Precision and Compact Dynamic Bending Tester

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**Background**

**Levitation Mass Method (LMM):**
An optical method for measuring force based on the definition, i.e. the product of mass and acceleration.

*Generation and measurement of varying force precisely*

**Applications:**
- Precision material testing
- Frictional characteristic measurement of linear bearings
- Dynamic force calibration of force transducers

**Optical interferometer in LMM: Bulk optical system**

More compact size with lower cost

- Demonstration of three point bending test using LMM
- Proposal for reducing size and cost of optical interferometer in LMM
Levitation Mass Method (LMM)

Rigid object
(Mass: \( M \))

Force: \( F \)
\[ F = Ma \]

Gravity: \( Mg \)

Small friction

Optical interferometer

Velocity, position, acceleration, force
Experimental setup for three point bending test

Doppler shift frequency: $f_{\text{Doppler}} = f_{\text{beat}} - f_{\text{rest}}$

Velocity: $v = \lambda_{\text{air}} (f_{\text{Doppler}})/2$

Acceleration: $a = dv/dt$

Reaction force: $F = Ma$

- Zeeman-type He-Ne laser
- PBS
- CC
- Moving part
- Gland-Thompson prism
- Signal beam
- Reference beam
- PD
- Counter
- Pneumatic linear bearing
- Guideway
- Aluminum bar under test
- Die
- Base
- Counter
- $f_{\text{beat}}$
- $f_{\text{rest}}$
Data processing procedure

Doppler shift frequency

Velocity

Position

Acceleration

Reaction force

Data processing procedure
Reaction force acting on moving part

**Reaction force against time**

**Reaction force against position**
Compact and low-cost interferometer

Conventional heterodyne interferometer using bulk optical system

- High precision
- Bulky
- High cost (Zeeman-type laser, etc.)
- Sensitive to vibration and temperature change

More compact size with lower cost

Interferometer using optical waveguide chip

![Diagram of interferometer using optical waveguide chip]
Some types of interferometer using optical waveguide chip

**Heterodyne interferometer**

- Frequency shifter
- Laser
- \( f_1 - f_2 - f_{\text{doppler}} \)
- \( f_1 - f_2 \)

**Homodyne interferometer with phase modulation**

- \( \Delta \phi \cos(2\pi ft) \)
- Phase modulator
- Laser
- \( I(t) = E_1^2 + E_2^2 + 2E_1E_2J_0(\Delta \phi) \cos(2k_0x) \)
- \( + J_1(\Delta \phi) \sin(2k_0x) \cos(2\pi ft) \)
- \( - J_2(\Delta \phi) \cos(2k_0x) \cos(2 \cdot 2\pi ft) \)
- \( - J_3(\Delta \phi) \sin(2k_0x) \cos(3 \cdot 2\pi ft) \)
- \( + \cdots \)

**Homodyne interferometer with 90° hybrid**

- \( 90° \) hybrid
- Laser
- \( I(t) = E_1^2 + E_2^2 + 2E_1E_2 \sin(2k_0x) \)
- \( I(t) = E_1^2 + E_2^2 + 2E_1E_2 \cos(2k_0x) \)
- PD1
- PD2
Integration of active devices (PDs and LDs) with optical waveguides

- Hybrid integration: Silica waveguides on Si substrate
- Monolithic integration: Semiconductor waveguides
Typical waveguide materials

Silica

- Low propagation loss
- Easy to couple to fibers
- Can control refractive index by UV irradiation
- Cannot realize active elements

Lithium niobate

- Low propagation loss
- Easy to form modulators and switching elements
- Cannot realize light sources and detectors

Semiconductor

- Easy to achieve compact chips
- Easy to form active elements
- Not easy to couple to fibers
- Relatively large propagation loss
- Relatively sensitive to crystalline orientation in formation process

Suitable for realizing passive lightwave circuits utilizing multiple-beam interference
Typical formation process of silica waveguides

1. Chemical Vapor Deposition
2. Photolithography
3. Reactive Ion Etching
4. Chemical Vapor Deposition
Conclusion

Demonstration of three point bending test using LMM

- A mass levitated using a pneumatic linear bearing with sufficiently small friction is made to collide with the object being tested.
- The velocity and acceleration of the mass are measured using an optical interferometer.
- The instantaneous value of the impact force is measured as the inertial force acting on the mass.

Proposal for reducing size and cost of optical interferometer in LMM

- Optical waveguide chip including interferometer
- Simple structure using homodyne interferometry
- Hybrid/monolithic integration of active devices