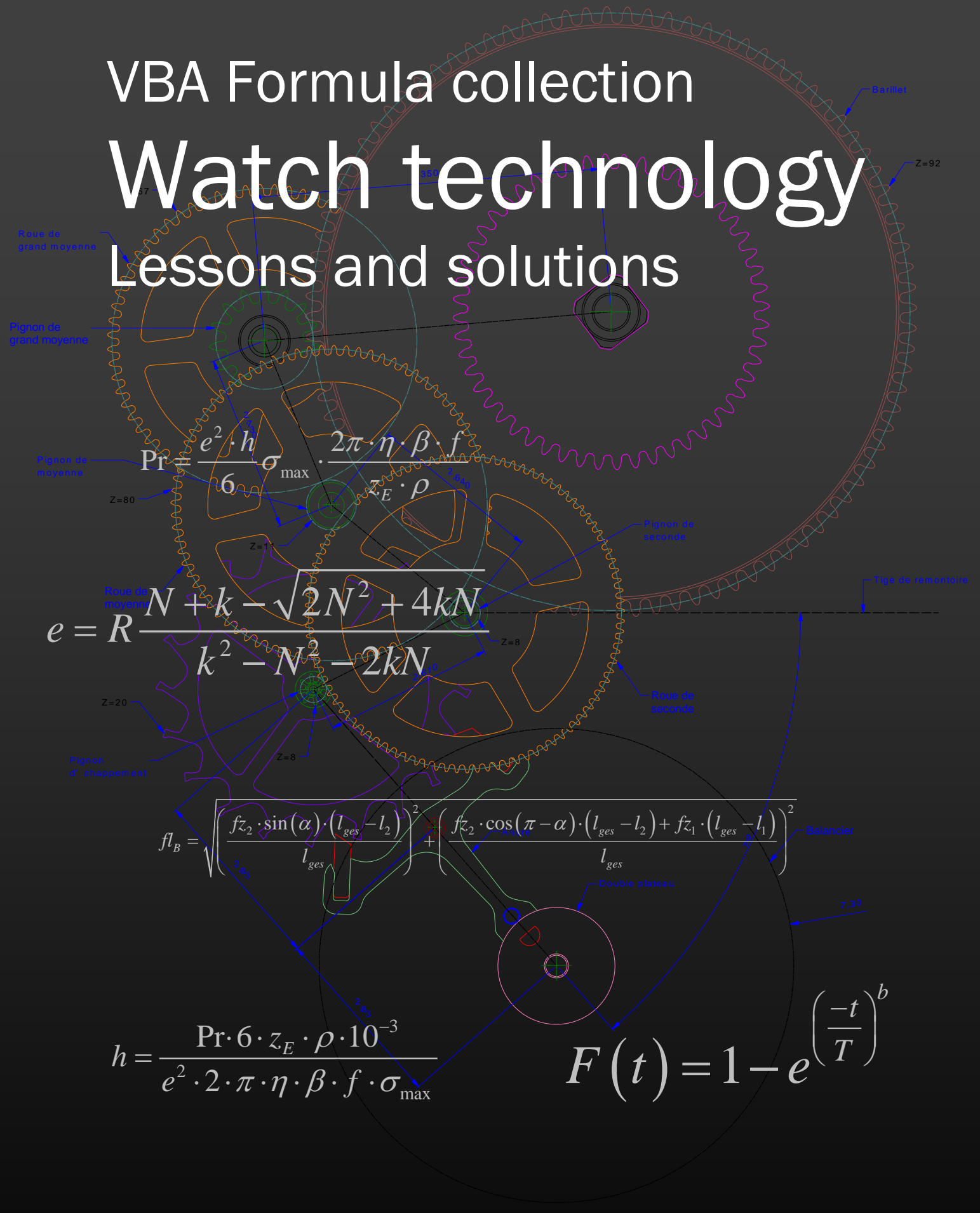


VBA Formula collection

Watch technology

Lessons and solutions



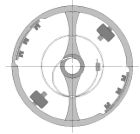
$$Pr = \frac{e^2 \cdot h}{6 \cdot \sigma_{\max}} \cdot \frac{2\pi \cdot \eta \cdot \beta \cdot f}{z_E \cdot \rho}$$

$$e = R \frac{N + k - \sqrt{2N^2 + 4kN}}{k^2 - N^2 - 2kN}$$

$$fl_B = \sqrt{\frac{fz_2 \cdot \sin(\alpha) \cdot (l_{ges} - l_2)}{l_{ges}} + \left(fz_2 \cdot \cos(\pi - \alpha) \cdot (l_{ges} - l_2) + fz_1 \cdot (l_{ges} - l_1) \right)^2}$$

$$h = \frac{Pr \cdot 6 \cdot z_E \cdot \rho \cdot 10^{-3}}{e^2 \cdot 2 \cdot \pi \cdot \eta \cdot \beta \cdot f \cdot \sigma_{\max}}$$

$$F(t) = 1 - e^{\left(\frac{-t}{T}\right)^b}$$



VBA Macros for Excel and OpenOffice

To accompany the lessons and book **Watch technology**, there are Add-Ins for calculating the mechanical movements.

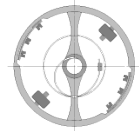
Author: Kilian Eisenegger
kilian.eisenegger@watchmaking.com
www.watchmaking.com
Update server of data
www.watchmaking.com

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1 VBA formula collection watch technology

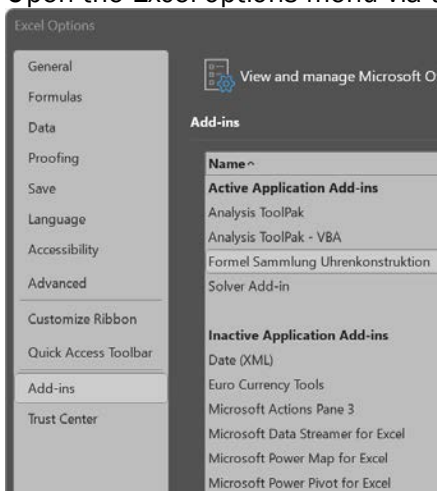
This document explains how to use the VBA Formula Collection for Microsoft Excel as well as OpenOffice and Libreoffice Calc. It is recommended to use the appropriate book **Watch Technology**, which can be found at watchmaking.com, for the application of formulas. The programs are constantly being expanded. The current version can be obtained from the server watchmaking.com.

2 Install Excel Add-Ins (Office 365)

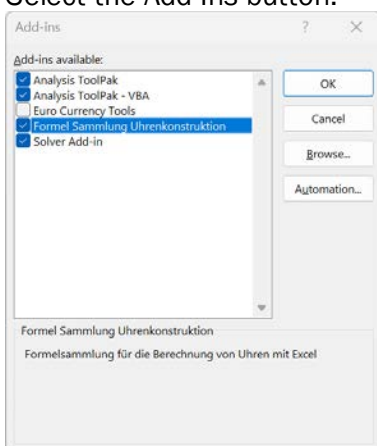
Before we start with the theory, it makes sense to install the macros in the form of an add-in for the Excel calculations on the computer. Excel VBA is supported on the Apple operating system from Office version 2011.

An add-in is used for the cross-file provision of code (macros or user-defined functions) and can be recognized by the file extension *.xlam. To be able to use an add-in, it must be installed and activated.

