Dutch Contributions to the Synchronisation of Pendulums

Hans de Zeeuw

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Museum of the Dutch Clock, Zaandam, The Netherlands

Academic Medical Center

Perfecting the Pendulum, BHI, Upton, June 9, 2008

MNU

Christiaan Huygens

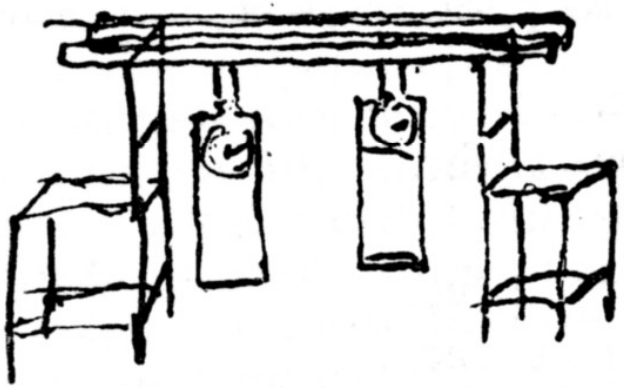
14 april 1629 - 8 juli 1695

P. Bourguignon ca 1688; coll KNAW

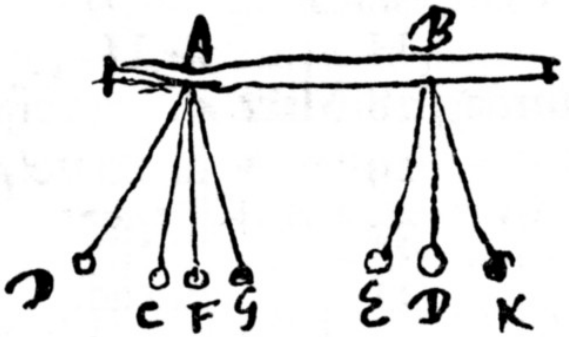
Dutch Contribution I: Huygens 22 February 1665

Mart. 1. Hora 10 mat. præcedebat A tribus ſecundis.

[Fig. 76.]



[Fig. 77.]



Utrique horologio pro fulcro erant ſedes duæ [Fig. 76] quarum exiguus ac plane inviſibilis motus pendulorum agitatione excitatus ſympathiæ prædictæ cauſa fuit,

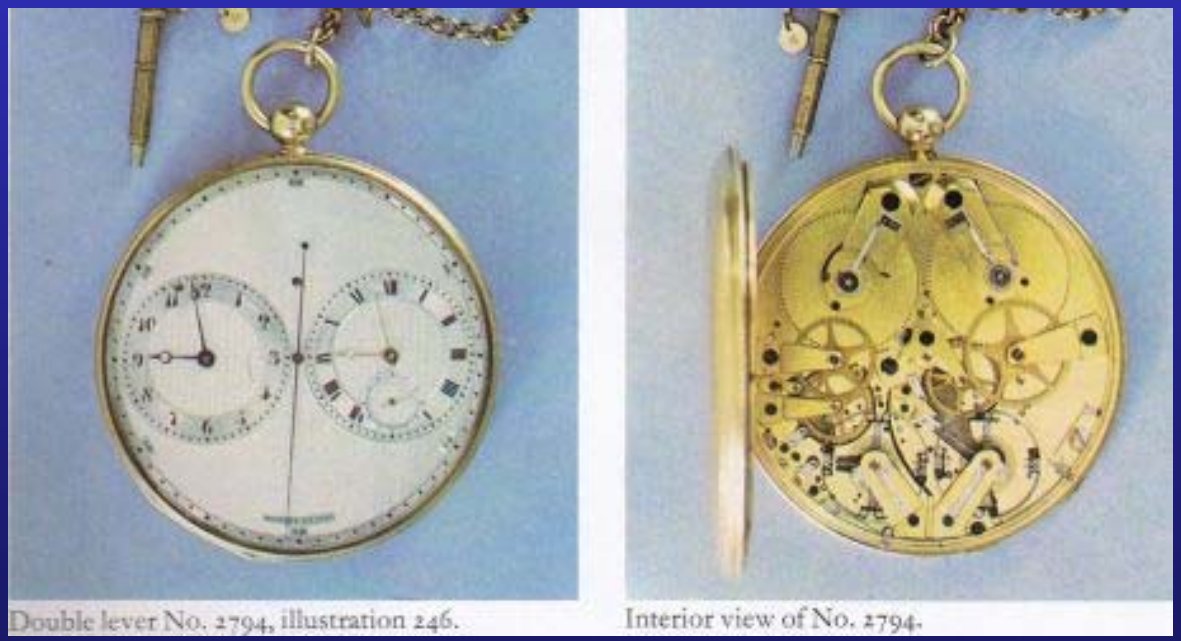
- During illness: Two pendulum clocks : Anti-phase swing
- March 1: Experiment: After ½ hour: “Sympathie des horloges”

Two pendulums; Janvier ca 1800

Antide Janvier (1751-1835)

- 1810, two independent trains, 1 s-remontoir

Two pendulums; Breguet ca 1825



Double lever No. 2794, illustration 246.

Interior view of No. 2794.

