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A Pneumatically Driven Stewart Platform Used as Fault Detection Device

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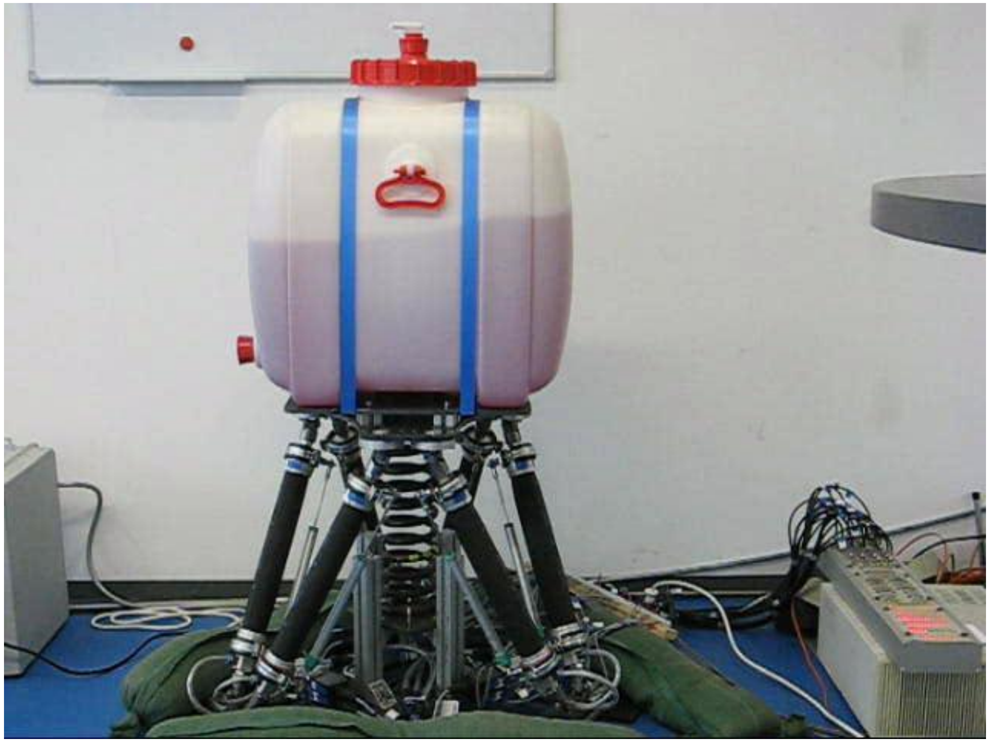
Introduction

Product tests:
• quality check
• extensive vibration during usage, shipping test

Test procedure:
• easy to reconfigure test pattern
• build in fault detection

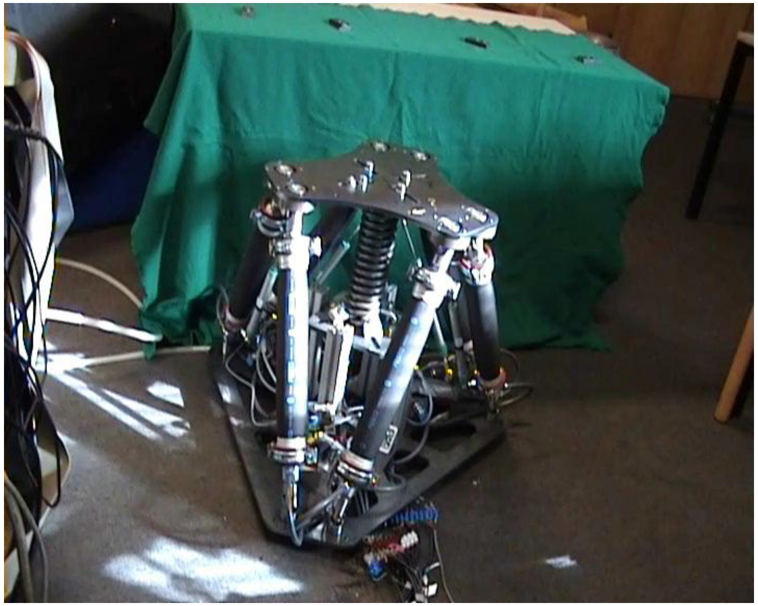


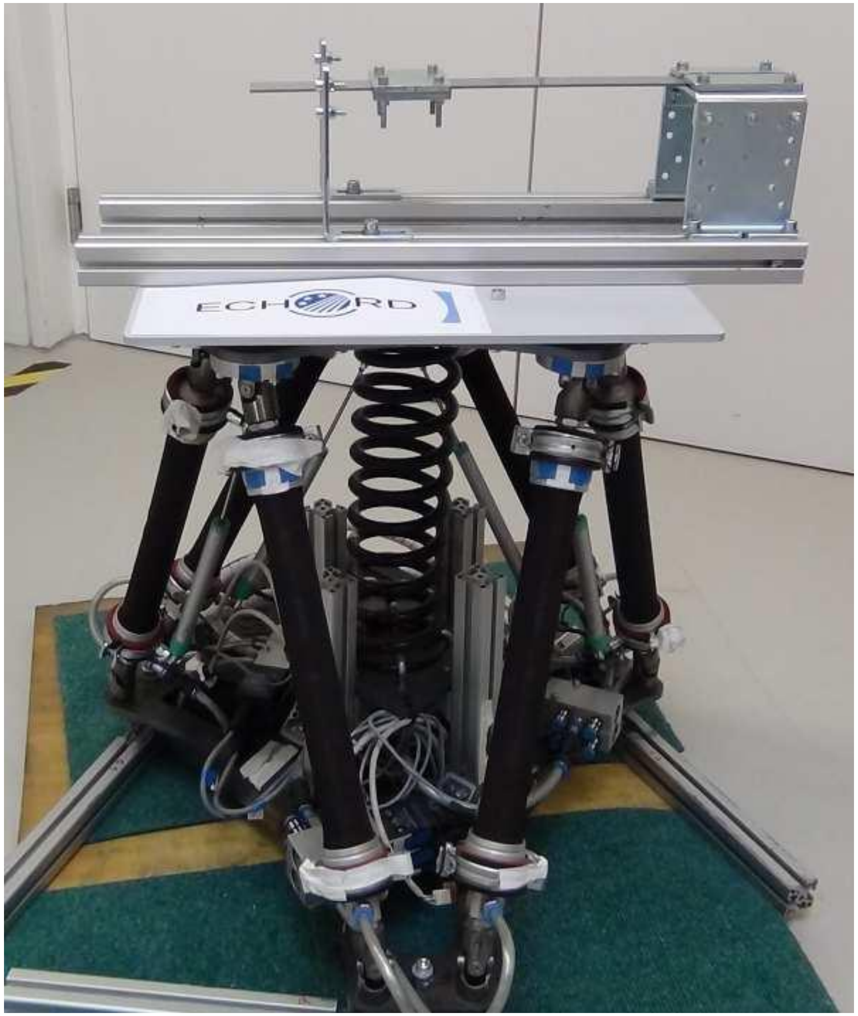
Specification:
Payload max: 300kg
Velocity max: 0.4 m/s
Acceleration: 3g
Frequency: 20 Hz

