Huygens
and the
Advancement of Time Measurements

Kees Grimbergen[1,2]

[1] Medical Physics, Academic Medical Centre, University of Amsterdam

[2] **Museum van het Nederlandse Uurwerk (MNU),**
Museum of the Dutch Clock, Zaandam, The Netherlands

Academic Medical Center

Titan: From Discovery to Encounter, Noordwijk 16 April, 2004

MNU

Zaans Uurwerkenmuseum

1976

2001

Museum van het Nederlandse Uurwerk

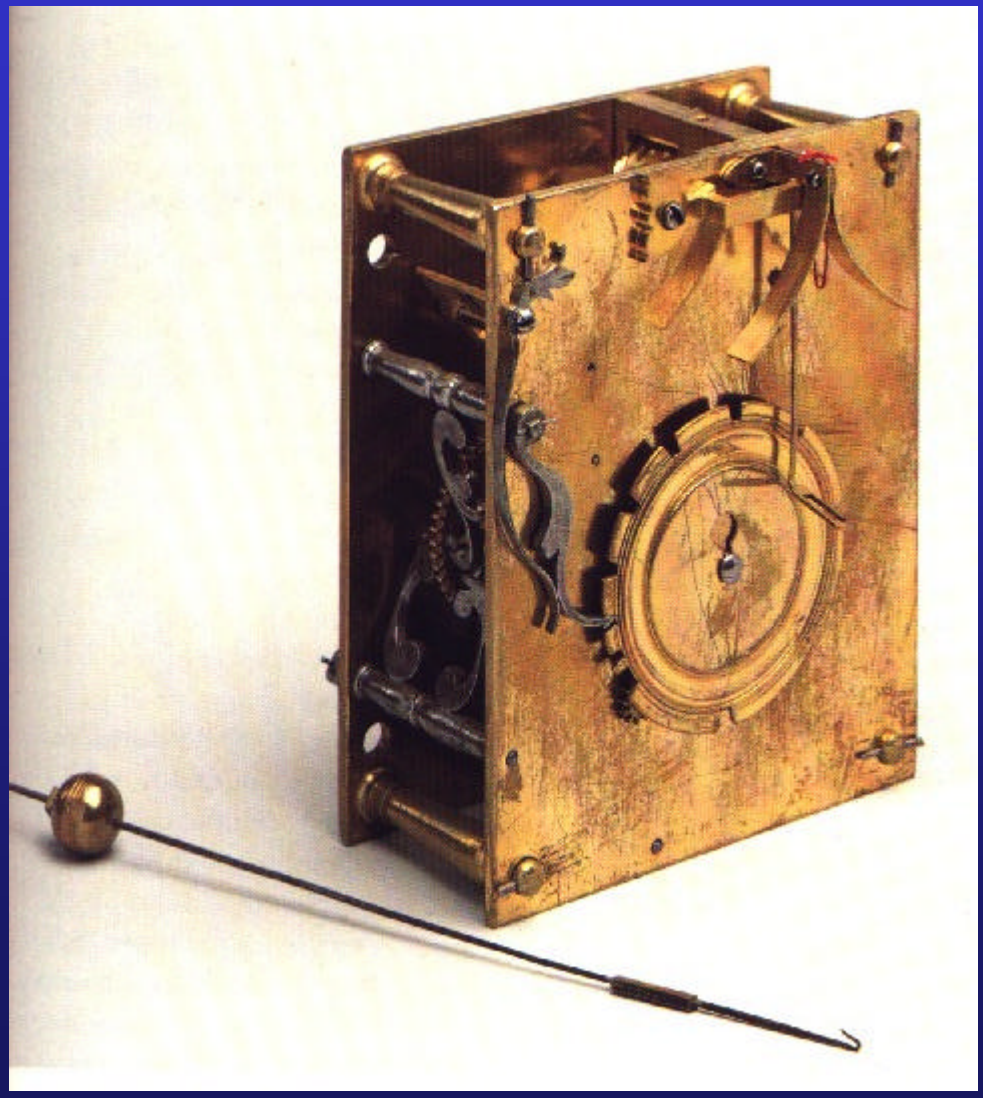
Museum van het Nederlandse Uurwerk

- Collection of Dutch Clocks; Period 1500 - 1850

  * Hague clocks
  * Longcase clocks
  * Wall clocks
  * Table clocks
  * Regional clocks (Zaan region, Brabant, Friesland)
  * Precision clocks

Salomon Coster with ‘privilege’ Christiaan Huygens;

Collection Museum van het Nederlandse Uurwerk, ca 1658



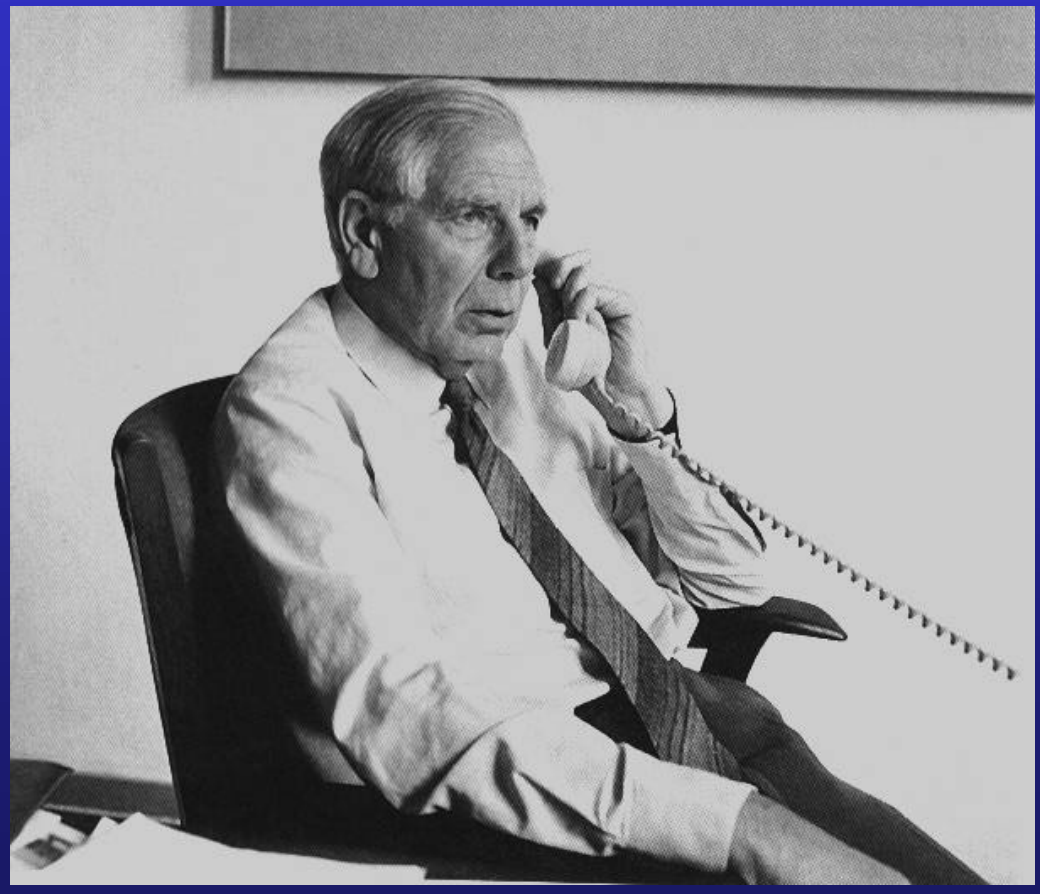
Christiaan Huygens

14 april 1629 - 8 juli 1695

P. Bourguignon ca 1688; coll KNAW

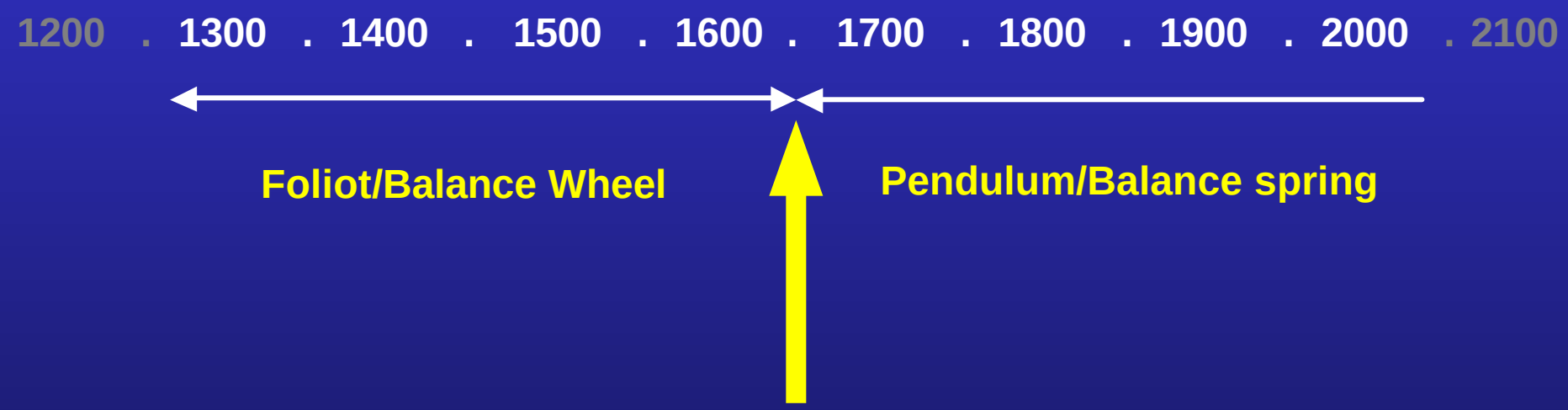
Museum of the Dutch Clock

Medical Physics Laboratory



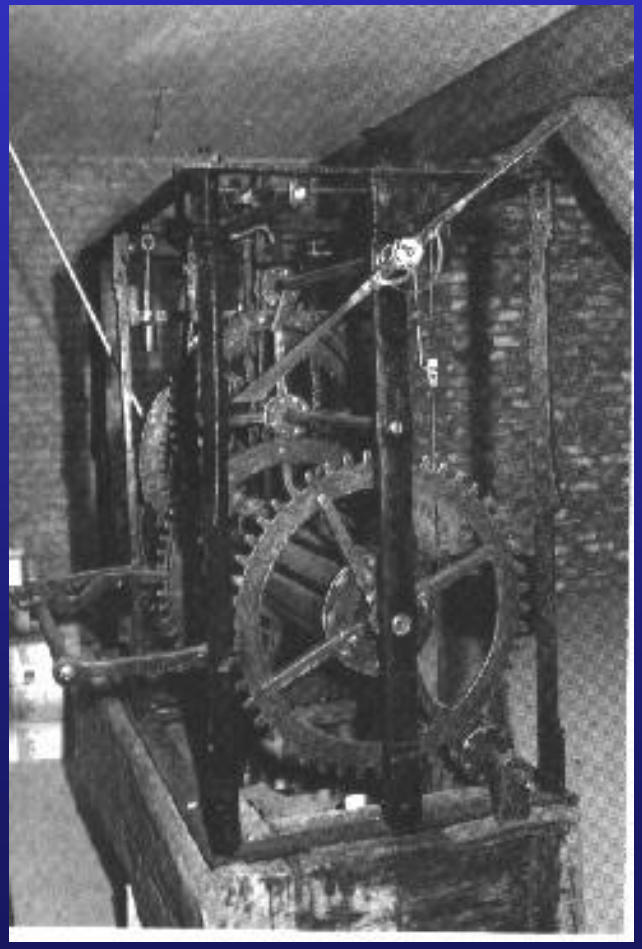
Henk van der Tweel 1915 - 1997

Mechanical Clocks (> 1300)

