General Testing Setup for Hyperelastic Transducers—DEEC-Tec & Marine Renewable Energy

Preprint

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General testing setup for hyperelastic transducers—DEEC-Tec & marine renewable energy

S. Chamot, J. Niffenegger, and B. Boren

Abstract— **Distributed embedded energy conversion technologies (DEEC-Tec), an emerging domain for ocean wave energy conversion technology, is showing promise for a range of applications. Research is being conducted at the National Renewable Energy Laboratory that leverages this domain to investigate the potential of ocean wave energy converters (WECs) constructed from hyperelastic forms of distributable and embeddable energy transducers. These transducers are available in forms such as disks, rectangles, or hexagons and can be combined in various ways to form energy-producing metamaterials and flexible WECs. DEEC-Tec, therefore, could open doors that enhance ocean wave energy conversion in ways not previously thought possible by allowing for many WEC topologies and morphologies. However, the same diversity and adaptability pose challenges for the development of these DEEC-Tec-oriented hyperelastic transducers. A commercial tensile testing setup was not found that was adaptable enough to accommodate the varied transducers while providing precise force control, range of motion, and noncontact data collection. Because of this lack, a comprehensive test rig was designed in house to be used with a 3D laser scanning device—providing contactless measurements while also allowing for different geometries and various uniaxial loadings. This paper and presentation will discuss these unique challenges and the processes for overcoming them to provide a robust and general testing setup for hyperelastic transducers, of any form, for the DEEC-Tec marine renewable energy domain.**

Keywords—**DEEC-Tec, Hyperelastic Transducers, Marine Renewable Energy**

I. INTRODUCTION

THERE are two main challenges to developing a robust testing setup to analyze hyperelastic transducers. First, the transducer, cannot come into physical contact with any measuring device. The transducer's hyperelastic materials are soft enough that contact with a measuring device could easily deform the material and adversely affect its measurement. Moreover, the relatively small size of the transducers makes physical contact increasingly infeasible. Second, due to the nature of hyperelastic materials and the varied geometries being tested, deformation can be complex and must be measured in all three dimensions during use. Such 3D deformations must be measured with a high degree of resolution (<0.1 mm) and cover a broad range of deformation types with corresponding elongations ranging from 150-800%. To overcome these challenges, the general test setup designed for the distributed embedded energy conversion technologies (DEEC-Tec) project, like many automated test setups, has three main systems: mechanical operation, electronics/software, and data collection. Mechanically, the test article is designed to provide uniaxial tensile and compressive stress sufficient to fully actuate the transducer. It is designed to be easily modified to adapt to various forms of transducers, and it is mounted on a controllable turntable to facilitate data collection. Electronically, the test article can be actuated autonomously, with the software being easily modified to provide different loading profiles and applications. For data collection, 3D data are collected via a Polyga Compact S1 scanner, and all force data are collected through a load cell in line with the transducer. Depending on the transducer, other measurements are required, which are handled by an oscilloscope. The three systems work in tandem to provide a robust testing setup that overcomes the challenges associated with analyzing hyperelastic transducers.

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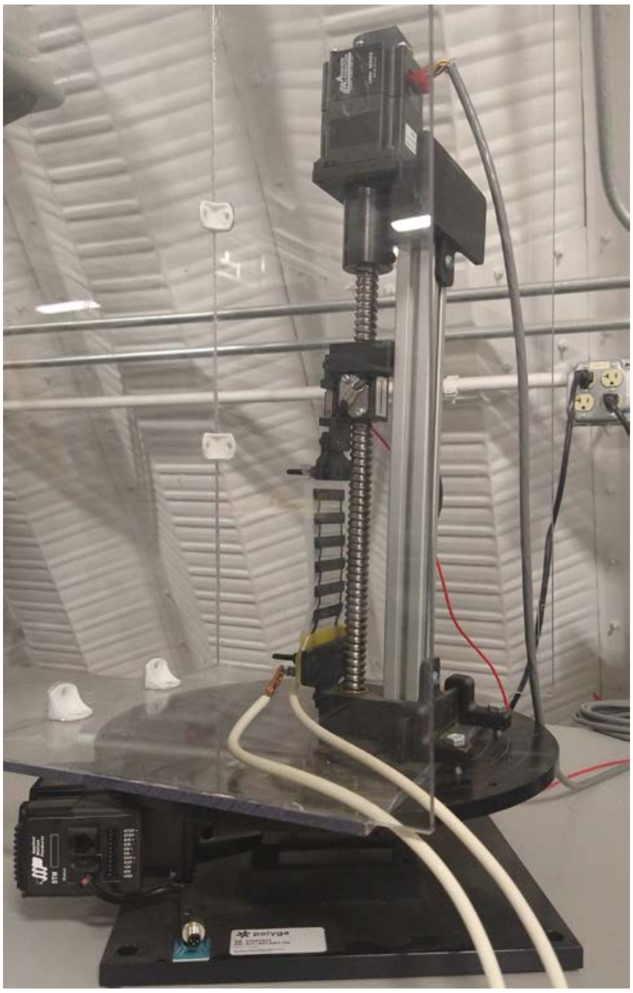

