High Powered Piezoelectric Actuator for Seismic Actuation

David Muse, dmuse@piezojena.com

Intro:

Technology can always be tied back to the resources of the Earth. That is why Geology is extremely important to understand. Specifically, geologic behavior and its effects on modern technology. Seismic activity and rock geomechanics impact a diverse portfolio of modern industries such as energy, infrastructure, and mining. These industries in turn cascade into smaller divisions which have impacts on everyday life. ***piezosystem jena*** has partnered with **Sandia National Labs** to improve the current understanding of geomechanics and seismology for carbon sequestration. This area is one of the most important fields of study in the ongoing battle against climate change. In development with Sandia, ***piezosystem jena*** has constructed a powerful device for the future of carbon sequestration and subsequently a multitude of applications for actuation under extreme pressure conditions.

Application background:

Carbon sequestration is the process of compressing CO_2 taken directly out of the atmosphere with Direct Air Capture (DAC) into a liquid state. The liquid is then pumped deep below the earth for storage. This capture and storage of CO_2 is the leading method in development to remove CO_2 emissions from the air to combat climate change. With success of this technology, the impact of CO_2 emissions from manmade operations could be greatly reduced. The drive towards the success of this process has led many companies and institutions, both federal and private, to finance large scale research and development of both carbon capture and carbon storage.

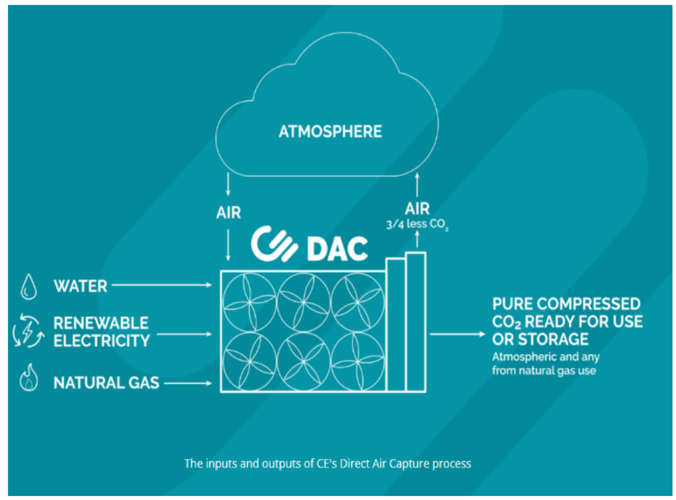

Figure 1: Direct Air Capture principle by Carbon

A large majority of national labs in the United States have been funded for this research including but not limited to Argonne, Lawrence Livermore, **Sandia National Labs**, National Energy Technology Labs, and the National Carbon Capture Center[1]. The US has also partnered with various institutions around the country to study different geologic settings for carbon sequestration. In the private sector, companies are looking to commercialize the process to build capital and incentivize investors for the technology. From small startups that solely focus on carbon capture and sequestration to large corporate energy companies like ExxonMobil and Linde, the carbon capture field is rapidly turning into a competitive market[2]. Some companies, such as 1PointFive, have gone as far as to declare their goal is to meet criteria set forth by environmental institutions around the world to establish enough sites to remove 20 billion tons

[1] DOE 2019

[2] Yanez, A, 2020

of carbon from the atmosphere per year. If successful this could prevent a global temperature increase of 1.5 °C, which experts advise as the tipping point of global warming[3]. With such a rapid moving and essential industry, it is crucial to determine how to safely utilize and store vast quantities of CO_2.

The sequestration process is essential to determining a correct solution. With this method already exists the means to capture the CO_2 and store it as well as a financial and social drive to understand and develop a working solution. In 2013, the USGS released the first ever comprehensive, nation-wide assessment of geologic carbon sequestration, which estimates a mean storage potential of 3,000 metric gigatons of carbon dioxide in the US alone[4]. What remains is to reduce the risks and establish safety precautions required when storing CO_2 under high pressure. Sandia National Labs has been tasked with investigating seismic activity and its impact on porous rock saturated with millions of tons of pressurized CO_2.