Louis Abraham Breguet

1747-1823

- Two independent trains with balances

Two balances; Journe 1984 - 2006

Dutch Contribution II:

Gravity measurements: Vening Meinesz 1915 - 1939

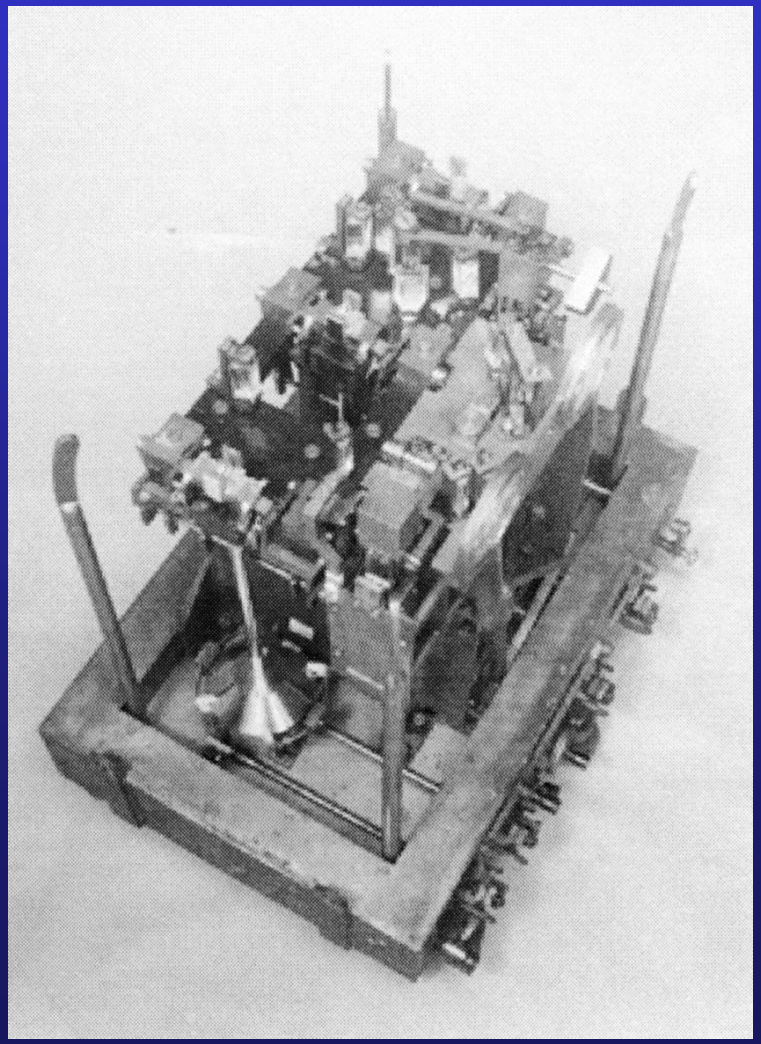
- $T = 2\pi\sqrt{l/g}$: Perfect Pendulum: $T = C/\sqrt{g}$

