ALLSENSORS 2021

Design of Surface Acoustic Wave Motors With Non-piezoelectric Stator Material
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July 2021
Introduction

Richard Günther

- 2003-2009: Study of Electronic Engineering at Dresden University of Technology
- 2009-2013: Research assistant for approach development of medical injection devices at Dresden University of Technology
- From 2015: Lectureship for design fundamentals and numeric simulation at Berufsakademie Sachsen
- Research on Surface Acoustic Wave motors since 2010 as part of PhD thesis
Motivation

- Growing demand of decentral electric small drives
  - Illustration: More than 120 small drives in a car [1]
  - Often linear motion and self-locking required
  - Apart from electromagnetic motors piezoelectric motors are increasingly important
    - Surface Acoustic Wave (SAW) motors have simple design and high operating frequency
      - Miniaturizable and powerful

Motivation

- Functional principle of SAW motors:

- Existing SAW motor:
  - Technical Data [2, 3]:
    - Normal deflection of SAW: 21 nm
    - Blocking force: 9 N
    - Idling speed: 0.55 m/s
    - Positioning accuracy: 1 nm

[2] Shigematsu et al., Nanometer stepping drives of surface acoustic wave motor
Motivation

- **Existing SAW motor:**
  - Disadvantage of existing SAW motor:
    - Whole stator is made from piezoelectric material (LiNbO$_3$)
      - Nearly no influence on material parameters (price, brittleness, friction coefficient)
  - SAW motor with non-piezoelectric stator material avoids these disadvantages
    - Needs additional piezoelectric units
Motivation

- We realized the first functional model of a SAW motor with non-piezoelectric stator material

- Characteristic values:
  - Operation frequency: 3.85 MHz
  - Applied voltage: 50 V
  - Duration: 50,000 periods

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Idling speed</td>
<td>29 mm/s</td>
</tr>
<tr>
<td>Blocking force</td>
<td>0.19 N</td>
</tr>
</tbody>
</table>

Slider position for load free operation
Gliederung

1 Numerical models

2 Guidelines for designing

3 Conclusion
Gliederung

1 Numerical models

2 Guidelines for designing

3 Conclusion
1 Numerical models

- Model for dimensioning of piezoelectric unit
  - Normal polarized PZT block with continuous bottom electrode and IDT as outer electrodes
  - Transient 2D model using finite element method
  - Coupling of electrostatics and mechanics
1 Numerical models

- Motor model
  - Based on **Existing model** (by Shigematsu and Kurosawa)
    - Considers one projection
    - Elliptical displacement of stator allows three states
      - No contact
      - Sticking
      - Sliding
    - Tangential average force equals motor force
    - Varying slider speed allows considering the whole characteristic
1 Numerical models

- Motor model based on existing model
  - Enhancement: Considering roughness and flatness
    - Assumption in existing motor model:
      - $\eta=0.36$: 36 % of all projections are contacted
      - Due to roughness and flatness this number would depend on contact force
    - Realistic implementation with normally distributed contact distances:
      - $F_N = n_{pr} K_{gesn} \int_{-\infty}^{u_{ln}} N(u_n,R_{au}) du_n$
      - $\eta = N(u_{ln},R_{au})$
1 Numerical models

- Motor model based on existing model
  - Enhancement: Dynamic losses
    - *Discrete Fourier transform* applied to $F(t)$
    - Determining mechanical Impedances for harmonic forces
    - Determining dynamic losses:
      \[ P_{\text{dyn}} = \sum_{i=0}^{m} P_i(\hat{F}_i, f_i) \]
1 Numerical models

- Motor model based on existing model
  - Enhancement: Dynamic losses
    - Exemplary power components of existing SAW motor (normalized to initial power)
Gliederung

1 Numerical models

2 Guidelines for designing

3 Conclusion
2 Guidelines for designing

- Limited for motors with PZT units adhered on metallic substrate and slider made from silicon
- Refeeding of SAW power not considered
2 Guidelines for designing

1. Determination of target values
   - Motor characteristic: Define blocking force and idling speed
   - Motor dimensions:
     - Width is proportional to motor power by constant SAW amplitude
     - Length is determined by travel range, length of piezoelectric units and the damper sections
2 Guidelines for designing

2. Dimensioning

- Dimensioning by motor model
  - Operating frequency: High values result in high idling speed
  - SAW amplitude and contact force: Vary by optimization to reach targeted motor characteristic for minimal SAW amplitude

- Determining PZT thickness by modal analysis: Thickness must fit to targeted operating frequency

- Dimensioning of stator by transient FEM model
  - Correction of PZT thickness and IDT's finger spacing
  - Fitting number of IDT's fingers: Increase number to avoid overload
2 Guidelines for designing

3. Manufacture
   - Slider: Thin-layer technology without special features
   - Stator:
     - Metal plate must be lapped and polished
     - Piezoelectric unit: Apply ground electrode on PZT plate by sputtering and IDT by thick film technology; electrode material is gold
     - Piezoelectric unit must be adhered on metal plate with thin adhesive layer and electric contact between metal plate and ground electrode
     - Piezoelectric unit must be polarized normally, with the help of a temporarily applied silver lacquer on the top surface
     - Apply dampers behind the piezoelectric units by viscoelastic material
     - Build up an electric impedance matching
2 Guidelines for designing

4. Checking motor characteristics
   - Test setup:
     - Connect waveform generator, amplifier, impedance matching and stator
     - Clean contact surfaces of stator and slider
     - Attach slider and magnets with iron counterplate carefully onto slider

![Diagram of surface acoustic wave motor with non-piezoelectric stator material]

[Diagram showing the components of the motor: Stator, Slider, Reflectors, Magnetic circuit, AOW, Matching, Amplifier, Oszilloscope, Waveform generator]
2 Guidelines for designing

4. Checking motor characteristics
   - Control: Input energy may be limited by sinusoidal excitation in burst mode
   - Measurements:
     - Idling speed: Determine by laser triangulator
     - Blocking force: Determine by force measuring device with force transducer crossing the travel path
Gliederung

1 Numerical models

2 Guidelines for designing

3 Conclusion
3 Conclusion

- We presented detailed guidelines for designing a novel type of SAW motor with non-piezoelectric stator material
- Required numeric models are described
- These information enable further investigations into this motor type
- Aim is the market launch of a compact linearmotor with
  - High positioning accuracy,
  - High power density and
  - Inexpensive manufacturing
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Many thanks for your attention!