Open the Excel options menu via the Office button.



Select the Add-Ins button.



Select the formula .xlam file via Browse....
Select and activate the corresponding program.

2.1 How do you activate an add-in?

Excel is open and there must be at least one workbook (extension: *.xls) open - it can also be a new unsaved workbook. Then go over *Menu > Extras > Add-ins...* and the dialog box *Add* jumps up. You will see all the add-ins that have already been installed, the activated ones are checked. Find the add-in you want to activate from the list and check it. *OK*. This means that the activation completed

Openoffice/Libreoffice Calc, How do you disable an add-in?

After add-in activation, new entries often appear in the menus or submenus, new icons in the toolbars or even generate their own toolbars. You can use these entries to access the add-ins.

Another way to use it is by calling by code or using the user-defined functions stored in the add-in, either in code or formulas.

2.2 How do you disable an add-in?

First of all: Deactivate does not mean delete! Disabled add-ins just don't load. However, they can be activated at any time.

Excel is open and there must be at least one workbook (extension: *.xls) open - it can also be a new unsaved workbook. Then go via *Menu > Extras > Add-Ins...* and the *Add-Ins* dialog box pops up. You will see all the add-ins that have already been installed, the activated ones are checked. Find the add-in you want to disable from the list and check it off. Exit the dialog by clicking the *OK* button. This completes the deactivation

2.3 How do I remove an add-in that is no longer needed from the list?

To keep the selection list clear, it is advisable to remove add-ins that are no longer needed there. This is how it works:

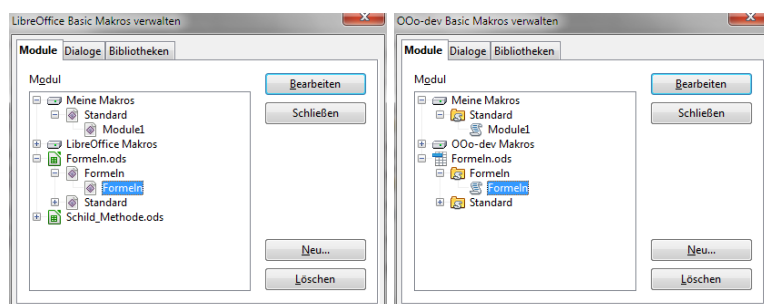
First, deactivate the add-in that you want to remove from the list. Switch to Explorer and move the corresponding *.xla file to any directory; if you are absolutely sure that you will never need it again, you can also delete this file. Switch back to Excel. Reactivate the add-in that you want to remove from the list. Now Excel provides you with a dialog because it no longer finds the file in the path; confirm the dialog. This removes this add-in from the list of the Add-ins dialog box. Exit the dialog by clicking the *OK* button

3 Openoffice/Libreoffice Calc

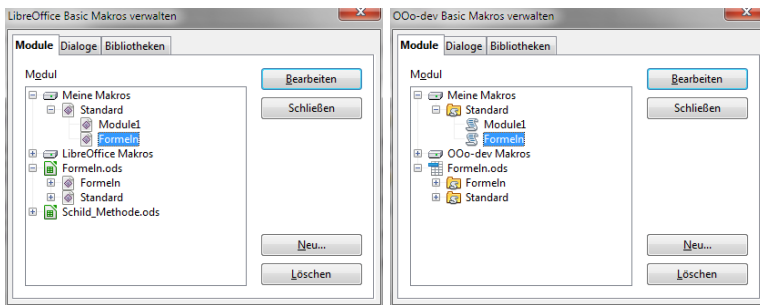
There is the free version of Microsoft Excel with OpenOffice or Libre Office. Both programs have a solver.

3.1 How to install an Add-In

Download the file Formlen.ods and activate the macros. Open the menu *Managing Macros*. The formula library must be manually stored in the *My Macros* can be postponed.

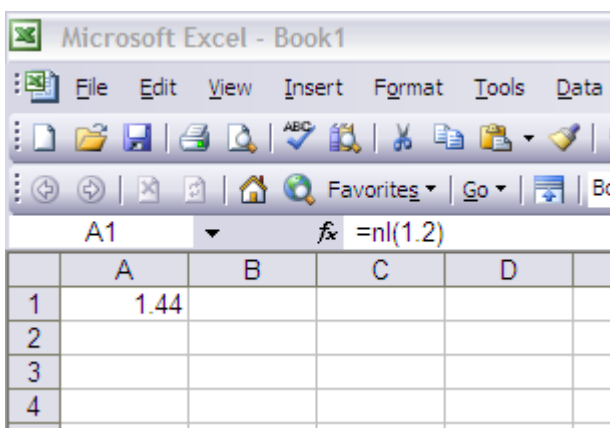
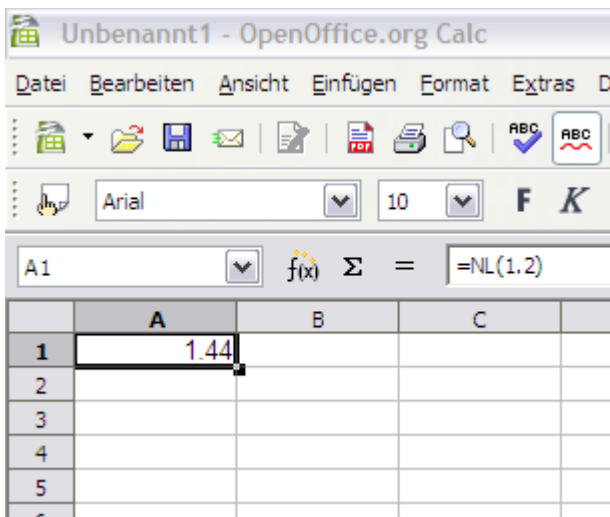


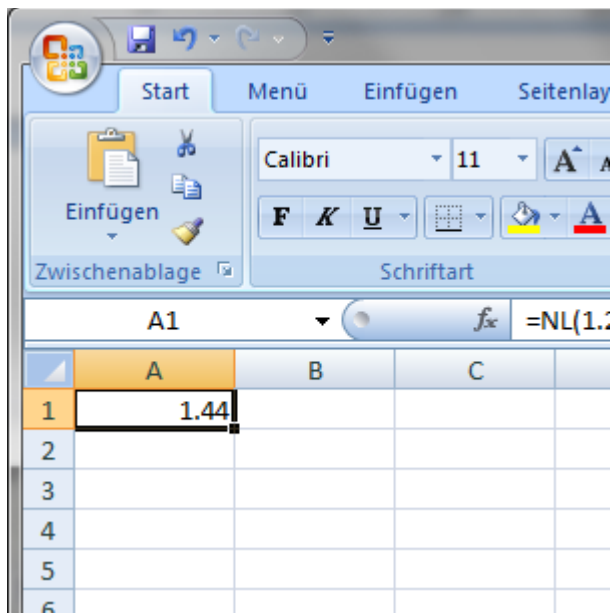
After moving, the dialog will look like this:



4 Using the Add-In formulas

If the formulas are installed correctly, they can be used directly in Excel or OpenOffice. The groove length of a rubber seal is then calculated as follows:





5 Formula reference

The additional formulas that can be used are documented in the documents as follows.