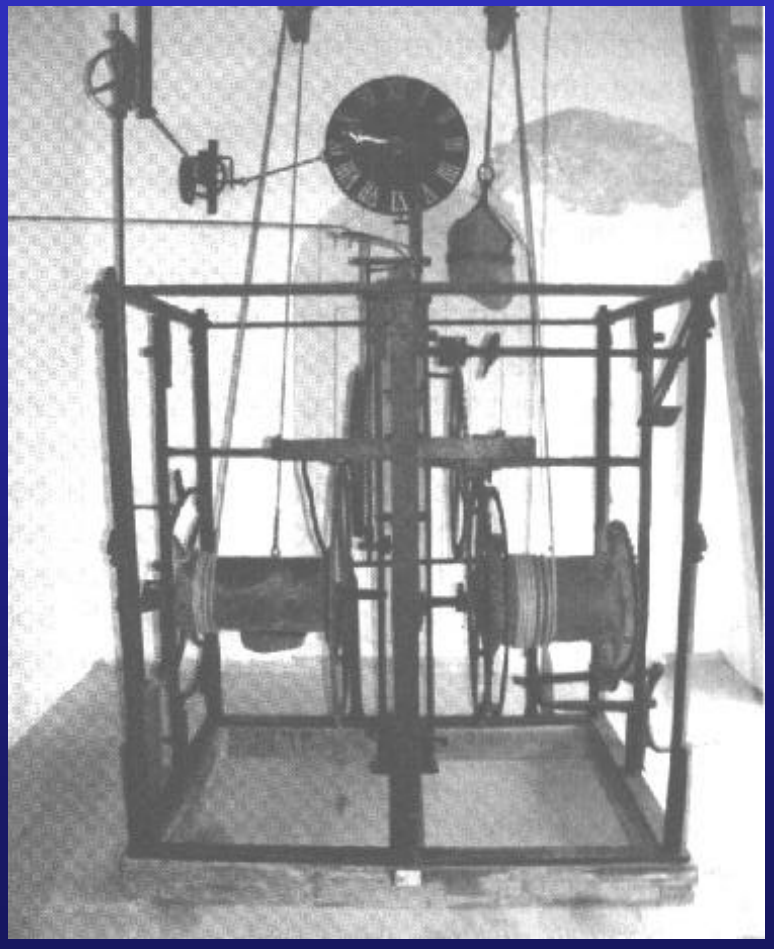


Early Turret Clocks

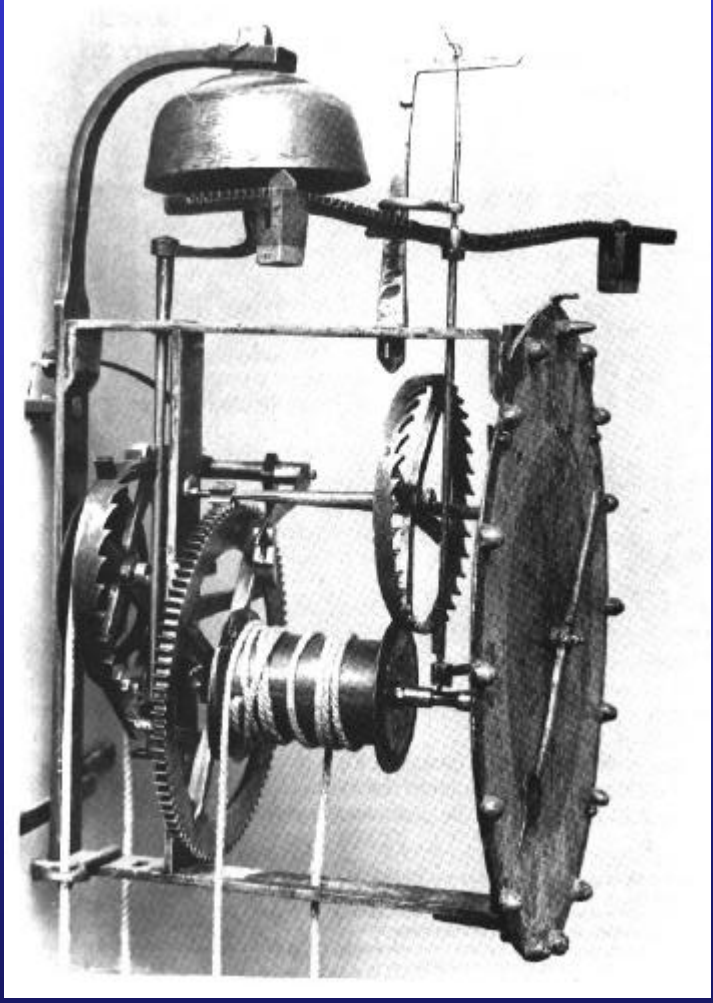
Maastricht 1400?;



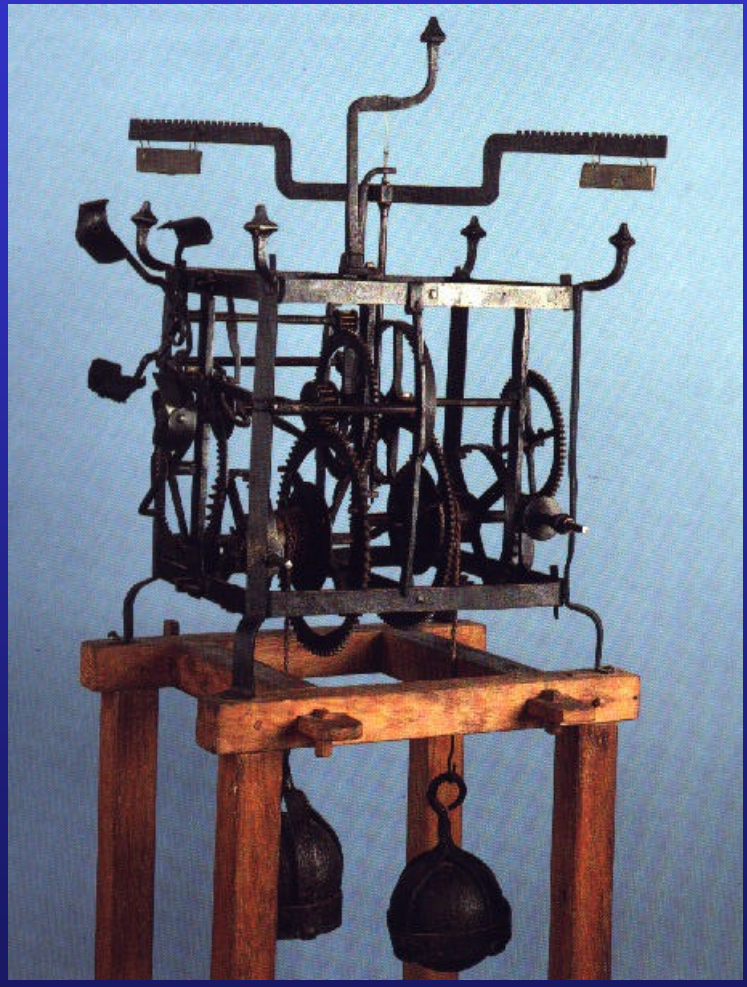
Winkel (N-H) ~1460



Early Mechanical Clocks



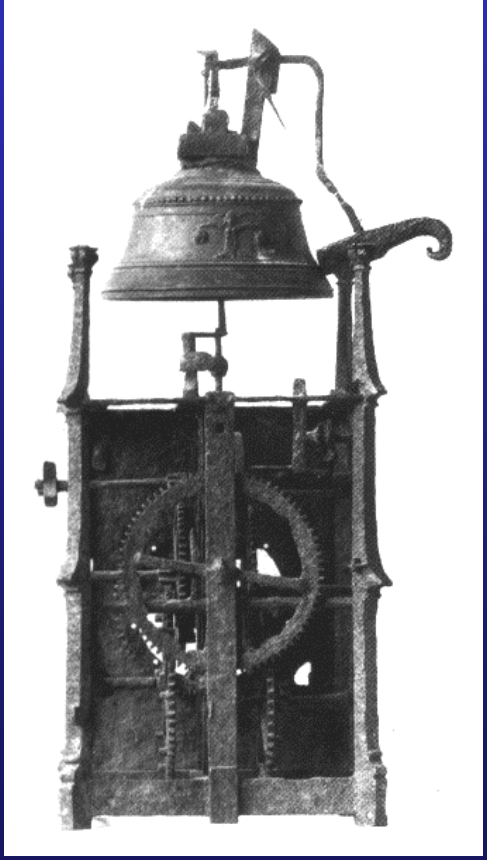
Nürnberg ca 1450



Nederland ca 1520 (MNU)