Fig. 1. Picture of the mechanical actuator mounted on the turntable for the general test setup developed for the DEEC-Tec project. A HASEL transducer is mounted in the test setup.

II. MECHANICAL DESIGN

The mechanical design consists of three parts: uniaxial loading of the transducer, adaptability, and the turntable.

A. *Uniaxial loading*

The uniaxial loading for this design is provided through a ball screw and carriage driven by a stepper motor. As shown in Fig. 1, the frame is designed around an aluminium extrusion with 3D-printed endcaps. The endcaps retain the ball screw while bolting securely to the aluminium frame; on the bottom, the endcap has mounting points for a clamp, whereas the top has a mount for a stepper motor. The carriage, depicted in Fig. 2, has 3D-printed parts to mount a load cell (silver-and-red component) and clamp in line with the transducer being tested. Importantly, the clamps and load cell positions are designed to be in line with the transducer such that the loading is purely uniaxial. At low loading, this arrangement is important to ensure the testing remains consistent and repeatable. This setup can provide a large amount of force while enabling fine positional control. Only 50 N of force in tension or compression was required for the testing done with this setup. The absolute force limits of the system are determined by the limits of the load cell—111.5 N (25 lbf) [1] in compression or tension. They were intentionally oversized to allow for unforeseen circumstances and for future tests that might require more force. A greater force could easily be applied to the transducer by swapping out the load cell. The stepper motor is directly connected to the ball screw with a coupler and can achieve a positional accuracy of 3.175 μm for the clamps, given a stepper motor resolution of 0.045 degrees and a ball screw ratio of one rotation to 25.4 mm of travel. The backlash was not quantified, but all tests remained fully in compression or tension; as such, it was not an issue. Additionally, the motor speed was ramped sufficiently to avoid any errors in measurements by sudden starts or stops. The holding torque was enough to prevent any back-driving of the system under load.

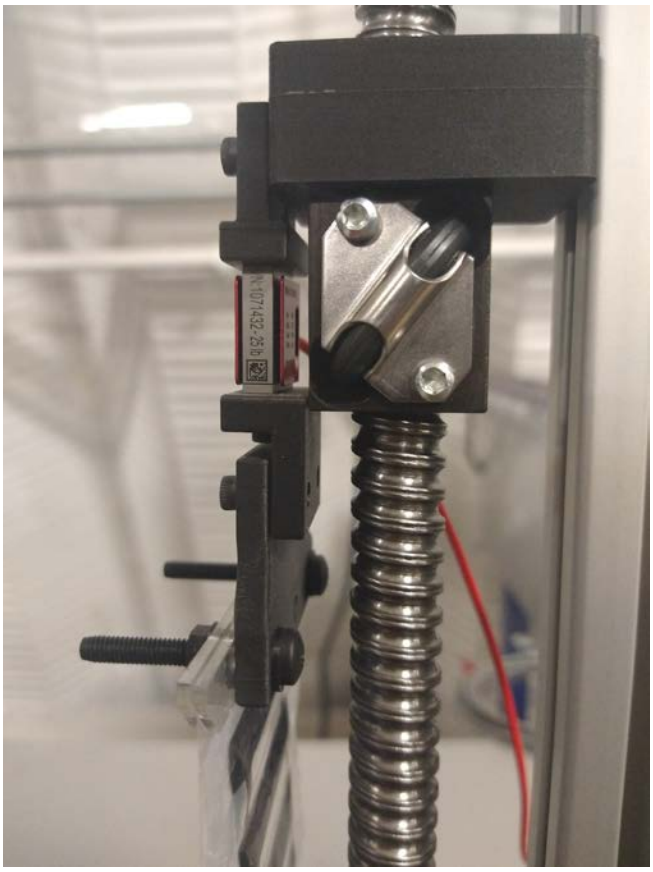

Fig. 2. Carriage of the mechanical actuator, showing the load cell in line with the transducer being tested. From top to bottom: 3D-printed adapter, load cell and ball screw carriage (left and right, respectively), 3D-printed clamp, and HASEL (example transducer).