Formula for deflection of the caseback under pressure $f_{\max \text{ Boden}} = \frac{p \cdot R^4}{64 \cdot D}$

Input form in Excel $f_{\max_b}(p; R; D)$

The order of the parameters must be observed. The parameters are colored blue. The simplification is particularly noticeable in complex formulas.

The force on the plain bearing B in Hertzian compression is calculated as follows:

$$f_{l_B} = \sqrt{\left(\frac{f_{z_2} \cdot \sin(\alpha) \cdot (l_{ges} - l_2)}{l_{ges}} \right)^2 + \left(\frac{f_{z_2} \cdot \cos(\pi - \alpha) \cdot (l_{ges} - l_2) + f_{z_1} \cdot (l_{ges} - l_1)}{l_{ges}} \right)^2}$$

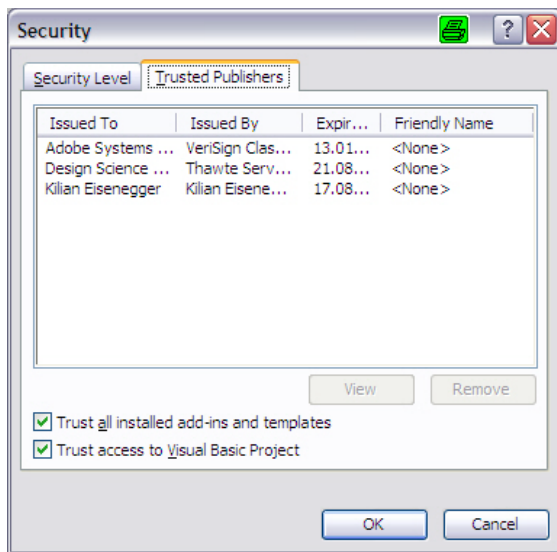
The simplification in Excel or Calc looks like this:

$f_{lb}(f_{z_1}; f_{z_2}; \alpha; l_{ges}; l_1; l_2)$

The program files such as Schild_Methode.xls or Schild_Methode.odt have already built in these formulas.

6 Macro security

The watch construction macros are certified. When starting for the first time, the new source must be specified as trusted.



The OpenOffice documents are also certified. (recognizable by the seal)



7 Solver

Using the Solvers Function in Excel allows you to optimize calculations afterwards. For example, if we look at the geometry of the oscillating mass to the elevator speed, the use of the solver is predestined.

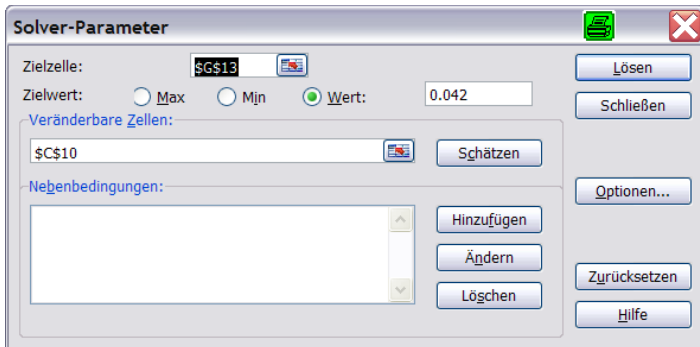
7.1 Microsoft Office

Schild Methode zum Berechnen einer Schwungmasse V1.2						Calibre:	XXXXXX
Segmet	Radius innen ri	Radius aussen Ra	Höhe h	Schrägsegment a	Schrägsegment b	Gewicht [N]	
1	1.100	1.800	0.400			0.00010714	
2	0.600	1.100	0.900			0.00010094	
3	0.600	1.100	0.900			0.00010094	
4	1.100	9.500	0.400			0.00469942	
5	9.500	10.000	1.000			0.00128648	
6	8.800	9.500	1.100			0.00398414	
7	9.500	10.000	0.500			0.00137837	
8	10.000	12.600	1.500			0.02492100	
9	11.000	12.600	0.700			0.00747347	
10-		12.600		0.550	2.200	0.00405982	
Total						0.03999208	

If we want to adjust the weight force to 0.042 grams in the above example by adjusting the outer diameter, the solution is quickly found with the solver.

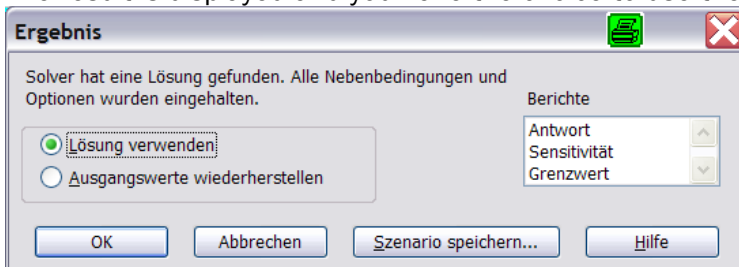
7.1.1 Solver parameters

The solver parameters are defined. Target value must be set to "Value".



7.1.2 Result

The result is displayed and you have the choice to use the solution or go back to the old value.



The weight force has been adjusted. C11 has been adjusted from 12.5mm to 12.73.

Schild Methode zum Berechnen einer Schwungmasse V1.2						Calibre:	XXXXXX
Segmet	Radius innen ri	Radius aussen Ra	Höhe h	Schrägsegment a	Schrägsegment b	Gewicht [N]	
1	1.100	1.800	0.400			0.00010714	
2	0.600	1.100	0.900			0.00010094	
3	0.600	1.100	0.900			0.00010094	
4	1.100	9.500	0.400			0.00469942	
5	9.500	10.000	1.000			0.00128648	
6	8.800	9.500	1.100			0.00398414	
7	9.500	10.000	0.500			0.00137837	
8	10.000	12.730	1.500			0.02632070	
9	11.000	12.730	0.700			0.00812667	
10-		12.730		0.550	2.200	0.00410439	
Total						0.04200041	

The c11 and c12 fields must be linked to c10.



7.2 Solver in Openoffice

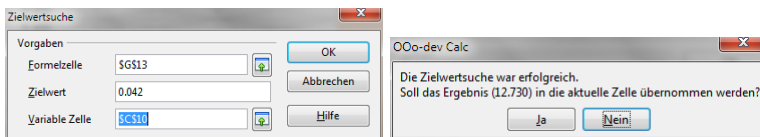
7.2.1 Solver parameters



Schild Methode zum Berechnen einer Schwungmasse V1.2							Calibre:	XXXXXX
Segmet	Radius innen ri	Radius aussen Ra	Höhe h	Schrägsegment a	Schrägsegment b	Gewicht [N]		
1	1.100	1.800	0.400			0.00010714		
2	0.600	1.100	0.900			0.00010094		
3	0.600	1.100	0.900			0.00010094		
4	1.100	9.500	0.400			0.00469942		
5	9.500	10.000	1.000			0.00128648		
6	8.800	9.500	1.100			0.00398414		
7	9.500	10.000	0.500			0.00137837		
8	10.000	12.600	1.500			0.02492100		
9	11.000	12.600	0.700			0.00747347		
10 -		12.600		0.550	2.200	0.00405982		
Total						0.03999208		

7.2.2 Solver parameters

In Openoffice, please use target value search. The solver does not work reliably right away.