Museum of the Dutch Clock

Exhibition Willem Barents and his Clock; 1596-1996

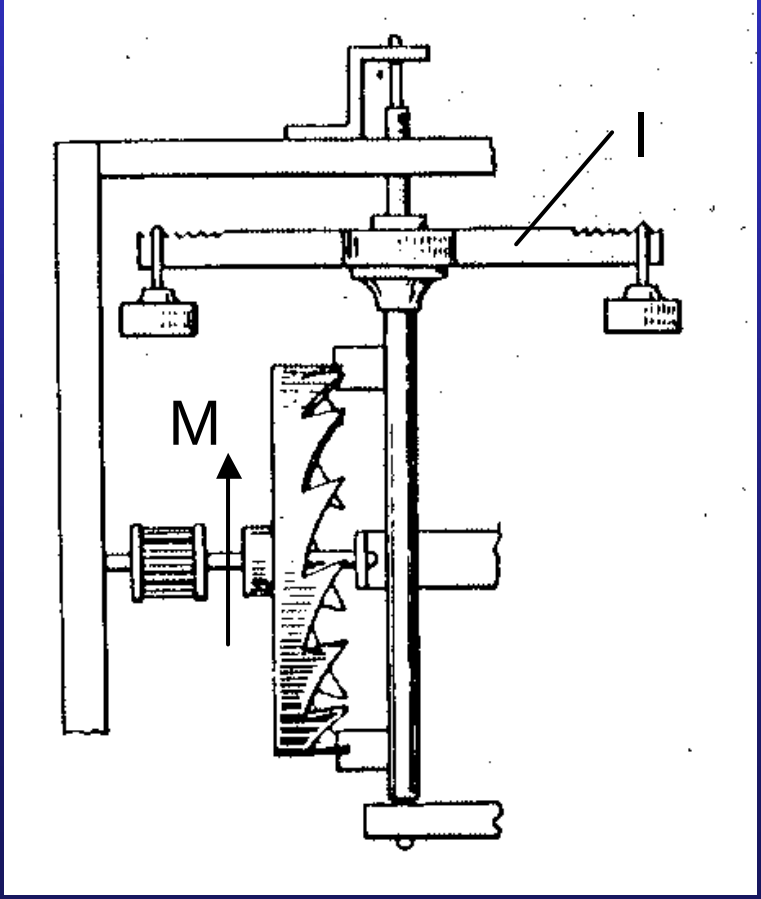


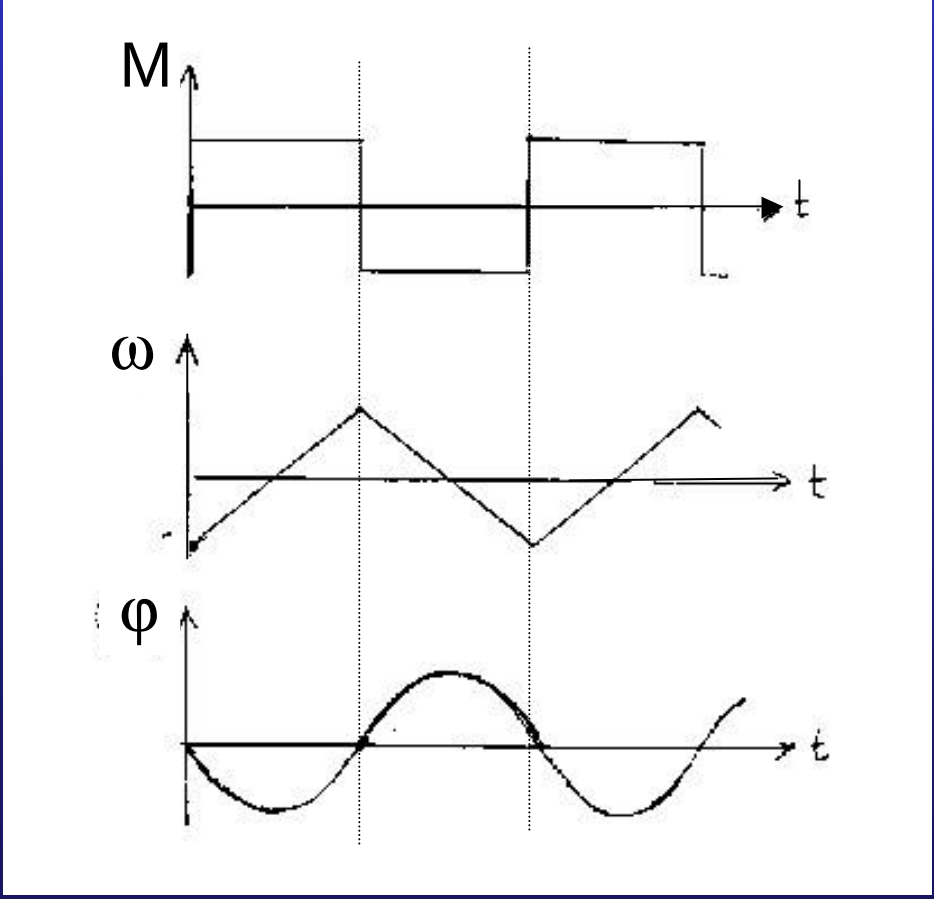
- Model from ca 1450
- Not touched since 1596
- Collection Rijksmuseum

Mechanical Clocks; 1300 - 1656

Foliot/Vertical Verge-Escapement

$M = I\,\partial\omega/\partial t = I\,\partial^2\phi/\partial t^2$

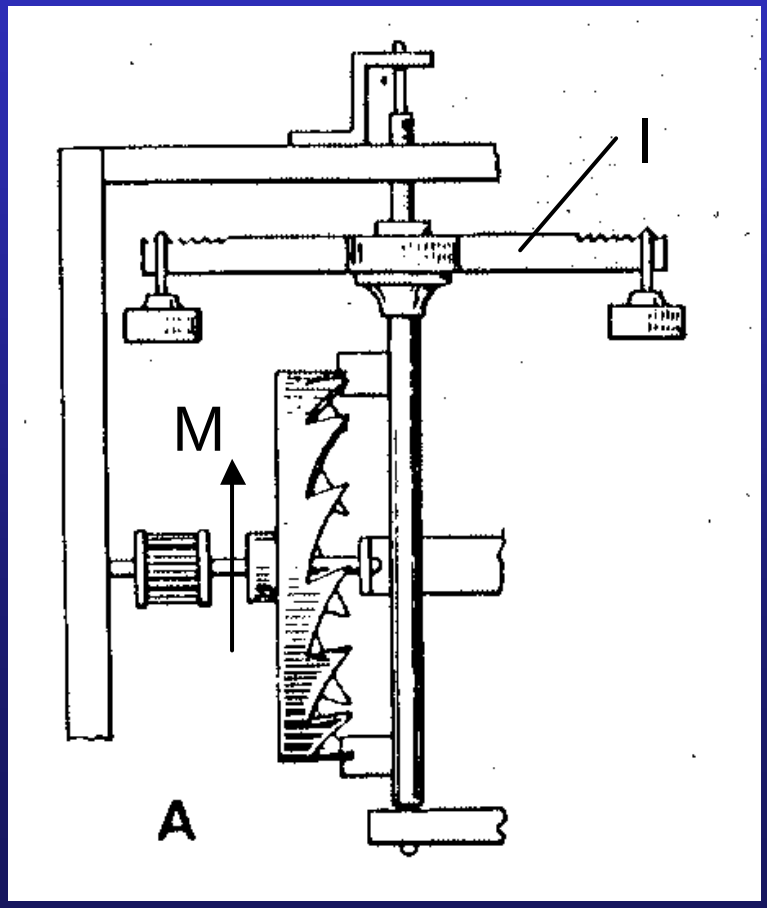


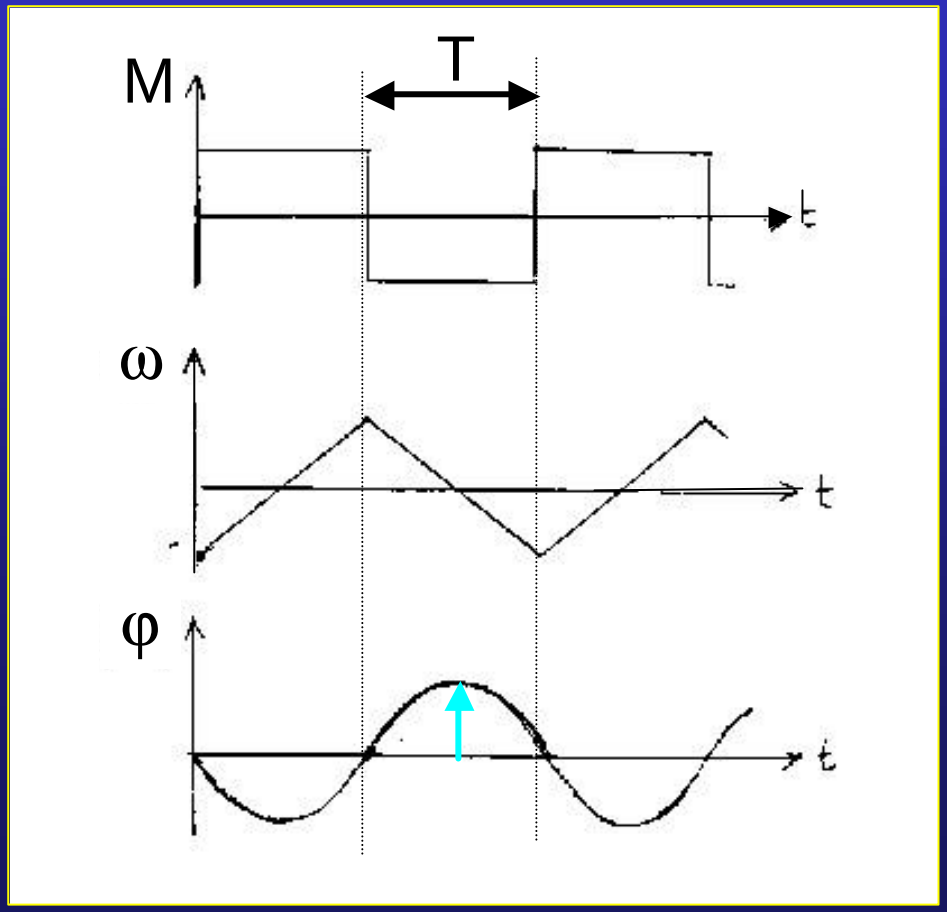


Mechanical Clocks; 1300 - 1656

Foliot/Vertical Verge-Escapement

$$T = 2\sqrt{2\,\phi_{max}(I/M)}$$





Mechanical Clocks; 1300 - 1656

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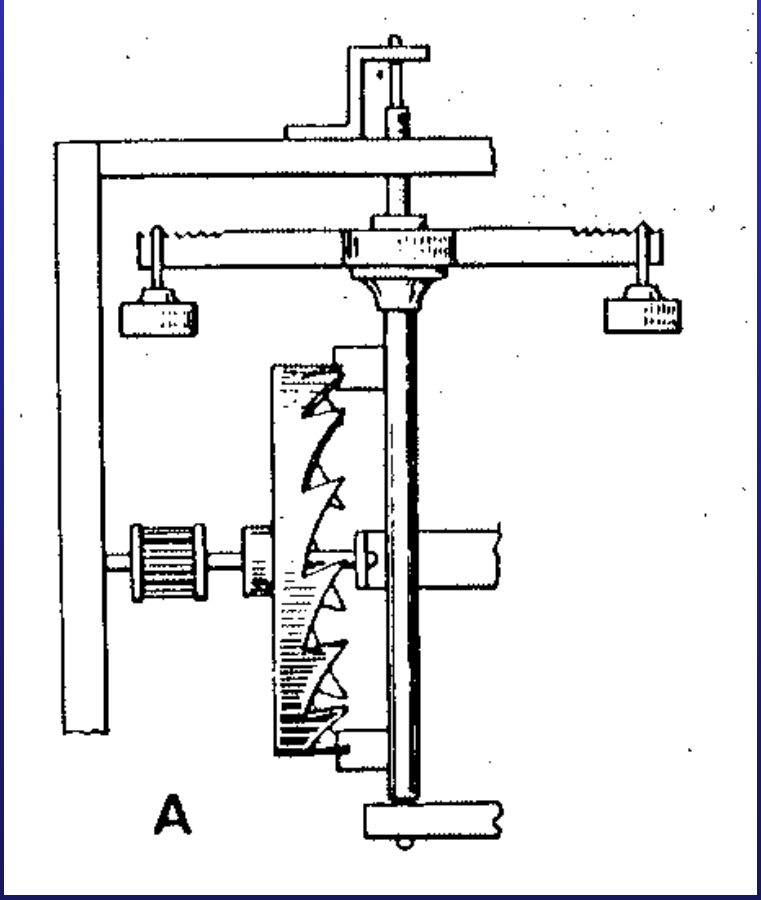


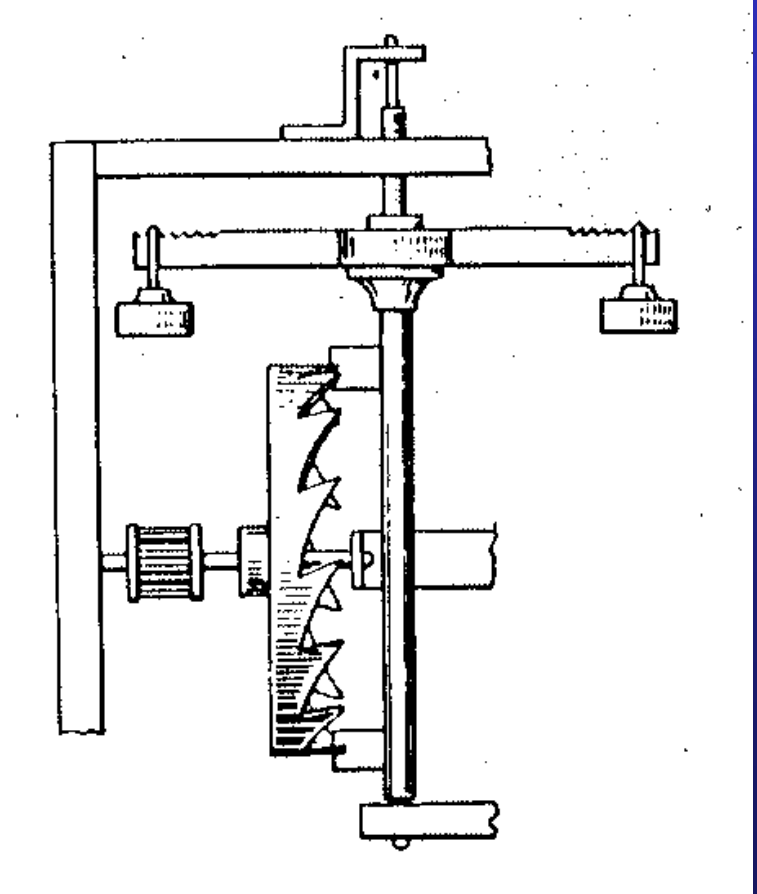
+ Balanced (independent of gravity)
+ Self starting