→ Gravity Measurement

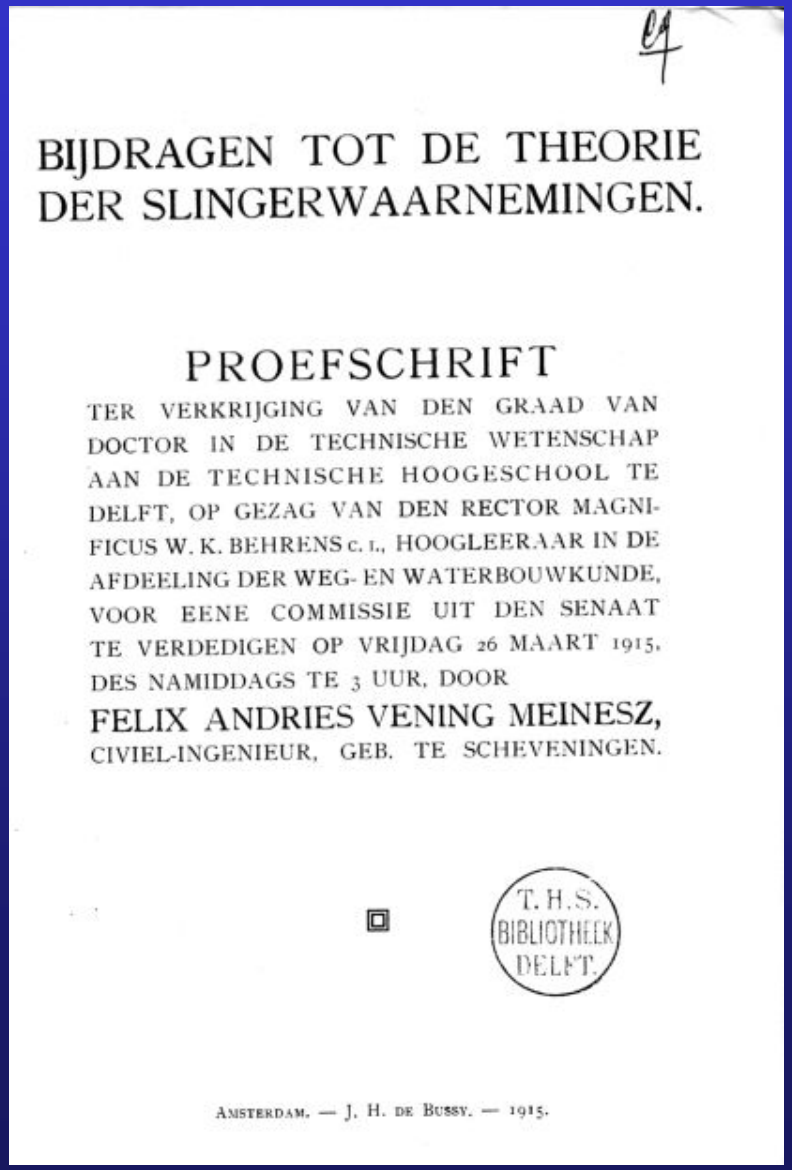
- Successor of Christiaan Huygens

Two pendulums; Vening Meinesz 1915 - 1939

$T = 2\pi\sqrt{l/g}$: Gravity Measurement : $T = C/\sqrt{g}$



Two pendulums; Vening Meinesz 1915 - 1939



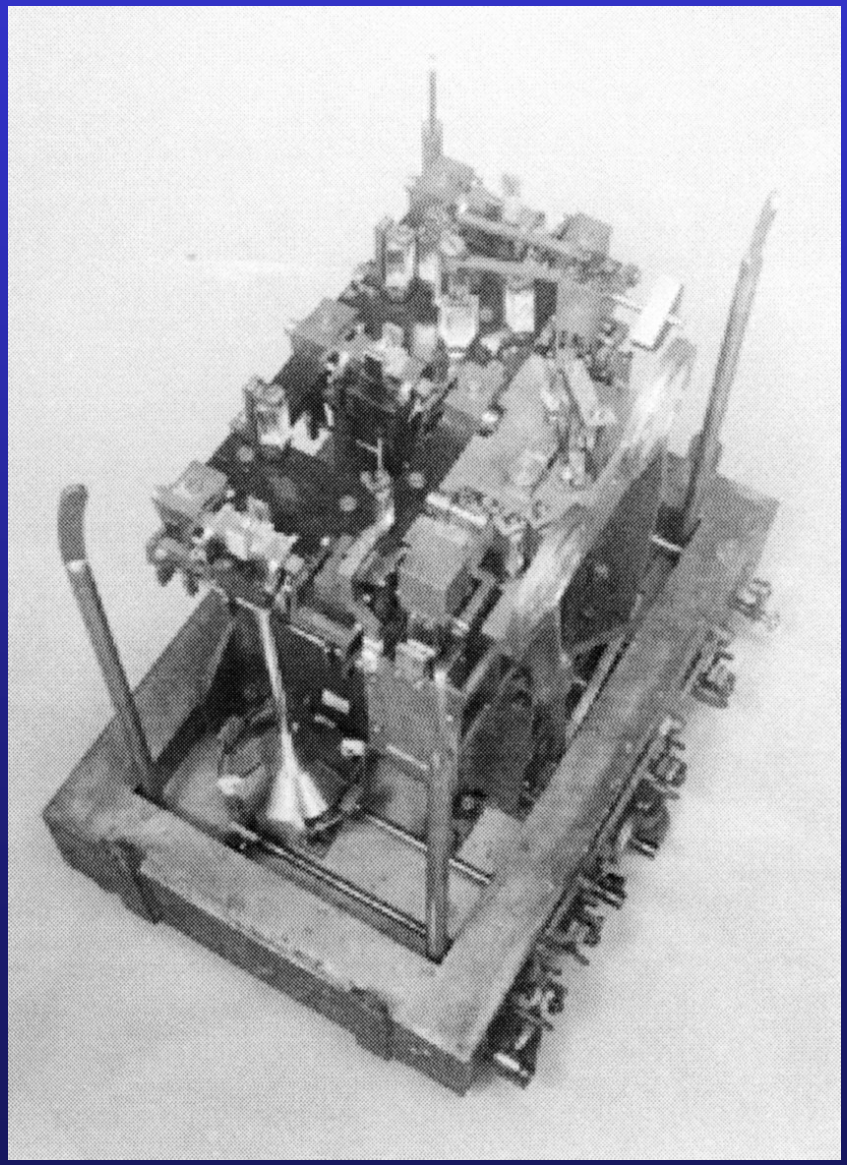
BIJDRAGEN TOT DE THEORIE
DER SLINGERWAARNEMINGEN.

PROEFSCHRIFT

TER VERKRIJGING VAN DEN GRAAD VAN DOCTOR IN DE TECHNISCHE WETENSCHAP AAN DE TECHNISCHE HOOGESCHOOL TE DELFT, OP GEZAG VAN DEN RECTOR MAGNIFICUS W. K. BEHRENS C. I., HOOGLEERAAR IN DE AFDEELING DER WEG- EN WATERBOUWKUNDE, VOOR EENE COMMISSIE UIT DEN SENAAT TE VERDEDIGEN OP VRIJDAG 26 MAART 1915, DES NAMIDDAGS TE 3 UUR, DOOR

FELIX ANDRIES VENING MEINESZ,
CIVIEL-INGENIEUR, GEB. TE SCHEVENINGEN.

AMSTERDAM. — J. H. DE BUSSY. — 1915.



