Development and Analysis of Structural Sensing and Actuation with Macro Fibre Composite

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Abstract— Macro Fiber Composite (MFC) is a new type of piezoelectric material with softness and big displacement, developed by NASA recently. It can be used for actuating, sensing and power generating. The purpose of our work is to develop new and intelligent mechatronic devices utilizing MFC. In this paper, the basic characteristic of MFC for sensing and actuating is investigated. Sensing ability of MFC is investigated .The Basic structure of a cantilever beam as self-sensing device is performed to the modeling, analysis and structural vibration control to be used as sensing and actuation. Control simulations of the cantilever beam with MFC are derived on the finite element model of the beam by the ANSYS Software. Experimental works are carried out to examine and analyzed the controller designed in the simulation stage. In addition, active damping of the cantilever beam with MFC and the cushion made of the leaf spring with MFC are experimented. The application possibility of MFC as the structural sensor and actuator is confirmed.

Key words: Passive Vibration Control, MEMS, Macro Fiber Composite

I. Introduction

Piezoelectric Effect shown in Fig.1 is the ability of certain materials to generate an electric charge in response to applied mechanical stress [1]. The word Piezoelectric is derived from a greek word called piezein, which means squeeze or press. The unique characteristics of Piezoelectric effect is that it is reversible, meaning the piezoelectric materials exhibit both direct and converse piezoelectric effect. Direct effect – Electrical charge is produced when mechanical stress is applied. Indirect effect – Mechanical stress is produced when electrical voltage is applied.

Piezoelectric effect is very useful within many applications that involve the production and detection of sound, generation of high voltages, electronic frequency generation, microbalances and ultrafine focusing of optical assemblies. It is also the basis of a number of scientific instrumental techniques with atomic resolution such as Scanning probe microscope.

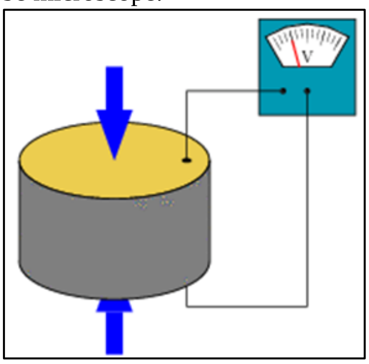

Fig. 1: Piezoelectric Effect

The piezoelectric effect was first seen in 1880 and was initiated by the brothers Pierre and Jacques Curie. By combing their knowledge of Pyroelectricity with their understanding of crystal structures and behavior, the Curie brothers first demonstrated the first Piezoelectric effect by using crystals of Tourmaline, Quartz, Topaz, Cane sugar and Rochelle salt. Their initial demonstration showed that Quartz and Rochelle salt exhibited the most piezoelectric effect at the time [2].

The MFC shown in Fig.2 is the leading low profile actuator and sensor offering high performance, flexibility and reliability in a cost competitive device. Developed at NASA Langley research center, MFC is an innovative low cost piezoelectric device designed for controlling vibration, noise and deflections in composite beams and structures. This was developed for helicopter blades and airplane wings as well as for the shaping of aerospace structures at NASA [3].

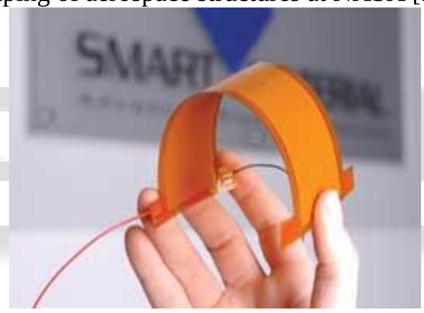
Fig. 2: Macro Fiber Composite

II. Materials and Methods

A. Development of Macro Fiber Composite

Performance of inter-digitated electrodes were ultimately limited by design and manufacturing issues in AFC. This limitation, combined with the epoxy beneath the electrodes but adjacent to the contact region, made for an inefficient transfer of the electric field into the PZT fibers. Additionally, the PZT fibers used in the AFC are obtained individually from an extrusion process, which required the thin, brittle fibers to be handled and aligned by hand. This procedure often times resulted in broken, poorly aligned fibers. Furthermore, the vacuum infiltration process that was used to apply the epoxy to the fibers can leave air bubbles (voids) and particulate inclusions, both of which greatly increased the chance of electrical failure.

In light of these limitations, the Macro Fiber Composite (MFC) was developed at NASA Langley [4]. The MFC is a layered, planar actuation device that employs rectangular cross-section, unidirectional piezoceramic fibers (PZT 5A – lead zirconate-titanate) embedded in a thermosetting polymer matrix. This active, fiber reinforced layer is then sandwiched between copper-clad Kapton film layers that have an etched interdigitated electrode pattern. In MFC the PZT fibers are aligned in the 3-direction and the copper electrode fingers are parallel to the 1-direction, according to standard piezoelectric notation.The MFC is available in two operational mode namely d33 and d31 mode, a unique feature of Macro Fiber Composite.