- Dependent on driving moment
- Dependent on friction
- Dependent on temperature
- Dependent on ϕ_{max}

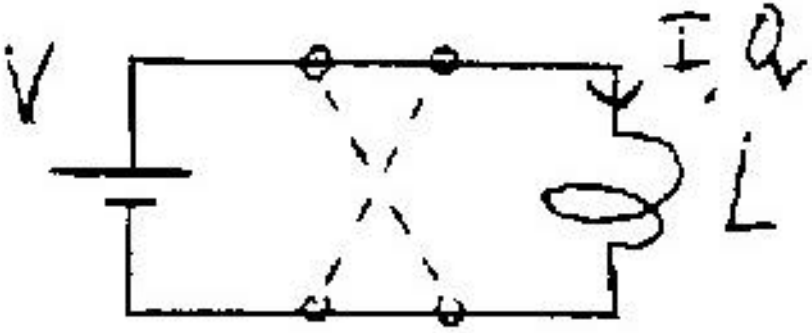
➡ NO INTRINSIC FREQUENCY

Analogons; Foliot/Vertical Verge Escapement

Relaxation Oscillator $V = L\,\partial I/\partial t = L\,\partial^2 Q/\partial t^2$

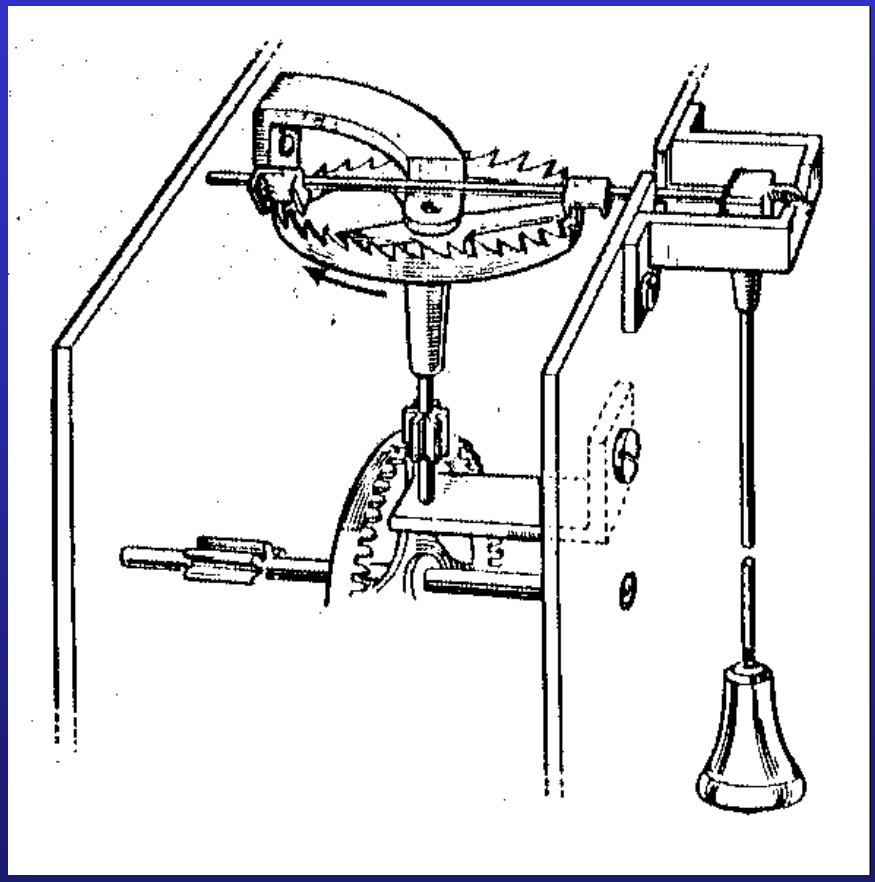


Electrical analogon



Voltage source, commutator, Coil

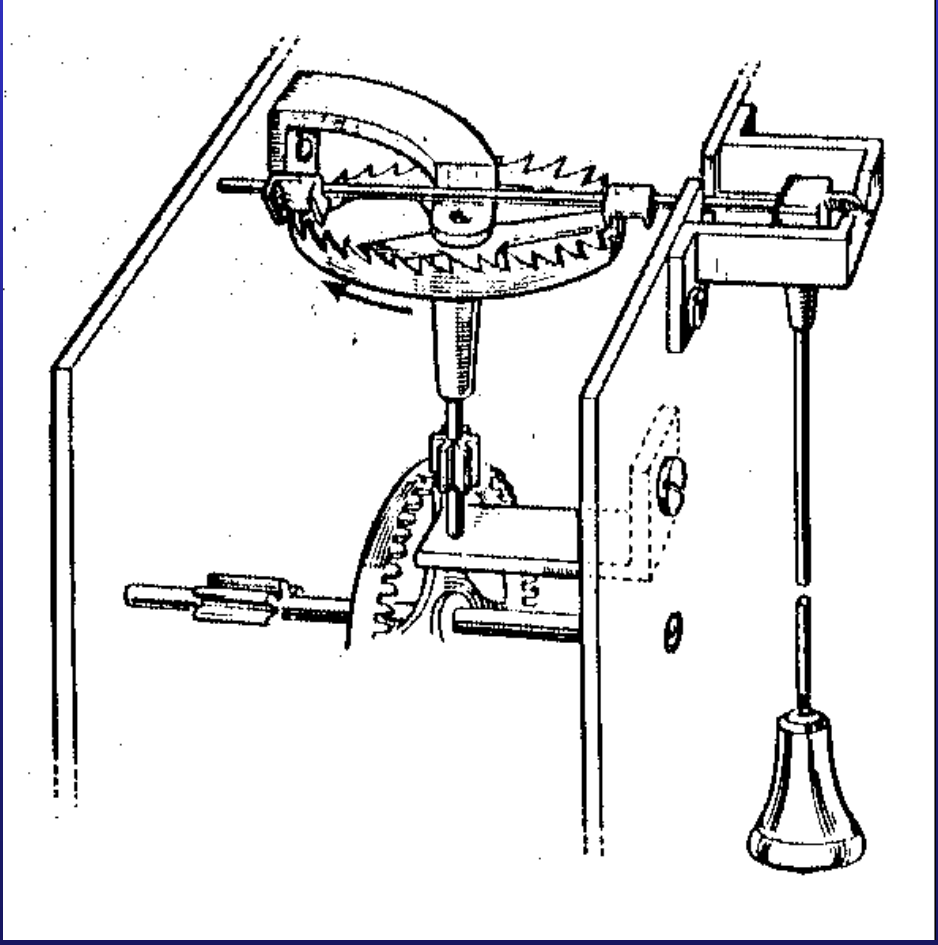
Christiaan Huygens 1629 - 1695



1657: Pendulum/horizontal verge escapement

Mechanical Clocks; > 1656

Pendulum/Horizontal Verge-Escapement $T = 2\pi\sqrt{l/g}$



Slinger / *Pendulum*

$$ml\,d^2\varphi/dt^2 = -mg\sin\varphi$$
$$d^2\varphi/dt^2 = -(g/l)\sin\varphi$$
$$\approx -(g/l)\varphi$$

Oplossing / *Solution* $\varphi = \varphi_{max}\sin(2\pi t/T)$

Periode / *Period* $T = 2\pi\sqrt{(l/g)}$
$$\approx 2.0\sqrt{l}$$

l = slingerlengte / *length of pendulum* [m]

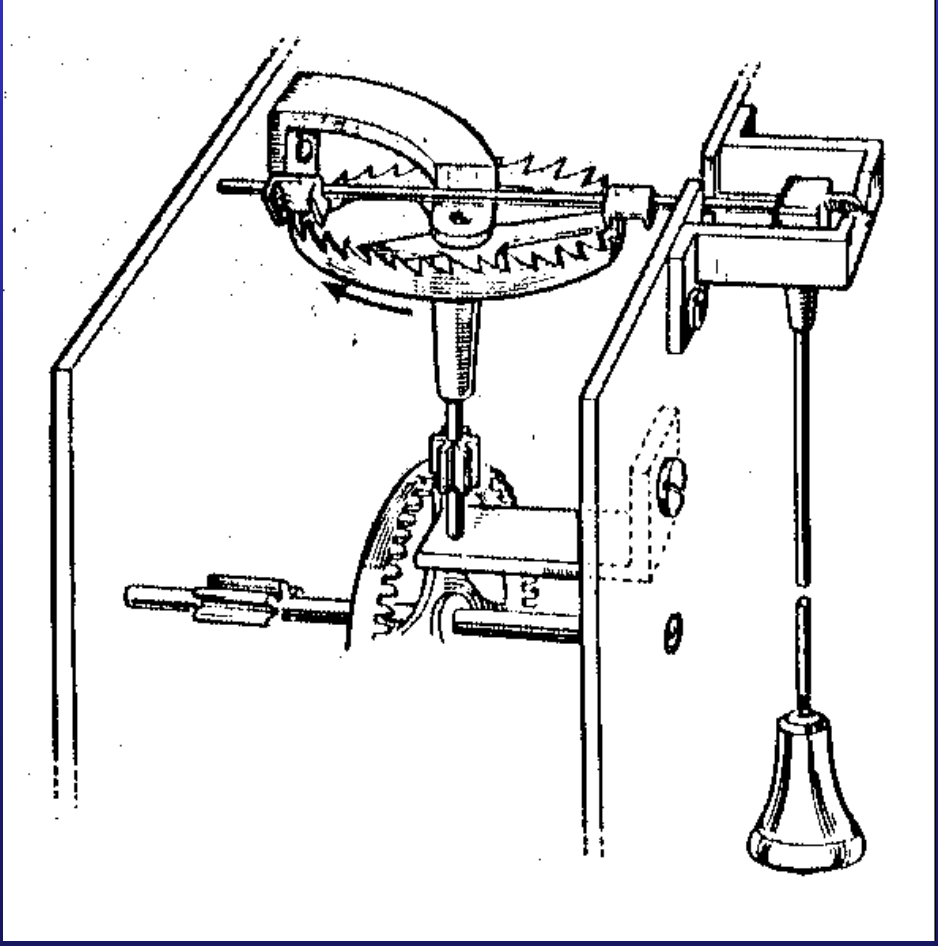
g = versnelling zwaartekracht *gravitation constant* [m/s²]