Dutch Contribution III: Henk Nijmeijer et al

Experimental Results on Huygens Synchronization

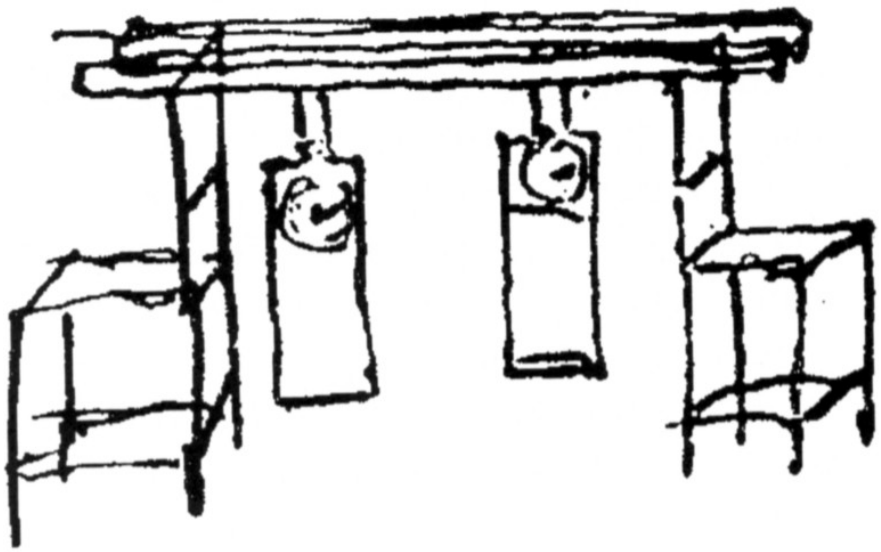


Fig. 1. Drawing by Christiaan Huygens of two pendulum clocks attached to a beam which is supported by chairs. Synchronization of the pendulums was observed by Huygens in this setup.

Professor Theoretical Mechanics

Technical University Eindhoven, 2000 -

Dutch Contribution IV : Amateurs

THE ANTIQUARIAN HOROLOGICAL SOCIETY

Dutch Section

Double (free) pendulum

Design according to Riefler

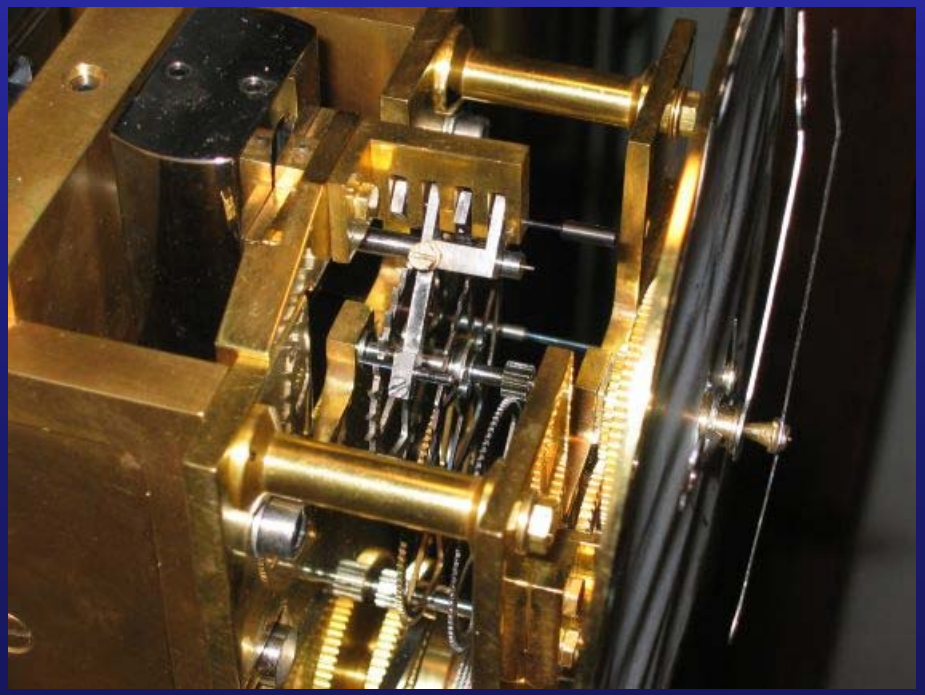
Hans de Zeeuw

Double (free) pendulum

Electromagnetic drive

Jan Pool

Regulator according to Riefler with two pendulums (gravity escapement)



