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Dresden University of Technology

Institute of Electromechanical and Electronic Design

ALLSENSORS 2021

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

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Introduction

- Richard Günther
  - 2003-2009: Study of Electronic Engineering at Dresden University of Technology
  - 2009-2013: Research assistant for approach developement 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

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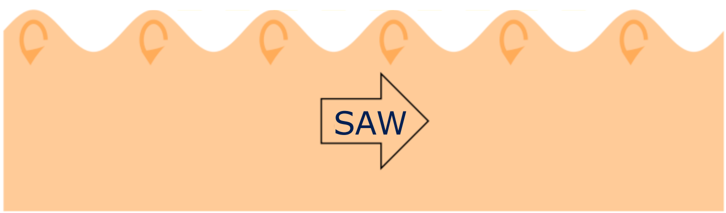
Motivation

- 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

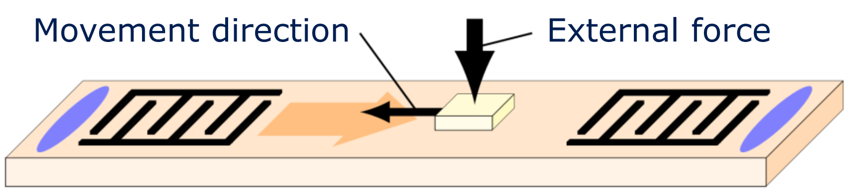
[1] Janocha, Hartmut. *Actuators*. Springer, 2004

Motivation

- Functional principle of SAW motors:



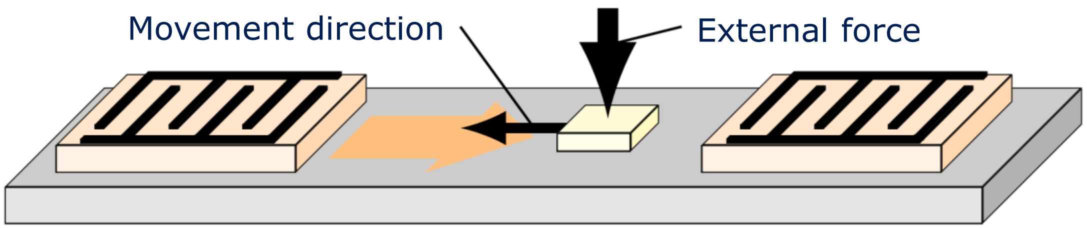
- Existing SAW motor:
    - Technical Data [2, 3]:
        - Normal deflection of SAW: 21 nm
        - Blocking force: 9 N
        - Idling speed: 0,55 m/s
        - Positioning accuracy: 1 nm



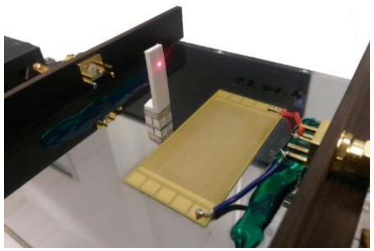
[2] Shigematsu et al., Nanometer stepping drives of surface acoustic wave motor
[3] Kurosawa et al., Elastic friction drive of surface acoustic wave motor