Design

Actuators:
- pneumatic muscles
- mass flow valves
- center spring

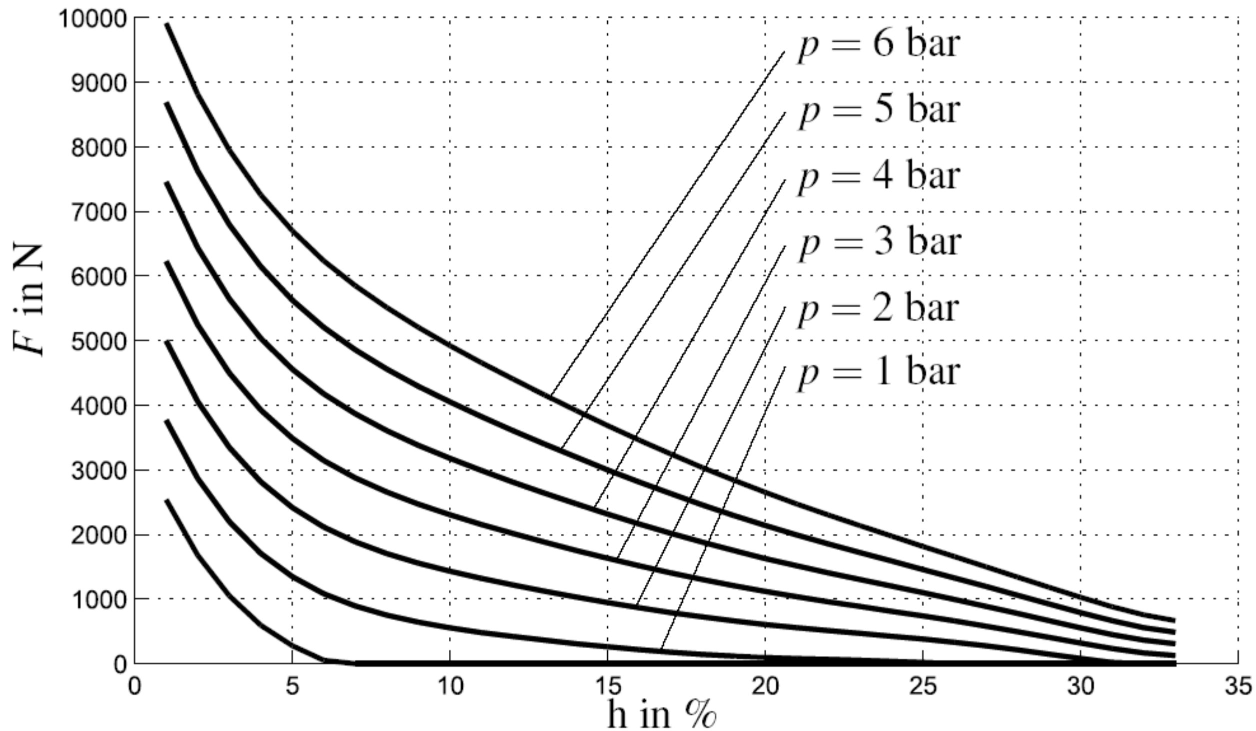
Sensors:
- position sensors
- pressure sensors





Pneumatic muscle

force – stroke – pressure relation



$$h_i = \frac{l_i}{l_0} 100\%$$

contraction of the muscle

Kinematics

Minimal coordinates for point P

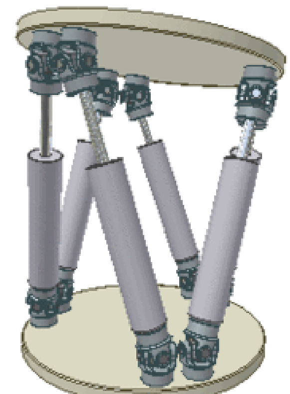
$$\mathbf{q}^T = (x \;\; y \;\; z \;\; \alpha \;\; \beta \;\; \gamma)$$

