



# Implementation of the high-accuracy variable rotation test bench: seismology options

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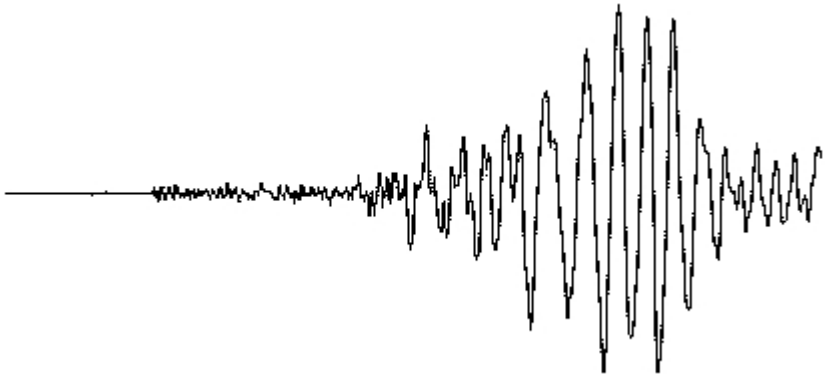
# Motivation

- Seismic rotations in general possess relatively low amplitudes: corresponding sensor resolution required
- Pure rotation measurements are preferable, which imposes certain limitations on the sensor type application
- Sensors must be calibrated in order to deliver reliable information about the rotations
- Existing calibration equipment is mostly suitable for testing rotational sensors for navigation where the amplitude-frequency ranges are substantially different

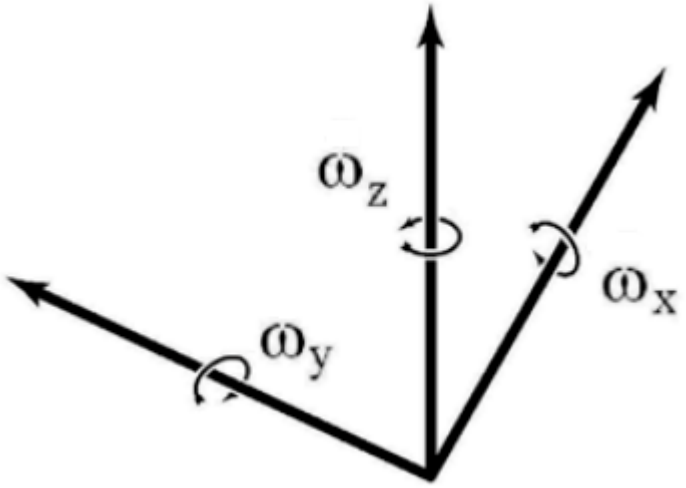
# Seismic rotation signals of interest

$10^{-11} \ldots 1\,\mathrm{rad/s}$

$10^{-3} \ldots 100\,\mathrm{Hz}$



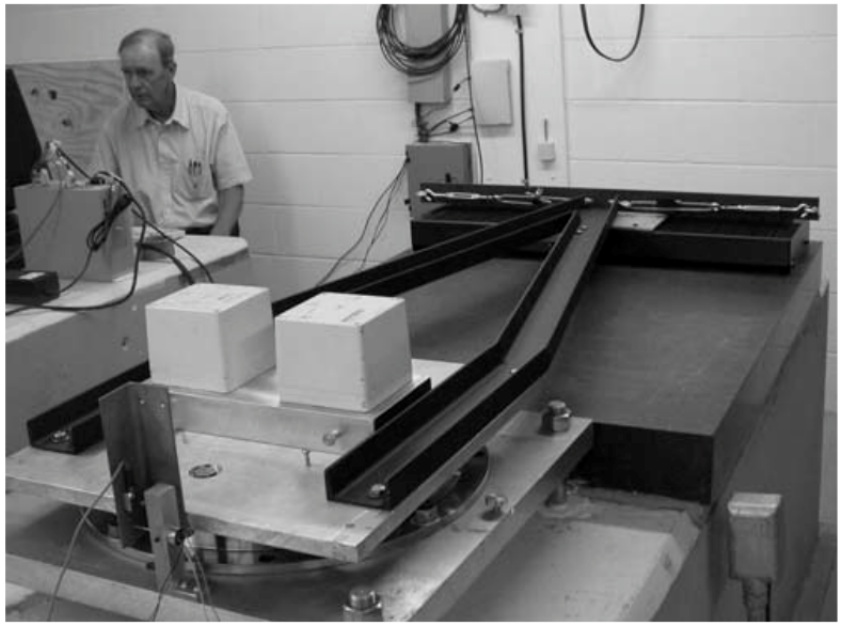
- Quasi-periodic signal
- Variable frequency
- Wide amplitude range