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

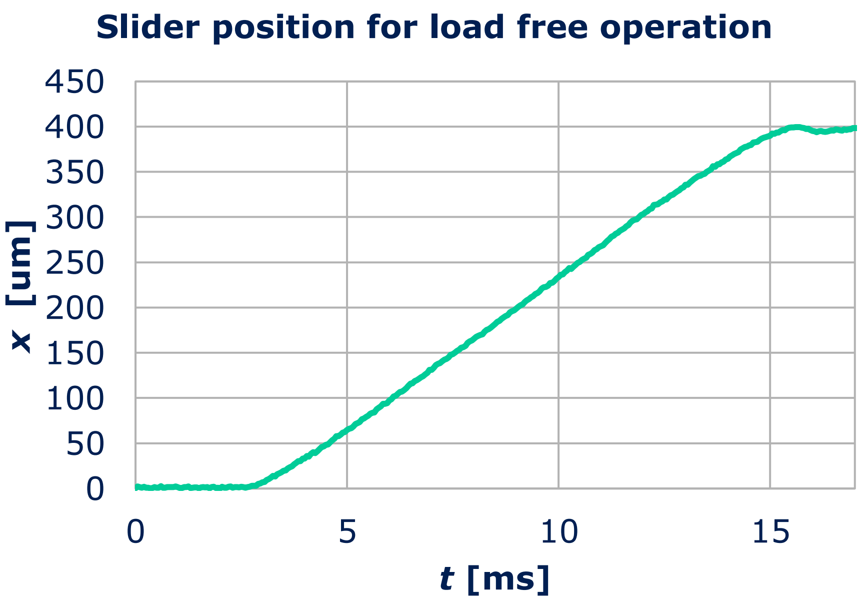


Motivation



- 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_{0p}
  - Duration: 50.000 periods

Parameter	Value
Idling speed	29 mm/s
Blocking force	0,19 N



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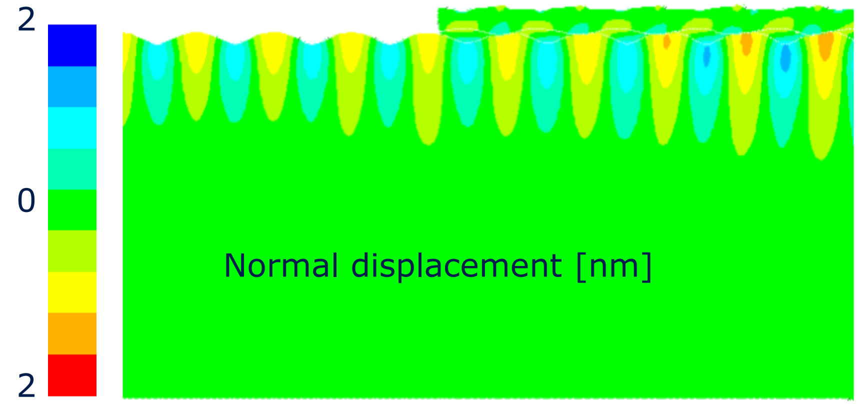
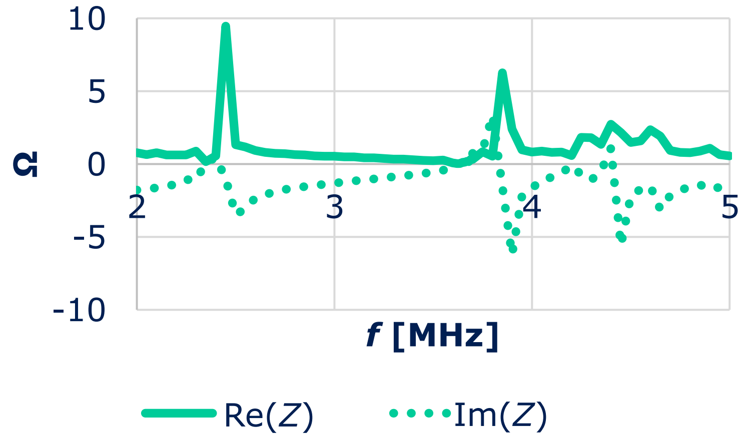
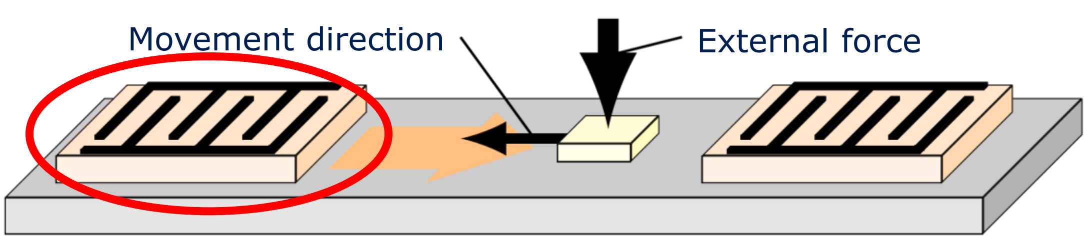
1 Numerical models

