Supporting Information

3D Printable and Fringe Electric Field Adhesion enabled Variable Stiffness Artificial Muscles for Semi-active Vibration Attenuation

Chen Liu,[a] Bo Li,*[b] Zhuoyuan Li,[b] Chongjing Cao,[c] Xing Gao,[c] Ketao Zhang*[a] and Hualing Chen*[b]

[a]Centre for Advanced Robotics (ARQ), Queen Mary University of London, London E1 4NS, United Kingdom, E-mail: ketao.zhang@qmul.ac.uk.
[b]State Key Lab of Manufacturing Systems Engineering, Shaanxi Key Lab of Intelligent Robots, School of Mechanical Engineering, Xi'an Jiaotong University, Xi'an 710049, P. R. China, E-mail: liboxjtu@xjtu.edu.cn, hlchen@xjtu.edu.cn.
[c]Research Centre for Medical Robotics and Minimally Invasive Surgical Devices, Shenzhen Institutes of Advanced Technology (SIAT), Chinese Academy of Sciences, Shenzhen 518055, P. R. China.

1. Preparation of printing conductive ink

During the 3D printing, the direct-writing approach specified the viscosity of the "ink". We chose the Carbon nanotube (CNT)/ Polydimethylsiloxane (PDMS) composite materials as electrode materials. CNT is the short multi-wall carbon nanotube (TNSM3 type) powder. The mass ratio of CNT to PDMS is 7:93.

Fig. S1 listed the process of preparing the print ink for artificial muscles. For the first step, the CNT powders are dispersed in the isopropanol (IPA) (Analytical Grade from Fuyu Chemical Co., Ltd) using the ultrasonic dispersion for half an hour. The component A of 184 silicone is added into the solution using the ultrasonic dispersion for one hour. Then the component B of 184 silicone is then added and mixed into the solution with the magnetic stirring for eight hours approximately until the isopropanol evaporates. At last, after twenty minutes of vacuum treatment, the conductive ink for printing electrodes is ready.

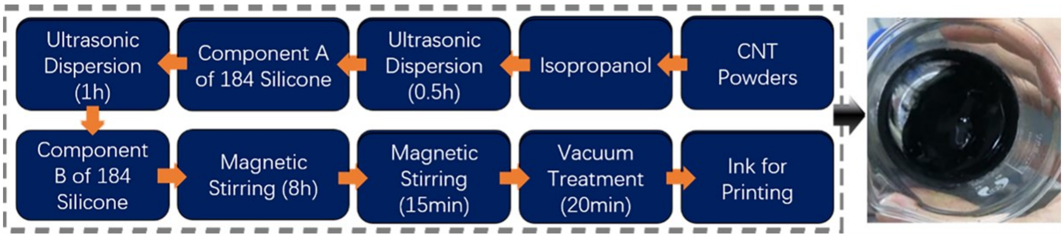

Fig. S1. The process of preparation of printing conductive ink.

2.The measurement of the natural frequency of the absorber

In Fig. S2, the vibration exciter produces the vibration force with a sweep frequency from 0 Hz to 100 Hz. The stack absorber is applied with different voltages from 0 kV to 3 kV. The laser displacement sensor and the acceleration sensor are used to detect the amplitude of the absorber. Then the control strategy of adjusting the natural frequencies of the absorber in various voltages will be obtained.

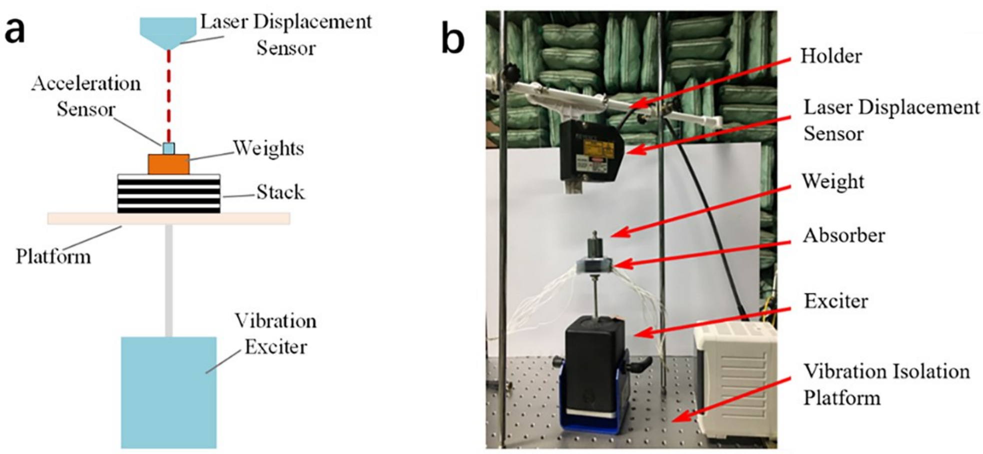

Fig. S2. Schematics of test for absorber adjusting the natural frequency. (a) Schematic of measurement of natural frequency. (b) The experimental setup of the measurement.

3. The layout of the exciter and the absorber

The principle of layouts is to avoid the model lines, which are shown in the Fig. S3.