The evolution of the Dutch Clock, MNU 1991

Mechanical Clocks; > 1656

Pendulum/Horizontal Verge-Escapement

$T = 2\pi\sqrt{l/g}$



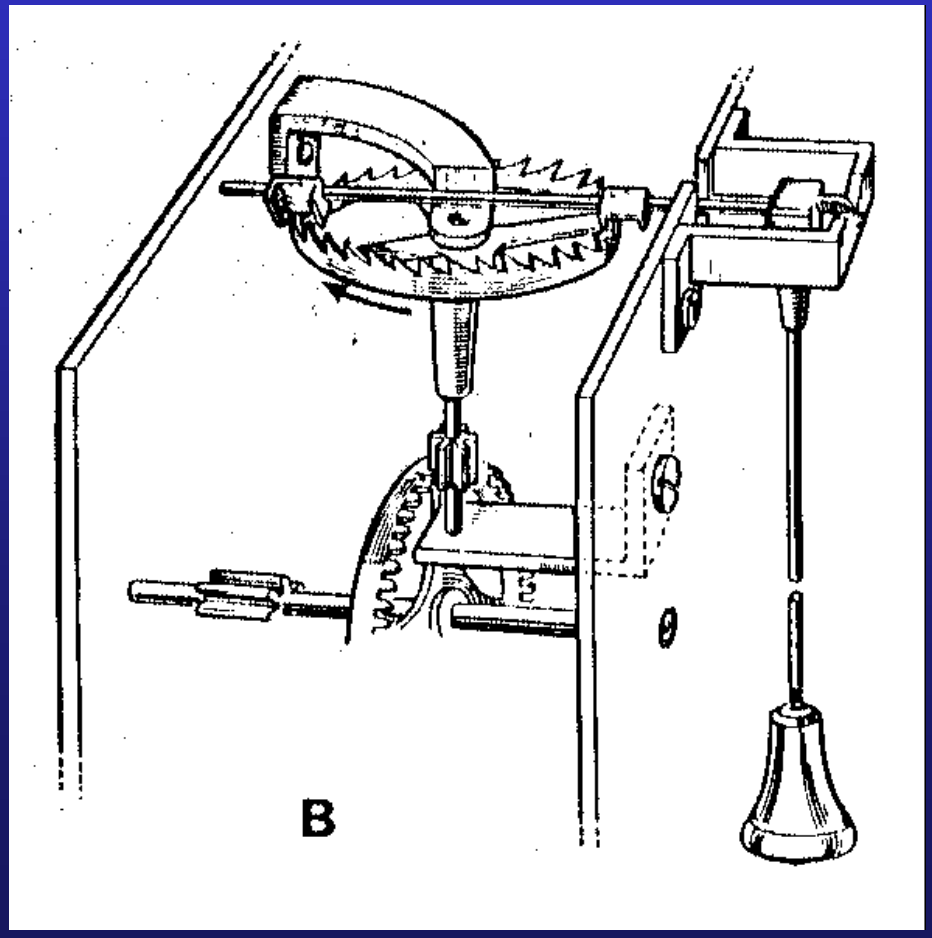
+ Dependent on length pendulum
+ Independent of friction
+ Amplitude dependence can be compensated (cycloidal cheeks)

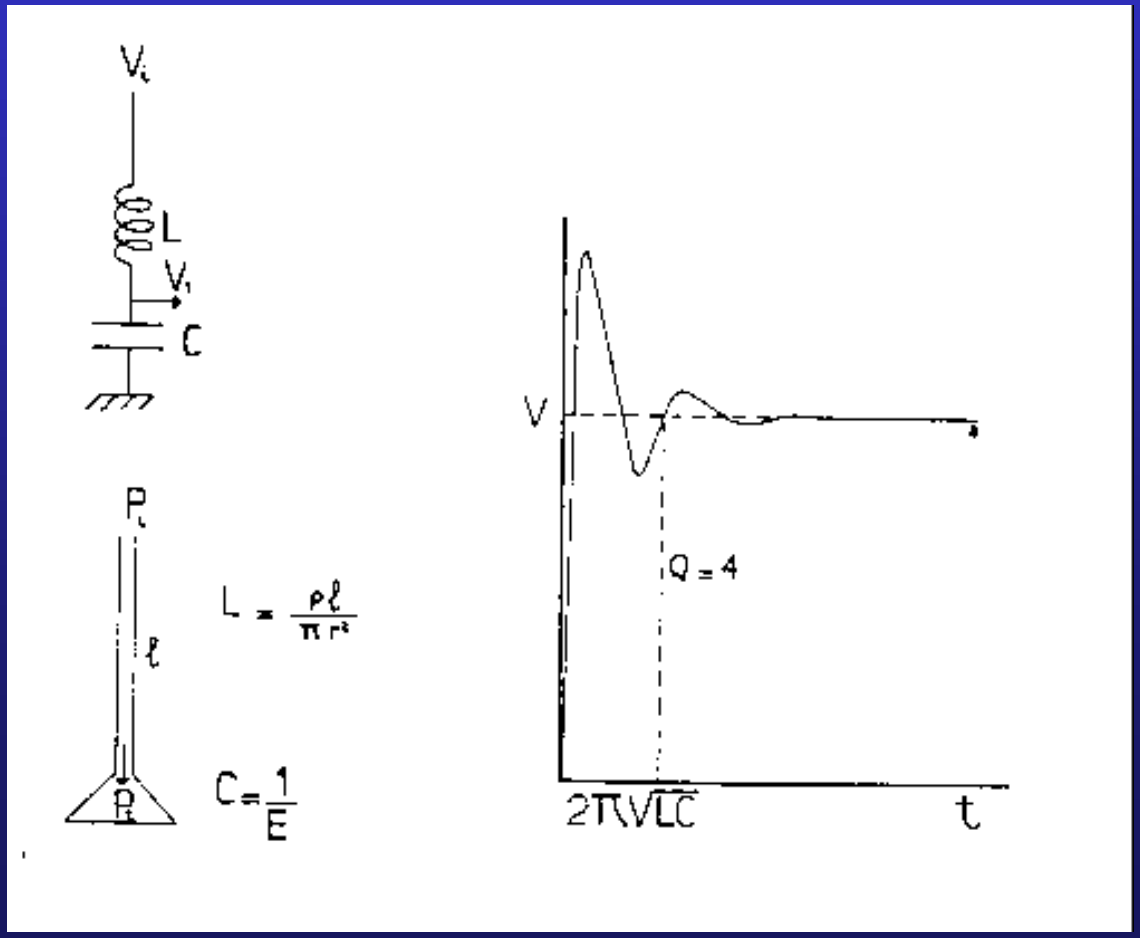
→ INTRINSIC FREQUENCY

- Dependent on gravity (g-tables)
- Can stand still
- Dependent on driving moment
- Dependent on temperature

Analogons; Pendulum

Blood Pressure Measurement





Coster Clocks 1657-1659

Salomon Coster

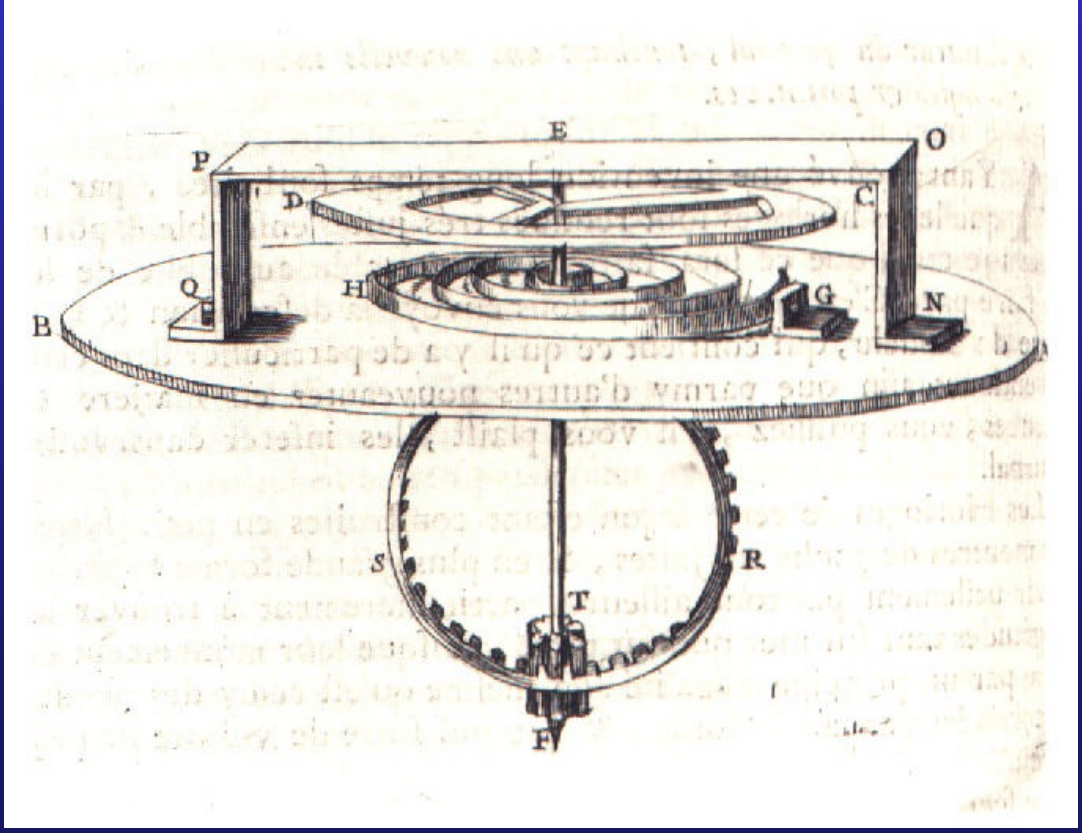
ca 1658

Collection MNU

- Double barrel
- Horizontal verge escapement
- Cycloidal cheeks/silk suspended pendulum
- Striking train

Balance Wheel with Spring

Journal des Sçavans, January 20, 1675



Balanswiel met spiraalveer
Balance wheel with spring

$$I d^2\varphi/dt^2 = -b\varphi$$
$$d^2\varphi/dt^2 = -(b/I)\varphi$$

Oplossing / *Solution* $\varphi = \varphi_{max}\sin(2\pi t/T)$

Periode / *Period* $T = 2\pi\sqrt{(I/b)}$
$= 2\pi\sqrt{(mr^2/2b)}$

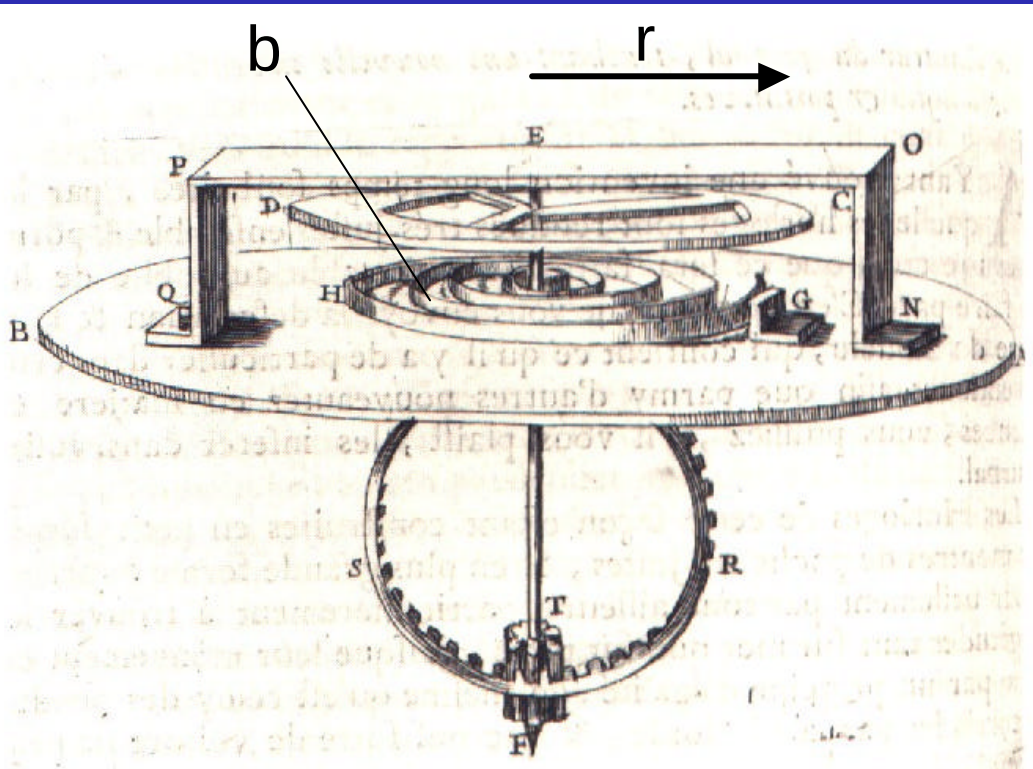
b = veerconstante / *spring constant* [Nm/rad]