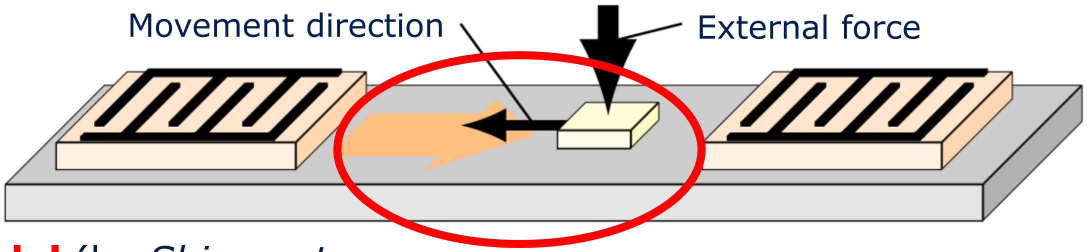
- Model for dimensioning of piezoelectric unit
  - Normal polarized PZT block with continuous bottom electrode and IDT as outer electrodes
  - Transient 2D model using finite element method
  - Coupling of electrostatics and mechanics



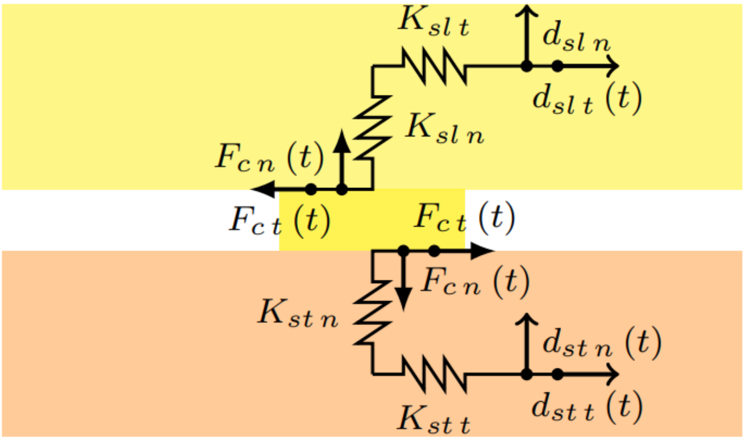




1 Numerical models



- 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



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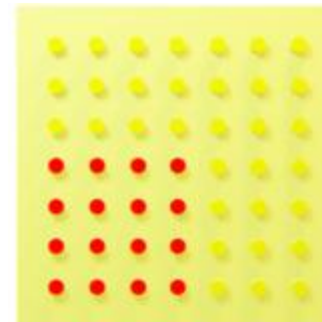
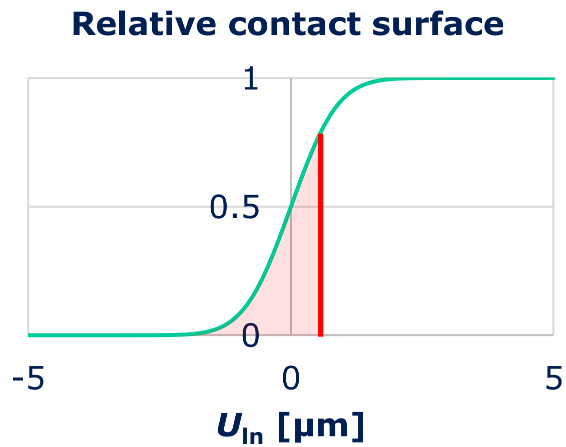


- Motor model based on existing model
  - Enhancement: Considering roughness and flatness
    - Assumption in existing motor model:
      - $\eta = 0.36$: 36 % of all projections are contacted
        - Due to roughness and flatness this number would depend on contact force
    - Realistic implementation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