B. *Adaptability*

The next key feature of this test setup is its adaptability. Everything was designed to be as configurable as possible to suit the varied types of hyperelastic transducers. The DEEC-Tec project has currently explored three types of hyperelastic transducers: hexagonal distributed embedded energy converters (HexDEECs), dielectric elastomer generators (DEGs), and hydraulically amplified self-healing electrostatic (HASEL) transducers. Each transducer necessitates a different clamp or mount to be analyzed correctly. The removable, 3D-printed clamps allow a new clamp to be used without needing to modify the entire setup. Additionally, the structure is composed of t-slot aluminium and 3D-printed components. The entire design can easily be modified to fit other requirements, e.g., larger or smaller transducers, more or less applied force, different stepper motors or hardware, or different mounting options. These modifications would take more effort than simply changing a pair of clamps, but the other systems (electronics/software and data collection) would all remain unaffected by any mechanical changes.

C. *Turntable*

The last part of the mechanical design is the addition of a turntable. The entire mechanical test setup is mounted vertically on the turntable, as seen in Fig. 1, such that the hyperelastic transducer is on the axis of rotation. The turntable was purchased from Polyga and consists of a robust aluminium design powered by a stepper motor. It can support 22.6 kg (50 lbs) and has a mounting plate with a 30-cm (12-in) diameter. Again, the turntable's capabilities allow for greater adaptability in the future with different mounting options and overdesigned weight limits. The rotation of a transducer along its axis is vital for it to be 3D scanned and allows the scanner to see all angles of the transducer while under load to render a complete scan. More details will be provided in the data collection portion regarding how the turntable fits and is calibrated with the 3D scanner.

Fig. 3. Electronics enclosure with the cRIO and modules in the back, the PLC511 motor controller in the middle, and wire connections in the front.

III. ELECTRONICS AND SOFTWARE

The electronics and software are in the same category because this testing setup uses a National Instruments (NI) CompactRIO (cRIO) and LabVIEW to run the majority of the features. The electronics enclosure is shown in Fig. 3. The NI system is used to actuate the testing setup, to measure and record the force data to a tdms file, and to run a graphical user interface to control the setup during testing. For actuation, the stepper motor is controlled by the PCL511 from Anaheim Automation, and commands are sent from the cRIO to the controller through RS-485 serial communication. The cRIO could directly control the stepper motor with the correct module; however, the dedicated PCL511 controller was easier to implement and frees up the cRIO to handle other tasks. It also has a built-in speed-ramping feature that was desired for smooth actuation of the system. To measure the force applied to the transducers, a Miniature S-Beam Jr.® Load Cell from Futek was used in combination with the NI-9237 strain/bridge module. Configuration of the load cell was simple with LabVIEW's built-in libraries, and a motor control library was built around the LabVIEW RS-485 library. To control the setup during testing, a user interface was built in LabVIEW. It displays the force data during the tests and includes buttons to actuate the motors in predefined profiles. These profiles can be easily modified in the user interface to achieve the desired output without having to recode the system. To ensure excess data were not being stored, force data were normally saved to a file only a little before and after each motion.

IV. DATA COLLECTION

The data collection of this device is split up into three parts: the force data (collected by the LabVIEW system), the 3D data, and the transducer-specific measurement data. These systems remained separate for a multitude of reasons. Namely, the time and effort spent on integrating the different data collection systems would only marginally increase the ease of use while making it less adaptable. Moreover, the amount of time needed to integrate the systems would most likely be longer than three weeks—the time it took to complete the tests.

D. *3D scanner setup*

The 3D scanner is the core of this hyperelastic transducer testing setup. There are multiple ways to achieve 3D data; in the end, the Polyga Compact S1 scanner proved to be the best for hyperelastic transducers. To be suitable for hyperelastic transducers, the scanning system must measure deformation in all three dimensions during use, it must measure deformation with a high degree of resolution (<0.1 mm) to capture important features, and it must cover a broad range of deformations with elongations from 150-800%. Three types of scanning setups were explored: stereo digital image correlation (DIC), photogrammetry, and 3D scanning.

Stereo DIC was explored first. With stereo DIC, two cameras take pictures of a speckle-patterned object from different positions. Through software, the speckle patterns can be compared between the two cameras to get 3D data of the surface topology. As the material is put under load, more pictures can be taken, and the comparison of the speckle patterns between different load states can be analyzed to determine the strain of the material. This system has great advantages for measuring small deformations very accurately and can measure in three dimensions; however, it does not meet all the requirements. Stereo DIC fails to capture the range of deformations necessary and struggles to capture 3D features that are hidden from both cameras, being only suitable for objects that are close to planar.