Regulator according to Riefler with two pendulums

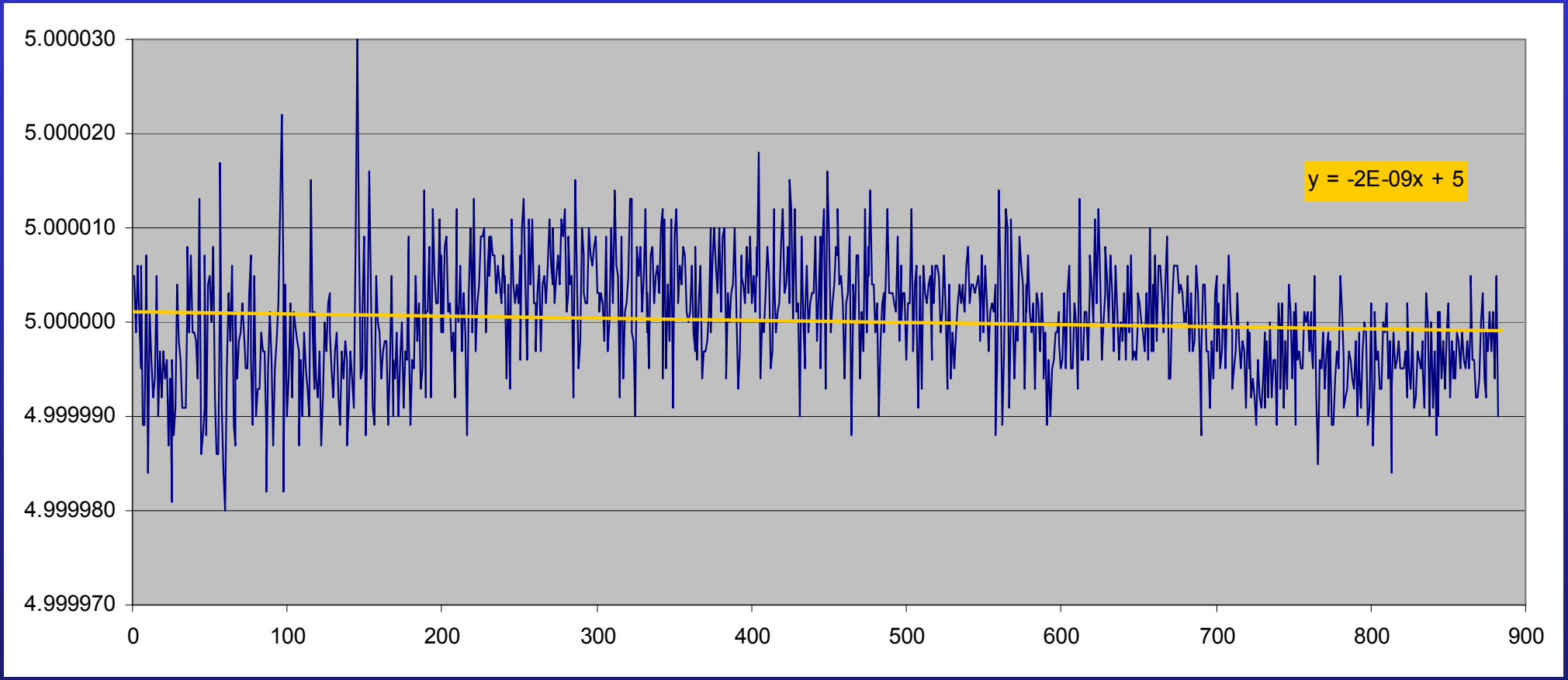
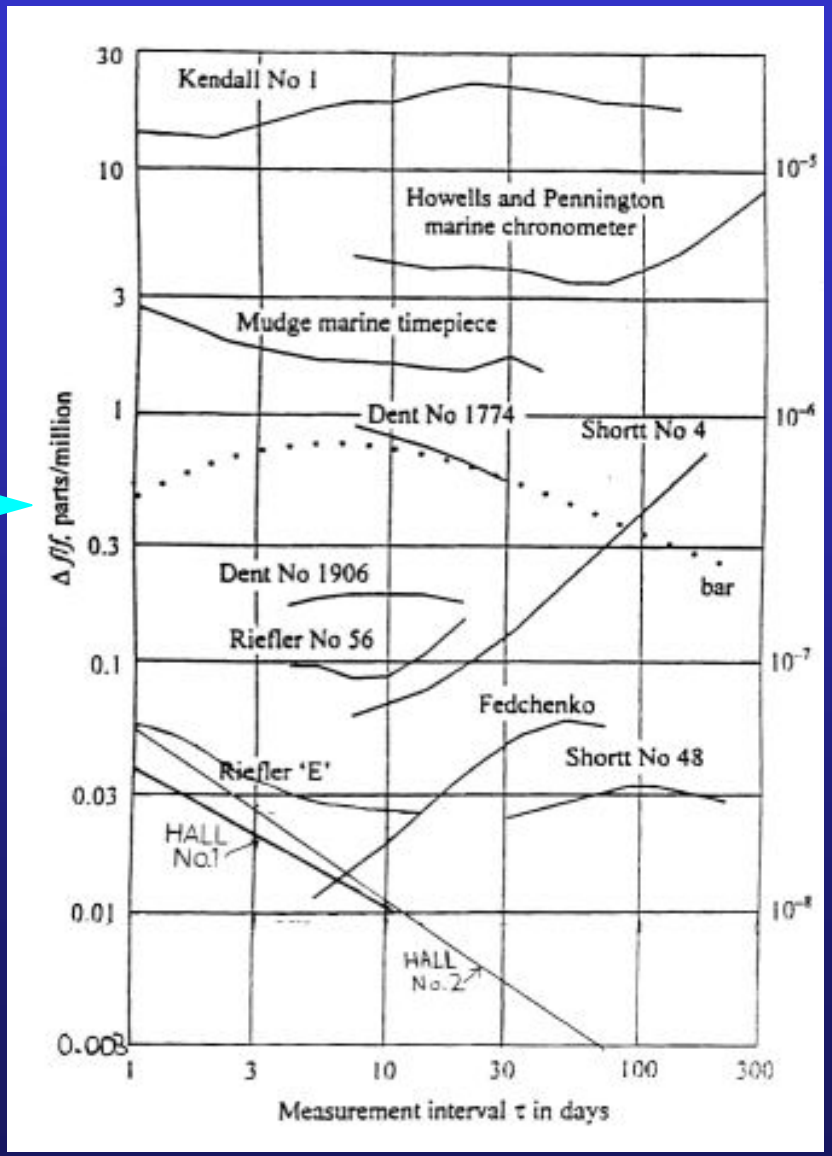
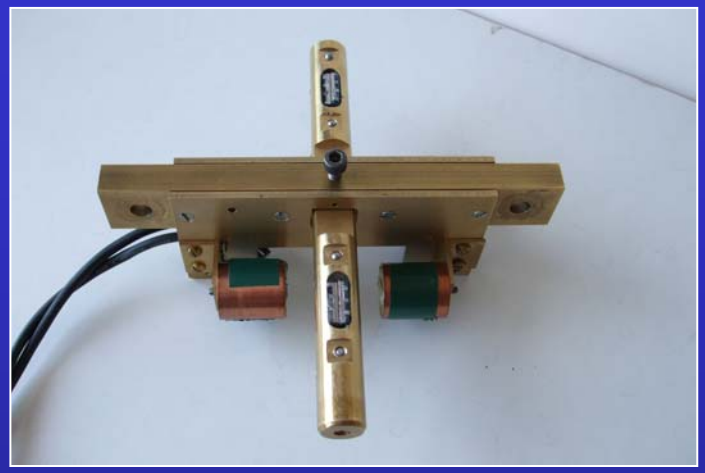


