Dynamic Force Calibration Methods for Force Transducers

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Dynamic Calibration

Static Calibration

Reference Force = Gravitational Force

\[ M \downarrow Mg \]

Dynamic Calibration

[A] Impact Force: Fujii (Gunma Univ.), Kobusch, Bruns (PTB)

[B] Oscillation Force: Kumme (PTB), Fujii (Gunma Univ.)

[C] Step Force: Fujii (Gunma Univ.)
The Levitated-Mass Method

Rigid object
(Mass: $M$)

Force: $F$

$F = Ma$

Gravity:
$Mg$

Optical Interferometer

Small friction
Cut-away view of the bearing

- **Moving part** (partially cut away)
- **Guideway** (partially cut away)
- Air supply tube
- Air supply
- Air outlet
- Air inlet
- Air passage channel (grooved on the moving part)
Solid figure of the mechanical part

- Base
- Force transducer under test
- Damper
- Additional mass
- Guideway
- Moving part

CC

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Photograph of the mechanical parts

Force Transducer (SYOWA DB-200N)

Damper

Additional mass

Guideway

Moving part
Setup for Impact Force Calibration

- DMM (HP 3458A)
- Computer
- Counter (Advantest R5363)
- Counter (Advantest R5363)

Amplifier

Moving part

Reference beam

Signal beam

CC

PD

Glan-Thompson prism

PBS

Guideway

Damper

Force Transducer under test

He-Ne laser

$\text{f}_{\text{beat}}$

$\text{f}_{\text{rest}}$

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Data Processing Procedure

\[ v = \frac{\lambda_{\text{air}}(f_{\text{Doppler}})}{2}, \]

\[ f_{\text{Doppler}} = -(f_{\text{beat}} - f_{\text{rest}}) \]

\[ \alpha = \frac{d}{dt} v \]

\[ F_{\text{inertial}} = M \alpha \]
Response against Impact force

**Damper A**
- $F_{\text{inertial, max}} = 102.1 \text{ N}$
- $F_{\text{transducer, max}} = 101.0 \text{ N}$
- $W_{kv} = 18 \text{ ms}$
- $\int F_{\text{inertial}} \, dt = 1.976 \text{ Ns}$
- $\int F_{\text{transducer}} \, dt = 1.965 \text{ Ns}$
- $\left( \frac{\int F_{\text{transducer}} \, dt}{\int F_{\text{inertial}} \, dt} \right) - 1 = -0.006$

**Damper B**
- $F_{\text{inertial, max}} = 100.9 \text{ N}$
- $F_{\text{transducer, max}} = 102.3 \text{ N}$
- $W_{kv} = 10 \text{ ms}$
- $\int F_{\text{inertial}} \, dt = 0.968 \text{ Ns}$
- $\int F_{\text{transducer}} \, dt = 0.991 \text{ Ns}$
- $\left( \frac{\int F_{\text{transducer}} \, dt}{\int F_{\text{inertial}} \, dt} \right) - 1 = 0.024$
Setup for Oscillation Force Calibration

- **Base**
- **Moving part**
  - Spring
  - Force Transducer under test
  - Hammer with damper
- **Guideway**
- **Amplifier**
- **DMM (HP 3458A)**
- **Computer**
- **Counter (Advantest R5363)**
- **Counter (Advantest R5363)**
- **He-Ne laser**
- **PD**
- **CC**
- **PBS**
- **Glan-Thompson prism**
- **Sig. beam**
- **Ref. beam**
- **f_{beat}**
- **f_{rest}**
- **PD**
- **Amplifier**
- **DMM (HP 3458A)**
- **Computer**
- **Counter (Advantest R5363)**
- **Counter (Advantest R5363)**
- **He-Ne laser**
- **PD**
- **CC**
- **PBS**
- **Glan-Thompson prism**
- **Sig. beam**
- **Ref. beam**
- **f_{beat}**
- **f_{rest}**
Response against Oscillation force
Setup for Step Force Calibration

\[ Ma = -Mg + F_{\text{mass}} \]

\[ F_{\text{mass}} = Ma + Mg \]
Response against Step force

Moving part collided with the transducer

- $Ma + Mg$ /N
- $F_{\text{transducer}}$ /N

Moving part free fall

Moving part supported by wire

100 ms

$F$ /N

$t$ /s
Uncertainty Evaluation

Major uncertainty sources:

(1) Acceleration measurement using optical interferometer

The uncertainty in acceleration measurement when the sampling interval is approximately 0.2 ms is estimated to be approximately 1 N in the described 3 types of measurements.

(2) Mass measurement of the moving part

The relative uncertainty in measuring the mass using a commercial electric balance is usually better than 0.01 %. This is negligible.

(3) Effect of the external force

For the external force acting on the moving part, the frictional force acting inside the pneumatic linear bearing is dominant under the condition that the air film of approximately 8 µm thickness inside the bearing is not broken. This is estimated to be negligible under the usual conditions.

The above estimates imply that the uncertainty in determining the instantaneous value of the force in the described 3 types of measurements is estimated to be approximately 1 N. This corresponds to be approximately 1 % of the maximum value of the typical applied force of approximately 100 N.
Future Prospects

Means for integrating the various calibration methods and appropriate sets of parameters for describing the dynamic characteristics of general transducers will be strongly required.

The author has proposed all three types of dynamic calibration methods that are for the impact force calibration, the oscillation force calibration and the step force calibration. However, these methods are in the initial stage of the development.

The mean square value of the difference between the instantaneous value of the inertial force measured by the proposed methods and the output signal of the force transducer calibrated statically will be an appropriate parameter for evaluating the dynamic response of force transducers under the three conditions.
Conclusions

Three experimental setups were built for the dynamic calibration using an impact force, an oscillation force and a step force.

In the methods, the inertial force of a mass is used as the known dynamic force and this reference force is applied to a force transducer under test.

Future prospects are discussed.