



THE UNIVERSITY of EDINBURGH
School of Engineering

Commissioning of rig at JC

CCUS Innovation 2.0

Key Knowledge Deliverable 4.1

August 2024

Key Knowledge Deliverable Cover Sheet

This Key Knowledge Deliverable (KKD) has been produced by The University of Edinburgh as part of the Department for Energy Security and Net Zero £1bn Net Zero Innovation Portfolio (NZIP) - CCUS Innovation 2.0 programme. The document is reflective of the status of the project at the time of writing. The material presented could have been subject to change as the project matured. These documents should not be considered a full representation of the final project.

Supercritical CO₂ power cycles are a novel process currently under consideration across the energy sector, including for carbon capture, usage, and storage (CCUS). Compared with conventional steam-driven systems, they boast higher cycle efficiencies, reduced emissions, and compact turbomachinery, resulting in reduced fuel and water consumption and lower capital expenditures. Through this project, John Crane—in collaboration with Cranfield University and the University of Edinburgh—aims to develop an innovative, uncooled high-temperature dry gas seal solution for supercritical CO₂ power cycles by using new simulations, material recipes and testing validations. This innovation, expected to work at high temperatures and pressure values, should significantly reduce leakages and potentially even enable the inclusion of an additional turbine expansion stage. Through a supercritical CO₂ cycle efficiency improvement, overall emissions will be significantly reduced, cutting the cost of CCUS and accelerating the adoption of supercritical CO₂ power cycles into existing and future power plants.

This KKD provides the design philosophy of test rig and related commissioning report.

KKDs to be released in full:

D2.2 Performance of 3D printed discontinuous fibre reinforced polymer composites.

D3.1 Conceptual design of the rig

D3.2 Component commissioning of CO₂ source (subsystem 1)

D3.3 Integrated sub-systems test - Shakedown test

D4.1 Commissioning of rig at John Crane

D4.2 Integrated system + seal rig commissioning at Cranfield University

KKDs to be released after being modified with critical information removed:

D3.4 Design and build of static/ dynamic test cell for 300 bar, 250 °C

D3.5 Design and build of static/ dynamic test cell for 200bar, 600 °C (CO2)

D4.3 Test of rig operating at 200 bar, 300 C (CO2)

D4.4 Testing to 200 bar, 250 °C

D4.5 Testing to 200 bar, 500 °C (CO2)

D5.1 Design/ build test seal with new seal head module/ bd-module

D5.2 Dynamic seal testing/ Benchmark testing, 140 m/s, to 200 bar, to 200 °C

D5.3 Dynamic Seal Testing, 140 m/s, to 200 bar, to 200 °C



28th August, 2024

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1 Introduction

1.1 Project overview

Supercritical CO₂ (sCO₂) power cycles represent a cutting-edge development in the energy sector, with broad applications that extend to carbon capture, usage, and storage (CCUS). These cycles are gaining increasing attention for their potential to revolutionise power generation and environmental impact. Compared to conventional steam-driven systems, sCO₂ power cycles offer a range of compelling advantages, including high cycle efficiency, reduced emissions, compact turbomachinery, and reduced fuel and water consumption. In pursuit of these benefits and to overcome critical challenges, John Crane, in collaboration with Cranfield University and the University of Edinburgh, has embarked on a visionary project. The project's objective is the development of an innovative, uncooled high-temperature dry gas seal solution tailored specifically for supercritical CO₂ power cycles. This endeavour involves cutting-edge simulations, advanced material recipes, and rigorous testing validations.

