Assembly Instructions

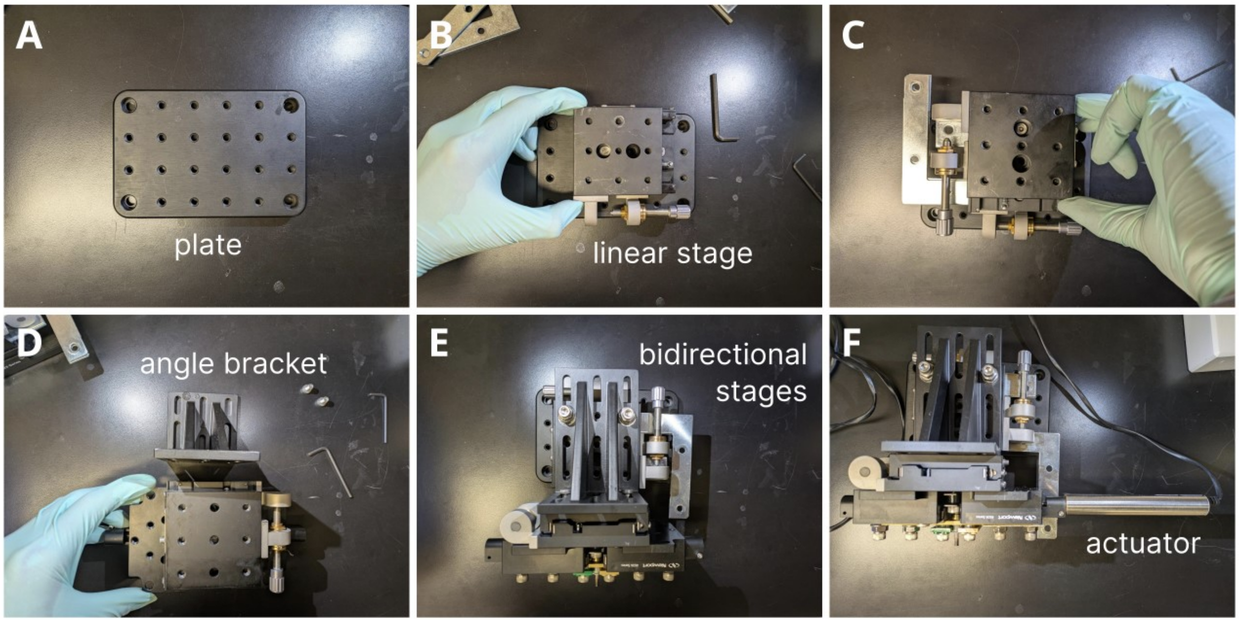

Fig 1. Step-by-step pictures of the assembly of the bidirectional mechanical tester

The core of the tensile tester is made up of three micrometer-driven linear stages (Newport Corporation #423-MIC) and an angle bracket (Newport #360-90) bolted together in such a fashion as to allow 3D positional adjustments (Fig 1). This was then bolted to a fourth linear stage driven by a computer-controlled linear actuator (Newport #CONEX-TRA25CC) and fastened to an aluminum optical breadboard (Newport #SA2-11).

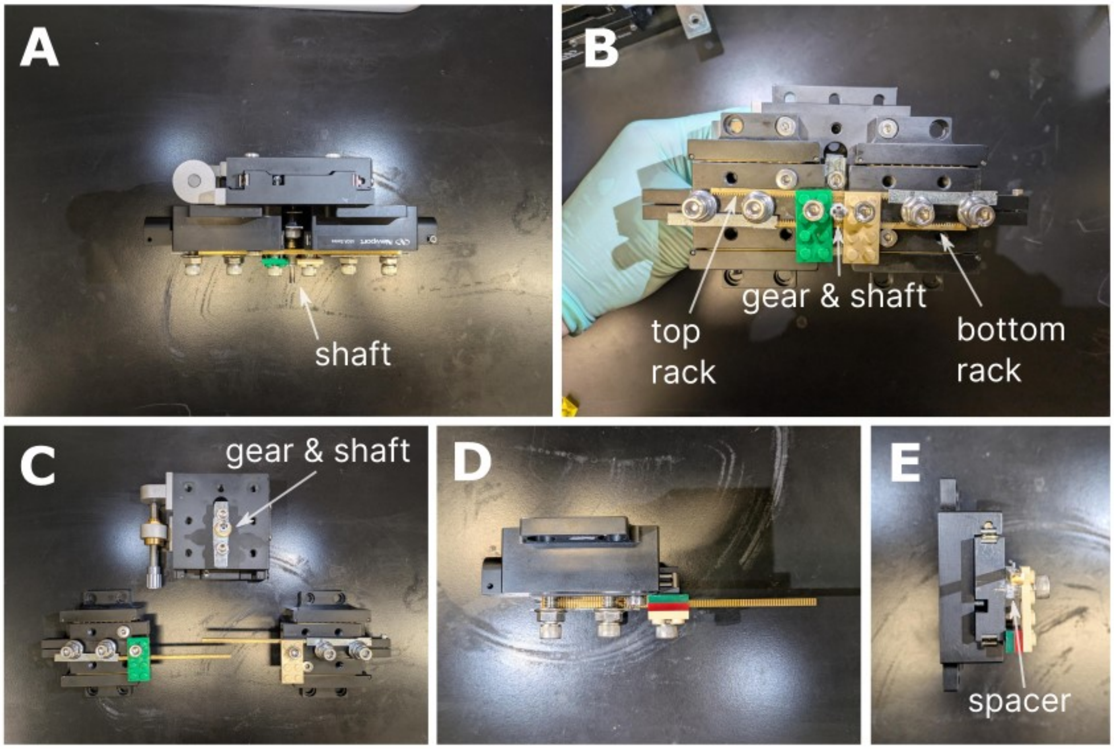

Fig 2. Pictures of the bidirectional tester from two different perspectives, with key parts of the design labeled. In this case, the actuator was connected to the right stage, so it would drive the right stage/cantilever rightward, the right rack's motion would rotate the gear on the central shaft, and the gear would then transfer the motion to the left rack, thereby driving the left stage/cantilever leftward at the same speed. (D) and (E) are side views of the right stage (top rack).