Vector loop for inverse kinematics

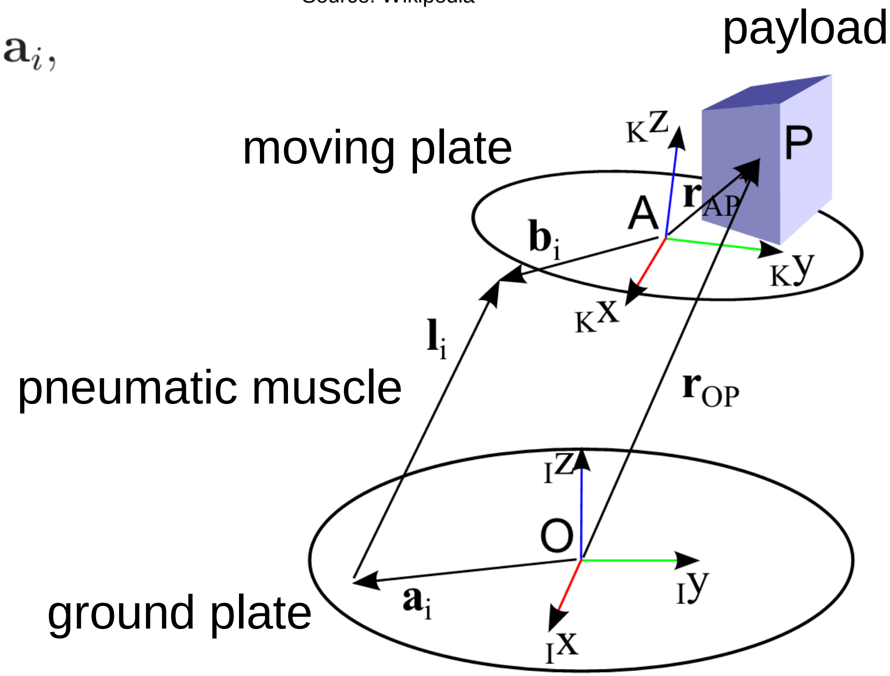
$$\begin{aligned} {}_I\mathbf{l}_i &= {}_I\mathbf{r}_{OP} + \mathbf{A}_{IK}({}_K\mathbf{b}_i - {}_K\mathbf{r}_{AP}) - {}_I\mathbf{a}_i, \\ l_i &= \sqrt{{}_I\mathbf{l}_i^T \; {}_I\mathbf{l}_i} \qquad i = 1..6. \end{aligned}$$

Rotation matrix for cardan angles

$$\mathbf{A}_{IK} = \mathbf{A}_{KI}^T = (\mathbf{A}_\gamma \mathbf{A}_\beta \mathbf{A}_\alpha)^T.$$



Source: Wikipedia



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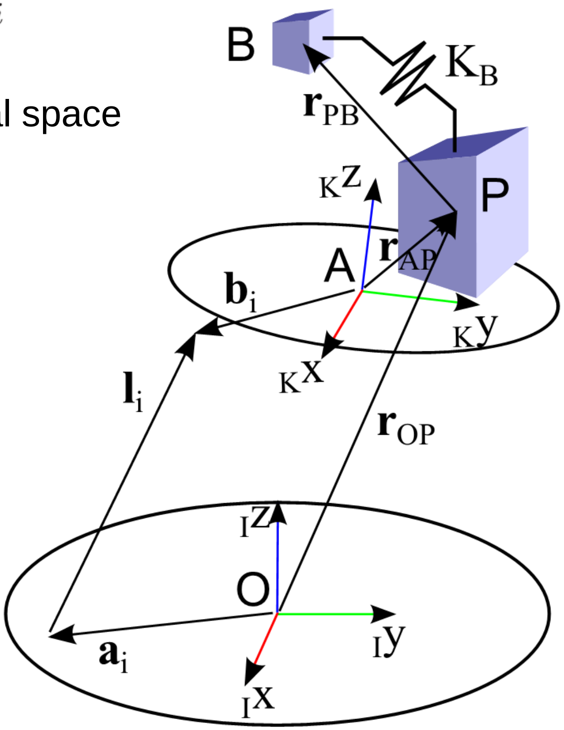
Equation of motion

Projection equation

$$\sum_{i=1}^{N}\left(\left(\frac{\partial_R \mathbf{v}_c}{\partial \dot{\mathbf{q}}}\right)^T \left(\frac{\partial_R \boldsymbol{\omega}_c}{\partial \dot{\mathbf{q}}}\right)^T\right)\begin{pmatrix} {}_R\dot{\mathbf{p}} + {}_R\widetilde{\boldsymbol{\omega}}_{IR}\ {}_R\mathbf{p} - {}_R\mathbf{f}^e \\ {}_R\dot{\mathbf{L}} + {}_R\widetilde{\boldsymbol{\omega}}_{IR}\ {}_R\mathbf{L} - {}_R\mathbf{M}^e \end{pmatrix}_i = \mathbf{Q},$$

Linear momentum and angular momentum are projected into minimal space
Representation in arbitrary coordinate systems *R*
Fading out of constrain forces due to the projection



Generalized muscle forces using virtual work

$$\delta W = \delta \mathbf{q}^T \mathbf{Q} = \sum \delta\ {}_I\mathbf{r}_i^T\ {}_I\mathbf{F}_i = \sum \delta \mathbf{q}^T \left(\frac{\partial_I \mathbf{r}_i}{\partial \mathbf{q}}\right)^T {}_I\mathbf{F}_i,$$

$${}_I\mathbf{F}_i = F_i \frac{{}_I\mathbf{l}_i}{\|\ {}_I\mathbf{l}_i\|}$$

$$\mathbf{q}^T = (x \;\; y \;\; z \;\; \alpha \;\; \beta \;\; \gamma \;\; u \;\; v \;\; w \;\; \vartheta \;\; \rho \;\; \varphi)$$

Dynamics

Generalized spring forces are introduced by the potential

$$V = \frac{1}{2}\mathbf{q}^T\mathbf{K}\mathbf{q}, \qquad \text{and calculated to} \qquad \mathbf{Q} = -\left(\frac{\partial V}{\partial \mathbf{q}}\right)^T = -\mathbf{K}\mathbf{q}.$$