1.2 Project scope

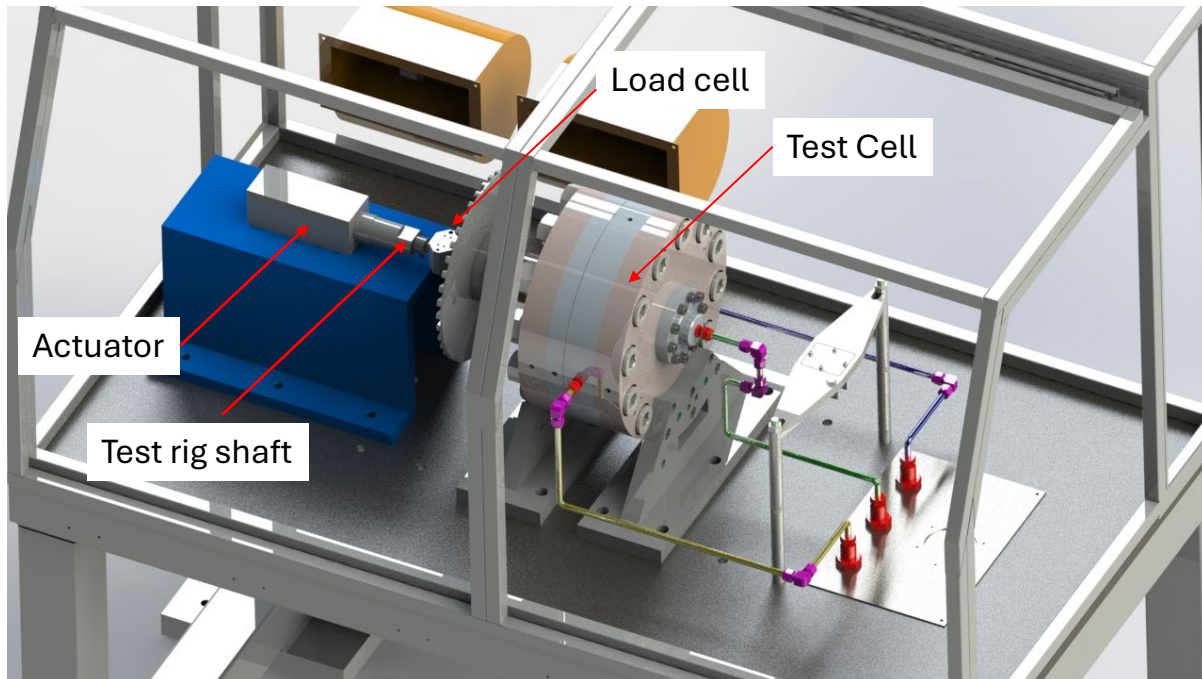
The project scope includes the design, fabrication, and laboratory testing of critical DGS components (balance diameter sealing module) and system prototypes for application in rotating equipment (turbine and compressors) used in sCO₂ power cycles up to typical pressures and temperatures of 200 barg and 500 °C. The project also includes the design and commissioning of test equipment to verify and demonstrate the innovative DGS concept/prototype. Modular testing will be conducted at John Crane Slough and Cranfield University (CU) using the University's existing sCO₂ test loop modified to the requirements of this project. The project scope excludes dynamic seal testing of the DGS prototype at sCO₂ conditions but in air at maximum velocity (140 m/s) and pressure rating (200 barg), which is expected to occur following the completion of this project.

This report provides the design philosophy of test rig and related commissioning report.

2 Rig design

Figure 1 shows a 3D CAD representation of the sCO₂ balance diameter seal rig, designed to integrate with the sCO₂ loop provided by Cranfield University. The sCO₂ balance diameter seal rig design replicates an existing test rig by John Crane, but with modifications to test seals at 500 °C. The test rig comprises a test pod (test cell) where the sealing test polymers are mounted. The rig includes a shaft driven by an actuator, which moves the balance diameter sleeve axially within the test cell. This setup simulates the movement and conditions that the balance diameter seal experiences during dry gas seal (DGS) operation. A load cell is positioned between the actuator and the shaft to measure the frictional resistance of the balance diameter seals.

