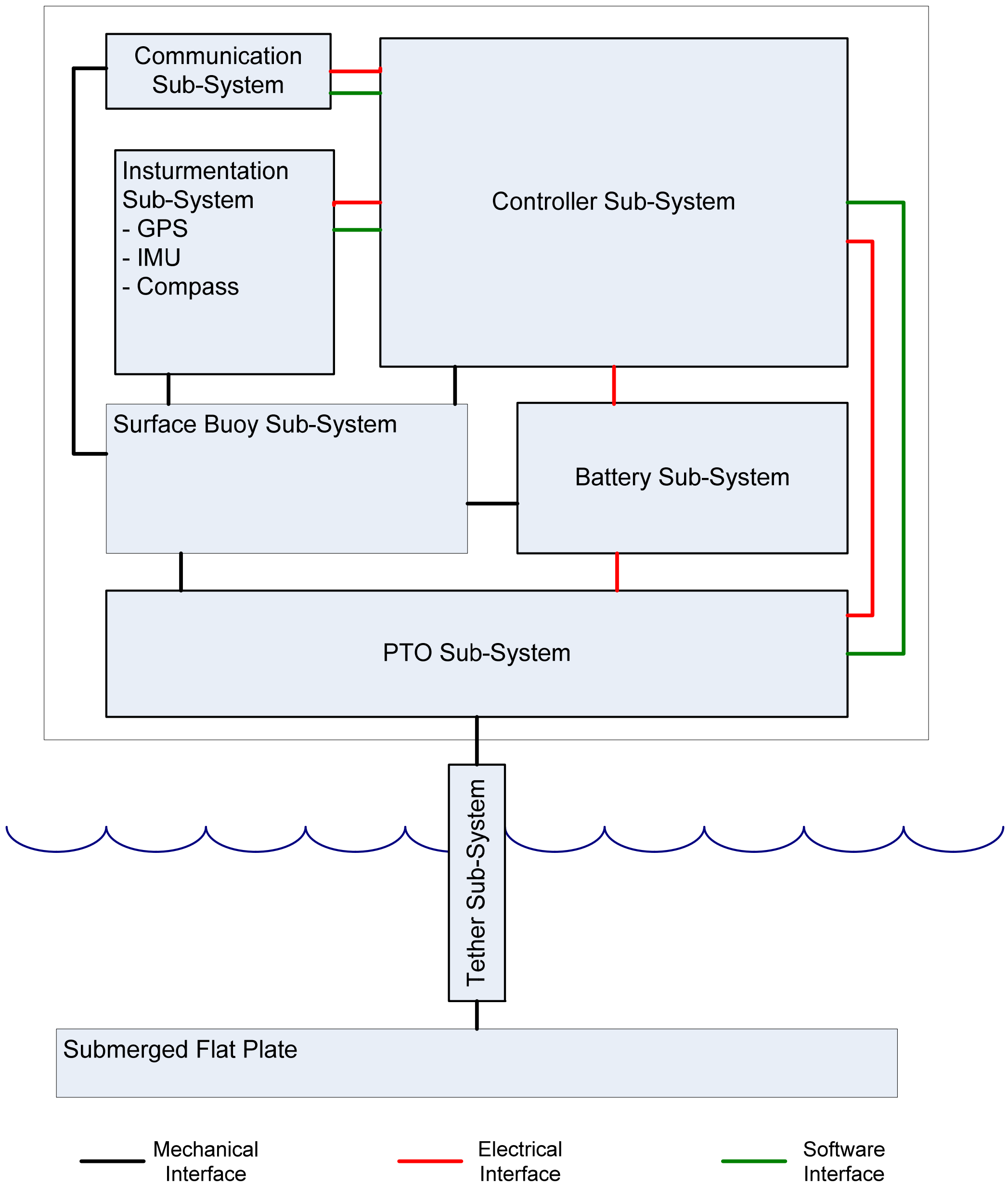

Figure 2: System block diagram for instrumented prototype being developed in stage two of the project.