To account for the damping a Rayleigh function is used

$$R_B = \frac{1}{2}\left(d_{t,xy}\left(\dot{u}^2 + \dot{v}^2\right) + d_{t,z}\dot{w}^2 + d_{r,xy}\left(\dot{\vartheta}^2 + \dot{\rho}^2\right) + d_{r,z}\dot{\varphi}^2\right)$$

and calculates to

$$\mathbf{Q} = -\left(\frac{\partial R_B}{\partial \dot{\mathbf{q}}}\right)^T.$$

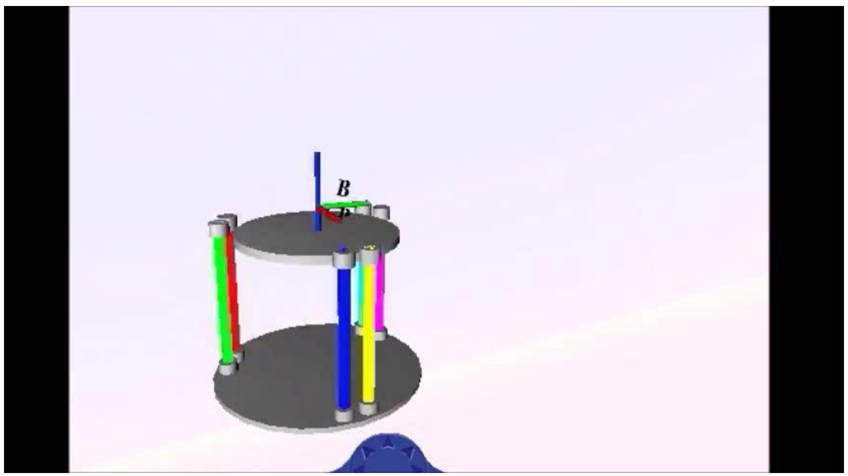
This results in the equation of motion

$$\boxed{\mathbf{M}(\mathbf{q})\,\ddot{\mathbf{q}} + \mathbf{g}(\mathbf{q},\dot{\mathbf{q}}) + \mathbf{K}\mathbf{q} = \mathbf{B}(\mathbf{q})\,\mathbf{u}} \qquad \mathbf{u} = \begin{pmatrix} F_1 & .. & F_6 \end{pmatrix}^T$$