I = traagheidsmoment / *moment of inertia* [kgm^2]

Balance Wheel with Spring

Journal des Sçavans, January 20, 1675

$T = 2\pi\sqrt{mr^2/2b}$

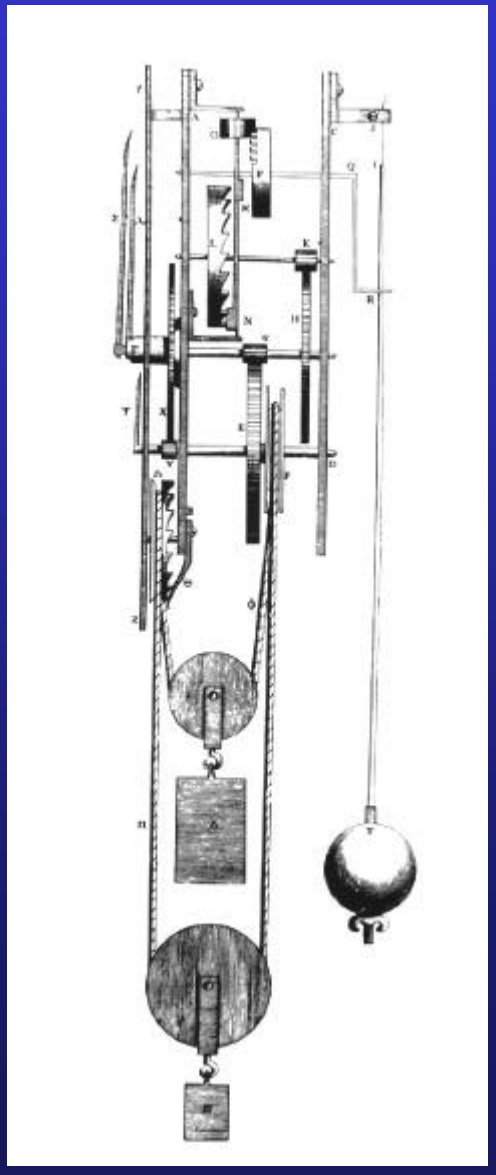


+ Dependent on diameter wheel, mass and spring constant
+ Independent of friction
+ Independent of gravity (balanced)

→ INTRINSIC FREQUENCY

- Can stand still (less easily)
- Dependent on driving moment
- Dependent on temperature

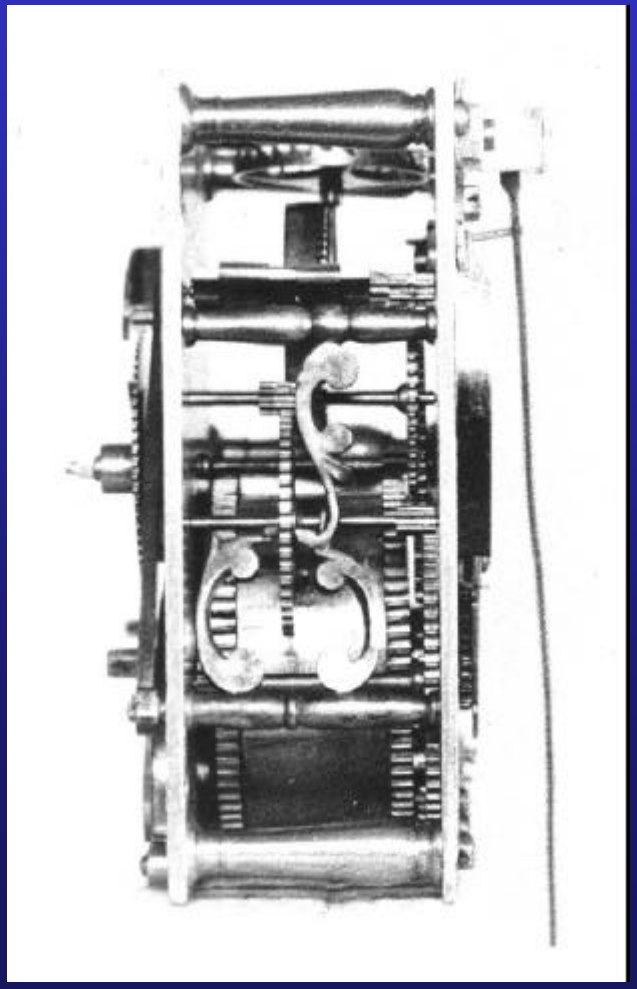
Limitations; driving moment,
maintaining power



Horologium 1658

Double barrel

Endless cord



Salomon Coster ca 1658
Collection MNU

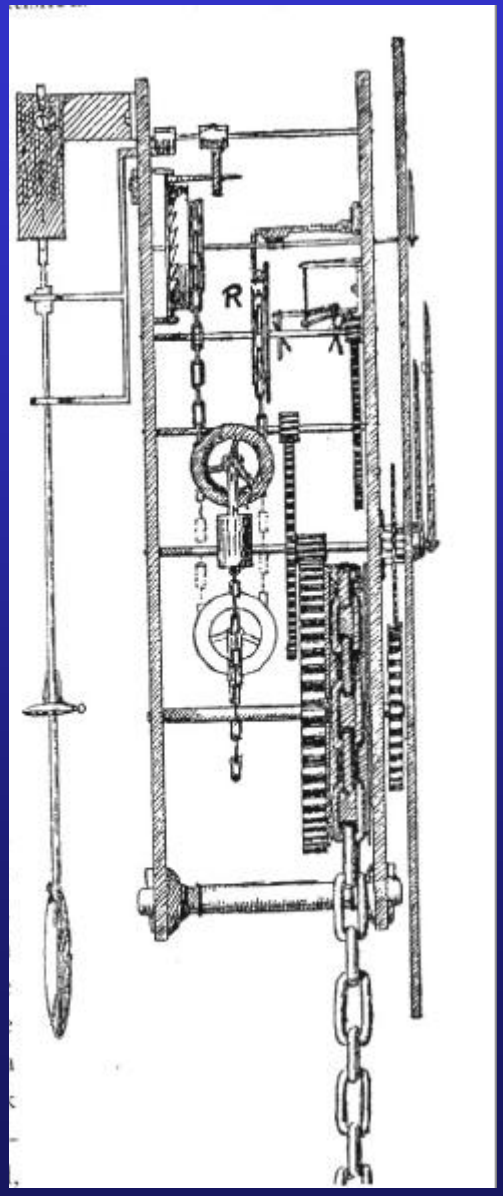
Limitations; driving moment,

Remontoir

Weight Remontoir,

period of half a minute

Design drawing ca 1664



Marine Timekeepers

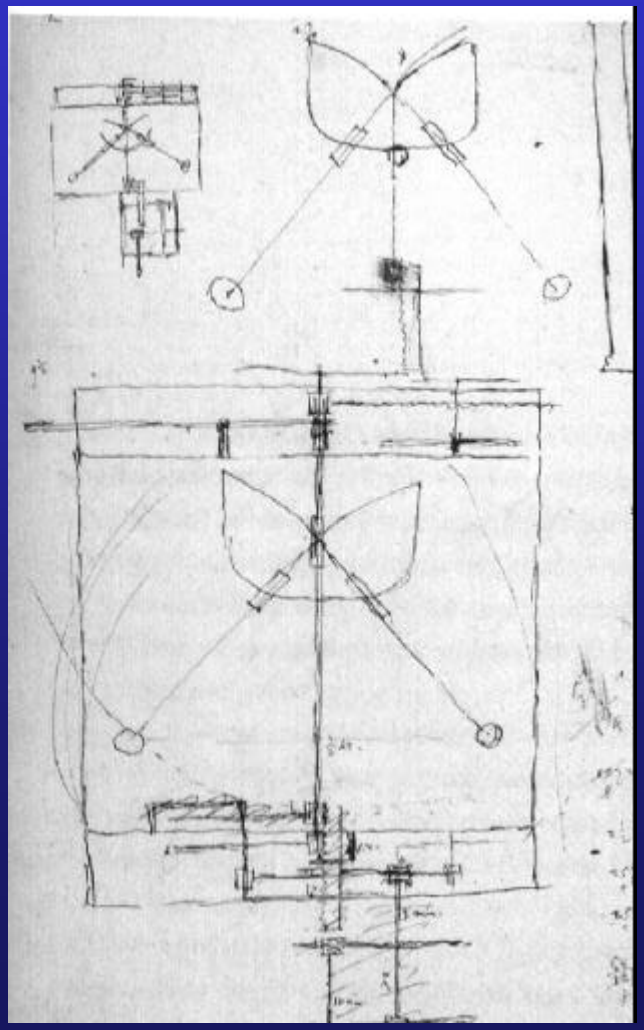
Determining longitude at sea

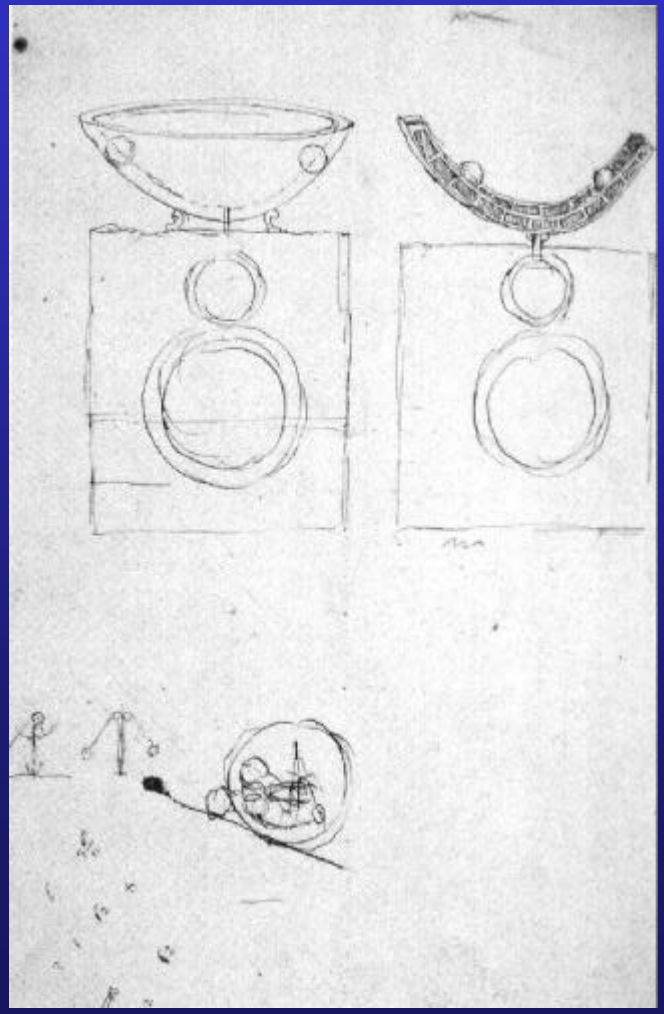
- Philips III, Spain 1598, 6000 ducats
- Proposal Galilei Dutch States General 1636
- England 1714 £ 20.000,-
- France 1715 10.000 Livres