To convert unidirectional movement of the linear actuator into opposing movement of the two cantilever arms for bidirectional stretching, two Newport #460A-X linear stages were mounted back-to-back on the terminal micrometer stage so that each could translate in opposite directions. A single linear actuator drove one "active" stage outward; to drive the opposing "passive" stage without a second actuator, we interposed a gear train: a central brass gear (McMaster-Carr #7880K14), free to spin on a perpendicular steel shaft (McMaster-Carr #1327K93), meshed with two parallel brass rack gears (McMaster-Carr #7854K11), one fixed to each stage (Fig. 2B). As the actuator pushed the active stage (and its rack) rightward, the central gear reversed that motion into leftward travel of the passive rack. The shaft and gear assembly were housed in a chassis machined from a metal plate; spacer shims under the racks ensured smooth translation clearance, and edge-sanded bolts alongside the racks served as linear guides to prevent bowing under load.

To mount the tungsten-wire cantilevers in-line with the imaging plane, we devised a quick-swap LEGO interface. Each wire was extended by ~2 cm and pinched between a 2×2 stud brick and plate, clamping the wire securely. To integrate with the manipulator stages, holes were tapped in 2×4 stud plates (LEGO) to accept threaded bolts that fasten each plate—and thus the LEGO assembly—to the face of its respective linear stage. Before installation, each bolt was slipped through the wide end of a 1000 µL pipette tip, which acted as a spacer to firmly secure to the stage.

Cantilevers are attached via lego pieces in an orientation parallel to the imaging plane, as shown in the main text Fig 1.

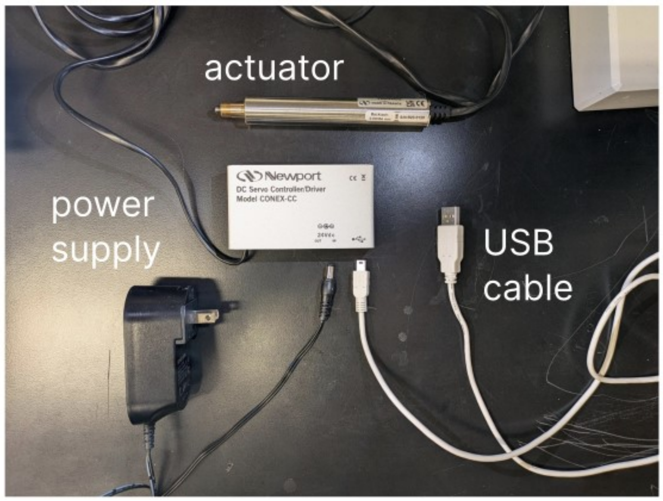

Fig 3. Newport CONEX controller and components, arranged to show how they connect to each other; Power supply (black, left), Actuator (silver, top) and USB A connection for computer control (white, right).

To run the tensile test, after connecting the wires as shown in Fig 3, the linear actuator software (Newport CONEXCC Utility) was set to a fixed velocity, slow enough to limit the confounding effects of time-sensitive viscous forces (Fig 4). Images were automatically collected every 15 s and tests were allowed to proceed until failure or for 10 minutes.

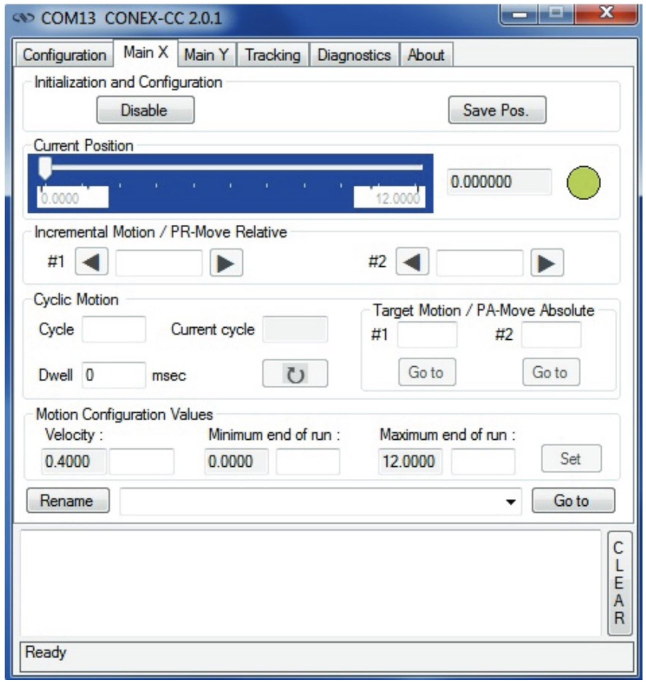

Fig 4. The CONEX CC Controller GUI - of particular note is the `Velocity` parameter.

* for more information on the capabilities of the software outside what was needed for our experiments, we refer to the manufacturer's official manual (https://www.newport.com/medias/sys_master/images/images/hc3/h1d/9044105035806/CONEX-CC-Controller-GUI-Manual.pdf)

Images are collected from above (using a Zeiss AxioZoom mesoscope)