Simulation

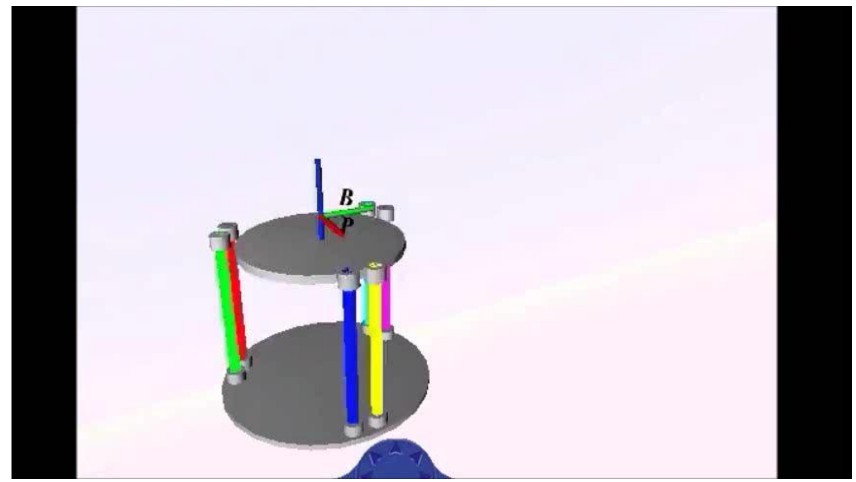
Simulation with Matlab Simulink

part is OK no extra vibrations



Spring matrix $\mathbf{K}_B$ is stiff

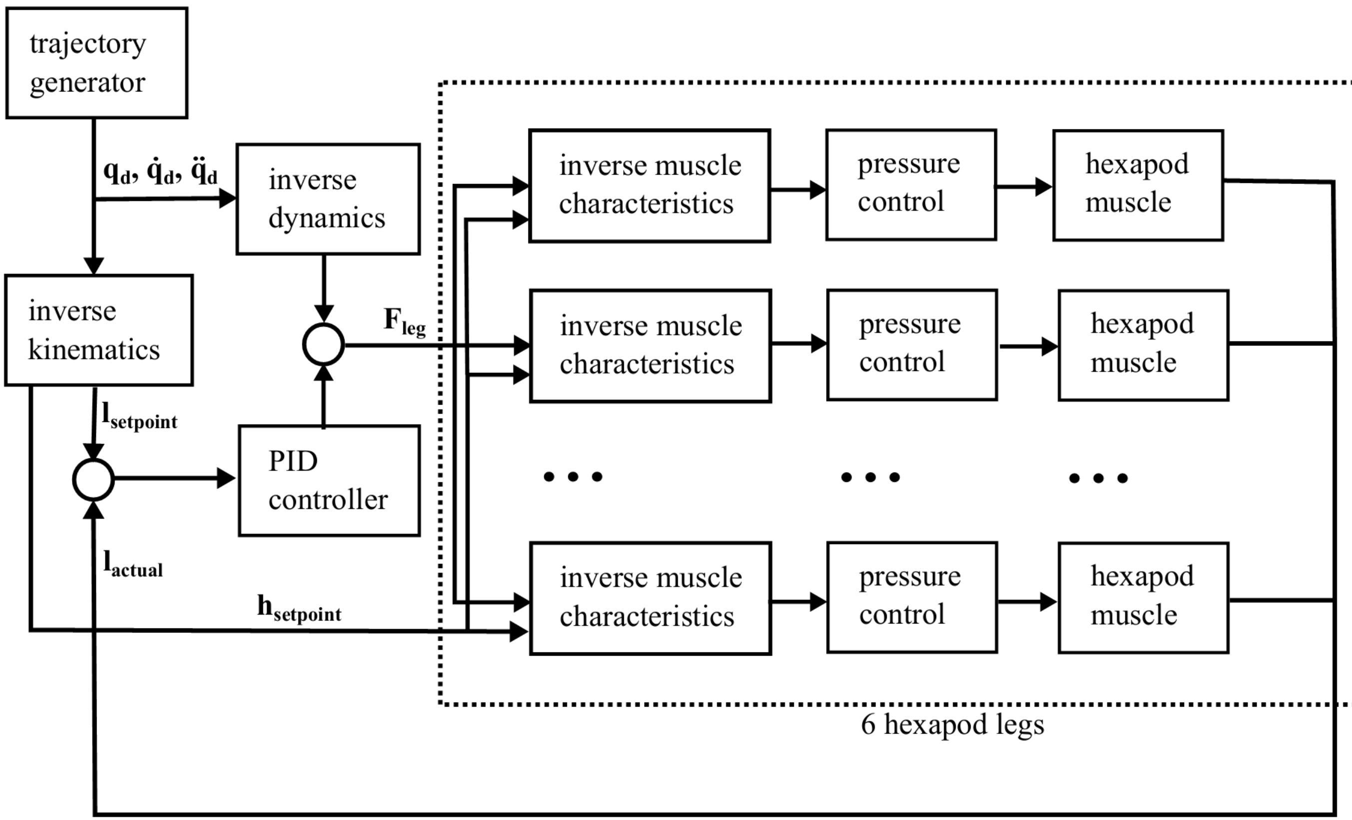
part is NOT OK extra vibrations



Spring matrix $\mathbf{K}_B$ is soft in z direction

Control

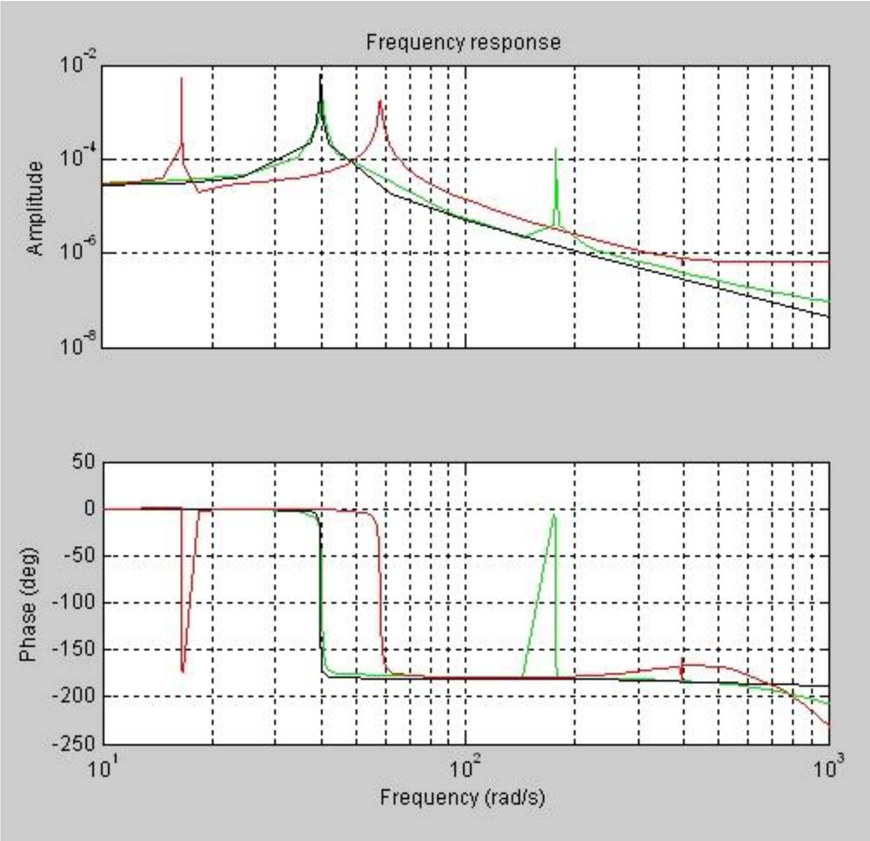
linearised feed forward force controller and
a PID position control law



Detection

Method

- Detection of fault parts using bode plots with model identification
- or FFT analysis



