Improved Multiple-DOF SAW Piezoelectric Motors

Actuators without bearings or lead screws could be integrated into mechanisms and structures.

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Surface-acoustic-wave (SAW) piezoelectric motors of a proposed type would be capable of operating in multiple degrees of freedom (DOFs) simultaneously and would be amenable to integration into diverse structures and mechanisms. These motors would be compact and structurally simple and would not contain bearings or lead screws. One example of a particularly useful motor of this type would be a two-dimensional-translation stage. Another such example would be a self-actuated spherical joint that could be made to undergo controlled, simultaneous rotations about two orthogonal axes: Such a motor could serve as a mechanism for aiming an "eyeball" camera or as a compact transducer in, and an integral part of, a joint in a robot arm.

The multiple-DOF SAW piezoelectric motors as now proposed would be successors to the ones reported in "Multiple-DOF Surface-Acoustic-Wave Piezoelectric Motors" (NPO-20735), *NASA Tech Briefs*, Vol. 24, No. 12 (December 2000), page 5b. The basic principle of operation of a multiple-DOF SAW piezoelectric motor is a straightforward extension of that of single-DOF SAW piezoelectric motors, which have been reported in several previous *NASA Tech Briefs* articles: For example, in the case of a linear SAW piezoelectric motor, piezoelectric transducers at opposite ends of a stator excite surface acoustic waves that travel along the surface of the stator. An object (denoted the slider) is pressed against the stator with sufficient pressure (in practice ≈300 MPa) that it remains in frictional contact with the stator at all times. The slider rides the crests of the waves and is thereby made to move along the surface of the stator. The direction of motion (forward or backward) is controlled by selecting the relative phase of waves generated by the two piezoelectric transducers. The speed increases with the amplitude of the waves and thus with the magnitude of the voltage applied to the transducers.

The extension of this actuation principle to multiple degrees of freedom can be illustrated via the example of a two-dimensional-translation stage as now proposed (see Figure 1). In this case, the slider would be clamped between an upper and a lower stator and there would be two pairs of SAW piezoelectric transducers (instead of a single pair) on each stator. Small bosses on the upper and lower surfaces of the slider would make contact with the upper and lower stators, respectively. The pairs of transducers would be oriented orthogonally so that they could generate orthogonally propagating waves, making it possible to move the slider along either of two orthogonal axes. Like other SAW piezoelectric motors, a motor as now proposed would hold its position when not energized because the static friction generated by the clamping force would act as a braking force.

The ability of a surface acoustic wave to travel on a curved surface would make it possible to design a spherical 2-DOF SAW actuator like that depicted in Figure 2. In this

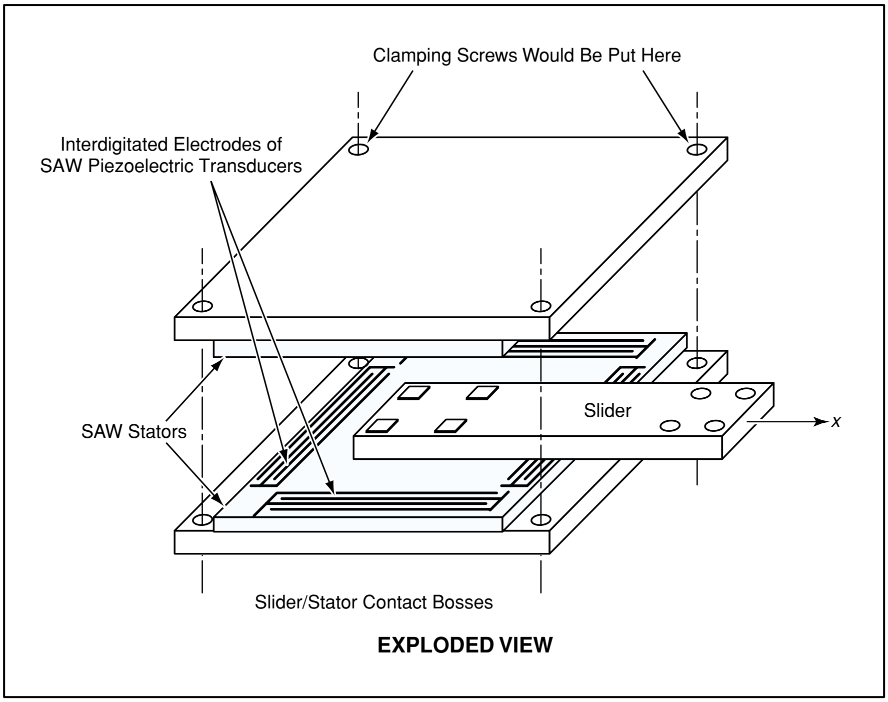

Figure 1. In this **Two-Dimensional-Translation Stage** the slider would move along the *x* or *y* direction when *x*- or *y*-propagating surface acoustic waves were excited in the stators.