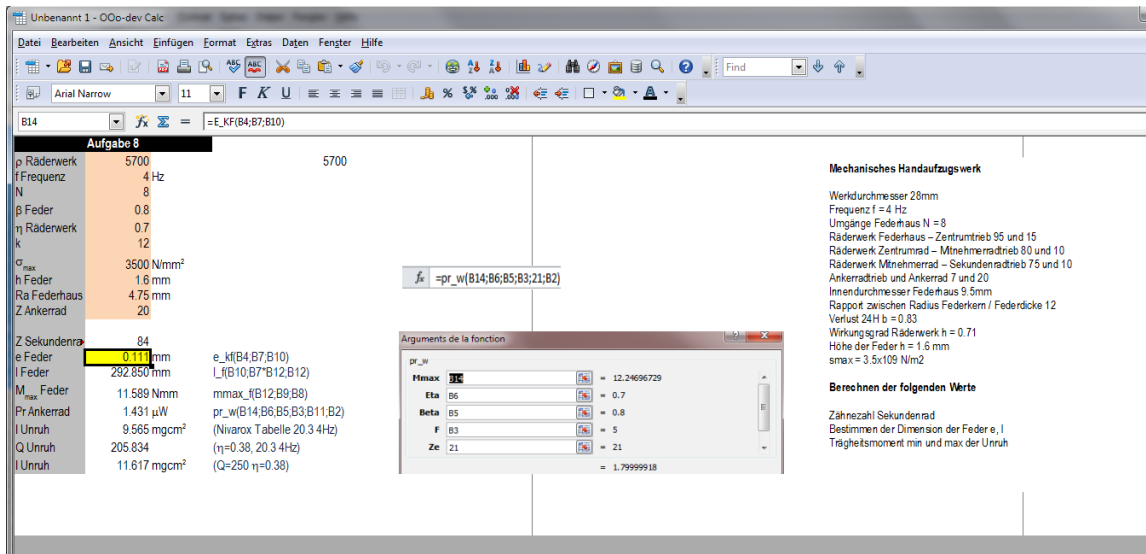
Schild Methode zum Berechnen einer Schwungmasse V1.2							Calibre:	XXXXXX
Segmet	Radius innen ri	Radius aussen Ra	Höhe h	Schrägsegment a	Schrägsegment b	Gewicht [N]		
1	1.100	1.800	0.400			0.00010714		
2	0.600	1.100	0.900			0.00010094		
3	0.600	1.100	0.900			0.00010094		
4	1.100	9.500	0.400			0.00469942		
5	9.500	10.000	1.000			0.00128648		
6	8.800	9.500	1.100			0.00398414		
7	9.500	10.000	0.500			0.00137837		
8	10.000	12.730	1.500			0.02632038		
9	11.000	12.730	0.700			0.00812652		
10 -		12.730		0.550	2.200	0.00410438		
Total						0.04199994		

8 How to use the VBA formulas

If the add-in is installed correctly, the VBA formulas can be used like Excel formulas. A click on the formula symbol provides information about the variables.

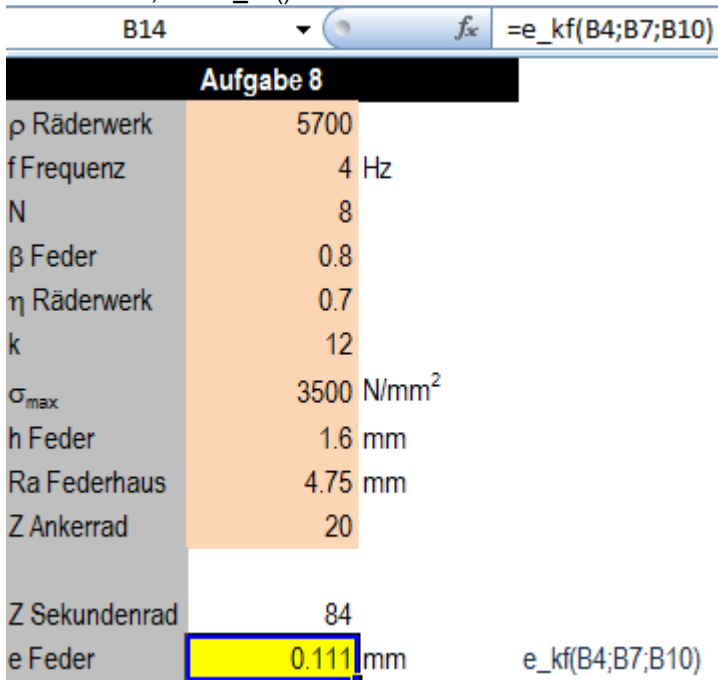
8.1 Microsoft Excel

8.2 Openoffice



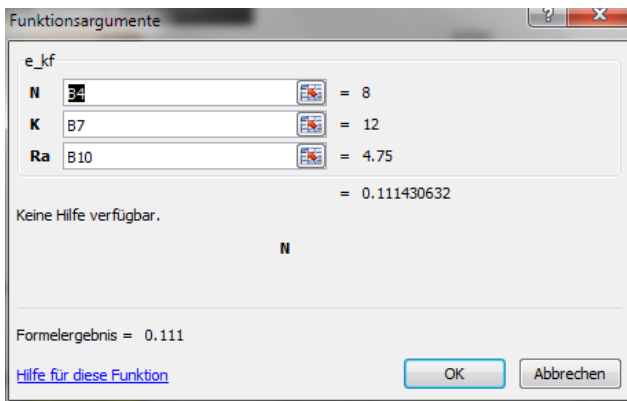
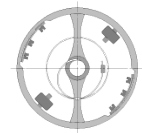
8.3 Enter the formula

In field B14, the `e_kf()` formula is used.



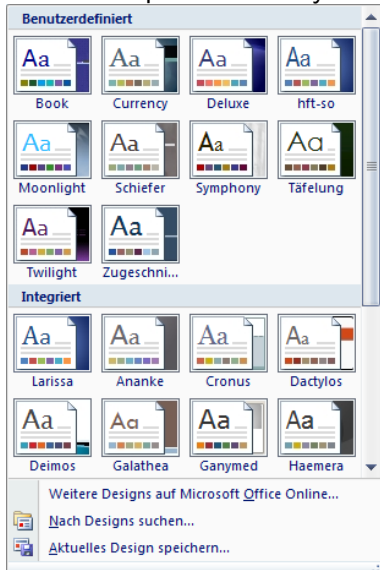
8.3.1 Formula parameters

The Formula Parameters can be viewed by clicking on the formula icon. In this case, N for the number of rounds of the barrel, k for the factor k of the spring, Ra for the outer diameter of the spring in the barrel.



9 Dynamic themes for Microsoft Office documents

The Excel tables use standard layouts. You can dynamically adjust the layouts starting with Excel 2007. The predefined layout is called hftm and uses Arial Narrow.



