Variable Stiffness Components

MSc project

Develop a computational framework to predict the mechanical behavior of Shape Memory Polymer (SMP) devices whose stiffness and damping properties are varied through thermal actuation. Actuation is assumed to be carried out through resistive heating, e.g., a heating wire is passed through the component core. When the SMP glass transition temperature is reached, the material changes from a glassy to a rubbery state, which causes a significant stiffness reduction and a parallel increase of damping due to viscoelastic effects. This effect can be employed in diverse applications including semi-active vibration control of structures (Figure 1) and compliant mechanism design for adaptive façade systems (Figure 2). A second activation method might be investigated that involves relative humidity. Depending on available resources, a parallel experimental agenda might be carried out to validate the predictions produced by the developed computational model.

Thesis supervision, writing, and examination will be carried out in English.

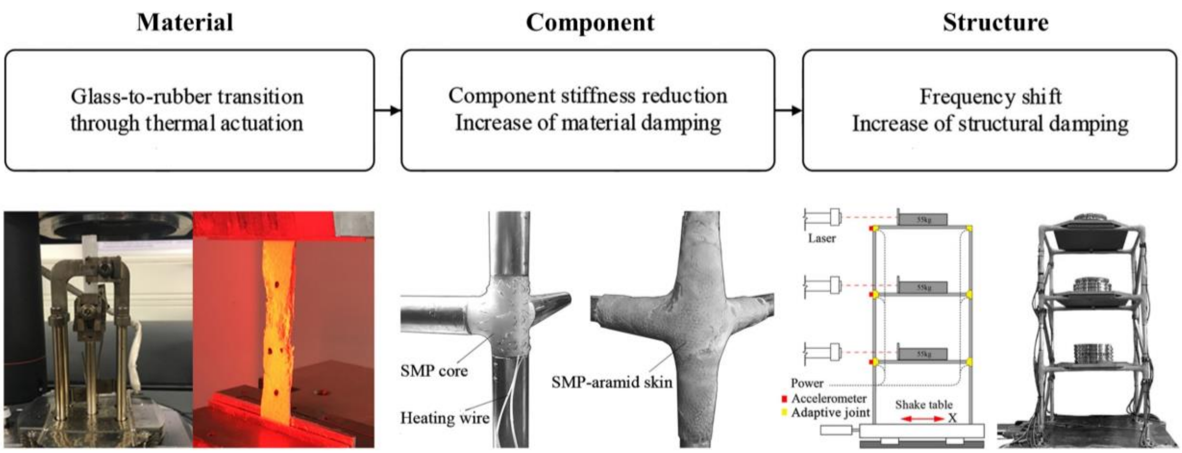

Figure 1 Semi-active vibration control through variable stiffness and damping structural components [1]

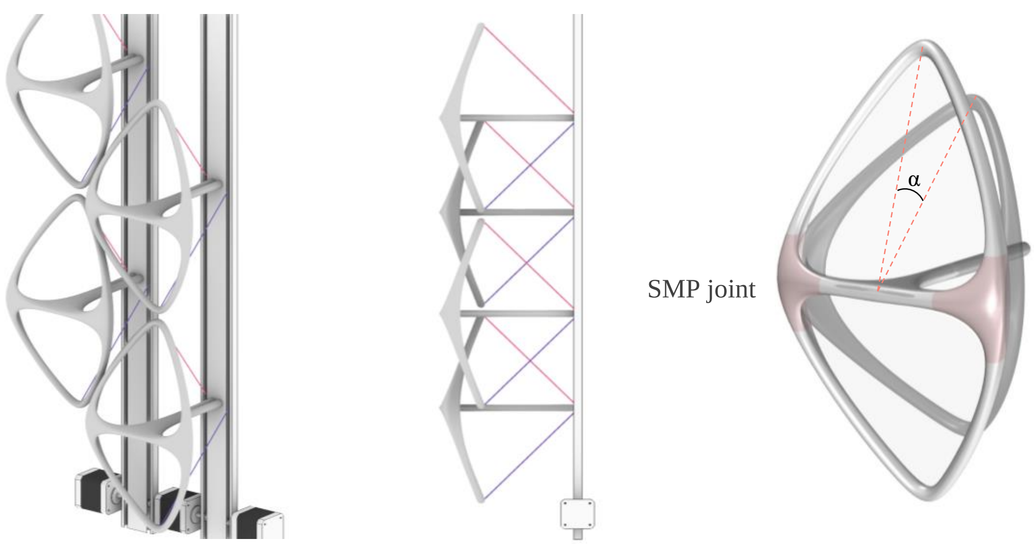

Figure 2 Adaptive façade system, component with SMP joints, change of inclination of upper and lower frames

Supervision

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Key requirements

Bachelor's degree in civil engineering and/or architecture.
Good knowledge of structural mechanics and material modelling.
Knowledge of (or strong interest to learn) MATLAB programming language.
Advanced spoken and written English.