Each subsystem is being designed with a short and long term application in mind, for instance the controller and communication subsystem are currently being designed for short term deployments (days) and are not intended to be suitable for a long term (months) demonstration but will be replaced at that time with appropriate hardware. This approach relaxes the power consumption requirements and allows common off-the-shelf hardware to be used in the initial proof of concept test deployments. In particular (with reference to Figure 2) the current designs for the controller, instrumentation and communication sub-systems consist entirely of commercially available systems. The communication sub-system is a 900Mhz ethernet bridge that will provide a connection over a wireless link to a range of several miles. The instrumentation subsystem is comprised of a GPS enabled attitude heading and reference system produced by Crossbow. This unit (NAV440) integrates a magnetic compass, gps, and inertial measurement unit to provide a smooth and high-rate output of buoy position, attitude, and heading. The controller subsystem is an embedded computer running standard Linux and is coupled with a range of commercially available periphials such as digital I/O, relays, and serial ports. The controller is responsible for logging data from the instrumentation, power take-off system and communicating that data in real time through the communication link. The Surface buoy sub-system is the actual buoy and will be custom designed for the project, or adapted from previous MBARI buoy designs. Similarly the battery sub-system will be comprised of standard lead-acid batteries but will be packaged in a manner suitable for use on a buoy platform. The submerged plate will be a simple steel or aluminum weldment for the initial testing but can be replaced at a later date with a flapping foil propulsion unit without changing the rest of the system. The tether sub-system consists of a single, commercially available spectra line and is the simplest sub-system at this stage, however, should a power or data connection be required to the sub-surface element at a later date, this rope could be replaced with an electro-mechanical cable without requiring changes to the remainder of the system.

The power take-off (PTO) system is the heart of the system, is the most challenging to design, and as a result is the most custom sub-system. In contrast to the sub-systems described above, the development plans for the power take-off system takes a longer view and it is expected that the hardware developed now, or a refined version of that hardware, will be present in all versions of the power producing buoy in the future. To be successful the power take-off system will need to effectively convert low speed, high force mechanical power to electricity that can be stored in batteries. A small company called Levant Power systems has been working for several years to develop a truck shock absorber that performs this same task and they have developed some interesting technology that is applicable to the wave-energy power take-off problem. After evaluating the technology and the company, Levant has been brought into the project as a sub-contractor to provide the power-conversion element of the power take-off system. They will be working to adapt their technology to the larger size, force, and speed requirements of the wave-energy buoy. Figure 3 shows pictures of their shock absorber prototypes, the picture on the right shows the key innovation which is a turbine and electrical generator integrated into the head of a hydraulic ram piston. This packaging eliminates losses due to oil moving through plumbing and efficiencies of 40% have been demonstrated in Levant's small scale prototypes.

Figure 3: Levant Power's GenShock and internal mechanism.

Levant will provide a scaled up GenShock device suitable for the buoy application. The agreement with Levant specifies that two generations of the device will be developed, an initial generation with a stroke of 2 meters and a second generation with a longer stroke if needed and refinements from the lessons learned in developing and testing the first generation. The GenShock device itself is just the power take-off system and will require controlling power electronics and a spring element coupled to the device for use in the wave-buoy application. Figure 4 illustrates the entire power-take-off system, the components in yellow will be supplied by Levant and the remainder are being designed and built by MBARI engineering. The main components produced by MBARI are the spring element shown mounted on top of the GenShock in the diagram and the controlling electronics. The spring design is a pneumatic device that will provide a restoring force to the system as gas in a chamber is compressed. The pneumatic solution appears to be smaller, lighter and more adjustable than an equivalent mechanical spring. Outstanding questions related to this component include the overall spring efficiency and the effects of heat loss through the walls of the device to the surrounding water, analysis is ongoing to address these issues. The controlling electronics in the power take-off system will include an embedded controller that is responsible for monitoring the performance of the system and reporting that information to the controller subsystem over a serial link or similar. The power take-off system will include necessary instrumentation such as pressure sensors and load cells so that the performance of the system can be analyzed and understood after each test deployments.

The other role of the power take-off system electronics is to provide guidance to the Levant supplied power electronics with regard to the desired damping the power take-off system should provide. The Levant system is capable of adjusting the damping coefficient the system sees by changing the rate at which mechanical energy is converted to electrical energy. This provides the opportunity to develop algorithms that maximize the power generated by adjusting the system in real time based on changing sea conditions. The MBARI supplied controller will be perform this task and any algorithmic development in this vein will be performed by MBARI in conjunction with the modeling tools previously developed.