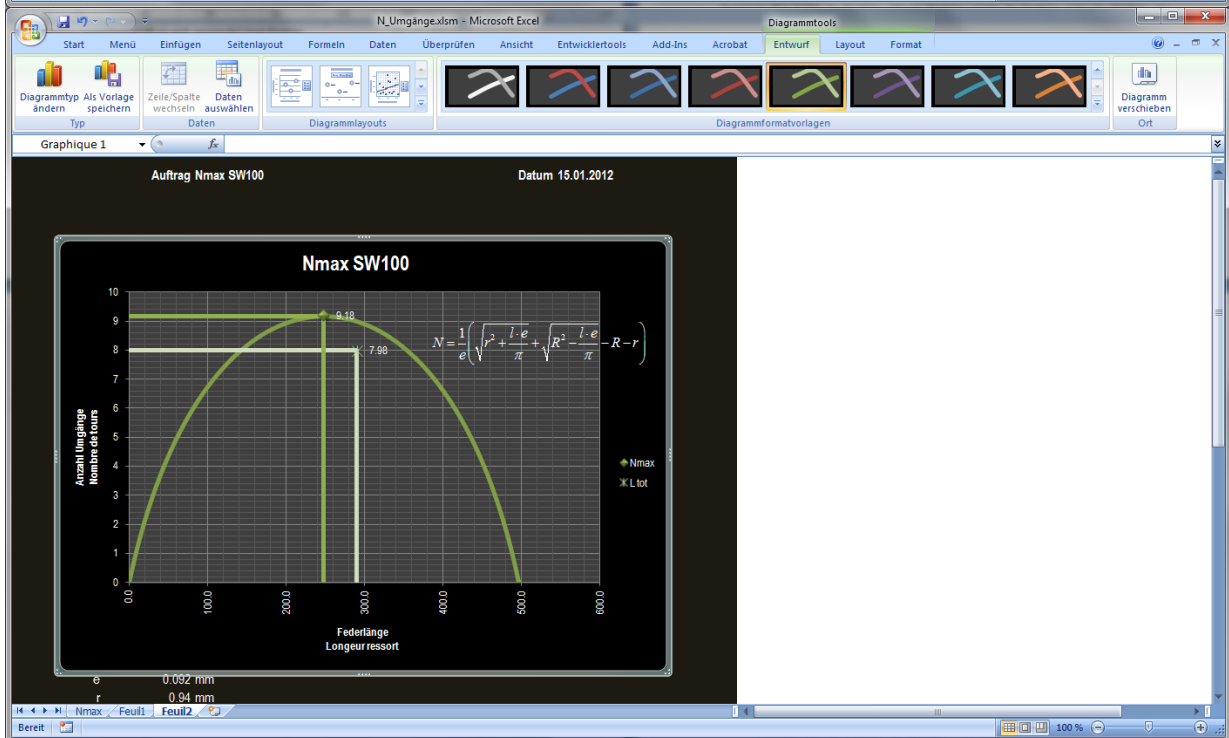
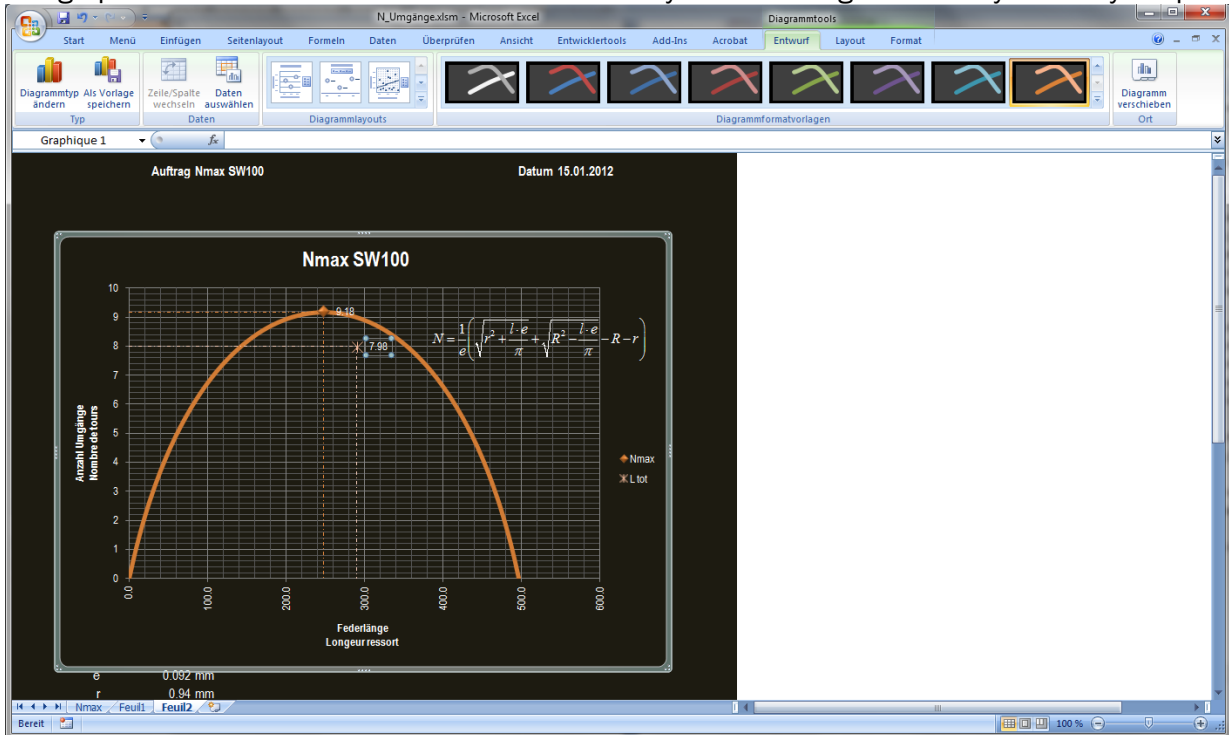
The Microsoft Office themes can be changed dynamically.

Aufgabe 8		
p Räderwerk	5700	
f Frequenz	4 Hz	
N	8	
β Feder	0.8	
η Räderwerk	0.7	
k	12	
σ _{max}	3500 N/mm ²	
h Feder	1.6 mm	
Ra Federhaus	4.75 mm	
Z Ankerrad	20	
Z Sekundenrad	84	
e Feder	0.111 mm	e_kf(B4;B7;B10)
l Feder	292.850 mm	l_f(B10;B7*B12;B12)
M _{max} Feder	11.589 Nmm	mmax_f(B12;B9;B8)
Pr Ankerrad	1.431 μW	pr_w(B14;B6;B5;B3;B11;B2)
l Unruh	9.565 mgcm ²	(Nivarox Tabelle 20.3 4Hz)
Q Unruh	205.834	(η=0.38, 20.3 4Hz)
l Unruh	11.617 mgcm ²	(Q=250 η=0.38)

Aufgabe 8		
p Räderwerk	5700	
f Frequenz	4 Hz	
N	8	
β Feder	0.8	
η Räderwerk	0.7	
k	12	
σ _{max}	3500 N/mm ²	
h Feder	1.6 mm	
Ra Federhaus	4.75 mm	
Z Ankerrad	20	
Z Sekundenrad	84	
e Feder	0.111 mm	e_kf(B4;B7;B10)
l Feder	292.850 mm	l_f(B10;B7*B12;B12)
M _{max} Feder	11.589 Nmm	mmax_f(B12;B9;B8)
Pr Ankerrad	1.431 μW	pr_w(B14;B6;B5;B3;B11;B2)
l Unruh	9.565 mgcm ²	(Nivarox Tabelle 20.3 4Hz)
Q Unruh	205.834	(η=0.38, 20.3 4Hz)
l Unruh	11.617 mgcm ²	(Q=250 η=0.38)

9.1 Dynamically adjust Excel graphics

The graphics of the tables are structured in such a way that the designs can be dynamically adapted.



