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Final Report for the WPTO Seedling Project Phase 1

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1 Overview of Piston Seals in Wave Energy Converters

Hydraulic cylinder seals are a critical component of hydraulic power take-off (PTO) systems in wave energy converters (WECs) [1, 2]. Primary hydraulic piston seal wear is a major concern for the longevity of hydraulic PTOs, especially in the context of the effort and expense associated with seal replacement. Piston seals, made from polymeric elastomers, are used to contain and isolate high pressure fluids within PTO systems. A specific challenge for WEC designers is knowing, with confidence, the relative expected lifetimes of commercially available seals and seal materials for the unique long travel and continuous use case of WEC hydraulic systems. This information is critical to accurately determine operating expense (OPEX) and levelized cost of electricity (LCOE). If failures of seals occur earlier than their designed lifetime, the estimated operations, and maintenance (O&M) and LCOE costs may double based on estimation. Unfortunately, information from seal manufacturers on longevity in these applications is not generally available and quantitative performance comparison between different manufacturers is not available, creating significant uncertainty on use of hydraulic PTO system in wave power generation.

In this project, PNNL, with advice from different WEC device and seal manufacturers, has created a framework to address the industry need for available, dependable and comparative data for seals and seals materials for WEC hydraulic applications including piston seals, glide rings, and shaft seals. Commonly used and candidate seal materials were identified and available information on the materials such as mechanical and fatigue performance, chemical (fluid) compatibility, and cost has been compiled. Hardware and strategy for bench scale measurement of key materials and seal performance and pathway for publicly available library of hydraulic seal materials, properties, suppliers, and options have also been identified for future implementation.

The results of this project were presented at WPTO Seedling Symposium 2023 and OCEANS 2023. The results of the literature review including identified polymer seals and ideal operating conditions were summaried and compiled to a database WEC-SealsDB hosted locally at PNNL.

2 Accomplishements: Phase I Seedling

2.1 Major objectives

The major objective of this project was to establish framework for identifying seal material options for WEC hydraulic systems, standards for material performance and longevity comparison, and strategy for laboratory testing of materials and publicly available WEC seal information database by literature review and collecting feedback from seals and WECs manufactuerers as shown in Fig 1. The team has successfuly finished the two tasks in the WPTO Seedling proposal.

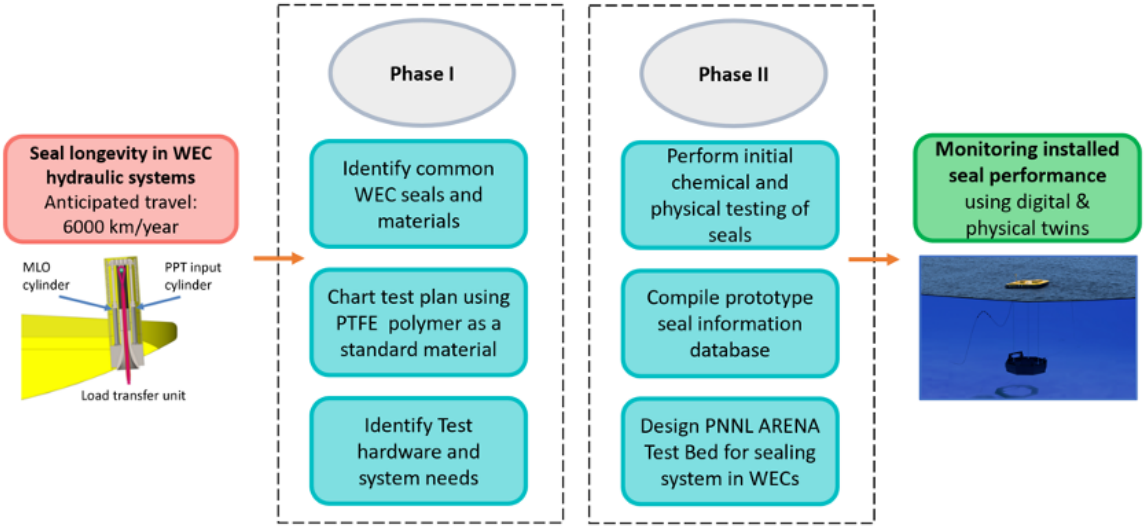

Figure 1: Flow chart of the study of durability of piston seals in hydraulic PTO in WEC systems. The phase I focuses on literature review on potential WEC seal candidates and test rigs.