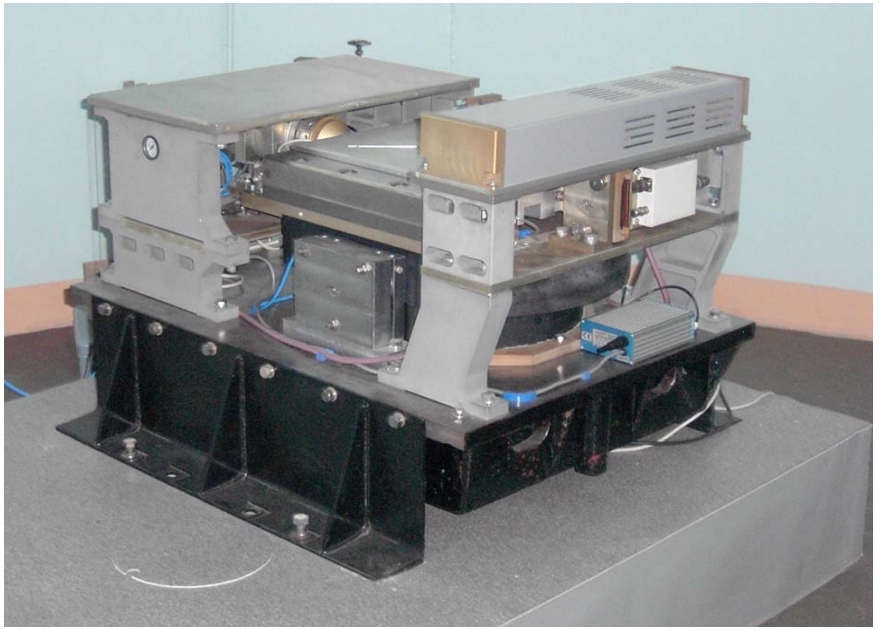


# Equipment required

- Rate tables (1, 2, multi-axis)
- Precise mounting fixture
- Positioning means (theodolite etc.)
- Centrifuges
- Vibration/shock machines
- Environmental chambers
- Data acquisition (ADC, counters, PC etc.)
- Few porters

# Test benches and rate tables





# Problems with traditional test equipment

- Tables are big, heavy and very expensive
- Barely available periodical motion regime
- Control sensor resolution might not be enough for testing in the lower range of rotational amplitudes
- No metrological methods exist yet for certification of periodical motion simulators (unless it's a specifically built standard)

