Piezoelectric Bending Elements for use as Motion Actuators in MR Elastography

P. Rossman[1], K. Glaser[1], J. Felmlee[1], R. Ehman[1]
[1]Mayo Foundation, Rochester, MN, United States

Synopsis

Magnetic Resonance Elastography (MRE) is a phase contrast method that utilizes propagating acoustic waves to determine elastic properties of tissues. A mechanical actuator coupled to the tissue provides cyclic motion synchronized to the imaging sequence. We have designed a system for generating such motion in the MR environment incorporating readily available piezoelectric bending elements. Our initial measurements of both phantom and in vivo system performance are presented and the results are promising.

Introduction

The method of Magnetic Resonance Elastography (MRE) for the purpose of determining the elastic properties of various substances or biologic tissues has been previously demonstrated (1,2). Cyclic motion in the MRI environment has typically been produced by electromechanical actuators which rely on the B_0 static magnetic field (1). More recently an actuator based on a piezoelectric crystal stack coupled to a lever arm has been described (3). Each type of actuator has its advantages and disadvantages. Although simple in design and easily manufactured, electromechanical devices can cause magnetic field distortions, are subject to power constraints (due to heating), and be limited in their physical orientation with respect to the object being vibrated (i.e.: the actuator coil must be correctly aligned with B_0 in order to produce motion). Current piezoelectric devices tend to be bulky, rather expensive to produce can cause image artifacts if placed to close to the imaging FOV and are subject to heating problems at higher frequencies. However, they do have the advantage of being able to operate in any orientation within the magnetic field.

We have constructed and tested MRE motion actuators based on piezoelectric ceramic bending elements. These thin, multi-layer elements can be manufactured to provide elongation or bending depending on crystal polarization and wiring configuration. Our preliminary phantom and in vivo animal tests indicate that these types of actuators can be useful in many MRE applications and have significant advantages over other actuator technologies.

Materials & Methods

Figure 1

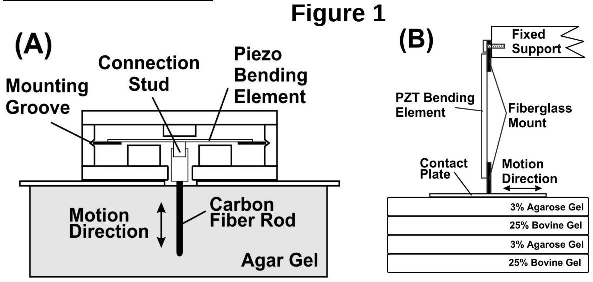


Figure 1 depicts how the piezoelectric bending element is configured to produce motion in two different directions. The configuration in Figure 1A produces longitudinal (up and down) motion of the carbon rod. The configuration in Figure 2B produces shear (side to side) motion along the surface of the phantom.

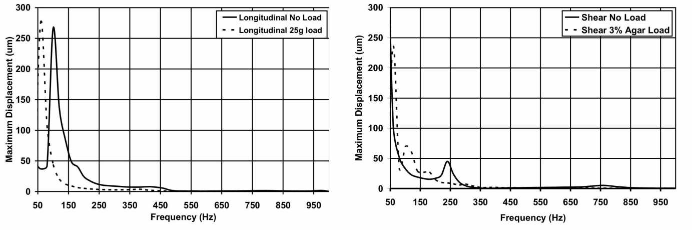
The multi-layer piezoelectric element (L220-A4-503Y, Piezo Systems, Cambridge, MA) is polled in such a way as to produce curvature when one layer contracts as the other expands in response to an applied external voltage. Motions can be on the order of tens to thousands of microns and forces can be produced from tens to hundreds of newtons. The actuator housing or support is made of acrylic or polycarbonate materials. Fiberglass supports are glued to the ends of the bending element. Mounting the support ends of the element in grooves (figure 1A) allows for greater motion in the center than if the ends were bolted or fixed. Fixing only one end of the element allows the other end to move similar to a cantilever beam (Figure 2B).

Measurements of displacement vs. frequency were made using an accelerometer (I C Sensors, Milpitas, CA) mounted at the end of the carbon rod for the longitudinal actuator or the unfixed end of the shear motion actuator. Displacements were measured under both unloaded and loaded (25g mass) conditions over a frequency range of 50 to 1000 Hz. Maximum displacements due to sine wave inputs were calculated using the equation: $\text{Displacement}_{max} = \text{Acceleration}_{max}/(2\pi f)^2$

Initial MRE tests of the longitudinal actuator were performed on a 2% agarose gel phantom. A rigid carbon-fiber rod was attached to the connection stud. The rod was inserted into the gel and the actuator was mounted to a plate within 5cm of the gel surface (figure 1A). Initial tests of the actuator for producing shear motion were performed on a phantom consisting of interleaved layers of 3% agarose gel and 25% bovine gel. One end of the actuator was bolted to a fixed, rigid platform above the phantom. The other end was bolted to a lightweight plastic plate in contact with the surface of the gel (figure 1B). Tests were also performed on the thigh of an anesthetized rabbit. The blunt end of a stiff rod attached to the longitudinal actuator was pressed against the skin of the animal just above the knee. Motion of the rod tip caused motion in the underlying muscle tissue. MRE experiments were performed over a frequency range of 100 to 500 Hz. The actuator was energized using a digital function generator (HP) and high voltage amplifier (EPA-104-15, Piezo Systems, Cambridge, Ma).

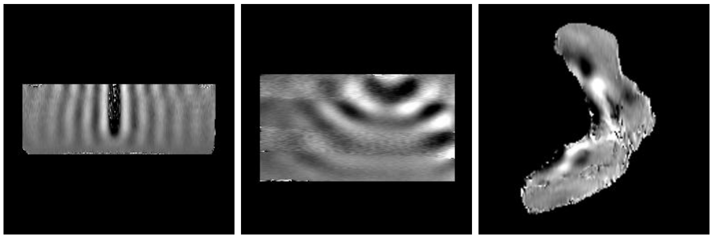
Results

Figure 2



(A) (B)

Figure 3



(A) (B)

(C)

Plots of displacement vs. frequency for the longitudinal (A) and the shear (B) bending element configurations are shown in Figure 2. Except for resonant peaks both configurations show a $1/f^2$ dependence which indicates a relatively linear acceleration response. As expected, addition of a load caused resonances to shift to lower frequencies. These results are similar to those demonstrated by our electromechanical actuators. Both plots are from data collected with the bending element excited at half of its maximum voltage.

Figure 3 shows typical MRE results. The images in figure 3A and 3B correspond to the configurations described for figure 1 and represent 300 Hz and 200 Hz excitations respectively. Figure 3C shows results obtained at 175 Hz in vivo in the leg of an anesthetized rabbit. Propagating transverse waves are well depicted in each image with no appreciable artifacts due to the piezoelectric element.

Discussion

Our initial experiments show that it is possible to use piezoelectric bending elements to generate transverse propagating waves in MRE applications. They have advantages over electromechanical actuators in that they do not depend on the direction of the B_0 field and cause few if any image artifacts. The elements can be manufactured in many shapes and sizes which should allow them to be highly configurable. One potential draw back is that benders may not generate as much force as electromechanical or piezoelectric stack based actuators. This is due to the limited amount of power that can be applied. However, they due not suffer from the problem of overheating.

References

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