B. Introduction to Self-Sensing Actuators

While designing a controller with advantages of stability to the system, it is necessary to have collocated sensors and actuators. Goh and Coughley (1985) presented the result showing that in the absence of actuator dynamics, structures controlled with collocated velocity feedback are unconditionally stable at all frequencies. In addition, collocated control eliminates possible closed loop instabilities caused by capacitive coupling between the sensor and actuator elements. A self-sensing actuator holds the ability to perform both sensing and actuating finitely.

The ability to use a piezoelectric material as a self-sensing actuator was first discovered and published by Dosch et al. (1992). The self-sensing actuator works through circuit that distinguish between sensing and control voltage applied to the piezoelectric material. That is that the circuit cancels the control voltage and return only the sensing signal. This makes the piezoelectric beam to actuate the beam and sense the signal at the same time. In order to show the effectiveness of self-sensing circuit, Dosch et al designed and used a positive position feedback controller to suppress the vibration in a cantilever beam.

Subsequent to the work of Dosch et al, other researchers have found self-sensing piezoelectric actuator to be very useful in control application. Frampton et al.(1995) used a self-sensing actuator bonded to an aircraft panel for the reduction in flutter at various Mach numbers. Dongi et al. (1995) also investigated the effectiveness of using a self-sensing actuator for active flutter suppression.

C. Technical Background

Piezoelectric transducers acting in the “direct” manner produce an electrical charge when mechanically stressed. Conversely, a mechanical strain is produced when an electric field is applied. The process to be used with the impedance based monitoring method utilizes both direct and inverse piezoelectric effect to obtain impedance signature from the structure. When a piezoelectric patch attached to the structure is driven by fixed alternating electric Field, a small deformation is produced in the piezoelectric material and to the structure attached. Since the frequency of excitation is very high, the dynamic response of the structure reflects only in local area to the sensor. The response of the local area to the mechanical vibration is transferred back to the piezoelectric material in the form of electrical response. When a crack or damage causes the mechanical dynamic response to change (change in magnitude of the mechanical dynamic response) which is manifested in the electrical response of the piezoelectric material.

D. Experimental setup

In this experiment, MFC is soft and thin-filmed, it can be pasted on curved surfaces. The relation between output of MFC sensors pasted on curved surfaces and linear displacement is investigate. Thin stainless leaf springs (thickness is 0.7mm) that is shown in figure 3and 4. Are bended and put in on both sides. MFCs are pasted on outside of curved surfaces with epoxide based adhesive. When an external force is exerted from above, the curved parts of both sides are transformed. In order to measure vertical displacement of this model with MFC sensors pasted on curved surfaces, a conversion circuit is made. From section II,it is known that output voltage of MFC is proportional to strain rate in the fiber direction. Therefore, by integrating output signals, the strain of MFC can be obtained.

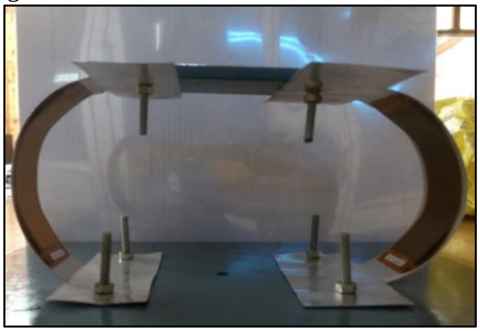

Fig. 3: Cushion type leaf spring setup

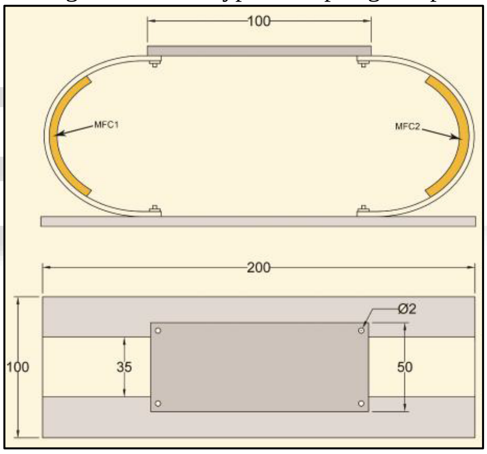

Fig. 4: Cushion made of Leaf Spring

III. Results and Discussion

This research has been successfully completed using Macro Fiber Composite as a self- sensing actuator, with all the considerations of self-sensing circuit and limitations of the components and techniques using in this critical circuit. Active vibration control of smart cantilever beam was achieved by positive position feed-back controller.

The variations between steel aluminium and varied by thickness of 0.1mm,0.2mm,0.3mm and by using LABVIEW software we measure the vibrations in the sense of displacements and by keeping field excitation as constant and giving load by magnetic weight of 4grams constant getting the value from LABVIEW software and after that plotting the graph between force and displacement.

