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QCONCEPT OF SMART CYMBAL STRUCTURE FOR STRUCTURAL HEALTH MONITORING APPLICATIONS

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Abstract: *The area of embedded sensors, adaptronics, smart material and smart structures has a key role in Structural Health Monitoring. The aim of embedding smart materials into engineering structures is to monitor a wide variety of material's properties and enabling continuous or permanent measurements of their structural integrity. The integration of sensors into the structure is limited to processing technology used for embedding sensors and the possibility to damage the structure during insertion. This study focuses on developing sensory structure with force to voltage amplifying capabilities. The base unit and periodic concept of such structure is developed, and FEM model of base unit is done to observe basic behavior under load. Experiments with base unit for its voltage response were carried out on a prototype. Furthermore, a three base unit sample is created and a concept of a planar three-layer structure is developed.*

Keywords: Adaptronics, cymbal structure, metamaterial, MFC, smart structure, sensing.

1. Introduction

Integration of embedded sensors and smart material sensors to form a smart structure that can be used for standard design practices, fabrication, construction, and general industrial use belongs to one of the greatest engineering research challenges (Varshney et al., 2021). When studying engineering structure's behavior, a set of approaches can be taken from the field of Structural Health Monitoring (SHM). Destructive techniques use methods of permanently damage structures such as drilling out samples or mechanically exciting testing structures. Non-destructive techniques (NDT) can be on-site with the presence of educated personnel or off-site where remote monitoring and/or testing takes place. The standard approach of NDT is to glue sensors on the surface or using devices with thermometers, ultrasonic sensors, or acoustic sensors. The lack of real-time monitoring during the lifetime of the engineering structure leads to unpredictable behavior and failures. This opens up the need of continuous monitoring and predictive maintenance of engineering structures (Askari et al., 2019; Gharehbaghi et al., 2022).

In the field of smart structures several studies focused on the use of optic fiber sensors, piezoelectric materials, and strain gauges. Ramly et al. (2012) deployed fiber bragg grating sensor in a composite honeycomb structure for monitoring strains in a composite structure (Ramly et al., 2012). To sense external stimuli and react to external stimuli a piezoelectric transducer can be used. Silva et al. focused on a research for nonlinear energy sink with the use of piezoelectric elements and achieve the vibration attenuation for wide range of frequencies (Silva et al., 2018). Yesner et al. (2019) deployed an energy harvesting smart structure for engineering civil structures as a monitoring and harvesting unit. They also evaluated the limitations of the adhesive layer thickness and uniformity (Yesner et al., 2019). Gurung et al. focused on using a shape memory alloy (SMA) for its self-sensing properties to exploit its self-actuation potential.

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They used extended Kallman filter for displacement prediction. Huang et al. used auxetic mechanical metamaterial foams with strain gauges to enhance sensitivity and an operation range of strain smart material sensors for bionic hand grip sensing. They also implemented a statistical correlation algorithm to run in real-time on a budget controller, and they achieved 100 ms response time (Huang et al., 2022).

We propose a concept of a periodic cymbal structure for a pressure to voltage converter with high sensitivity and scalability properties. The proposed structure converts compression forces in one axis into tensile forces in the second axis. The compression force is amplified and converted into a larger tensile force that creates a high sensitivity range.

2. Methods

The base unit in 0 consists of a top and bottom cymbal structure that converts compression into a higher tension. Between top and bottom lamellas is a smart macro fiber composite (MFC) in a d33 operation mode. For larger planar vibration monitoring a periodic cymbal structure with piezoelectric macro fiber composites is considered. The idea comprises of determining the mechanic vibration wave characteristics and direction. The prototype testing unit has a dimension of 28 x 7.5 x 5.5 mm.

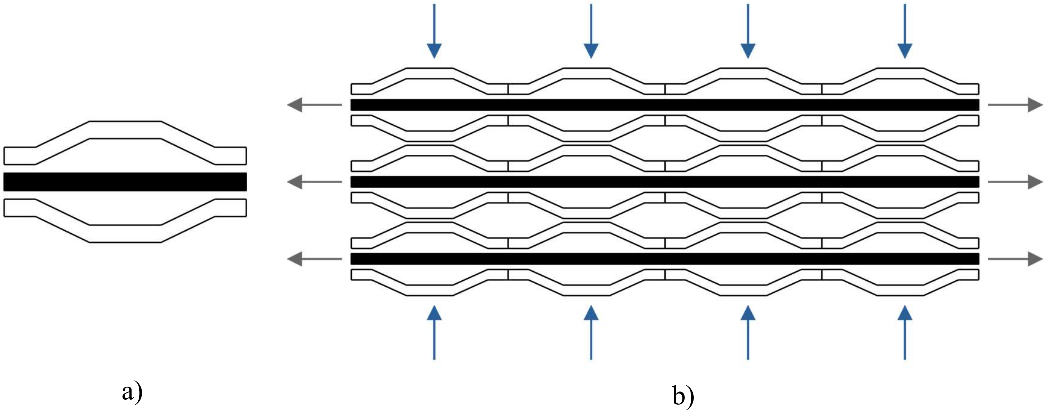


Fig. 1: A concept of smart sensory structure a) base unit with MFC, b) planar metamaterial; structure with MFC patches.

3. Results

3.1. Finite element analysis of the cymbal transducer

FE analysis (0) was performed to investigate the behaviour of a single transducer under static loading. The cymbal (bridge) transducer was fixed in the base and a compressive force of 10 N was applied to the top cap. The converted tensile force applied to the MFC film between the caps of the transducer was 30.4 N. The ratio of these values gives the transducer gain, which is approximately 3.