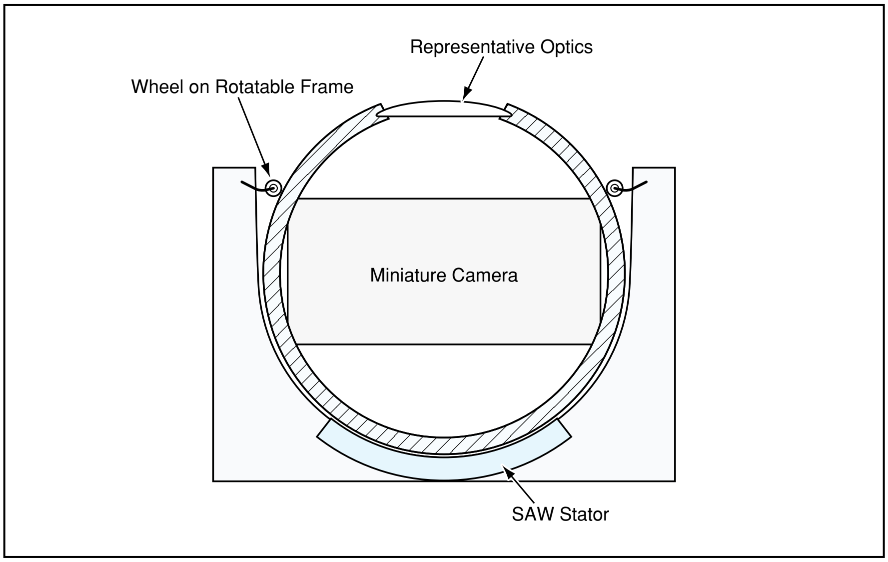

Figure 2. The **Sphere Would Rotate** about either of two orthogonal horizontal axes when surface acoustic waves were excited in the stator by use of either of two orthogonal pairs of SAW piezoelectric transducers in the stator.

case, two pairs of SAW piezoelectric transducers would be oriented orthogonally on a concave spherical stator instead of a flat stator, and the slider would be a sphere of nearly equal radius pressed against the stator.

In general, the minimum actuation step size would be approximately inversely proportional to the SAW excitation frequency. At contemplated maximum excitation frequencies of the order of tens of megahertz, minimum step sizes of nanometers could be achieved. Another advantage of using high excitation frequencies is that it would make it possible to achieve high force densities, thereby enabling the design of relatively small, lightweight actuators.

This work was done by Yoseph Bar-Cohen, Xiaoqi Bao, Anthony Hull, and John Wright of Caltech for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP [see page 1].*

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Propulsion Flight-Test Fixture

Subscale engines can be flight-tested early in the development cycle.

Dryden Flight Research Center, Edwards, California


NASA photo by Jim Smolka

Figure 1. The **PFTF Holds the Test Article** underneath the F-15B airplane during flight.

NASA Dryden Flight Research Center's new Propulsion Flight Test Fixture (PFTF), designed in house, is an airborne engine-testing facility that enables engineers to gather flight data on small experimental engines. Without the PFTF, it would be necessary to obtain such data from traditional wind tunnels, ground test stands, or laboratory test rigs.

Traditionally, flight testing is reserved for the last phase of engine development. Generally, engines that embody new propulsion concepts are not put into flight environments until their designs are mature: in such cases, either vehicles are designed around the engines or else the engines are mounted in or on missiles. However, a "captive carry" capability of the PFTF makes it possible to test engines that feature air-breathing designs (for example, designs based on the rocket-based combined cycle) economically in subscale experiments.

The discovery of unknowns made evident through flight tests provides valuable information to engine designers early in development, before key design decisions are made, thereby potentially affording large benefits in the long term. This is especially true in the transonic region of flight (from mach 0.9 to around 1.2), where it can be difficult to obtain data from wind tunnels and computational fluid dynamics.

In January 2002, flight-envelope expansion to verify the design and capabilities of the PFTF was completed. The PFTF was flown on a specially equipped supersonic F-15B research testbed airplane, mounted on the airplane at a center-line attachment fixture, as shown in Figure 1.

NASA's F-15B testbed has been used for several years as a flight-research platform. Equipped with extensive research air-data, video, and other instrumentation systems, the airplane carries externally mounted test articles. Traditionally, the majority of test articles flown have been mounted at the center-line tank-attachment fixture, which is a hardpoint (essentially, a standardized weapon-mounting fixture). This hardpoint has large weight margins, and, because it is located near the center of gravity of the airplane, the weight of equipment mounted there exerts a minimal effect on the stability and controllability of the airplane.

The PFTF (see Figure 2) includes a one-piece aluminum structure that contains space for instrumentation, propellant tanks, and feed-system components. The PFTF also houses a force balance, on which is mounted the subscale engine or other experimental apparatus that is to be the subject of a flight test. The force balance measures a combination of inertial and aerodynamic forces and moments acting on the experimental apparatus.

The PFTF instrumentation system is a slave to the instrumentation system of the F-15B airplane. At present, as many as 128 parameters can be monitored by use of the PFTF; however, it is possible to expand the capabilities of the PFTF to monitor more parameters, if necessary. These monitored parameters can include, but are not limited to, pressures, temperatures, accelerations, vibrations, and strains. Sample rates are variable, generally between 10 and 400 samples per second, but much higher data-acquisition rates are possible. Parameters can be recorded aboard the F-15B airplane by use of a digital recorder or telemetered to a control room.

An experimental apparatus as heavy as 500 lb (≈227 kg) and as long as 12 ft (≈3.7 m) can be mounted on the PFTF. The PFTF can accommodate experiments in which are produced thrusts or drags as large as 2,000 lb (≈8.9 kN) and side forces up to 500 lb (≈2.2 kN). For envelope-expansion