High Power Shaker for Seismic Studies

To study the effect of seismic activity, **Sandia National Labs** is creating an environment to simulate these conditions on the lab bench. Rock cores are removed from up to 5 km below the surface of the earth from areas determined to be optimal for sequestration. Carbon sequestration is simulated by putting the rock core within a pressurized vessel, filling it with CO_2 that has undergone the sequestration process, and then heating the vessel up. This replicates the air pressure and thermal conditions of the porous rock that the CO_2 is stored in. To recreate the physical pressure of the overburden, an MTS load frame applies up to 142 kN of pressure via a piston that actuates through a port in the vessel. The final step of the process would be to pass simulated seismic waves through the rock core

Figure 2: High Power Seismic Shaker by piezosystem jena

and study the reaction. To accomplish this goal, **Sandia National Labs** required an actuation system that could be integrated within the MTS load frame, provide actuation to the rock core up to 200 Hz with nanometer motion precision, all while surviving 142 kN of pressure.

With such high requirements set, Sandia labs contacted piezosystem jena's ***hpower*** division to develop a new actuator not yet existing in the industry. To withstand the force, ***piezosystem jena*** created a new kind of actuator that utilizes three high powered piezo's working in parallel, effectively tripling the blocking force and load capacity of a standard ***hpower*** actuator which already leads its competitors in these areas. The system precisely distributes the applied load across the three piezo's using a specially developed support system, allowing all three ceramics to work together as one motion against one force. A single signal is sent from the amplifier that is split in parallel across the piezo's, ensuring that the same exact inputs are received. The special structure concept allows the system to actuate in sync with a single uniform motion. Without this achievement, an unbalanced load or out of sync motion would cause the system to fail due to irregular strains. The assembly of the finished system is so precise that at the full extension of 9 µm, an absolutely

[3] Rogelj, 2019

[4] Blondes, 2019

straight movement is realized with hardly any measurable deviation.

Sandia National Lab's aim was to translate up 75 nm of compression at up to 200 Hz to the rock core. To accomplish this, ***piezosystem jena*** considered the stiffness of each component, from the piston within the frame all the way down to various types of rocks that would be put through this test. Stiffer samples can limit the total displacement, so the system was built with high enough force to counteract this. With this accounted for, the required displacement can be achieved on samples as stiff as 350 kN/µm, far surpassing the stiffness of even granite at 2.2 kN/µm. The high force ability of the developed system means that for future experimentation purposes, the actuator can cause displacements of average rock cores between 4.4 µm and 6.6 µm for standard high pressure testing machines. The frequency of the actuator easily achieves the required 200 Hz. Due to the high resonant frequency of the system of 3.5 kHz, higher excitation above 200 Hz is also possible.

Testing with IFW Jena

This first of its kind system was tested at the **Günter-Köhler-Institut für Fügetechnik und Werkstoffprüfung GmbH (ifw Jena)** in Jena, Germany. ifw Jena is a research and service partner for industrial and service companies as well as for research institutes, universities and private individuals. Its materials testing laboratory has been monitored by DAkkS since