At this load, the stress in the MFC in the constant region between the caps is about 11.5 MPa. This region is responsible for generating the electrical charge in the pizoelectric material and is also the most critical point of the entire transducer in terms of stress.

3.2. Compression to stretching base unit capabilities

The integrated piezoelectric material serving as a sensing element is a macro fiber composite (MFC). The chosen smart material is suitable for sensing applications because of its lower power densities and more robust to cracks compared to fragility of lead zirconium titanate (PZT), however the Young's modulus of MFC is five times less than PZT (Shen et al., 2007).

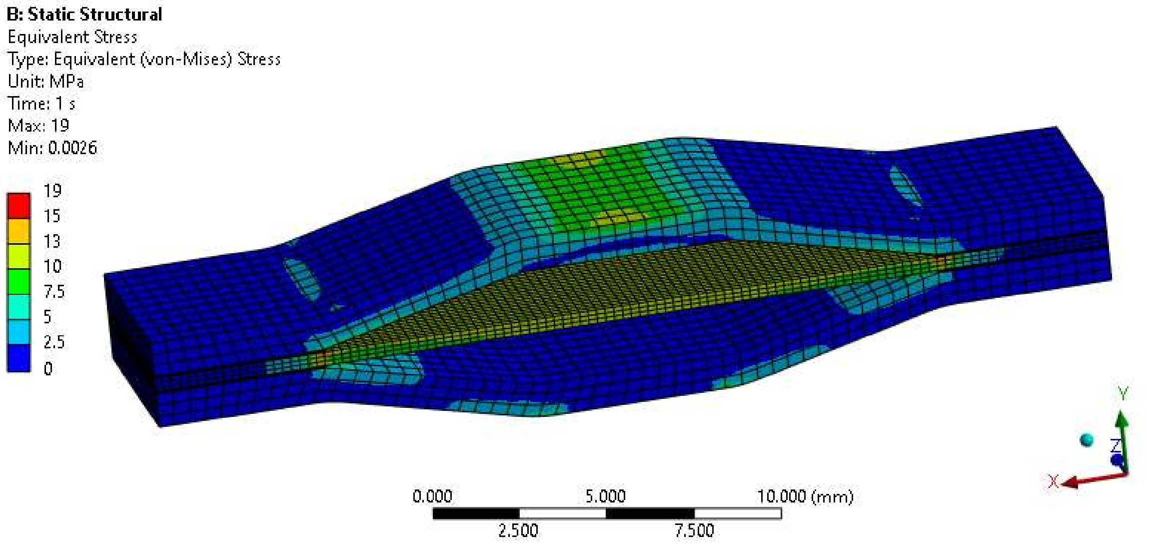
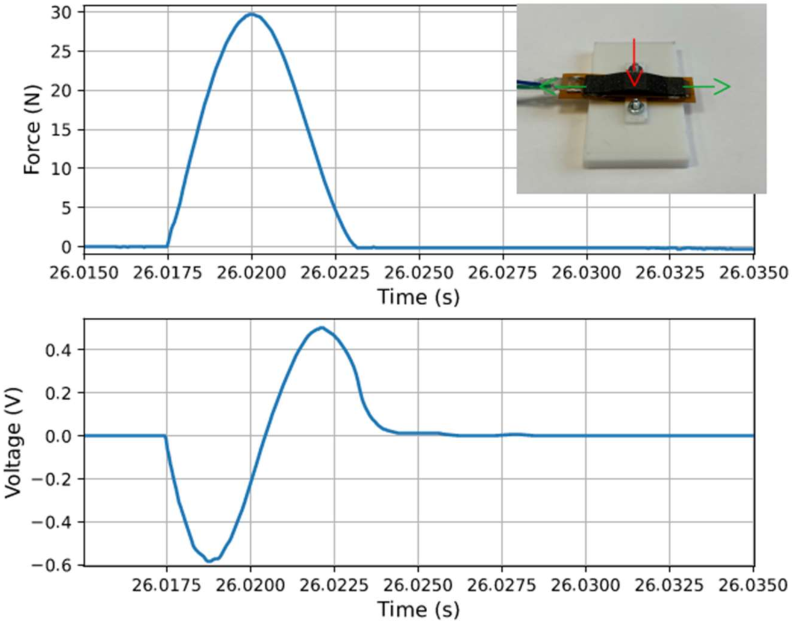


Fig. 2: FEA results for equivalent stress in cymbal transducer.

The measurement was conducted with an impact hammer and an oscilloscope probe with a 1 MΩ input impedance. The impact hammer and the probe were connected to the National Instruments measurement card. The base unit was connected to a voltage divider to lower the output voltage and prevent damaging the measurement card. While measuring the voltage response with the NI card a voltage divider was used to lower the output voltage of a base unit. The periodic oscillation character of the system will be analyzed further for sensing applications.



Fig, 3: Experimental response measurement of a smart structure's base unit.

4. Conclusion

The smart material structure's base unit with integrated MFC was tested to evaluate voltage response. Firstly, a concept was developed based on composite smart structure with integrated piezoelectrics as is illustrated in 0. Secondly, FEM analysis for static response of proposed geometry was performed. A base unit of proposed smart structure was manufactured and its voltage response to external impact force was measured. Lastly, a concept for three base units and three-layer planar structure was constructed as shown in 0. From the measurements of the base unit, further investigation of its planar and spatial capabilities will be performed.

Fig. 4: Three base unit testing sample and a planar three-layer concept smart structure.

Future research will be aimed at the embedding smart materials in a structure in 0, and on the design of a sensory platform for sensing and identification of external stimuli, characterization, identification of a mechanical wave propagation in the structure, and identifying the load characteristics across the spatial geometry.

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