Fig. 8 Recording with the MICROSET. Over a period of 14 hours, 48 minutes each minute the average of 5 oscillations is measured (881 measurements). In this period this average is varying +/- 10 micro-seconds.
The trend line shows the rate accuracy to change less than -2 microseconden corresponding to - 0,4 microseconds per oscillation, so 0,4 ppm in 15 hours; this latter number is a measure for the stability of the clock [5].

Regulator according to Riefler with two pendulums

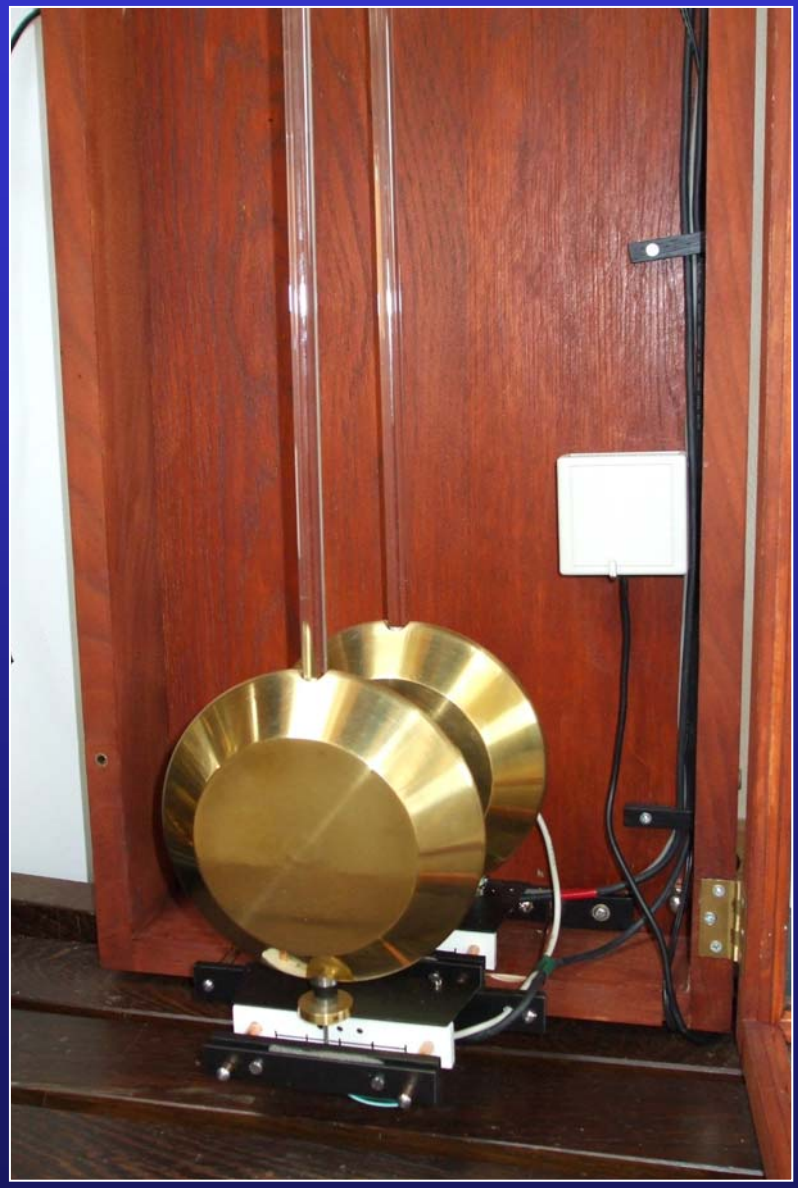