After determination of the nod line by FEM, we place the exciter at the up point and two sensors at up and low point at the both side of the plate, respectively. The absorber is at an opposite place of the sensor.

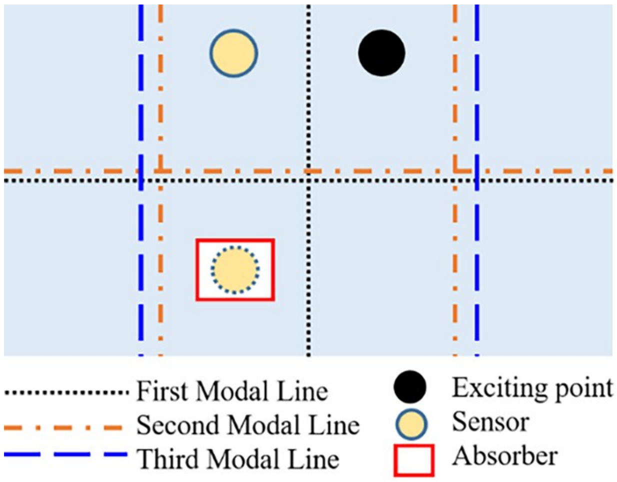

Fig. S3. The layouts of sensors, exciting point and the absorber in vibration testing.

4. The experimental setup for semi-active control

The semi-active vibration reduction test system is shown in Fig. S4. A voltage signal was generated by the signal generation to the vibration exciter so that it could produce vibration force to the steel plate. According to the vibration frequency of the exciter, the absorber is applied the matching voltage to adjust its natural frequency by the voltage amplifier. The amplitude information was measured by the laser displacement sensor and the acceleration sensor. Then the data were analyzed by a computer. By exciting the steel plate with sweep frequency (from 0 Hz to 100 Hz), it was obtained the first natural frequency with the absorber was about 32 Hz.

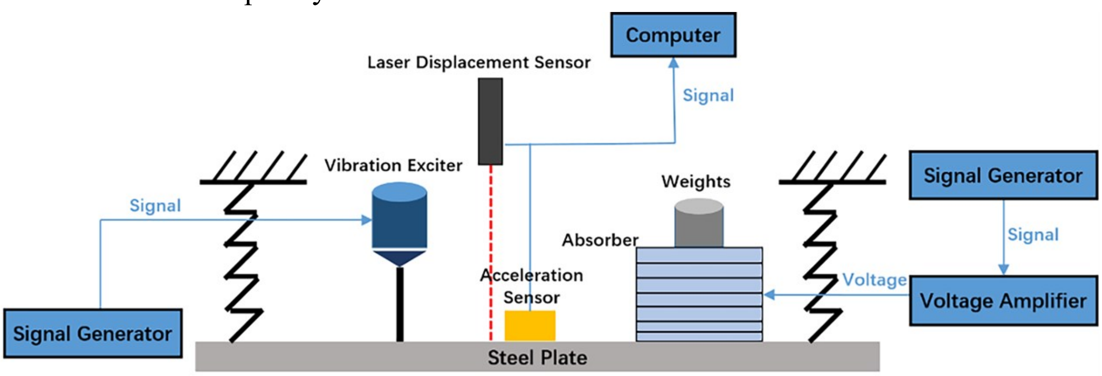

Figure S4. The schematic of vibration control measurement

5. Time-domain response of steel plate in amplitude attenuation

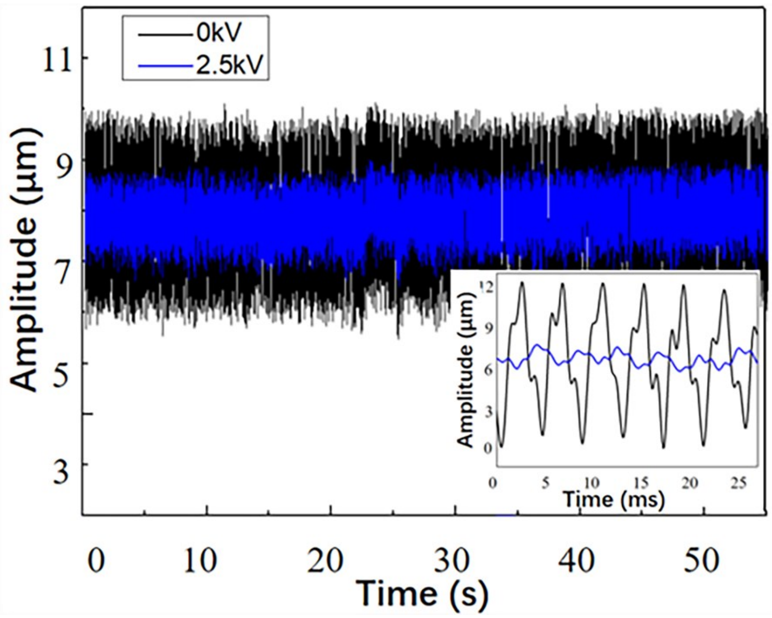

Figure S5. Time-domain response of steel plate in amplitude attenuation