Most important problem to be solved by time measurements

Huygens from 1658 on

Marine Timekeepers (I)



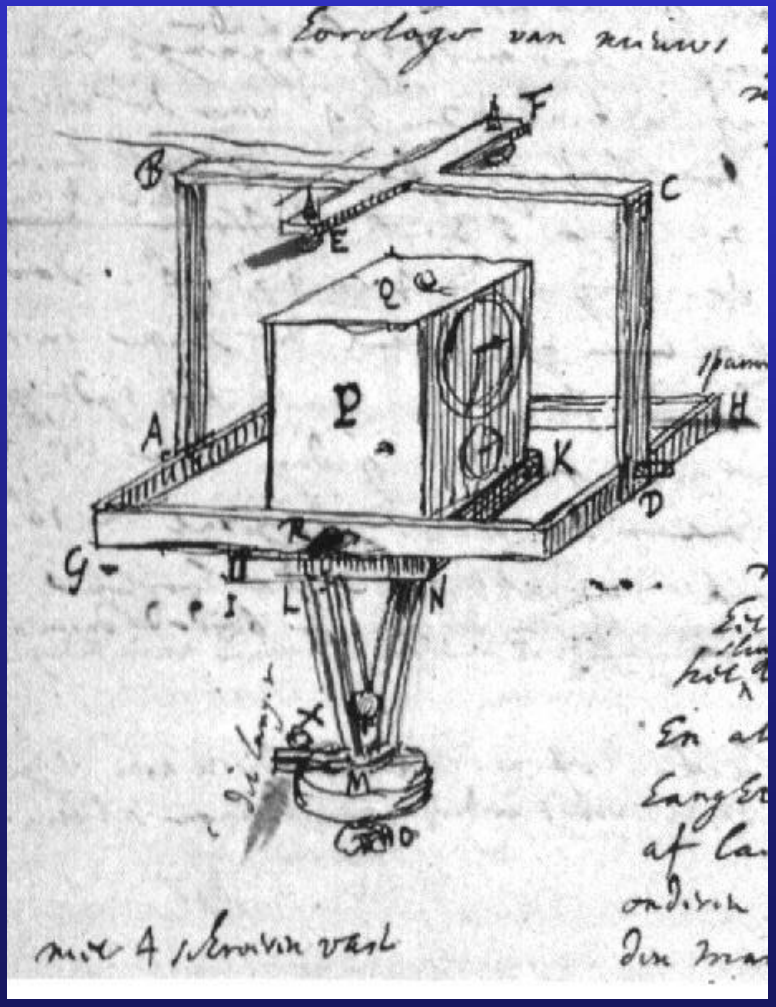


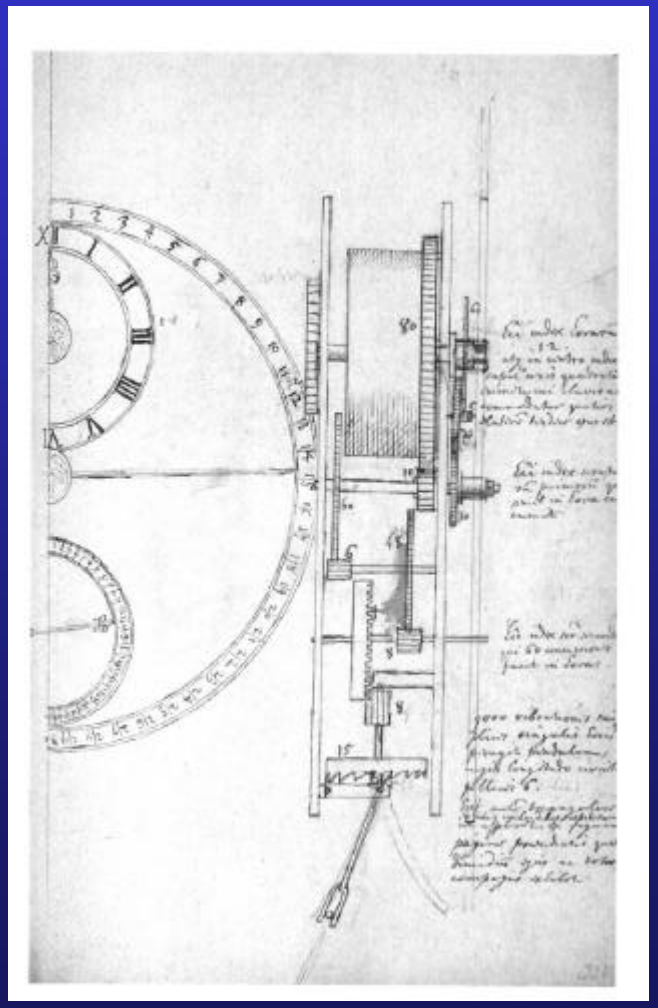
Design drawings

- Clock with two parabolic-conical pendulums 1666
- Clock with a parabolic track 1666 (right)

Marine Timekeepers (II)

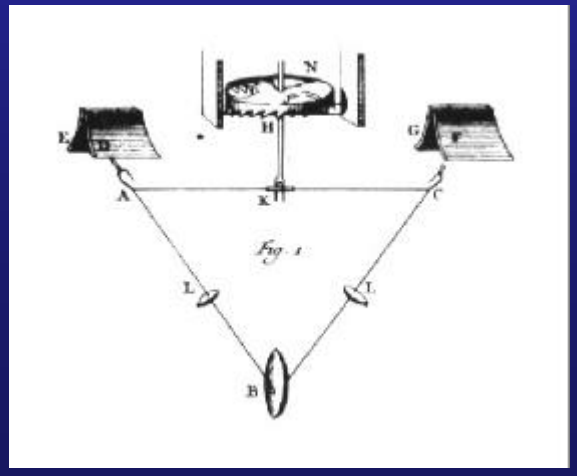
Triangular pendulum





- Sea clock in gimbals with triangular pendulum 1671

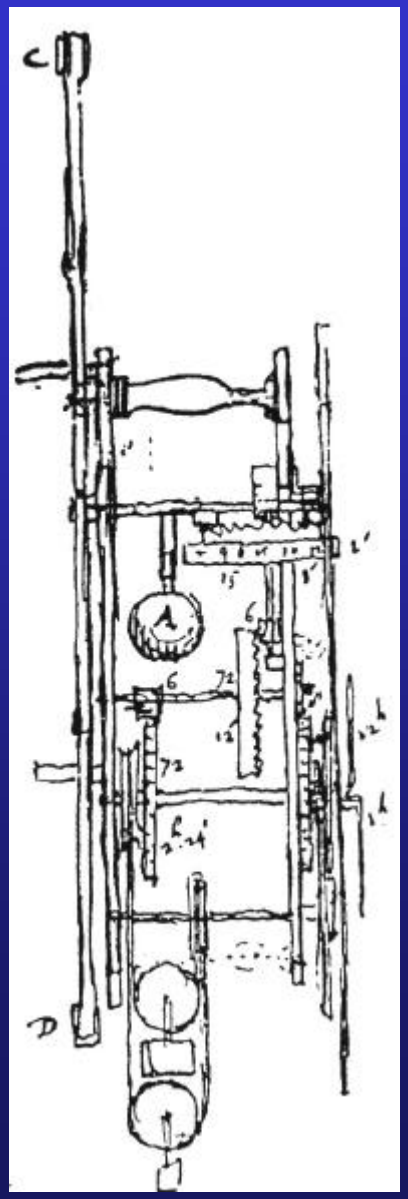
- Design drawing for a clock with a triangular pendulum 1672 (right)

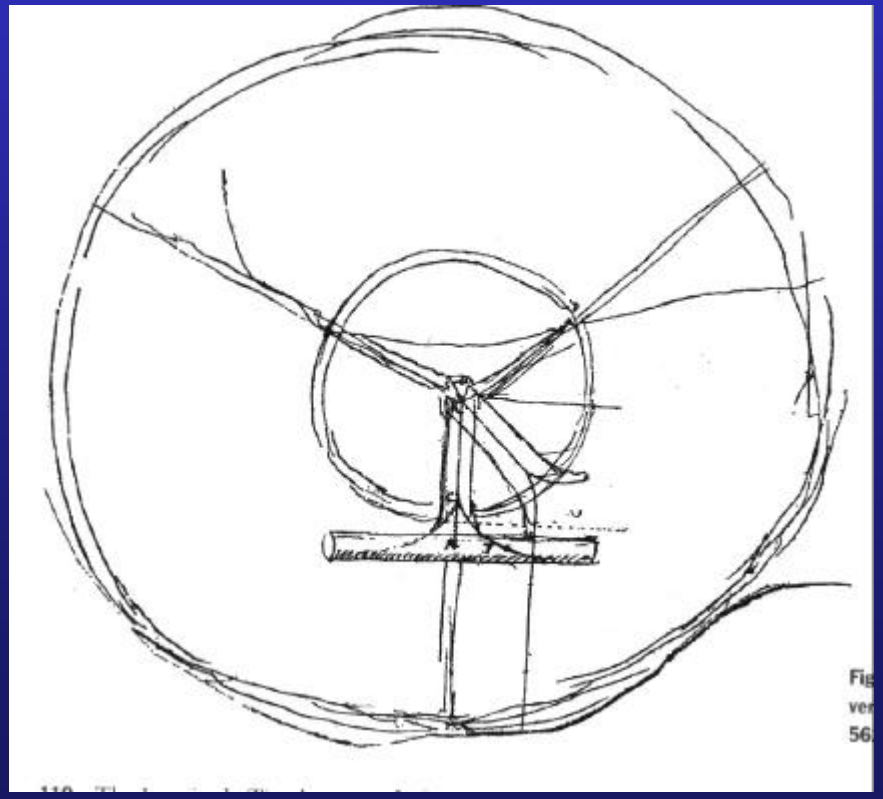


Marine Timekeepers (III)

‘Perfect Marine Balance’

(Balancier Marin Parfait)