# Example

$$A = 10^{-6} \ldots 10^{-2}\, m$$

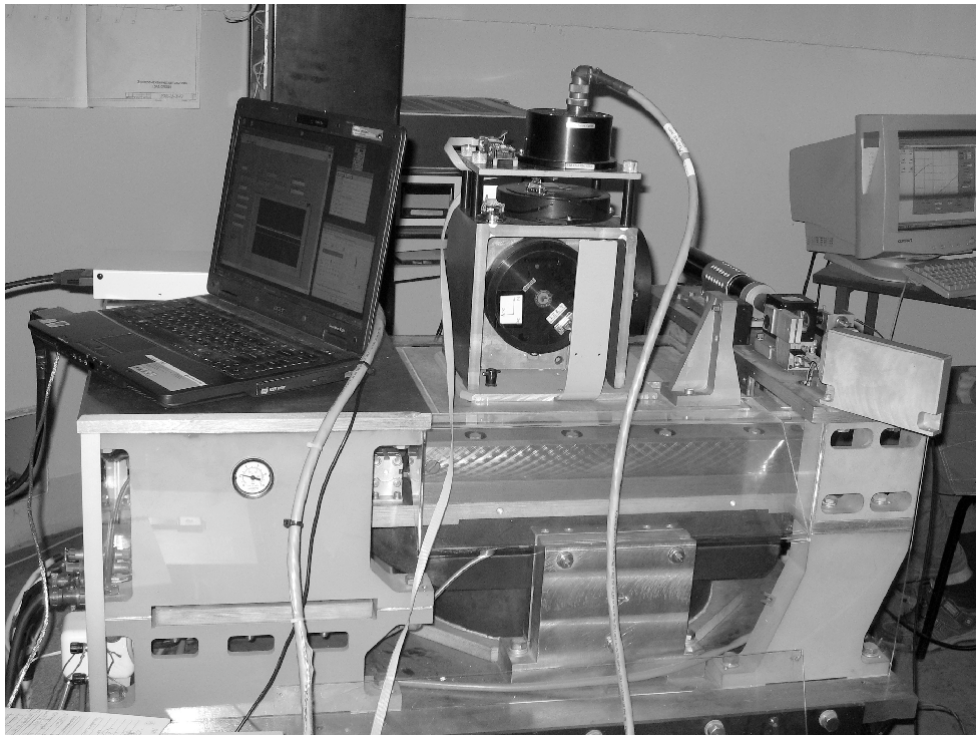
$$\phi = 10^{-7} \ldots 10^{-3}\, rad$$

$$f = 10^{-3} \ldots 1\, Hz$$

$$L = A_0 \sin(2\pi f t)$$

$$\varphi = \frac{L}{R} = \frac{A_0}{R} \sin(2\pi f t)$$

$$\omega = 2\pi f \frac{A_0}{R} \cos(2\pi f t)$$



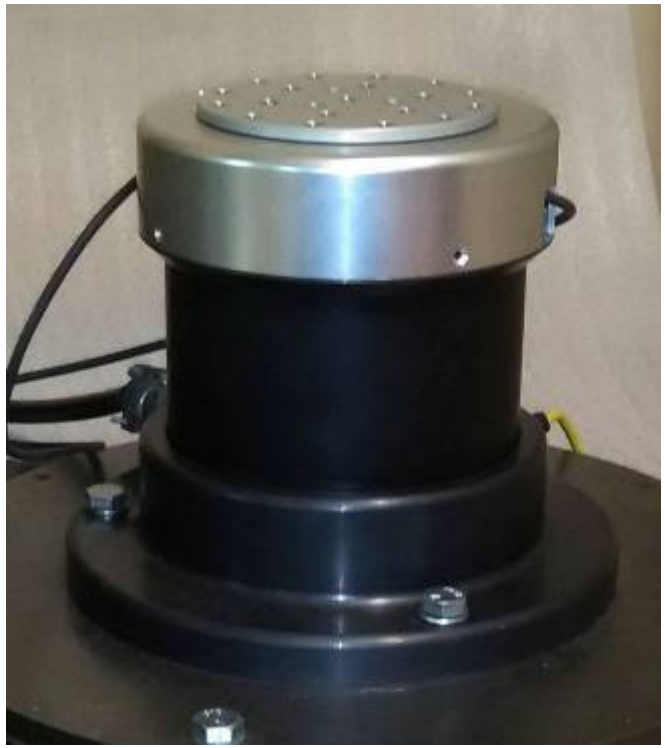
Good precision but limited amplitude and frequency range

# Calibration options for seismology

- Rotational shake table (see Nigbor, Evans, Hutt 2009)
- Direct accurate measurements of the platform angular position (high-accuracy angular encoder: ±1″) + interferometry
- Controllable variable rotation motion (tight motor control)
- Reasonably high bandwidth