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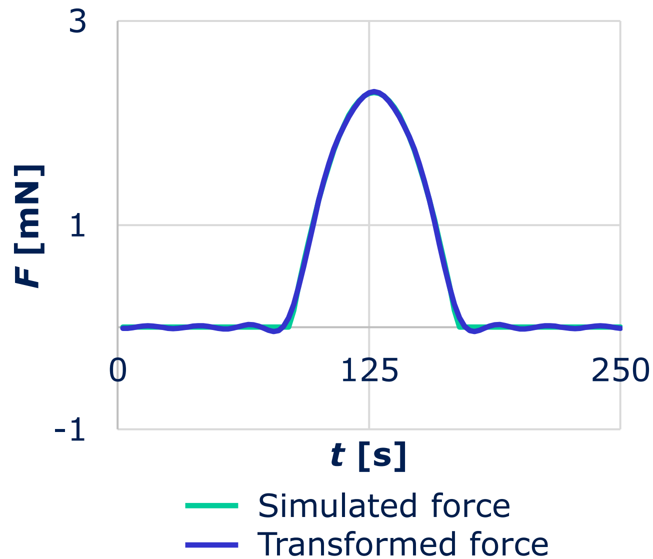
1 Numerical models

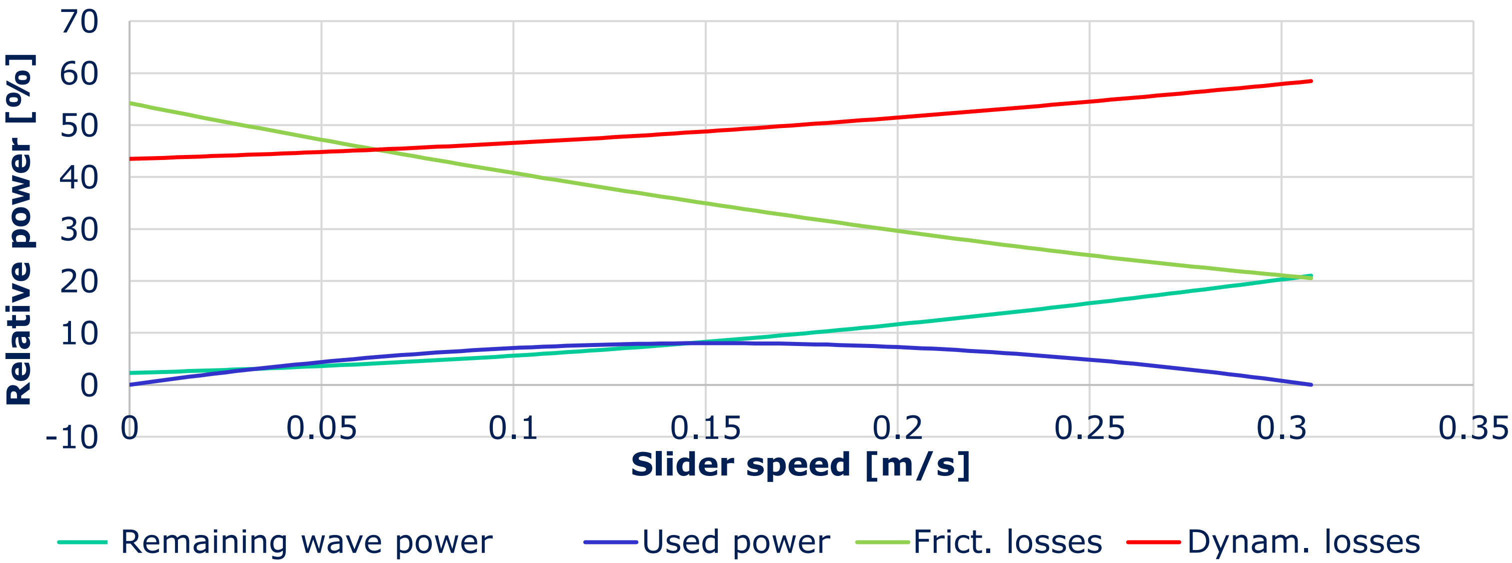
- Motor model based on existing model
  - Enhancement: Dynamic losses
    - *Discrete Fourier transform* applied to $F(t)$
    - Determining mechanical Impedances for harmonic forces
    - Determining dynamic losses: $P_{\text{dyn}} = \sum_{\text{i}=0}^{m} P_{\text{i}}(\hat{F}_{\text{i}}, f_{\text{i}})$