Background

Shape memory polymers (SMPs) can recover their original shape in stress-free conditions from a deformed state through thermal, actuation, exposure to light, pH change, and moisture [2]–[6]. SMPs have been 3D printed through stereolithography (SLA) and fused deposition modeling (FDM) [7]. The low mechanical and recovery stress of SMPs have been improved with the use of short and continuous fibers (e.g., carbon, glass) in SMP composites (SMPCs) [8]. SMPCs have been employed in solid-state actuators, smart textiles, and diverse applications in aerospace engineering including foldable SMPC truss booms, deployable solar array panels and morphing wings [9].

Most existing solutions for vibration control consist of complex devices that are external to the structure and require complex detailing for installation. A new vibration control device has been developed made of a polyurethane-based shape memory polymer (SMP) core that is reinforced by an SMP-aramid skin [10]. This control device can be seamlessly integrated into diverse structures including multi-story buildings, bridges, roof systems, airplane wings, wind turbine blades, etc. because it also functions as a joint that connects the structure's load-bearing elements [1]. For brevity, the device is referred to as 'adaptive joint' hereafter. The joint behaves as a moment connection in the "locked" state (glassy) and transitions to a pin connection when in the "released" state (rubbery). Stiffness and damping properties are controlled through thermal actuation without involving complex mechanisms based on moving parts. The actuation mechanism is inherent within the properties of the material enabling a reliable control system. The adaptive joint system can be potentially integrated into any structural system subjected to dynamic excitation hence it is relevant to applications in civil, mechanical, automotive, marine and aerospace engineering. Consider a frame or a plate/shell structure that is equipped with such adaptive joints and subjected to external loading. The ability to vary the joints mechanical properties enables to change the structure natural frequencies and to increase the damping ratio, which can be employed as an effective semi-active control strategy to reduce the dynamic response under a wide range of loading conditions (e.g. harmonic loading, strong winds, earthquakes, pedestrian/vehicular traffic, etc.). Numerical simulations on a four-story frame subjected to earthquake loading (Figure 1), have shown that when the adaptive joints are actuated to the transition range (55-65°C, which is specific to the SMP material adopted in this study), the acceleration peak amplitude reduces by up to 87% with respect to the uncontrolled case [11]. Shake table tests on a 3-story frame prototype (1/10 scale) equipped with 12 adaptive joints have confirmed that the structural damping ratio increases from 2.6% to 11.3% and the 1st modal frequency shifts by up to 37%. Under El-Centro earthquake, top-story acceleration and base shear are drastically reduced by up to 50% and 52%, respectively [12]. A video demonstration can be accessed at this location. Further investigation could be carried out for plate and shell structures (e.g., slab systems, wind turbine blades, airplane wings), in which variable stiffness and damping components could be integrated as an inner layer, similar to a sandwich panel.

A similar joint component could be considered to enable the motion of adaptive façade systems [13], [14] that are being investigated within the framework of the CRC 1244 Collaborative Research Centre. The aim is to reduce the energy demand for cooling in buildings. The façade system is made of several modules whose geometric reconfiguration enables controlling indoor solar heat gains and illuminance. A façade module consists of a pair of triangulated frames. The frames are covered by two different textile materials. The upper frame reflects the solar radiation toward the sky while the lower frame transmits diffused sunlight indoors. Each frame is connected to an actuator through a cable that is deviated by a rail system (Figure 2). Compliant joints made of SMPs could be employed to enable changing the inclination of the frames using a minimum number of actuators. Several modules could be driven by one cable. The target change of inclination of the frames could be realized through different thermal loads that change the joint stiffness independently. This would allow for a significant reduction in the number of moving parts and actuators, making the system suitable for high-rise building applications.

References

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