Sensitivity

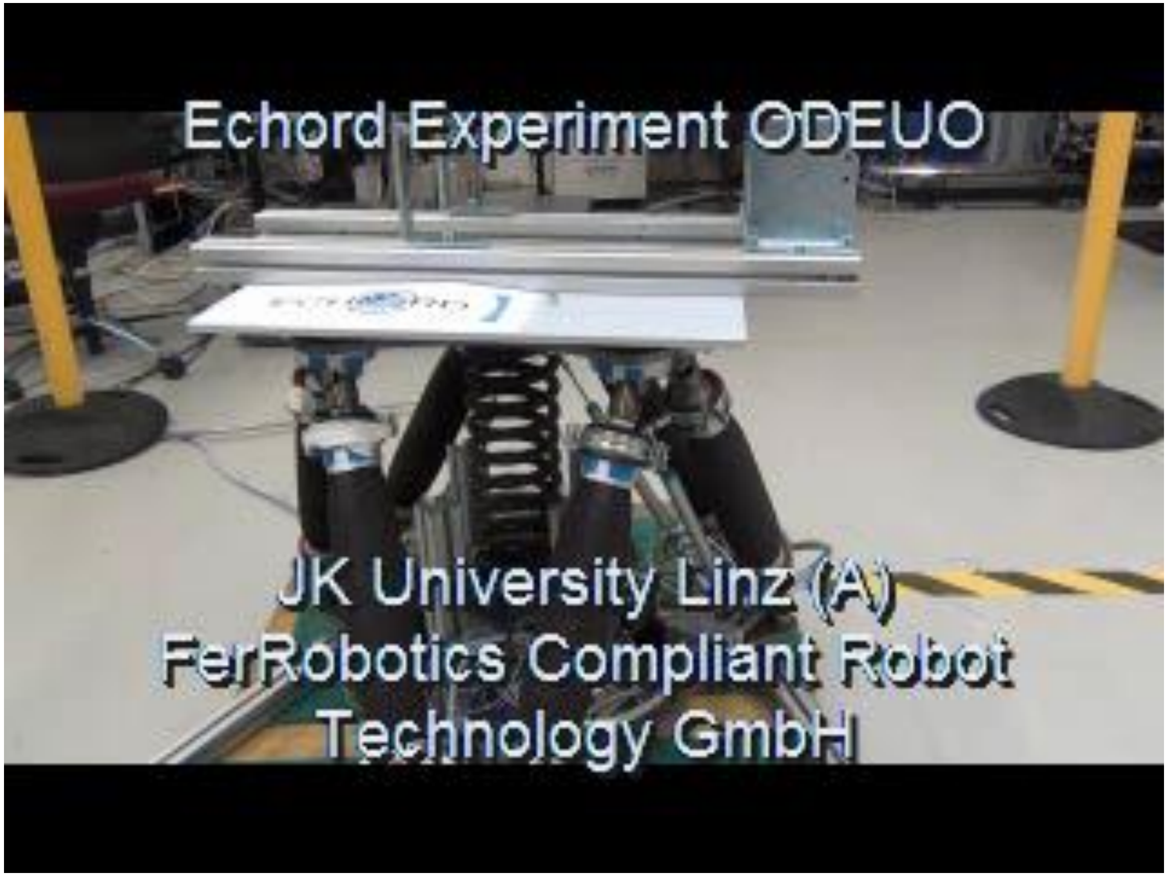
it was possible to detect 0.5% of the

overall mass mounted on the plate.

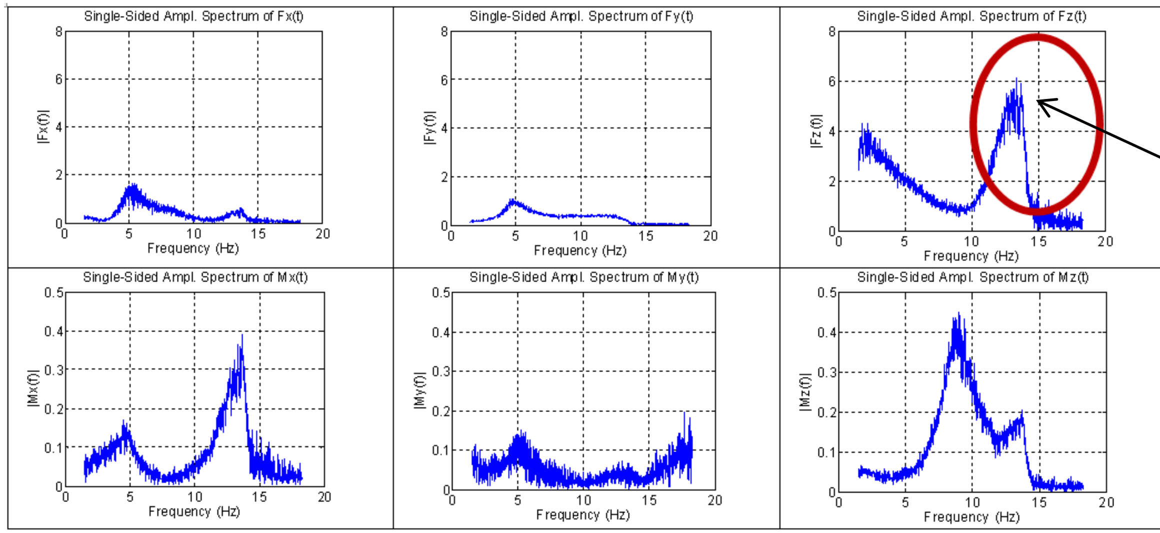
Experiment

Frequency sweep from 0 to 18Hz in z direction

plate mass: 20kg
beam mass: 0.1kg
vibration mass 0.2kg
resonant frequency: 11Hz



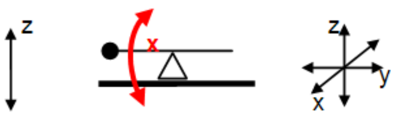
Measurements (FFT)