Figure 1: sCO₂ balance diameter rig

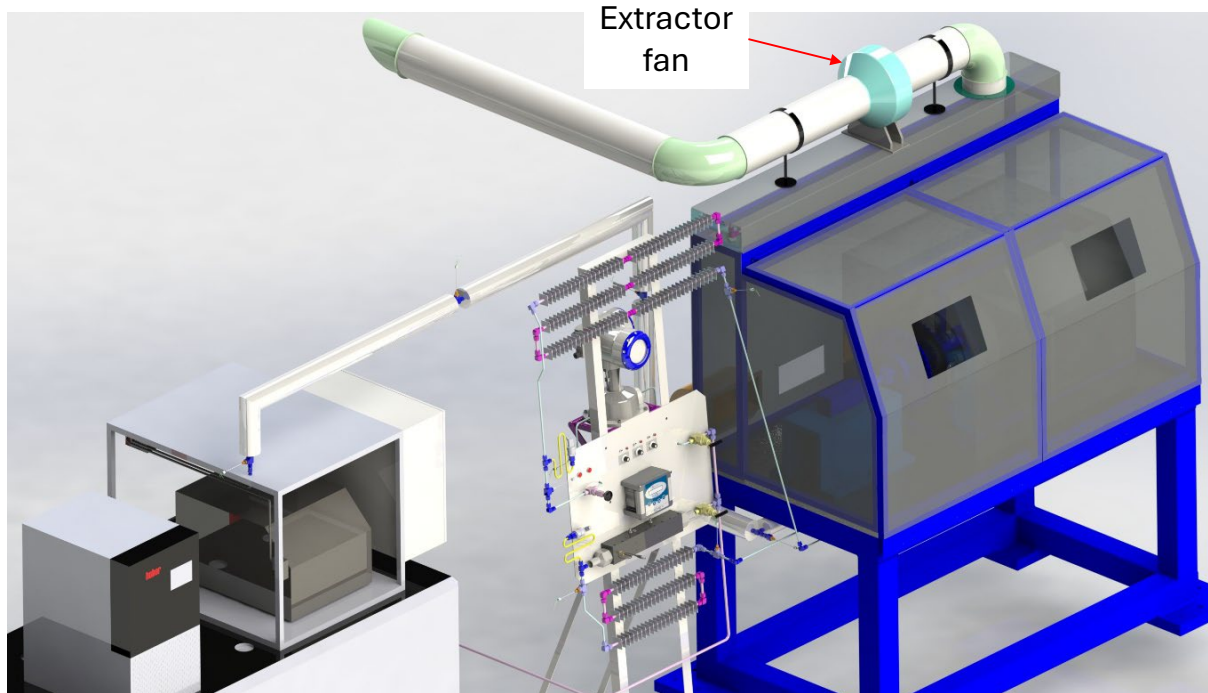


This test rig is an essential component in evaluating the performance and reliability of balance diameter seals under sCO₂ conditions. The modifications ensure the rig can withstand the increased thermal stresses associated with higher operational temperatures, allowing for more accurate and relevant data collection for high-temperature applications.

Key features added over the standard John Crane test rig design include:

- **Heater band:** Like John Crane's current BD rig, the test pot is wrapped by a heater band. The heater band is rated to 600 °C and is covered by an insulation jacket to prevent heat dissipation from the testing cell. This heater band design minimizes the temperature difference between the sCO₂ input and the test pod, thereby improving testing efficiency. By maintaining a consistent temperature, this setup ensures more reliable and accurate test results, which are essential for evaluating the performance of components under high temperature sCO₂ conditions.
- **Fan blower:** Unlike the current BD rigs, this design incorporates two blowers (Orange box in Figure 1) into the rig. The blowers cool the rig cavity, ensuring that the load cell and sensors operate within their temperature limits and by maintaining optimal temperatures for these components, accurate and reliable data collection is ensured.
- **Extractor:** The extractor (Figure 2) is installed to collect the air and any CO₂ leakage. The system ensures that any escaping gases inside the test rig are safely managed and directed away from critical components, maintaining the integrity and safety of the testing environment and laboratory, where the rig is installed.

Figure 2: Extractor for sCO₂ BD rig



3 Rig commissioning

3.1 Test/ Pass-off criteria

A shakedown test was performed at John Crane in Sough prior to the rig being despatched to Cranfield University. As this shakedown test is designed to verify the correct functioning of the rig mechanical parts, electrical components and control system, actuator, heater, and load cell, tests were limited to 200 °C for safety reasons. The actual commissioning of the rig to 500 °C will be conducted at Cranfield University with the sCO₂ loop connected.

- **Actuator:** The actuator should be able to move the shaft inside the testing cell by +/- 3 mm. The shaft movement will be detected by an Encoder laser.
- **Heater:** The heater should be able to heat the center core of the testing cell up to 200 °C where the sealing polymer is located. The inside the testing cell will be measured using thermocouple that being fitted inside the cell close enough to the sealing polymer.
- **Load Cell:** The load cell should work properly.

3.2 Test results

Figure 3 shows the records of the temperature, friction force and displacement of the shaft during the shake-down test. The test specification is list in the Appendix. It confirms that heater is functioning and reaching to the desired temperature, 200 °C. The load cell picks up the friction force value that shaft experience while moving axially. The recorded load cell values

range from -80 to -20 N, due to inherent compression or tension in the threads of the load cell, which affects the initial zero-point calibration and results in the observed force measurements. The load cell will be re-calibrated during the commissioning at the Cranfield facility. The encoder laser measured initially a shaft displacement of +3.00 and -3.5 mm. The discrepancy between the positive and negative travel was caused of the laser position, which initially was positioned incorrectly, beyond its reading capability. By re-positioning the laser, this issue was resolved, shown in Figure 4.