Motor		Alternator		Transformer		MFC	
Frequency 0-100%	Voltage 0-440v	Field Excitation 0-10v (%)	Output Voltage 0-230V	Input Voltage 0-230V	Output Voltage 0-2000V	MFC Input Voltage 0-1500V	Displacement 0-10mm

0	0	80	0	0	0	0	0.892
10	12	80	12	12	80	80	2.265
20	16	80	18	18	144	144	2.987
30	24	80	28	28	185	185	3.154
40	31	80	34	34	215	215	4.154
50	36	80	39	39	284	284	5.123
60	40	80	45	45	354	354	5.948
70	48	80	51	51	432	432	6.158
80	54	80	55	55	461	461	7.786
85	65	80	65	65	498	498	8.654

Table 1: Observed Values of D33 Mode Fiber Orientation MFC with Al Leaf Spring-0.3mm Thickness

Motor		Alternator		Transformer		MFC	
Frequency 0-100%	Voltage 0-440v	Field Excitation 0-10v (%)	Output Voltage 0-230V	Input Voltage 0 230V	Output Voltage 0-2000V	MFC Input Voltage 0-1500V	Displacement 0-10mm
0	0	35	0	0	0	0	0.554
5	5	35	2	2	8	8	1.58
10	8	35	4	4	19	19	2.98
15	11	35	5	5	25	25	3.146
20	15	35	6	6	31	31	3.96
25	19	35	8	8	45	45	4.47
30	21	35	9	9	49	49	4.95
35	25	35	10	10	54	54	5.14
40	32	35	12	12	58	58	5.98
45	40	35	13	13	62	62	6.34

Table 2: Observed Values of D3 Mode Fiber Orientation MFC with Al Leaf Spring-0.3mm Thickness

The MFC cushion that can change stiffness by driving MFC is proposed. Thin stainless leaf springs (thickness is0.7mm) are bended and MFC are put on the curved surface. When the positive voltage is added, it expands in the direction of the piezoelectric fiber, the bending moment is generated in MFC and the cushion becomes hard. Conversely, when a negative voltage is added, the cushion becomes soft. The width of MFC for sensing is 3.5mm and50mm for the actuation part.

The results from the Table 1 shows that observed values of d31 mode fiber orientation MFC with Al leaf Spring-0.3mm thickness and Table 2 shows observed values of d33 mode fiber orientation MFC with Al leaf Spring-0.3mm thickness.

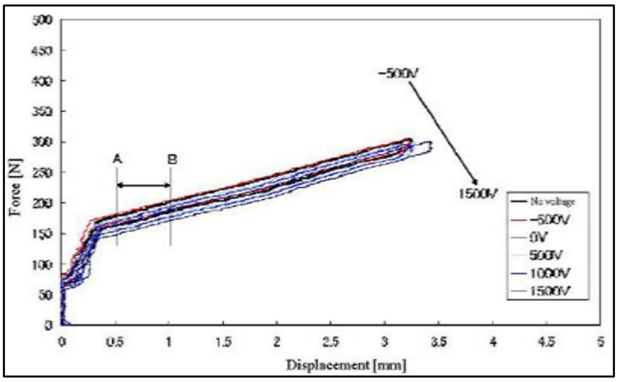

Fig. 5: Forcevs Displacement

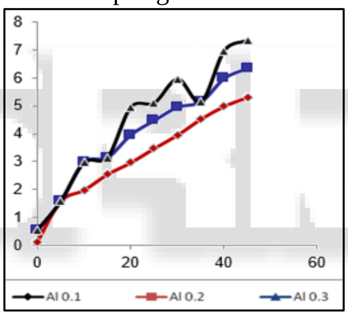

Fig. 6: Aluminium (0.1, 0.2 & 0.3mm) – d33 mode

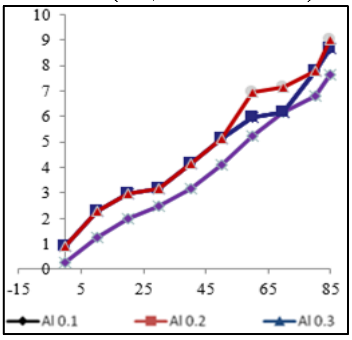

Fig. 7: Aluminium (0.1, 0.2 & 0.3mm) – d31 mode

IV. CONCLUSION

This investigation aims at the development of new intelligent robots or mechatronic devices using smart material Macro Fiber Composites. The basic characteristic of Macro Fiber Composites for sensing and actuation is performed. In the application of MFC, active damping of the cantilever beam with MFC and the cushion made of curved leaf spring with MFC are experimented. It is shown that structural MFC mechanisms are effective for the vibration control and the energy-absorption. The application possibility of MFC as the structural sensors and actuators has been confirmed.

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