Budget and Spending

As shown in the attached report, half way through the first two years of the project, 65% of the budget for that time period remains unspent. This corresponds to a spending rate that is a little slower than the originally proposed budgeting but the build and test activities planned for the next nine months will be more expensive than the first years analysis work and it is expected that the spend rate will remain close to the original targets.

Attachments

1. MBARI Grant Status Report

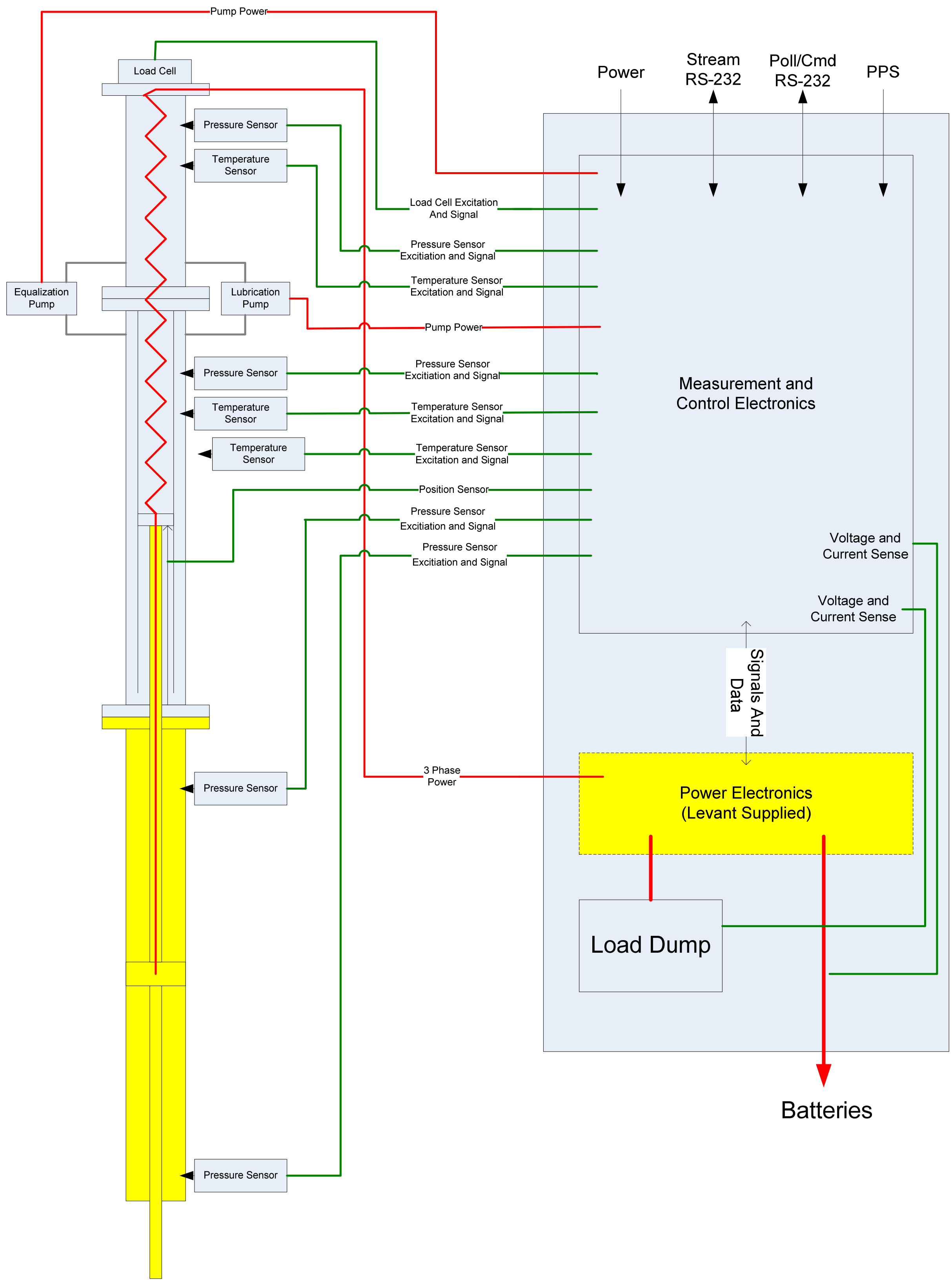

Figure 4: Power take-off system block diagram. Items colored in yellow will be provided by Levant.