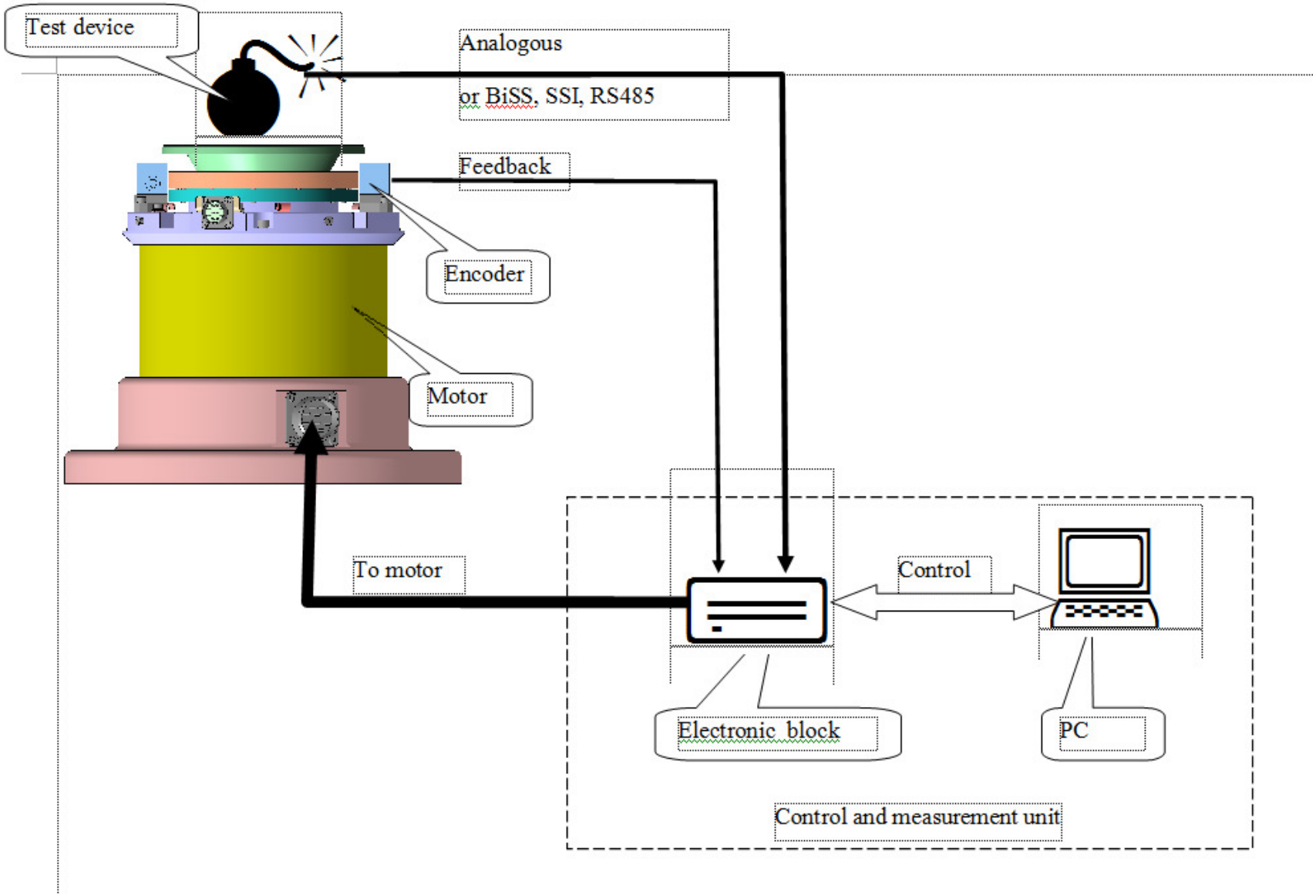
# Variable rotation test bench prototype

- Intended for calibration of angular accelerometers, eg. for robotic cars
- Reproduces sinusoidal and random angular acceleration
- Dimensions ∅200×250 mm