2.2 Accomplishments under objectives

For Phase I Task 1, Frame the need and opportunity, literature review was done to identify and collect seal candidates based on different WEC applications, catalog seal vendors, and available degradation knowledge. First, papers were found related to WEC devices, but only several of them were related to seal degradation and no publicly available database was found to address the concern about WEC seals durability. Secondly, the team created a questionaire to gather information about different wave energy converters, types of polymer seals, and their applications. The survey was sent out via Portal and Repository for Information on Marine Renewable Energy (PRIMRE) Blast at PNNL. Based on the current responses from several manufacturers, there is a data gap in the durability of seal materials used in WEC devices and a testbed for comparing durability of different seal materials for WEC devices can significantly accelerate R&D activities.

For Phase I Task 2, test hardware and system needs have been identified. The development of WEC devices is in its early stage. Limited number of test rigs have been reported. To compare different seal materials from different manufactuerers, our team has obtained materials based on the list of potential candidates indentified in Task 1. A test plan using reciprocating wear test rig is proposed with potential seal material candidates such as polytetrafluoroethylene (PTFE), nitrile butadiene rubber (NBR), polyurethane, ultra-high-molecular-weight polyethylene (UHMWPE). The properties such as wear resistance, friction coefficient, surface chemical information, and tenstile strenght will be monitored before and after wear test.

The team also built up a WEC seals database, called WEC-SealsDB as shown in Table 1, to save and update the data collected in this project using open source database and programming languages such as CrateDB, Python, and R. The data can be easily transferred to a DOE-hosted seal information database. The information can also be shared through AWS Cloud to make it publicly availble for the WEC industry. This subtask was planned as a subtask in Phase II but the

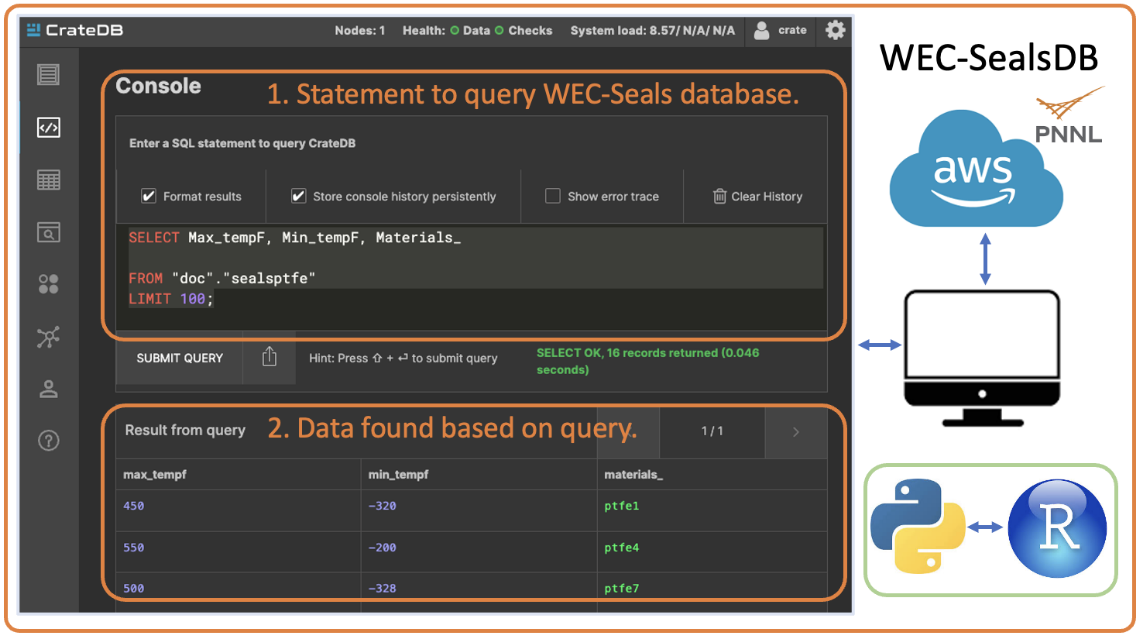

Figure 2: WEC-Seals database (WEC-SealsDB) hosted in a local computer or AWS Cloud. The database was set up using open-source database CrateDB and Python.

team was able to finish it in this Phase I.