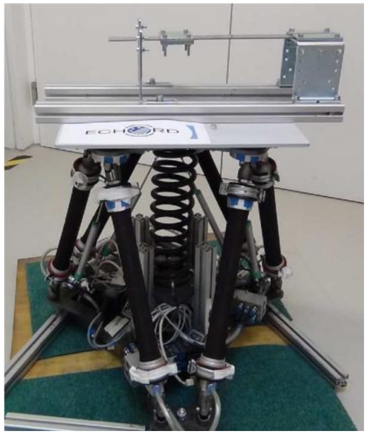


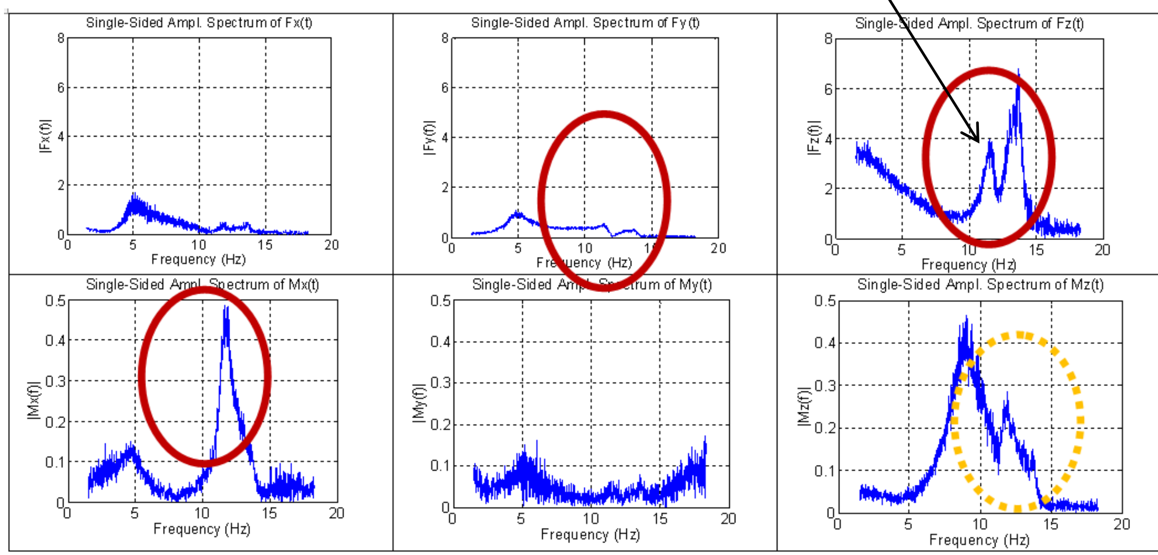
no fault detected,
calibration curve.

Hexapod resonant frequency

fault resonant frequency







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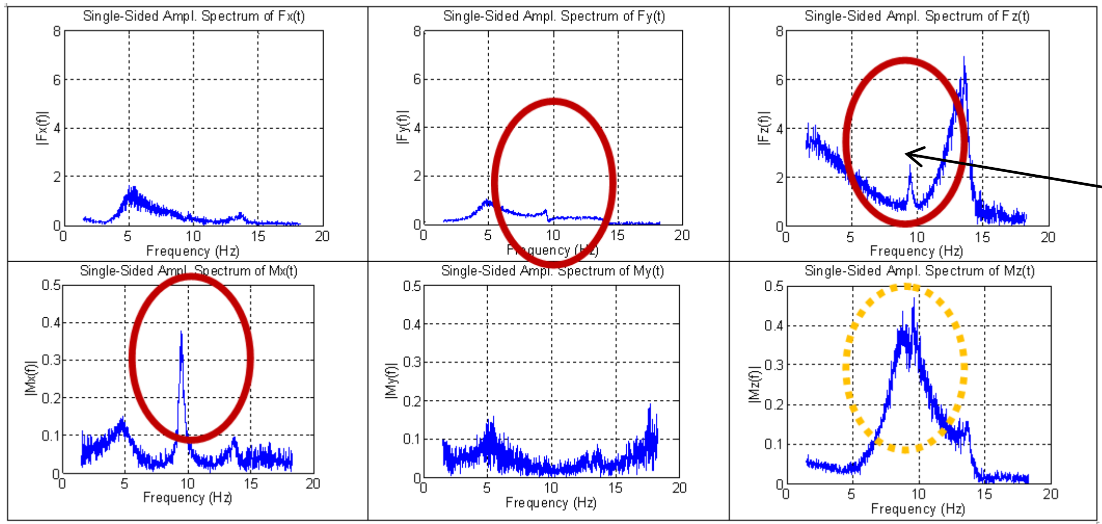
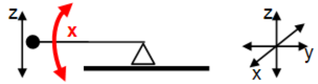
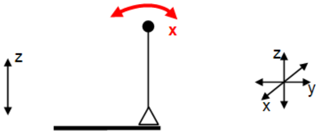
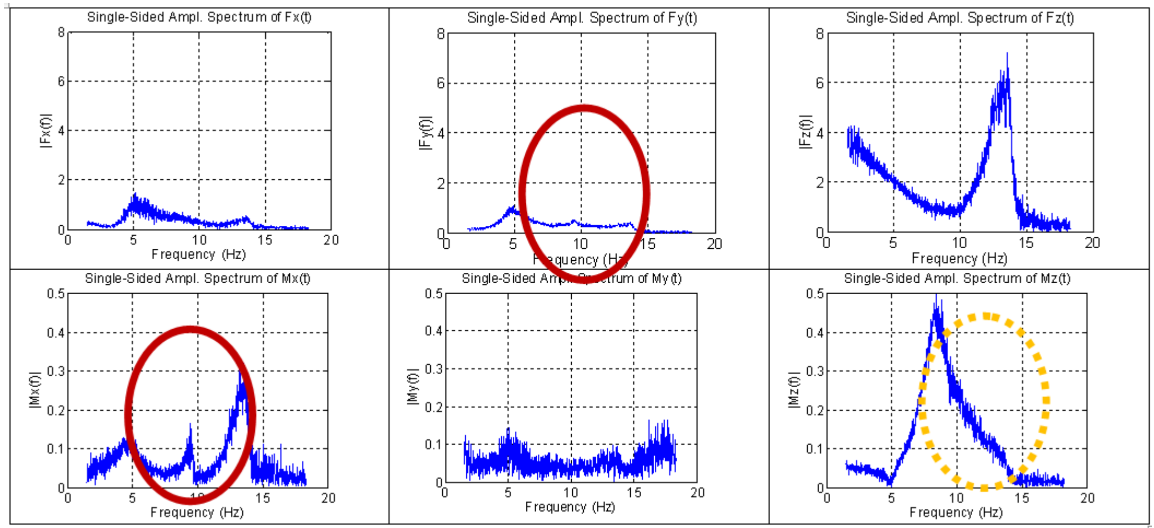




Hexapod resonant frequency shifts to a lower value



radial movement,
- moment in x direction
- no peak in z direction
- no rotation around z axis