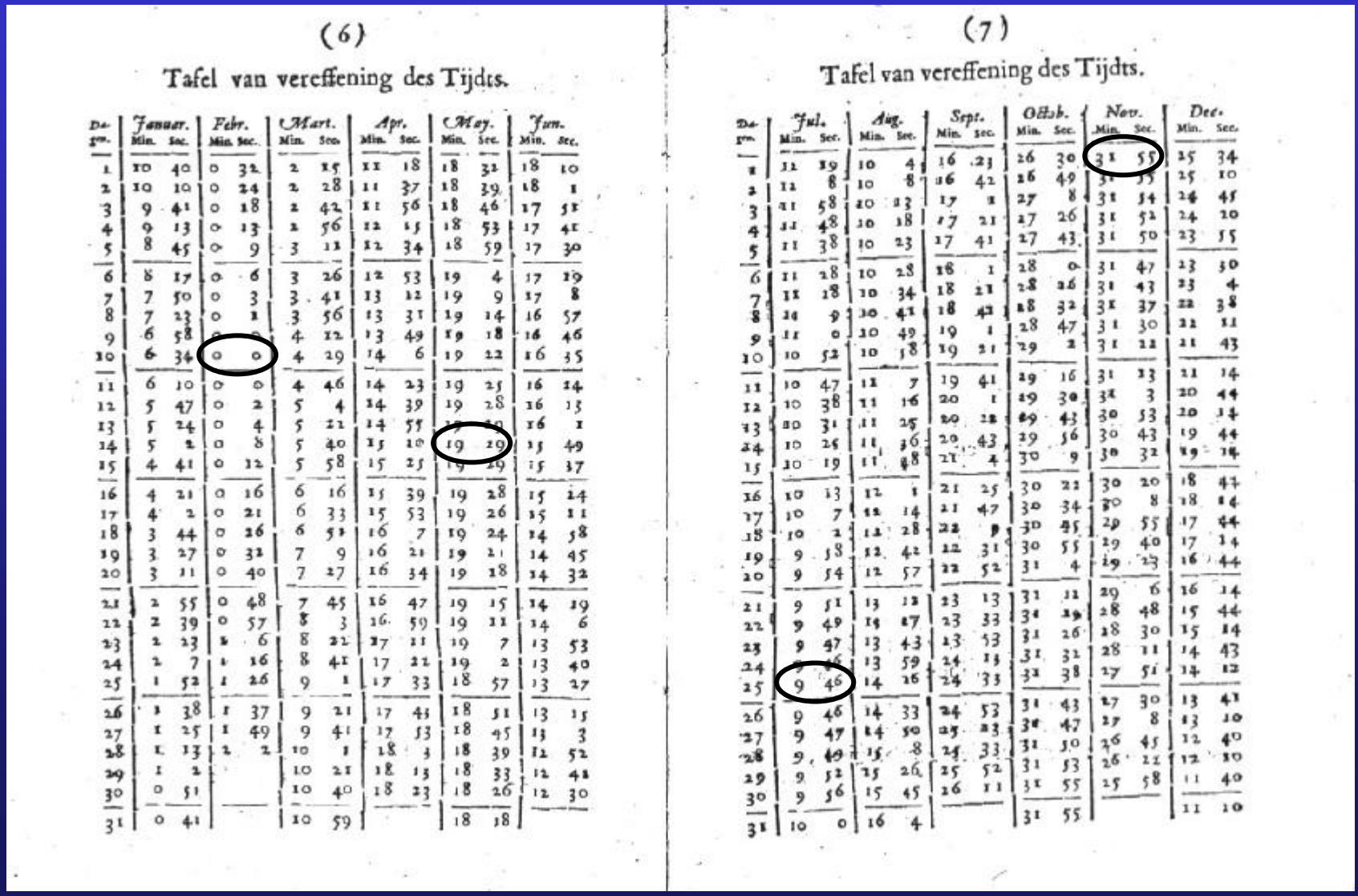


- The Perfect Marine Balance, version of March 1693

- Sea clock with Perfect Marine Balance, March 1693 (left)

Table Equation of time, Kort Onderwys, 1665

Instructions Concerning the Use of Pendulum-Watches for finding the Longitude at Sea, 1669



(6)

Tafel van vereffening des Tijdts.

Dag.	Januar. Min.	Sec.	Febr. Min.	Sec.	Mart. Min.	Sec.	Apr. Min.	Sec.	May. Min.	Sec.	Jun. Min.	Sec.
1	10	40	0	32	2	15	11	18	18	31	18	10
2	10	10	0	24	2	28	11	37	18	39	18	1
3	9	41	0	18	2	42	11	56	18	46	17	51
4	9	13	0	13	2	56	12	15	18	53	17	41
5	8	45	0	9	3	11	12	34	18	59	17	30
6	8	17	0	6	3	26	12	53	19	4	17	19
7	7	50	0	3	3	41	13	12	19	9	17	8
8	7	23	0	1	3	56	13	31	19	14	16	57
9	6	58	0	0	4	12	13	49	19	18	16	46
10	6	34	0	0	4	29	14	6	19	22	16	35
11	6	10	0	0	4	46	14	23	19	25	16	24
12	5	47	0	2	5	4	14	39	19	28	16	13
13	5	24	0	4	5	21	14	55	19	29	16	1
14	5	2	0	8	5	40	15	10	19	29	15	49
15	4	41	0	12	5	58	15	25	19	29	15	37
16	4	21	0	16	6	16	15	39	19	28	15	24
17	4	2	0	21	6	33	15	53	19	26	15	11
18	3	44	0	26	6	51	16	7	19	24	14	58
19	3	27	0	32	7	9	16	21	19	21	14	45
20	3	11	0	40	7	27	16	34	19	18	14	32
21	2	55	0	48	7	45	16	47	19	15	14	19
22	2	39	0	57	8	3	16	59	19	11	14	6
23	2	23	1	6	8	22	17	11	19	7	13	53
24	2	7	1	16	8	41	17	22	19	2	13	40
25	1	52	1	26	9	1	17	33	18	57	13	27
26	1	38	1	37	9	21	17	43	18	51	13	15
27	1	25	1	49	9	41	17	53	18	45	13	3
28	1	13	2	2	10	1	18	3	18	39	12	52
29	1	2			10	21	18	13	18	33	12	41
30	0	51			10	40	18	23	18	26	12	30
31	0	41			10	59			18	18		

(7)

Tafel van vereffening des Tijdts.

Dag.	Jul. Min.	Sec.	Aug. Min.	Sec.	Sept. Min.	Sec.	Octob. Min.	Sec.	Nov. Min.	Sec.	Dec. Min.	Sec.
1	11	39	10	4	16	23	26	30	31	55	25	34
2	11	8	10	8	16	42	26	49	31	55	25	10
3	11	58	10	13	17	1	27	8	31	54	24	45
4	11	48	10	18	17	21	27	26	31	52	24	20
5	11	38	10	23	17	41	27	43	31	50	23	55
6	11	28	10	28	18	1	28	0	31	47	23	30
7	11	18	10	34	18	21	28	16	31	43	23	4
8	11	9	10	41	18	42	28	32	31	37	22	38
9	11	0	10	49	19	1	28	47	31	30	22	11
10	10	52	10	58	19	21	29	2	31	22	21	43
11	10	47	11	7	19	41	29	16	31	13	21	14
12	10	38	11	16	20	1	29	30	31	3	20	44
13	10	31	11	25	20	22	29	43	30	53	20	14
14	10	25	11	36	20	43	29	56	30	43	19	44
15	10	19	11	48	21	4	30	9	30	32	19	14
16	10	13	12	1	21	25	30	22	30	20	18	43
17	10	7	12	14	21	47	30	34	30	8	18	14
18	10	2	12	28	22	9	30	45	29	55	17	44
19	9	58	12	42	22	31	30	55	29	40	17	14
20	9	54	12	57	22	52	31	4	29	23	16	44
21	9	51	13	12	23	13	31	12	29	6	16	14
22	9	49	13	27	23	33	31	19	28	48	15	44
23	9	47	13	43	23	53	31	26	28	30	15	14
24	9	46	13	59	24	13	31	32	28	11	14	43
25	9	46	14	16	24	33	31	38	27	51	14	12
26	9	46	14	33	24	53	31	43	27	30	13	41
27	9	47	14	50	25	13	31	47	27	8	13	10
28	9	49	15	8	25	33	31	50	26	45	12	40
29	9	52	15	26	25	52	31	53	26	22	12	10
30	9	56	15	45	26	11	31	55	25	58	11	40
31	10	0	16	4			31	55			11	10

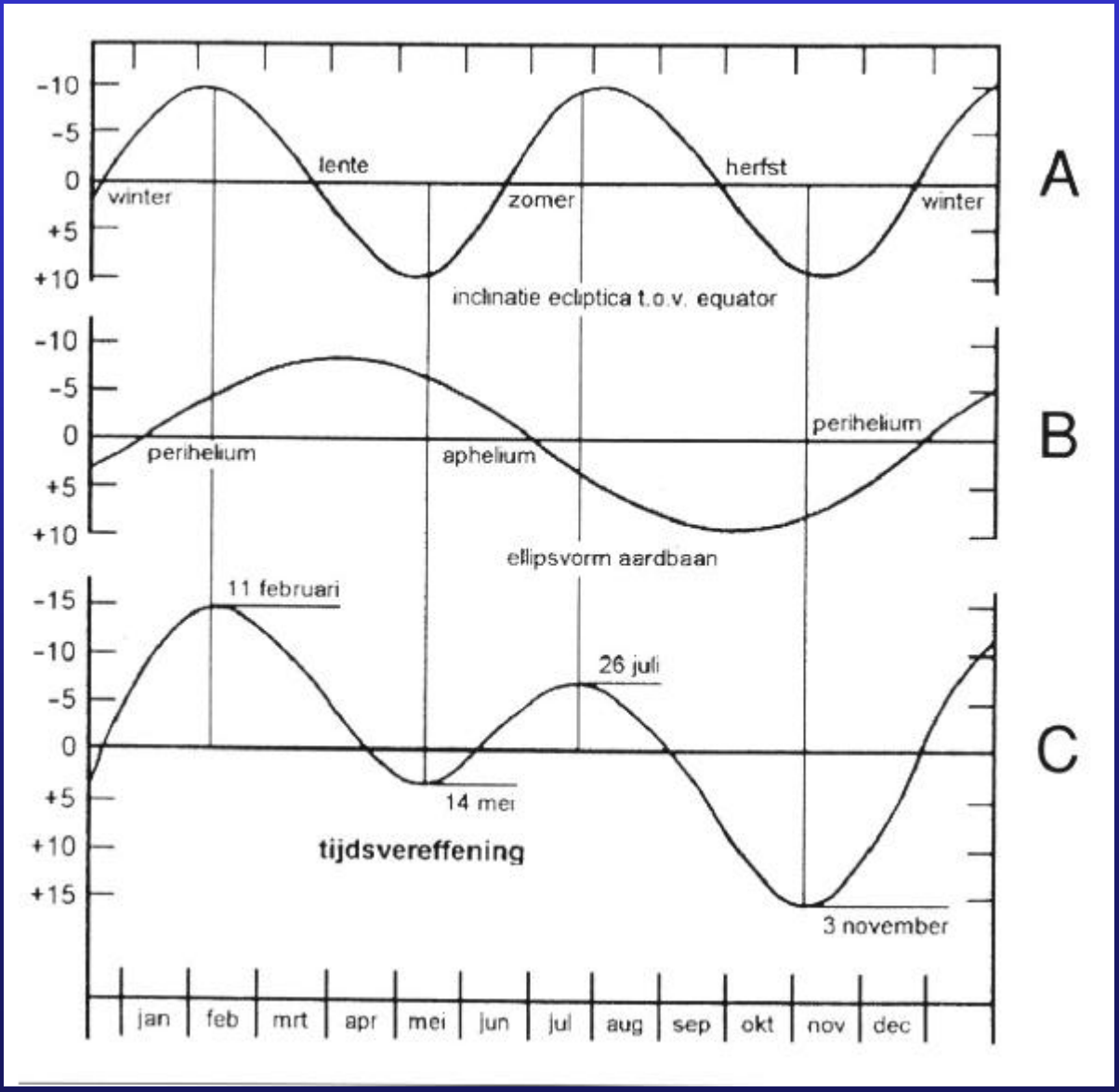
1 nov
31m55s

10 feb
0m0s

14 mei
19m29s

25 jul
9m46s

Table Equation of time



Kort Onderwys
1665

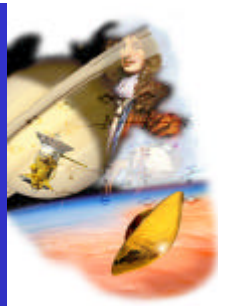
10 feb
0m0s

14 mei
19m29s

25 jul
9m46s

1 nov
31m55s

Discussion



- Huygens man of science with insight in second order **(resonant) systems**
- Using this insight he produced two major break-throughs in timekeeping: The **pendulum** and the **balance spring**
- His science was stimulated by **important practical questions**
- Produced **solutions for most limitations** in time-keeping, except for temperature dependence

Christiaan Huygens: Appreciation

Eppo Doeve 1955