Two Pendulums with electromagnetic drive

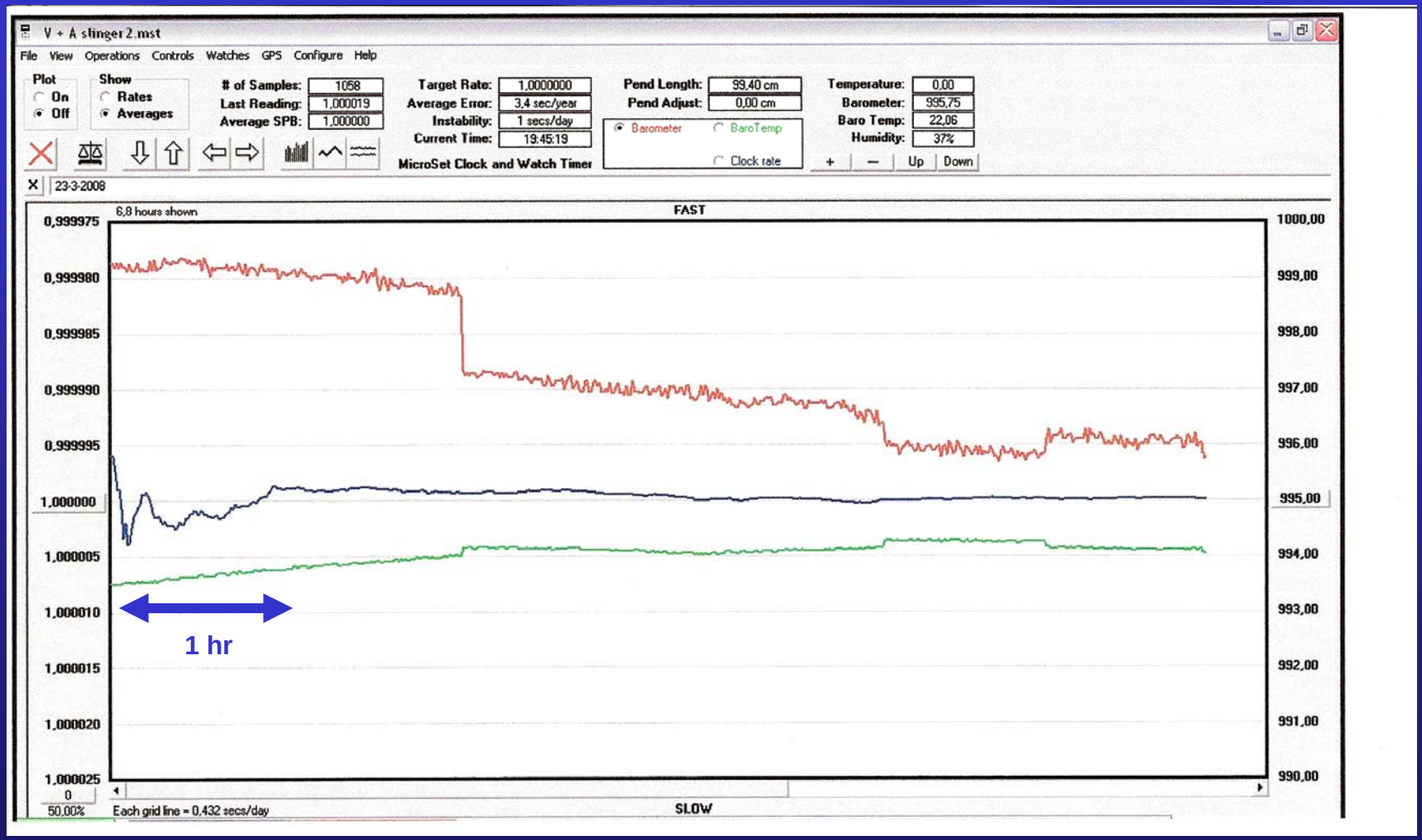


- Opto-electronic control
- Knife suspension
- Quartz pendulum
- Barometric compensation

Jan Pool, Bunnik



Two Pendulums with electromagnetic drive



Jan Pool, Bunnik

Results MICROSET (5 µs/div)

Discussion

- Synchronization still not well understood
- High Q Pendulums: Reaction time very high

  H. de Zeeuw: 5 – 10 hrs

  J. Pool: up till 40 hrs
- High Q Pendulums: Stabilizing effect only when

  $\Delta F < 1$ s/day = 10 ppm
- More mechanical stability (shocks)