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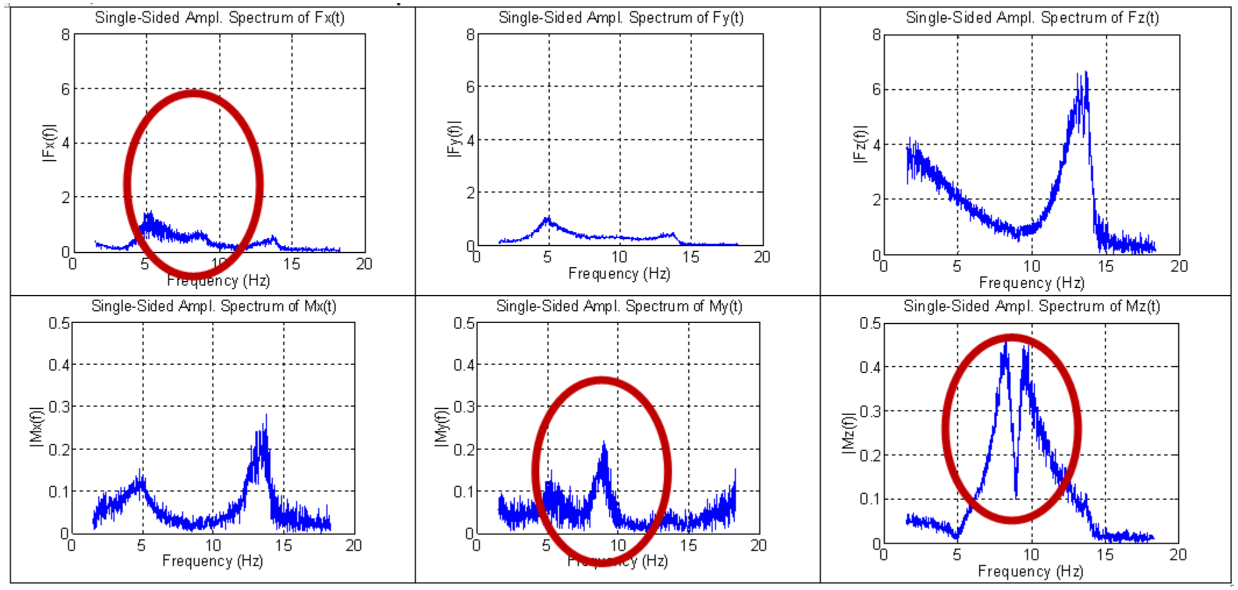
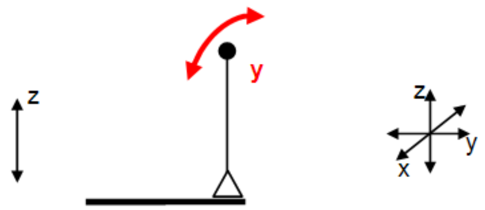


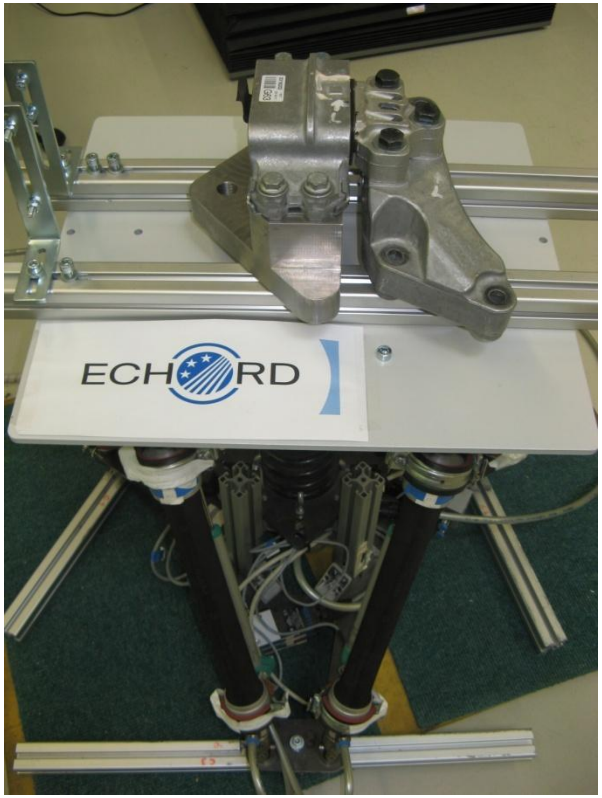


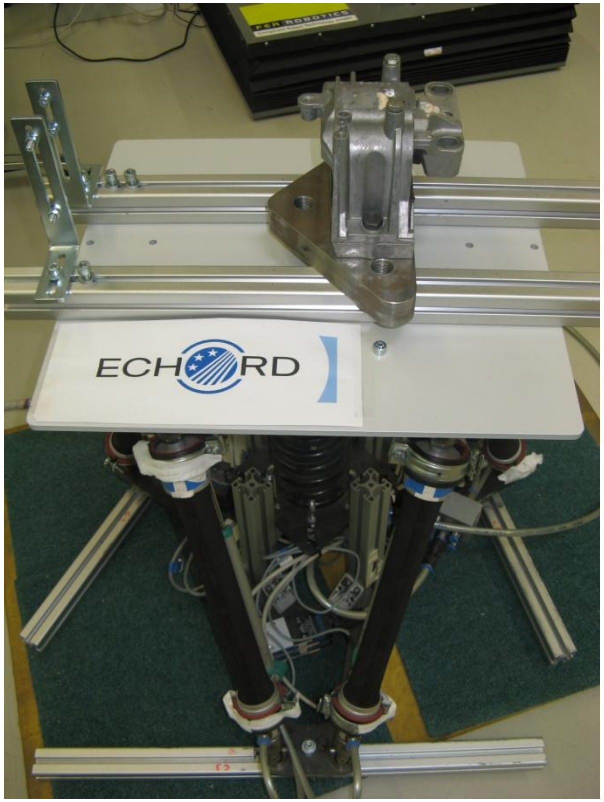
tangential movement,
- implies a rotation around z axis
- moment in y direction

Application

Test part automobile industry: motor rubber bearing.

Investigation for changing behavior in the dynamics of the rubber.





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