Next, photogrammetry was explored. Photogrammetry consists of taking multiple pictures of an object from many different angles and, via software, correlating the pictures to produce a 3D model. In theory, photogrammetry meets all the requirements for hyperelastic transducer testing. It can measure in all three dimensions, it can measure with a high degree of accuracy depending on the lens and camera used, and it can measure any amount of deformation. However, in practice, the limits of photogrammetry become apparent. First, the accuracy of the measurement is limited. Theoretically, the correct lens and camera can achieve any resolution, but trying to balance field of view to capture large deformations conflicts with the accuracy requirements. In our testing, the accuracy of the system was insufficient. Another issue with photogrammetry arose with the software. In most cases, it is a “black box”—proprietary software where the inner workings are unknown to the user. This situation became an issue during testing, where the software would incorrectly assume a hole or feature was an error and either fill in or skip the feature in the final 3D model. Another issue arose with lighting and internal cavities. The lighting requirements for photogrammetry are very stringent, which posed issues wherein internal features did not receive enough light and therefore were ignored by the photogrammetry software in the final model. These challenges could be overcome to some degree with time and effort; however, 3D scanning met our requirements with an out-of-the-box solution.

Fig. 4. Polyga Compact S1 scanning setup with turntable. The mechanical actuator and transducer (HASEL) are rotated together to achieve a complete scan while under load.

Fig. 5. Genvolt high-voltage power supply with activation switch (left), and high-voltage measurement and actuation circuit in a blue electrical enclosure (right).

3D scanning was the final, and ultimately best, option for analyzing hyperelastic transducers. 3D scanning—in this case, blue light scanning—projects a series of parallel lines onto a part and takes pictures from two different camera angles, much like stereo DIC. These two pictures are correlated, and the amount of deviation in the lines (from parallel) produces a 3D model. With this alone, the 3D scanner can produce a 3D model of the object with high accuracy (0.035 mm), high resolution (0.085 mm) [2], and a field of view that is large enough to capture the 150-800% deformation of the hyperelastic transducers. To achieve a full 3D model of the transducer, the scanner is calibrated with the turntable, and multiple scans of the object from different angles are aggregated. The full 3D scanner setup is shown in Fig. 4. FlexScan3D was the software used to produce and compile the models for this test setup. Natively and with an out-of-the-box solution, the 3D scanner solves the main issues with photogrammetry. It has great accuracy without sacrificing field of view. Also, its software does not incorrectly add erroneous data to the model and instead will display a gap in the model if bad data are collected. Additionally, there are no lighting requirements to correctly replicate internal features, as the scanner itself projects the required light onto the object.

A. Transducer-specific measurements

The last consideration for this hyperelastic transducer testing setup is the addition of any transducer-specific measurements. Each transducer has specific requirements; as such, the measurements for the transducers in this setup are handled by an oscilloscope and power system that are separate from the other forms of data collection. This setup makes the system very adaptable and is necessary for the variable-capacitance-based transducers that we are testing in the DEEC-Tec project. HexDEECs, DEGs, and HASEL transducers are all based on variable capacitance, and to achieve high energy production, they must be brought to high voltage (2 kV-10 kV). As such, a circuit was designed to provide high voltage to the transducers from a Genvolt power supply (Fig. 5). The circuit has probe attachment points to safely hook up the oscilloscope to the high voltage and measure the responses and power generation capabilities of the hyperelastic transducers under load. Because this high-voltage circuitry is kept completely separate, the test setup has less risk of high voltage damaging other components, increased control and safety while operating at high voltage, and the ability to gather measurements during a potential failure, short, or unexpected occurrence in the transducer.

Fig. 6. Full DEEC-Tec testing setup for hyperelastic transducers. From left to right: High-voltage power supply, mechanical actuator and turntable, and NI system and electronics. Not pictured: oscilloscope and 3D scanner setup.

V. CONCLUSION

Hyperelastic transducers are an exciting avenue of research for the DEEC-Tec and marine renewable energy domains. Their advancement opens doors to enhanced ocean wave energy conversion with improved conversion performance and converter resilience. However, these hyperelastic transducers pose unique challenges in their testing and development. This paper outlined a general testing setup that can handle these various forms of hyperelastic transducers in a way that is easily modifiable to test any number of different designs and configurations. This testing framework will be constantly iterated and improved upon as more hyperelastic transducers are developed. Some pending improvements include adding native time syncing, increased data processing, and increased automation of certain tasks. The full, general, and accurate testing setup for hyperelastic transducers is depicted in Fig. 6.

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DISCLAIMER

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