10 Table protection

The tables are protected against incorrect manipulation with a page protection. You can disable leaf protection without a password. A design change with active blade protection is not possible.



11 VBA Formulas

11.1 Units for the formulas

Units for movement calculation			
Torque	N·mm	daN·mm	μN·m
Pressure	N/mm ²		
Moment of inertia	mg·cm ²		
Angular Torque	mg·cm/rad		
Imps γ	N/cm ³		
Density ρ	g/cm ³		
Power wheel	μW		

11.2 VBA listing

```
'Watch Design Formula Collection as VBA Add-In Excel 2003 - 2013
'Accompanying the book Uhrenkonstruktion hft-so/hftm by Kilian Eisenegger
'Case and movement formulas
'Version: 07.03.2013
'General mass: N·mm, N/mm2, mm, N, g, mg·cm2, μW
'© ' 2012 Kilian Eisenegger, watchmaking.com ®
Option Explicit
Public Const pi As Double = 3.14159265358979
```

11.2.1 Formulas for calculating Hertzian pressure

```
'
Function flfa_h(Mmax As Double, zk2 As Double, rfed As Double, l1 As Double,
l2 As Double, ltot As Double) As Double
    'Bearing force on the barrel drum
    'Mmax Torque Barrel
    'rfed radius inside barrel
    'l1, l2, ltot heights for the vector forces according to sketch
    'zk Tooth Force
    flfa_h = (Mmax * 1000 / rfed * l1 + zk2 * l2) / ltot
End Function

Function flfb_h(Mmax As Double, zk2 As Double, rfed As Double, l1 As Double,
l2 As Double, ltot As Double) As Double
    'Bearing force on the barrel drum
    'Mmax Torque Barrel
    'rfed radius inside barrel
    'l1, l2, ltot heights for the vector forces according to sketch
    'zk Tooth Force
    flfb_h = (Mmax * 1000 / rfed * (ltot - l1) + zk2 * (ltot - l2)) / ltot
End Function

Function fla_h(zk1 As Double, zk2 As Double, alpha As Double, lges As Double,
l1 As Double, l2 As Double) As Double
    'Bearing force A with respect to angles alpha and heights L1, L2 and Lges
    'alpha in rad
    fla_h = ((zk2 * Sin(alpha) * l2 / lges) ^ 2 + ((zk2 * Cos(pi - alpha) *
l2 + zk1 * l1) / lges) ^ 2) ^ 0.5
End Function
```

VBA Formulas, VBA listing

```
Function flb_h(zk1 As Double, zk2 As Double, alpha As Double, lges As Double,
l1 As Double, l2 As Double) As Double
    'Bearing force B with respect to angles alpha and heights L1 L2 and Lges
    'alpha in rad
    flb_h = ((zk2 * Sin(alpha) * (lges - l2) / lges) ^ 2 + ((zk2 * Cos(pi -
alpha) * (lges - l2) + zk1 * (lges - l1)) / lges) ^ 2) ^ 0.5
End Function

Function Phmax_h(fl As Double, s As Double, b As Double, h As Double, dl As
Double) As Double
    'Hertzian pressing PH max
    'fl to mN
    's in mm
    'b to mm
    'Phmax in N/mm2
    Phmax_h = 0.5642 * ((fl / 1000 * (s / 2)) / (b * h * (dl - s) / 2 * dl /
2)) ^ 0.5
End Function

Function H_h(v1 As Double, e1 As Double, v2 As Double, E2 As Double) As Double
    'Factor H for Hertzian pressing
    'E in N/mm2
    'v Poisson's number
    H_h = (1 - v1 ^ 2) / e1 + (1 - v2 ^ 2) / E2
End Function

Function dl_h(fl As Double, s As Double, b As Double, h As Double, ph As
Double) As Double
    'Bearing geometry given compression
    'fl to mN
    'ph in N/mm2
    'dl = (0.56422 * (fl/1000) / (b * H) * 2 * s / ph ^ 2 + s ^ 2 / 4) ^ 0.5
+ 1 / 2 * s
    dl_h = ((0.5642 ^ 2 * (fl / 1000) * 2 * s / (b * h * ph ^ 2)) + (s ^ 2 /
4)) ^ 0.5 + s / 2
End Function
```

11.2.2 Formulas for calculating the energy on the escape wheel

```
'
'
Function Mmax_f(e As Double, h As Double, smax As Double) As Double
    'Calculates Mmax with the spring cross-section
    'smax in N/mm2 e.g. 3400N/mm2
    Mmax_f = (e ^ 2 * h) / 6 * smax
End Function

Function pr_w(Mmax As Double, eta As Double, beta As Double, f As Double, ze
As Double, rho As Double) As Double
    'Calculating the available energy on the escape wheel
    'Pr in µW
    'Mmax in N·mm
    pr_w = Mmax * 1000 * (2 * pi * eta * beta * f) / (ze * rho)
End Function

Function pr_iw(I As Double, q As Double, n As Double, ampl As Double, f As
Double) As Double
    'Pr calculated with moment of inertia I
    'I in mg·cm2
    'ampl mostly 220°
```



```

'Q factor between 150 - 350
'n Efficiency of the escapement approx. 0.4
Dim w As Double, phi As Double
w = 2 * pi * f
phi = ampl / 360 * 2 * pi
pr_iw = (I / 1000 * phi ^ 2 * w ^ 3) / (2 * q * n)
End Function

Function Ibal(q As Double, n As Double, pr As Double, ampl As Double, f As
Double) As Double
'Moment of Inertia Calculated by Balancer with Pr
'pr in µW
'Ibal in mg·cm²
'ampl mostly 220°
'Q factor between 150 - 350
'n Efficiency of the escapement approx. 0.4
Dim w As Double, phi As Double
w = 2 * pi * f
phi = ampl / 360 * 2 * pi
Ibal = (2 * q * n * pr * 10000) / (phi ^ 2 * w^3)
End Function

Function I20_3(pr As Double) As Double
'I 20.3 for pr at 220°, Calculation of the moment of inertia with the
available energy on the escape wheel
'Formula according to Nivarox values
I20_3 = 4.8309 * PR ^ 1.9069
End Function

Function Qbal(I As Double, pr As Double, f As Double, n As Double)
'Q Factor of escapement 20.3 at 220°
Qbal = I * (2 * pi * f) ^ 3 * 14.74 / (2 * pr * n * 10000)
End Function

function dbal(I as double) as double
'NIHS 34-04 Column 4, Optimal Diameter of Balance
Dbal = 4.923 * I ^ 0.2714
End Function

Function phi_20_3(pr As Double, q As Double, n As Double, I As Double, f As
Double) As Double
' Amplitude VG after 24H = should be 220°
'Omega = 2 * pi f
' phi = 220/360 * 2 * pi
phi_20_3 = 360 * ((pr * 2 * q * n * 10000) / (I * (2 * pi * f) ^ 3)) ^ 0.5
/ (2 * pi)
End Function

```

11.2.3 Formulas for calculating oscillating weights

```

Function G_a(wichte As Double, h As Double, Ra As Double, ri As Double) As
Double
'Weight of the flywheel mass (segment)
Weight in N/mm³
G_a = weights * pi / 2 * h * (Ra ^ 2 - ri ^ 2)
End Function

Function G_aseg(wichte As Double, r As Double, a As Double, b As Double) As