Figure 3: Shake down test

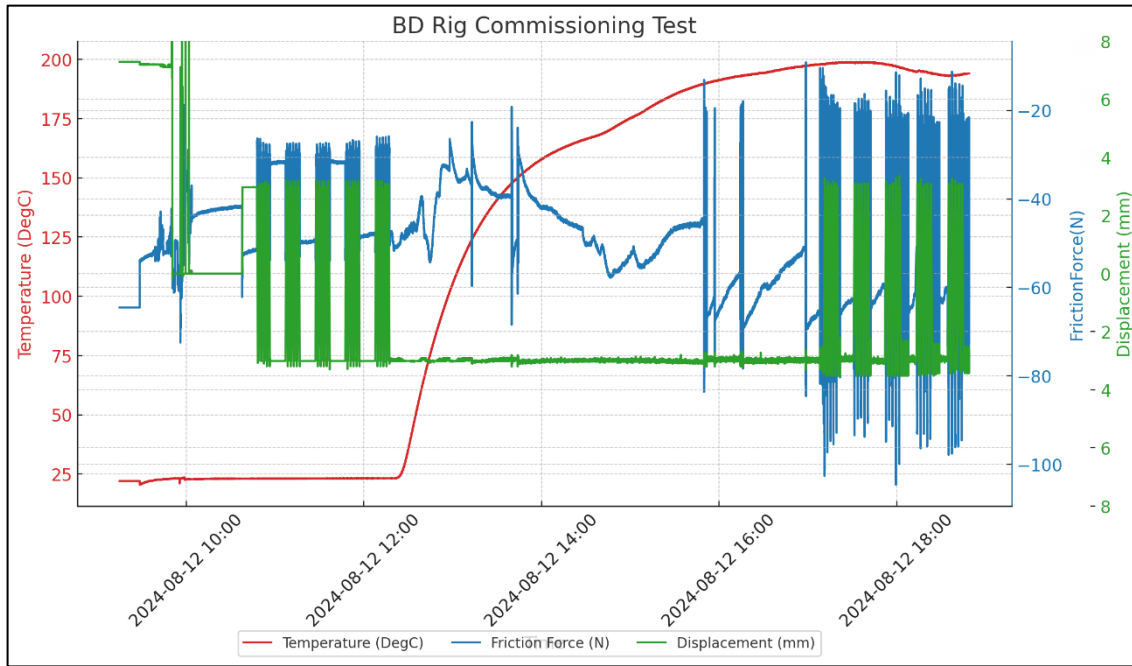
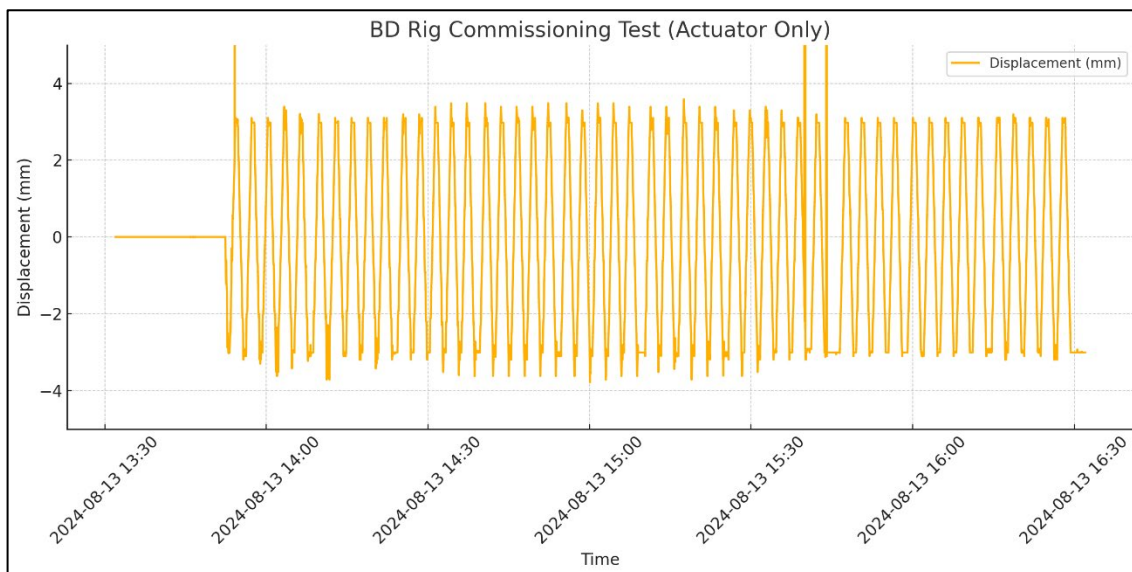


Figure 4: Shake-down test for the actuator check



4 Conclusions

The shake-down test confirms that the sCO₂ BD rig successfully meets its design objectives. The forthcoming commissioning test at Cranfield will verify whether the ventilation system effectively maintains the actuator temperature close to ambient levels

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