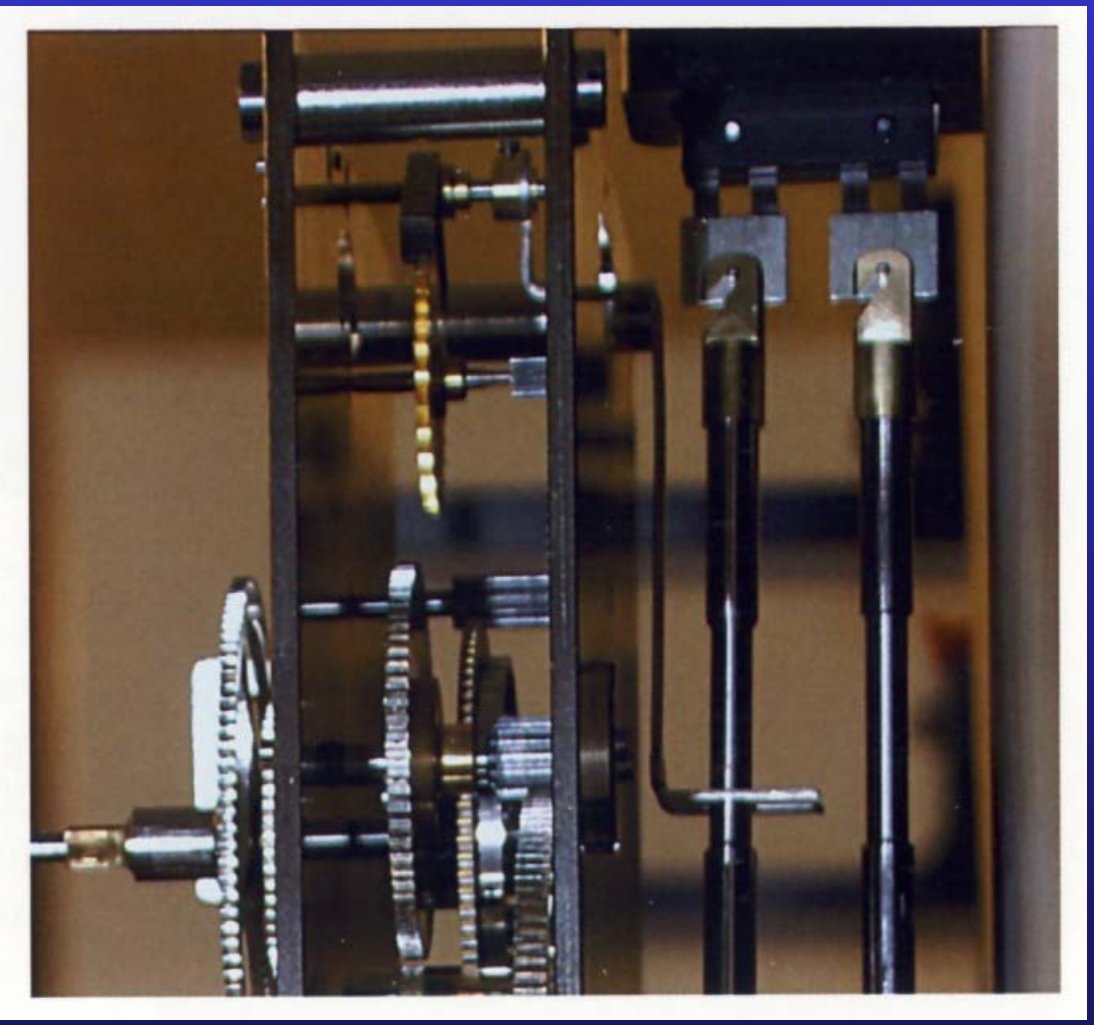
Question

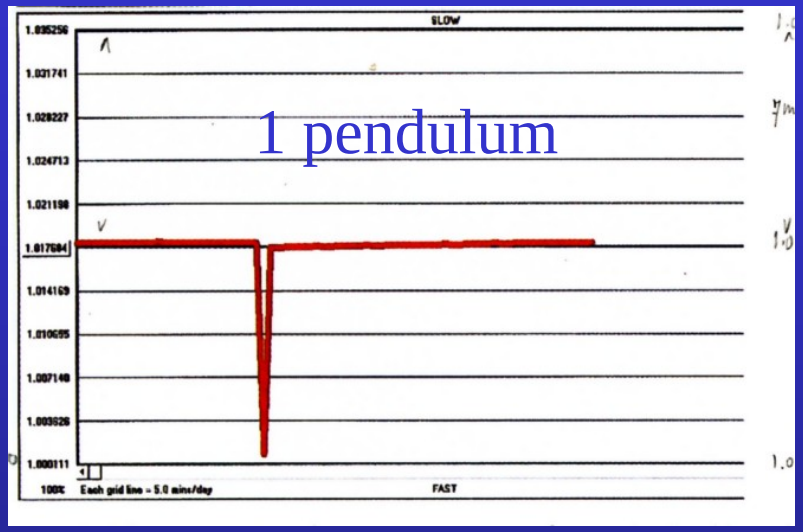
Is synchronisation a solution for mechanical disturbances?

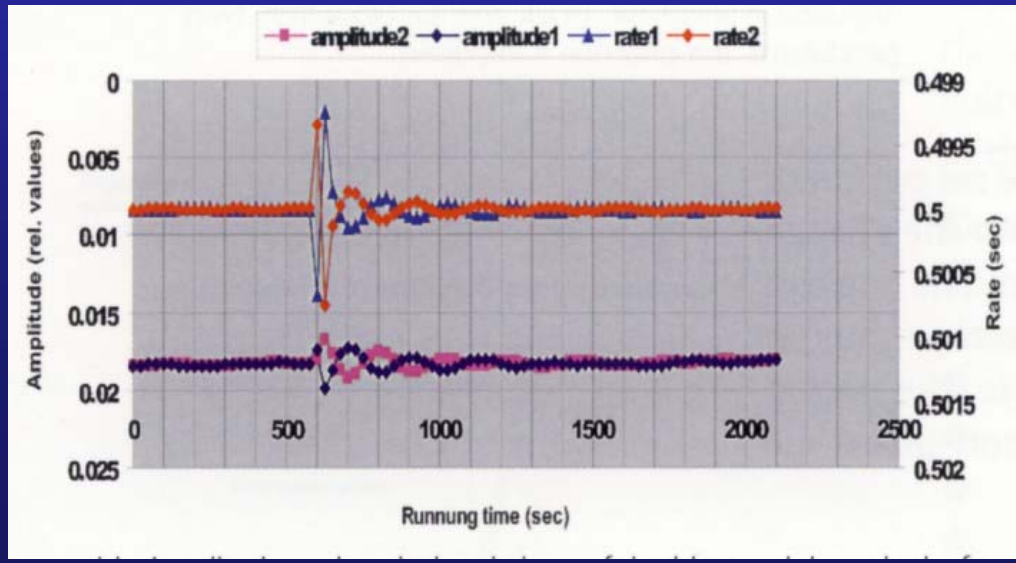
- Soft soil
- Heavy traffic
- Stand still

Is synchronisation a solution for mechanical disturbances?

Gagneux 2008







Is synchronisation a solution for mechanical disturbances?

Stephan Gagneux 2008