Development of Controlled Surface Acoustic Wave Planar Actuators

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Abstract
This paper describes the development of Surface Acoustic Wave (SAW) actuators under closed loop control, which can be applied as ultra precision multi-axis manipulators. Some key issues in the development of a planar version are discussed. Furthermore, reasons are given why other types of SAW generating transducers are being investigated.

1. Introduction
The working principle of SAW actuators gives them characteristics that make them very suited for application in e.g. ultra precision machines. One of them is the straightforward way of closed loop position control, on the condition that the inherent dead band in its response is solved in e.g. the way described below. Another one is the suitability to use it in planar actuator, without the need of stacking axes.

Often so called IDTs (Inter Digital Transducer) are used to generate the SAWs. In literature alternative transducers have been described, which may have some advantages over the IDTs. These alternatives are currently under investigation.

2. SAW actuation principle
The actuation principle of a SAW actuator is based on moving a slider across an elastic solid medium, called stator, through the surface of which Rayleigh waves are propagating [1]. These traveling waves cause elliptical movement of particles at the surface, showing a fixed ratio between tangential and perpendicular motion. The waves are generated by applying a sinusoidal voltage to so-called Inter Digital Transducers (IDTs), finger shaped galvanic patterns applied at a locally polarized stator surface. At practical voltages applied to the IDTs, amplitudes in the order of 20 to 40 nm occur, demanding a $R_s$ surface roughness of about 20 nm. By ELID grinding a surface roughness of 10 nm has been attained. In order to generate sufficient traction force to move the slider and to prevent a squeeze air film between slider and stator, the contact surface of the slider (1 cm²) consists of many ball-segments, closely packed, made by lithographic etching of silicon [1]. To achieve high accelerations it is necessary to preload the slider. Depending on the application, several force generating principles can be used, e.g. a vacuum force, a magnetic force, etc.

3. Closed loop control
In papers presented so far, very small steps of 2 nm have been reported for SAW actuators operating in open loop [2]. In an industrial environment, disturbances will harm the reproducibility of this kind of steering. Therefore, we focused on closed loop control of the SAW actuator. Step response measurements on our first linear demonstrator showed a first order response from the amplitude of the high frequency sine used to energize the IDTs to the speed of the slider. This first order behavior can be represented by the simple first order model, given in Figure 1. The damper $d$ is part of the actuator model and the amplitude of the driving sine is proportional to the force $F$ on the mass $m$.

![Figure 1: Model of SAW actuator](image)

This system resembles the behavior of a voltage driven DC actuator. For that actuator type (with internal resistance and negligible self-inductance), the damper in the model can be physically explained by a back EMF: for increasing speed, the induced voltage rises. For the SAW actuator, the physical explanation of the damper lies in the ‘running-in and -out’ of fresh material in the contact between stator and slider.
The model proposed above suggests a linear system. However, measurements have shown that the linearity between sine amplitude and steady state speed does not exist for very low amplitudes, see Figure 2. The problem is that if a very small steady state speed is required, the tangential motion must be so small that the perpendicular amplitude becomes smaller than the indentation of the preloaded slider against the stator and the surface roughness of the stator. For amplitudes below this threshold, no slider movement results so this dead band hampers good control.

![Figure 2: Speed against input voltage, dead band present](image)

This problem can be solved if one could use waves for which the relation between tangential and perpendicular motion is not fixed. In that case, the tangential motion can be chosen such that the low speed is achieved, but that the perpendicular motion is large enough. This decoupling between tangential and perpendicular motion can be achieved by using two Rayleigh waves from opposite sides: the longitudinal waves will interfere destructively (if they both have the same amplitude), while the transversal waves will interfere constructively. So the tangential motion is controlled by the difference in amplitude of the two Rayleigh waves, while the perpendicular motion is controlled by the sum of the amplitudes of the two Rayleigh waves. This idea was tested and proved to work, as is shown in Figure 3. This technique was named ‘Dual Side Actuation’, or DSA. Since we believe that high performance in closed loop can only be achieved when this dead band is eliminated, a patent application has been filed. When DSA is used, the SAW actuator may now be considered as a linear system, so we can characterize it by a frequency response function (FRF).

![Figure 3: Speed against input voltage, using DSA](image)

Note however, the large difference in behavior when the waves are present or when there are no waves. In the absence of waves, the pretension leads to a contact stiffness between slider and stator. Modeling the slider as a mass, this leads to a simple mass-spring system, with low damping. Once the waves are present, the contact stiffness disappears macroscopically spoken. Instead of stiffness, damping is encountered.

4. The planar actuator

Considering the set-up as shown Figure 4, showing the carrier being supported by three sliders A, B and C. Each slider is driven in only one direction. When the carrier has to be moved e.g. in y-direction, both the sliders B and C are driven. Note that DSA is applied here, so IDTs at both sides of the accompanying stators are energized. In that particular case, moving the carrier implies that slider A has to slide across the stator, requiring a large (static) friction force.

![Figure 4: Planar SAW actuator with reduced number of actuators, constructed by three linear SAW actuators](image)

Practically, sliders B and C cannot overcome this force and no motion will occur. However, when applying DSA by energizing both IDTs that actuate slider A equally, a standing wave is created for slider A. Whereas no
motion occurs in x-direction, the behavior of that slider has changed to that of the mass-damper model of Figure 1, implying that a damper is encountered instead of a friction force (in addition to the dampers felt at the locations of sliders B and C). Generally spoken, by generating a standing wave in a stator in a particular direction, the slider can be moved across that stator in any direction across the stator plane, without introducing a friction force. Only a damper force should be compensated for. Driving the carrier in x-direction is analogous in this set-up, when taking into account the distance from slider A to center of gravity of the carrier, that has to be compensated by a torque supplied by the sliders B and C. Note that the orientation of the stators can be made such (3 times at 120°) that the driving behavior becomes equal for both x- and y-direction. Experiments have shown that this set-up (Figure 5) is feasible to drive the carrier in three degrees of freedom.

5. Alternative transducers

Many of the designs currently found in literature use one part made out of piezo electrical material that combines two functions: 1) wave generation, for which purpose a finger like pattern is etched upon it, and 2) wave conduction/interaction with the slider. In this way the issue of a SAW crossing the boundary between two materials is avoided.

The disadvantage is that one is not free to choose the best materials for the two different functions. For the part of the stator that only conducts the SAW and makes contact with the slider, piezo electrical material may not be the best choice considering tribology, manufacturing and cost effectiveness.

Other transducers like proposed in [4] have a structure that makes it much easier to use a different material for the conducting/contacting part of the stator. Furthermore, it is claimed that some are more efficient in converting electrical energy into wave energy than the IDT type of transducer.

Such a module-like transducer with higher efficiency would enable other applications that can benefit even more from the SAW actuation principle than the present designs.

6. Conclusions

This paper describes some key elements to arrive at a planar SAW actuator under closed loop control. The Dual Side Actuation principle solves the inherent dead band in the response of a SAW actuator, which facilitates straightforward control of this type of actuator. Secondly, it has been shown that a planar version can be built using sliders that are propelled in one direction only. This too is only possible by the DSA principle.

Finally, arguments are given to investigate other types of SAW transducers.

7. References