2.3 Dissemination of results to communities of interest

During the WPTO seedling Symposium 2023, the team presented initial results and a questionaire to other researchers in Session 1, Track 2: Marine energy inspection, maintenance, and operation. The results of this project were accepted as an oral presentation in OCEANS 2023 conference hosted by IEEE Ocean Engineering Society and Marine Technology Society. A conference paper, Investigating the Longevity of Hydraulic Power Take-Off Piston Seals in Wave Energy Converters, was also published by the conference. This project was able to support conference travel for a postdoc, and three postdocs were able to contribute to this project with different background in composites and tribology. To fill the data gap in durability of seal materials for WEC devices, the team worked with Oscilla Power one a TEAMER proposal to test and compare seal materials at PNNL.

3 Conclusion

In this project, commonly used and potential seal material candidates for WEC devices have been identified by literature review and a survey sent to WEC and seal manufacturers.The team also cataloged hydraulic seal venders, available seal options, and operating conditions. However, a primary concern is that the lack of durability data of seals in WEC devices has created uncertainty in the design, development, and deployment of PTO systems for WEC. Although this work extensively reviewed seal materials, slection cirteria, degradation mechanisums, and material properties, there is a need for further resarch to test durability of different seal materials and predict the service lifetime of seals used in hydraulic PTO systems. By filling the data gap in durability of seal materials in WEC devices, the reliability of the WEC devices can be improved significantly hence make it more economically competitive with other forms of renewable energy.

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Materials	The Ranges of Materials Properties						Suggested operating range		
	Hardness (a.u.)	Tensile Modulus (MPa)	Tensile Strength (MPa)	EAB (%)	Abrasion Resistance (mm^3)	Density (g/cm^3)	Pressure (bar)	Temperature (F)	Velocity (m/s)
Thermoplastic Polyurethane (HPU^{TM})	87 - 97 A	7 - 207	30 - 97	300 - 600	7 - 29	1.1 - 1.2	25 - 700	-75 - 257	0.4 - 2
Nitrile Butadiene Rubber (NBR)	66 - 91 A	11 - 17	7 - 27	130 - 310	90 - 100	1.0 - 1.3	25 - 700	-70 - 392	0.5 - 1
Polytetra fluorethylene (PTFE)	51 - 67 D	300 - 2800	15 - 32	100 - 390	-	2.2 - 3.1	69 - 690	-450 - 575	1 - 40
Fluorocarbon Rubber (FKM)	72 - 90 A	> 6	7 - 15	190 - 25	150 - 175	1.8 - 2.5	25 - 250	-31 - 446	0.5 - 1
Ethylene Propylene Rubber (EPDM)	70 - 90 A	-	11 - 18	110 - 165	120	1.1 - 2.5	-	-70 - 302	-
Vinyl Methyl Silicone Rubber (MVQ)	70 - 90 A	> 4	> 6	120 - 175	-	1.5	-	-75 - 400	-
Polyether Ether Ketone (PEEK)	86 - 87 D	3500- 14000	96 - 226	1.3 - 50	-	1.3 - 1.4	-	-70 - 500	-
Polyethylene	58 - 64 D	570 - 675	17 - 49	50 - 350	-	0.9	-	-324 - 194	-
Polyoxy methylene (POM)	82 - 88 D	2900 - 3000	64 - 85	24 - 40	-	1.4	-	-58 - 212	-
Polyamide	80 D	1500	50	20	1365	1.1	-	-	-

Table 1: Potential WEC seal material candidates with corresponding publicly available materials properties and suggested operating range [3]. (These values may change depending on primary seal material, presence of additives, varying seal profiles such as material used for backup rings, O-rings, and energizers.)

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