Electromechanical system

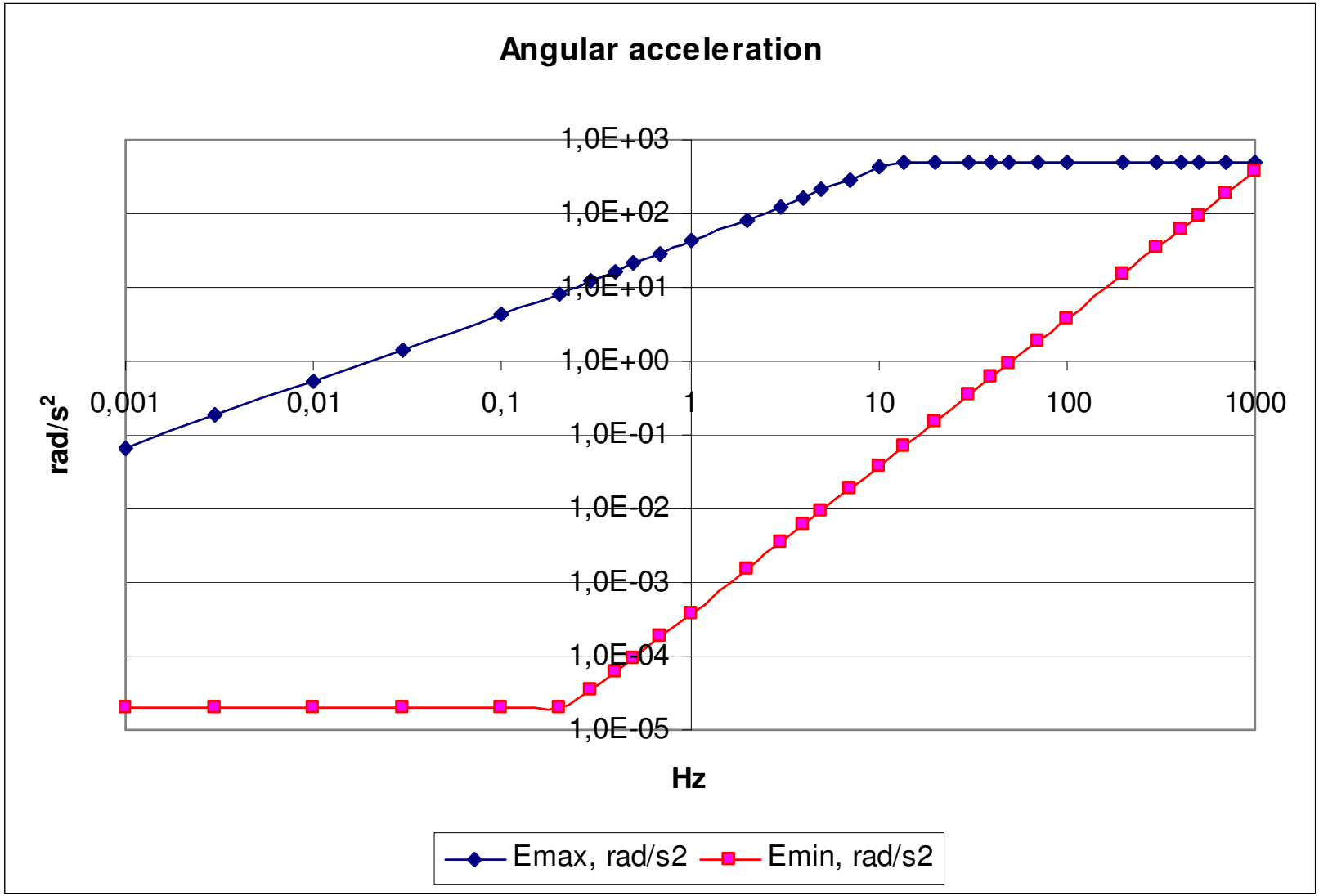
# Bench construction



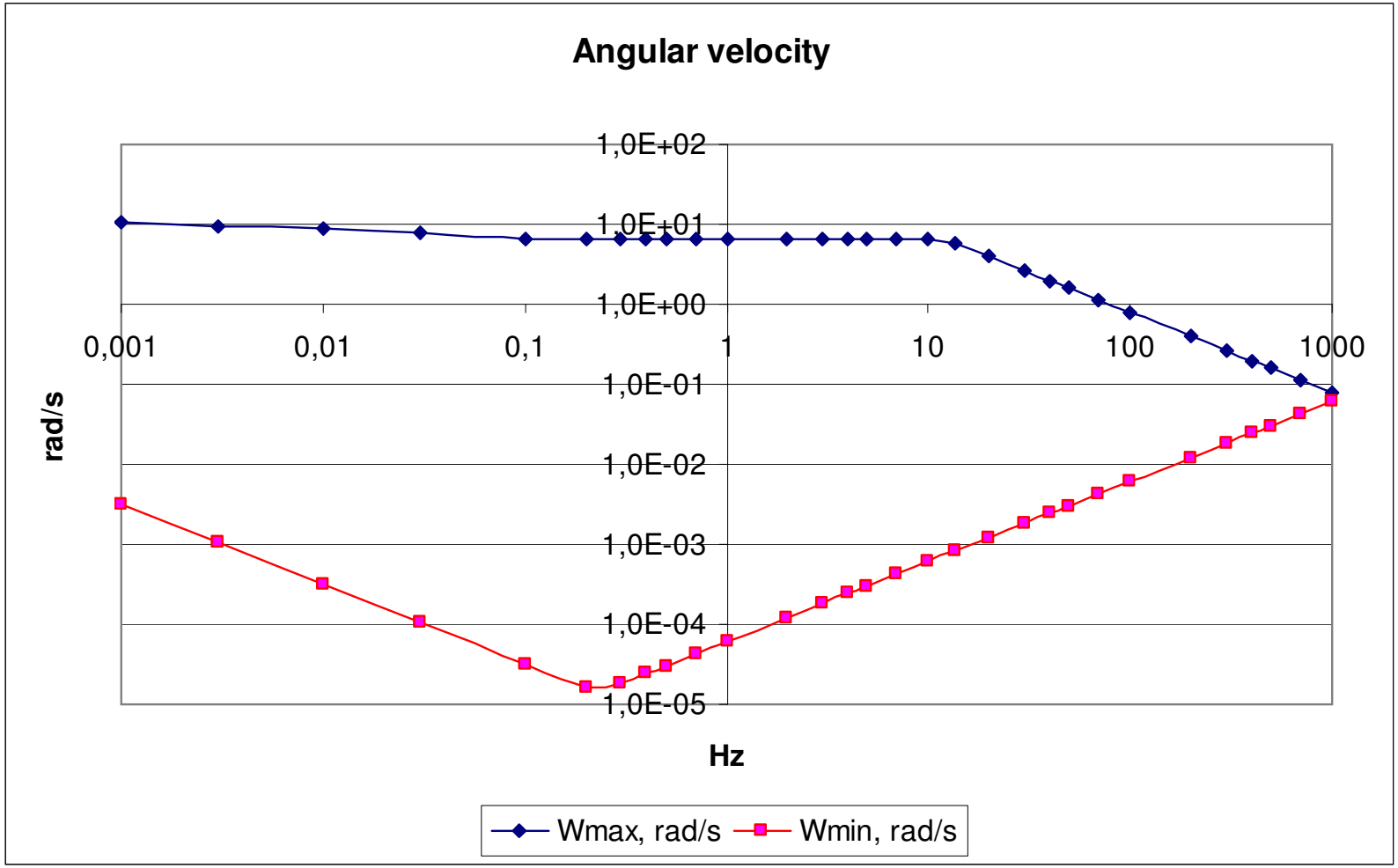
# Test bench parameters

- Angular acceleration, rad/s$^2$ — up to 500
- Angular velocity, rad/s — 0,0002-35
- Angles, rad — $10^{-5}$-1700
- Frequency range, Hz — 0,001-1000
- Angular acceleration amplitude measurement uncertainty, % — 0,5
- Payload
  - mass, kg — 5
  - moment of inertia, kg×m$^2$ — 0,01

# Transfer function (acceleration)



# Transfer function (velocity)



# Test bench hardware overview

- Absolute angular encoder (Renishaw Resolute) – self noise is about 0,01″ RMS
- Brushless synchronous motor – up to 20 Nm
- Smart drive controller for accurate waveform reproduction (Elmo Motion Control, National Instruments, etc.)
- Precise ball or aerostatic bearing
- Laser interferometer or precise autocollimator for control of amplitudes below 1″

# Test bench options

- Improvements
  - Payload (for frequencies below 100 Hz) – up to 20-30 kg
  - Uncertainty (for heavy payloads) – 5 to 10 times better
  - Ranges – up to 10 times in lower regions
- Aerostatic support for seismic applications (low frequencies and amplitudes)
- Integration of various measurement means for accurate waveform reproduction (encoder + interferometer, autocollimator + gyroscope, etc.)

# Improved test bench prototype

- Reversed aerostatic bearing
- Lower disbalance susceptibility (up to 1.5 kg)
- Better stiffness

# Conclusions

- For accurate seismic rotation measurements the calibration/test of a sensor under “field” conditions is preferable
- Accurate reproduction of variable low amplitude rotational motion in a broad frequency band is possible with modern technologies
- Metrology can provide the necessary means (methods and hardware) for precise measurements of the rotational motion in the A-F ranges of interest (particularly strong motion)