```

```

Double
    'Weight of the oscillating mass (inclined segment)
    'Weight in N/mm3
    G_aseg = weights * pi / 2 * a * b * (r - 1 / 3 * b)
End Function

Function Mr_a(wichte As Double, h As Double, Ra As Double, ri As Double) As Double
    'Force moment of the flywheel mass (segment)
    'Weight in N/mm3
    Mr_a = 2 / 3 * weights * h * (Ra ^ 3 - ri ^ 3)
End Function

Function Mr_aseg(wichte As Double, r As Double, a As Double, b As Double) As Double
    'Force moment of the flywheel mass (inclined segment)
    'Weight in N/mm3
    Mr_aseg = weights * a * b * (r ^ 2 - 2 / 3 * r * b + 1 / 6 * b ^ 2)
End Function

Function J_a(dense As Double, h As Double, Ra As Double, ri As Double) As Double
    'Moment of inertia of the flywheel mass (segment)
    'Density in g/mm3
    J_a = 0.25 * density * h * pi * (Ra ^ 4 - ri ^ 4)
End Function

Function J_aseg(dichte As Double, r As Double, a As Double, b As Double) As Double
    'Moment of inertia of the flywheel mass (oblique segment)
    'Density in g/mm3
    J_aseg = 0.25 * density * a * b * pi / 2 * (r ^ 3 - r ^ 2 * b + 0.5 * r *
b ^ 2 - 0.1 * b ^ 3)
End Function

Function S_a(Mr As Double, g As Double) As Double
    'Center of gravity of the flywheel mass
    S_a = Mr / g
End Function

Function bw_a(Mmax As Double, n As Double, s As Double, ge As Double, I As Double) As Double
    'Brake angle for flywheel masses
    'Mmax Torque Barrel M0 or M24
    'Efficiency of the gear train
    'i Rapport Gears
    'g Weight of the flywheel mass
    bw_a = Application.Asin(Mmax / (n * I * ge * s)) * 180 / pi
End Function

```

11.2.4 General mathematical formulas

```

' (Attention with OpenOffice)
'
Function Arcsin(X As Double) As Double
    ' Alternative for Arc Sin within VBA
    If X < 1 And X > -1 Then
        Arcsin = Atn(X / Sqr(-X * X + 1))
    ElseIf X = 1 Then
        Arcsin = 2 * Atn(1)
    End If
End Function

```



```

ElseIf X = -1 Then
    Arcsin = -2 * Atn(1)
End If
End Function

Function asin_(X As Double) As Double
    'Alternative for Arc Sin within VBA (not Openoffice)
    asin_ = Application.Asin(X)
End Function

Function sqr_(X As Double) As Double
    'Excel function of the root VBA (not OpenOffice)
    sqr_ = Application.Sqrt(X)
End Function

```

11.2.5 Formulas for calculating the spring

```

Function Nmax_f(e As Double, Ra As Double, ri As Double) As Double
    'Maximum number of revolutions of the spring in the barrel
    Nmax_f = 1 / e * ((2 * (Ra ^ 2 + ri ^ 2)) ^ 0.5 - Ra - ri)
End Function

Function N_f(e As Double, Ra As Double, ri As Double, l As Double) As Double
    'Number of revolutions of the spring in the barrel
    N_f = 1 / e * ((ri ^ 2 + l * e / pi) ^ 0.5 + (Ra ^ 2 - l * e / pi) ^ 0.5 - Ra - ri)
End Function

Function N_fd(D As Double, f As Double, ze As Integer, rho As Double) As Double
    'Calculates the number of revolutions from the barrel as a function of the
    power reserve d
    N_fd = 3600 * D * f / (ze * rho)
End Function

Function Nmax_x(e As Double, X As Double, ltot As Double, ri As Double, Ra As Double) As Double
    'Calculates the Anzal revolutions taking into account the physical dis-
    tance of 2 slats of approx. 0.002mm
    ' e1=e/R
    ' l1=Ltot/R
    ' X=0.002mm'
    ' r1=r/R
    Dim e1 As Double, l1 As Double, r1 As Double
    e1 = e / Ra
    l1 = ltot / Ra
    r1 = ri / Ra
    Nmax_x = 1 / (e1 + X) * ((r1 ^ 2 + (l1 * (e1 + X) / pi)) ^ 0.5 + (1 - (l1 * (e1 + X) / pi)) ^ 0.5 - 1 - r1)
End Function

Function l_f(Ra As Double, ri As Double, e As Double) As Double
    'Calculates the length of the spring
    l_f = pi * (Ra ^ 2 - ri ^ 2) / (2 * e)
End Function

Function ltot_f(l As Double, ri As Double, e As Double)
    'Calculates the optimized length of the spring (Nivaflex spring)
    ltot_f = l * (-0.006 * 2 * ri / e + 1.33)

```

End Function

```
Function e_kf(n As Double, k As Double, Ra As Double) As Double
    'Calculates the thickness of the spring using factor k
    e_kf = Ra * (n + k - (2 * n ^ 2 + 4 * k * n) ^ 0.5) / (k ^ 2 - n ^ 2 - 2 * k * n)
End Function
```

End Function

```
Function e_rf(n As Double, Ra As Double, ri As Double) As Double
    'Calculates the thickness of the spring with the spring radius
    e_rf = 1 / n * ((2 * (Ra ^ 2 + ri ^ 2)) ^ 0.5 - Ra - ri)
End Function
```

End Function

11.2.6 Formulas for calculating the driving lever spring

```
'
'
```

```
Function fl_w(f As Double, e As Double, b As Double, alpha As Double, h As Double, l As Double) As Double
```

```
    'Calculates the deflection of the angle lever spring
    fl_w = 12 * f / (e * b * Tan(alpha) ^ 2) * (h / (2 * h * Tan(alpha) + 2 * l * Tan(alpha) ^ 2) + h * l / (2 * (h + l * Tan(alpha) ^ 2)) - l / (h + l * Tan(alpha))) + 1 / Tan(alpha) * Log(1 + l * Tan(alpha) / h) - 1 / (2 * Tan(alpha))
End Function
```

End Function

```
Function f_w(fl As Double, e As Double, b As Double, alpha As Double, h As Double, l As Double) As Double
```

```
    'Calculates the force F with a given deflection
    f_w = fl * e * b * Tan(alpha) ^ 2 / (12 * (h / (2 * h * Tan(alpha) + 2 * l * Tan(alpha) ^ 2) + h * l / (2 * (h + l * Tan(alpha) ^ 2)) - l / (h + l * Tan(alpha))) + 1 / Tan(alpha) * Log(1 + l * Tan(alpha) / h) - 1 / (2 * Tan(alpha)))
End Function
```

End Function

11.2.7 Formulas for calculating the hairspring

```
'
'
```

```
Function M_sp(Emodul As Double, Dicke As Double, Hoehe As Double, Length As Double) As Double
```

```
    'Calculates the torque of the hairspring'
    M_sp = modul * thickness ^ 3 * height / (12 * length)
End Function
```

End Function

```
Function I_bal(M_sp As Double, Frequenz As Double) As Double
```

```
    'Calculates the moment of inertia of the balance wheel based on the frequency and torque of the hairspring
```

```
    I_bal = M_sp / (4 * pi ^ 2 * frequency ^ 2) * 10000000
```