f_{i}… Frequency of oscillation i
$\hat{F}_i$… Force amplitude of oscillation i
P_{i}… Dynamic loss for frequency f_{i}
m… Number of interferring oscillations
P_{dyn}… Overall dynamic loss

1 Numerical models

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



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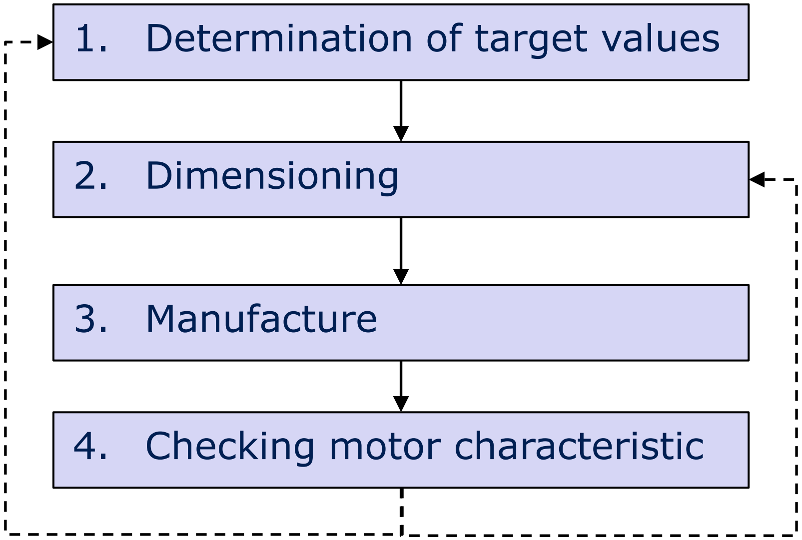
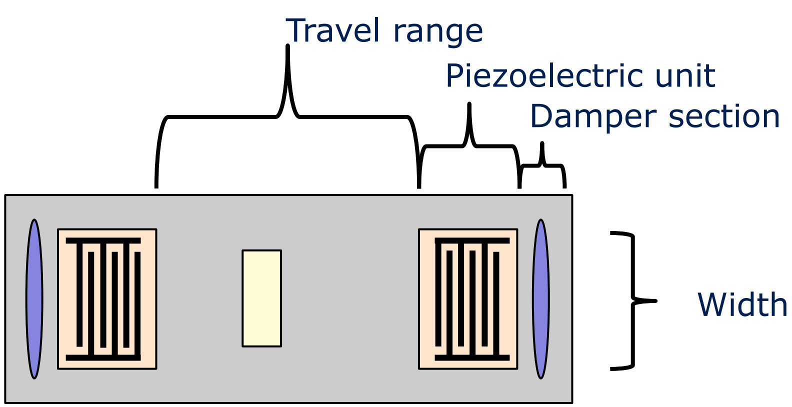
2 Guidelines for designing