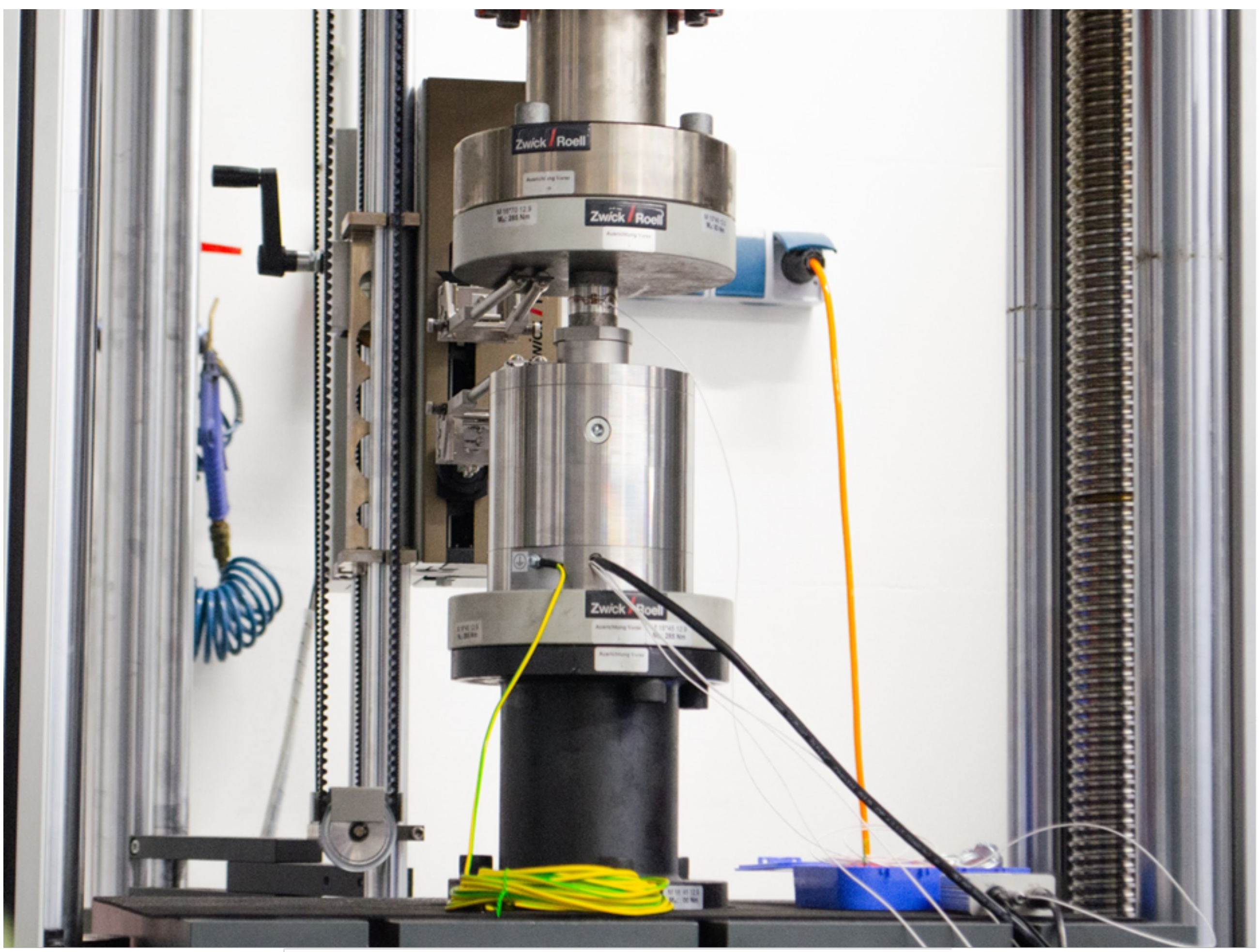

Figure 3: High Powered Seismic Actuator at IFW Jena test facility

1998 and is currently accredited according to DIN EN ISO/IEC 17025:2018 (accreditation number D-PL-17030-01-00). For the testing of the new actuator, ***piezosystem jena*** used the latest material testing machine of the institute - ZwickRoell Vibrophore 250.

The actuator was thereby equipped with additional sensor technology. An integrated strain gauge placed on each piezo stack allowed for continuous monitoring of the stack and its expansion. The data was then cross referenced with the extensometer of ifw Jena's testing machine, which was placed between the cover plate of the actuator and the upper compression plate of the machine. Together, they were used to monitor the expansion of the ceramics and the total actuator as voltage was applied.

For monitoring the force applied to and output by the new actuator, ***piezosystem jena*** developed a new high force sensor, H-FS35, to be placed between the testing machine and the actuator. The design was based on the off the shelf high force sensor solutions ***piezosystem jena*** already manufactures and supplies for force sensors for.

Once all of the sensors were set up, the actuator was subjected to up to 150 kN of pressure. Using ifw Jena's software, ***piezosystem jena's*** was able to capture the performance of the system at force:

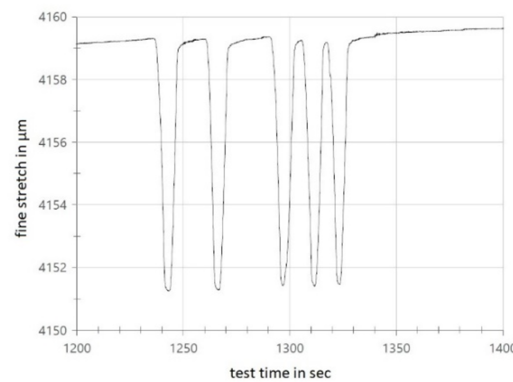

Figure 4: 1000 V signal displacement tests at

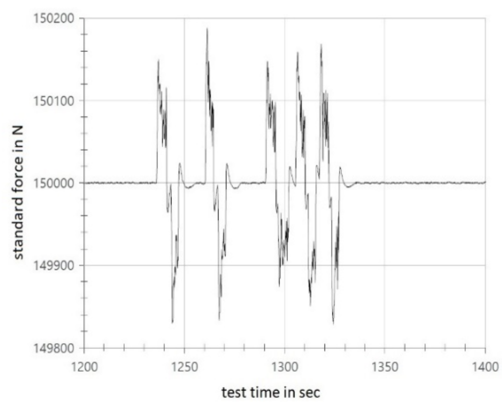

Figure 5: Force Measurement of 1000 V signal at 150 kN

With a 1000 V signal, the system achieved nearly full stroke, about 8 µm with even force distribution across all the piezo's. The test replicated the maximum force conditions that the piezo will be used in for carbon sequestration testing, proving the system is robust and ready to be implemented. The actuator specs are shown below:

Maximum amplitude	µm	9
Electrical capacitance	µF	1,4
Voltage range	V	0 … +1000
Blocking force (Large signal)	kN	66
Stiffness (Large signal)	kN/µm	9
Resonant frequency (Stand alone)	kHz	3,5
Permissible load	kN	150
Dimensions (h x d)	mm	180 x Ø145
Temperature range	°C	-20 to +80 (-4°F to 176°F)
Material	-	stainless steel
Weight (Without or	kg	16
With cables)		18,5

Figure 6: High power seismic actuator specification sheet

In Conclusion

This new actuator is the first system for material testing under very high loads of its kind that allows for samples under pressure to be tested across a full range of frequencies. With its compact size, it can easily be implemented into any existing load frame, allowing for an entire new range of testing for users who already own such a system. This device is critical for developing new studies such as the impact of seismic activity for carbon sequestration done by **Sandia National Laboratories**. It also has the ability to surpass these required specs and provide compression up to 6 µm and reach frequencies 3500 Hz, allowing for a wide range of test capabilities to be added to many MTS or similar load frames.

If you are interested in our new actuation systems, or you're ready to see how we can bring your applications to the next level, contact us at: https://www.hpowermotion.com/contact or contact(at)psj-usa.com

References

1PointFive. (2021). Direct air capture. 1PointFive. Retrieved October 15, 2021, from https://www.1pointfive.com/.

Blondes, M.S., Merrill, M.D., Anderson, S.T., and DeVera, C.A., 2019, Carbon dioxide mineralization feasibility in the United States: U.S. Geological Survey Scientific Investigations Report 2018–5079, 29 p., https://doi.org/10.3133/sir20185079

Carbon Engineering. (2021, February 1). *Direct Air Capture Technology*. Carbon Engineering. Retrieved October 15, 2021, from https://carbonengineering.com/our-technology/.

DOE. (n.d.). *Regional Carbon Sequestration Partnerships (RCSP) initiative*. netl.doe.gov. Retrieved October 15, 2021, from https://netl.doe.gov/coal/carbon-storage/storage-infrastructure/regional-carbon-sequestration-partnerships-initiative.

Rogelj, J., D. Shindell, K. Jiang, S. Fifita, P. Forster, V. Ginzburg, C. Handa, H. Kheshgi, S. Kobayashi, E. Kriegler, L. Mundaca, R. Séférian, and M.V.Vilariño, 2018: Mitigation Pathways Compatible with 1.5°C in the Context of Sustainable Development. In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]. In Press.

Yanez, A. (2021, September 29). *11 companies across Greater Houston could capture, store carbon dioxide emissions underground in the Gulf Coast region in the future*. Communityimpact. Retrieved October 15, 2021, from https://communityimpact.com/houston/bay-area/city-county/2021/09/29/11-companies-across-greater-houston-could-capture-store-carbon-dioxide-emissions-underground-in-the-gulf-coast-region-in-the-future/.

https://www.ifw-jena.de/werkstoffprueflabor/

https://www.zwickroell.com/