- 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



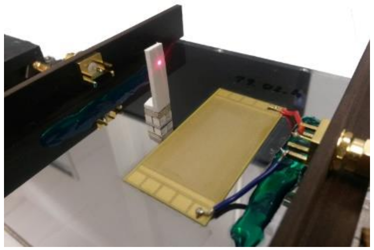
2 Guidelines for designing

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

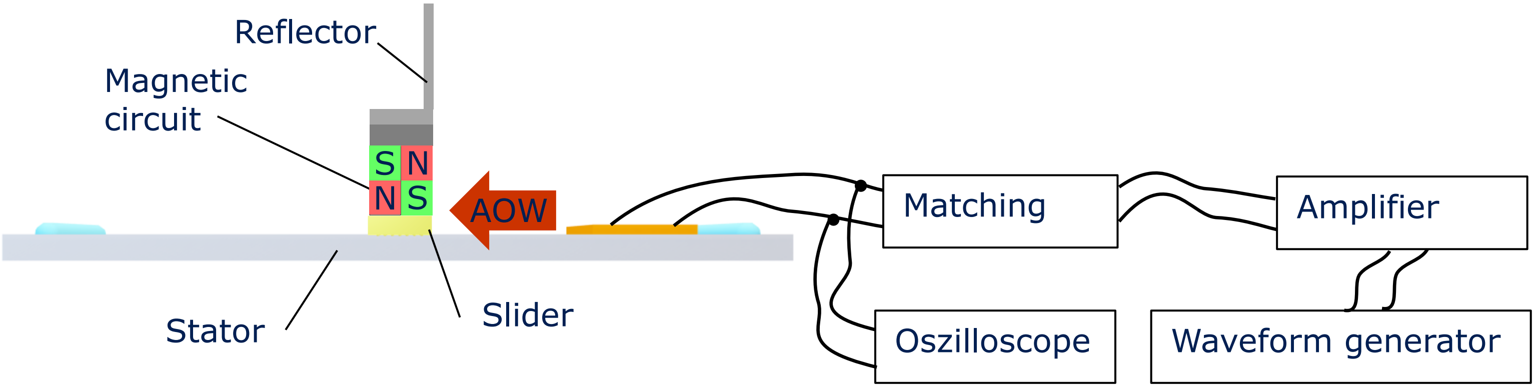
2 Guidelines for designing

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

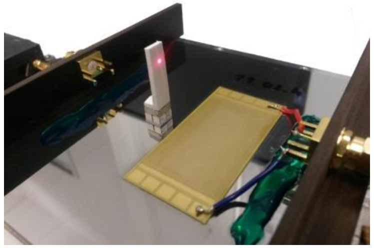
2 Guidelines for designing



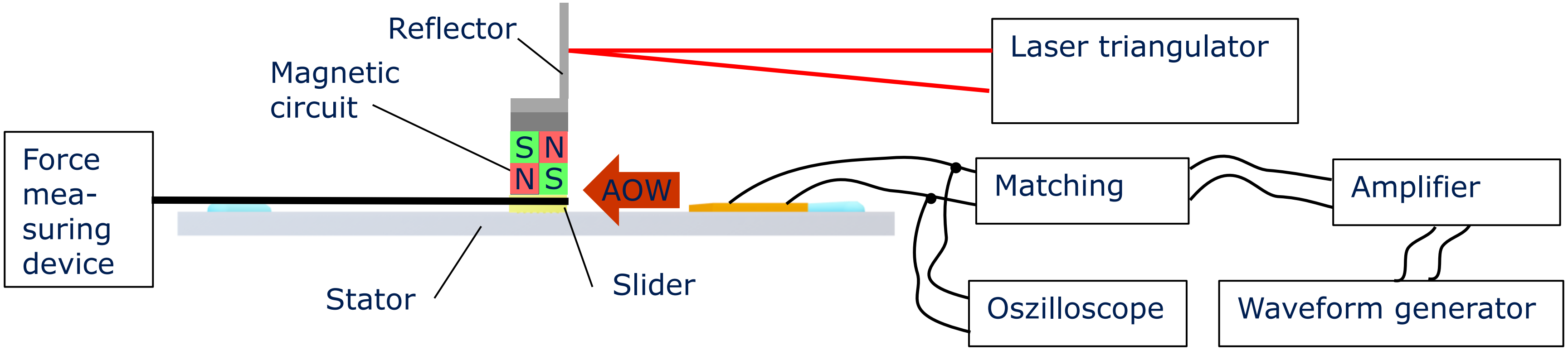
4. Checking motor characteristics
   - Test setup:
     - Connect waveform generator, amplifier, impedance matching and stator
     - Clean contact surfaces of stator and slider
     - Attach slider and magnets with iron counterplate carefully onto slider



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



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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!