End Function

```
Function h_sp(I_bal As Double, Laenge As Double, Emodul As Double, Dicke As Double, Frequenz As Double) As Double
```

```
    'Calculates the height of the hairspring with the moment of inertia, active length, thickness, emodul of the hairspring, and frequency
```

```
    h_sp = I_bal * 4 * pi ^ 2 * frequency ^ 2 * 12 * length / (modul * thickness ^ 3)
```

End Function

```
Function f_sp(I_bal As Double, Laenge As Double, Emodul As Double, Dicke As
```



```

Double, Hoehe As Double) As Double
    'Calculates the frequency of the hairspring, moment of inertia, active
    length, modulus, thickness and height
    f_sp = ((Height * Emodul * Thickness ^ 3) / (I_bal * 4 * pi ^ 2 * 12 * Length)
    * 1000000) ^ 0.5
End Function

Function L_sp(Outer Diameter As Double, Inner Diameter As Double, Turns As
Double) As Double
    'Calculates an Archimedes spiral length
    L_sp = pi * turns * (outer diameter + inner diameter) / 2
End Function

```

11.2.8 Formulas for the O-Ring

```

'
'
Function dg(d1 As Double, d2 As Double, a As Double, b As Double) As Double
    'Calculates the elongation of an oring
    dg = d2 * ((2 * (d1 + d2)) / (a + b)) ^ 0.5
End Function

Function mm(mass As Double, tob As Double, tun As Double) As Double
    'Mediocrity
    mm = (dimension + tob + dimension + tun) / 2
End Function

Function mma(tob As Double, tun As Double) As Double
    'Center tolerance
    mma = (-tob + tun) / 2
End Function

Function comp(a As Double, b As Double, dg As Double) As Double
    'Injection of the oring in percent
    comp = (1 - (a - b) / (2 * dg)) * 100
End Function

Function nl(d2 As Double) As Double
    'Groove length for Oring me diameter d2
    nl = 1.2 * d2
End Function

```

11.2.9 Formulas for compressive case glass and case back

```

'
'
Function d_g(Emodul As Double, e As Double, my As Double) As Double
    'my Poissonzahl Material
    d_g = (Emodul * e ^ 3) / (12 * (1 - my ^ 2))
End Function

Function fmax_b(p As Double, r As Double, D As Double) As Double
    'Deformation of the case back
    'p Pressure
    fmax_b = (p * r ^ 4) / (64 * D)
End Function

Function fmax_g(my As Double, p As Double, r As Double, D As Double) As Double
    'Deformation of the glass
    fmax_g = (5 + my) / (1 + my) * (p * r ^ 4) / (64 * D)

```

```
End Function
```

```
Function e_b(D As Double, bar As Double) As Double
    'Empirical formula for the necessary bottom thickness in enclosures
    e_b = 0.011 * D * (bar) ^ 0.5
End Function
```

```
Function fz(g As Double, n As Double) As Double
    'Shear force per dial foot
    FZ = 5000 * g * 9.81 / (1000 * N)
End Function
```

11.2.10 Diameter of barrel when using a great wheel pinion

```
'
'
```

```
Function renc(m As Double, z1 As Double, Z2 As Double, ha As Double, s As Double) As Double
    'Calculates the outer radius of the plate based on the size of the barrel and the great wheel pinion
    renc = m * (z1 + Z2) / 2 + m / 2 * (z1 + ha) + s
End Function
```

```
Function mrenc(renc As Double, s As Double, z1 As Double, Z2 As Double, ha As Double) As Double
    'Calculates the module with the radius plate, barrel and great wheel pinion
    MRENC = 2 * (RENC - S) / (2 * Z1 + Z2 + HA)
End Function
```

11.2.11 Formulas for life span and probability of failure

```
'
'
```

```
Function Ry(lamda As Double, time As Double) As Double
    'Reliability
    'Ry = Exp(1) ^ (-lamda * time)
    Ry = Exp(-lamda * time)
End Function
```

```
Function Fy(ta As Double, tb As Double, b As Double) As Double
    'Failure behaviour with b 0.5, 1 and 2
    If b < 1 Then
        'Fy = 1 - Exp(1) ^ -((ta/tb)^b)
        Fy = 1 - Exp(-(ta / tb) ^ b)
    Else
        'Fy = 1 - Exp(1) ^ ((-ta / tb) ^ b)
        Fy = 1 - Exp((-ta / tb) ^ b)
    End If
End Function
```

```
Function aw(ta As Double, tb As Double, b As Double) As Double
    'Probability of default with b 0.5, 1 and 2
    If b < 1 Then
        aw = 1 / tb * Exp(1) ^ -((ta / tb) ^ b)
    Else
        aw = 1 / tb * Exp(1) ^ ((-ta / tb) ^ b)
    End If
End Function
```



```
Function wb(ta As Double, tb As Double, b As Double) As Double
    'Weibull with b 0.5, 1 and 2
    WB = B / TB * (TA / TB) ^ (B - 1)
End Function
```

12 Introduction exercises and solutions

This document contains tasks and solutions for the book Watch Technology. To calculate the tasks, both the VBA programs from the author's homepage are watchmaking.com as well as simple formulas that can be used with the calculator. The color code of the tasks depends on the level of difficulty. For the sensible application of these tasks, the book Watch Technology (printed or as an e-book, see homepage watchmaking.com) and the VBA programs of the author should be used. In the following I wish you a lot of fun with the tasks and good luck with the solutions.

12.1 Exercises

12.1.1 Exercise 1: Seat diameter

1. Movement diameter 28mm
2. NIHS 20-02 Gearing Standard
3. Safety distance gearing barrel to movement diameter 0.09mm
4. Inner diameter of barrel 11.93mm
5. Safety distance tooth base to diameter barrel 0.03mm
6. Thickness of barrel wall 0.25mm
7. Number of teeth for great wheel pinion 15

Calculating the following values

1. Number of teeth of the barrel
2. Module of the engagement barrel - great wheel pinion

12.1.2 Exercise 2: Movement diameter

1. Movement diameter 17.2mm
2. Number of teeth of the barrel 78
3. Number of teeth for the great wheel pinion 12
4. Module between barrel and great wheel pinion 0.098
5. Tooth profile NHS 56702/56703

Calculating the following values

1. Safety distance from the movement diameter to the tooth of the barrel

12.1.3 Exercise 3: Movement diameter

1. Number of teeth barrel 72
2. Number of teeth great wheel pinion 9
3. Module Intervention Barrel Great wheel pinion 0.124
4. Safety distance from the movement diameter to the tooth of the barrel 0.05mm
5. Tooth profile NIHS 20-02

Calculating the following values

1. Movement diameter
2. What is the safety distance for tooth profile NHS 56.702?

12.1.4 Exercise 4 Barrel

1. Movement diameter 23.3mm
2. Number of teeth great wheel pinion 8

3. Module barrel - great wheel pinion 0.135
4. Safety distance barrel tooting movement diameter 0.175mm
5. Tooth profile ETA73
6. Barrel wall thickness 0.25mm
7. Safety distance barrel to tooth base

Calculating the following values

1. Number of teeth barrel
2. Inner diameter of the barrel

12.1.5 Exercise 5: Energy transmission

1. Barrel $z = 96$
2. Great wheel pinion $z' = 16$
3. Great wheel $z_1 = 78$
4. Third wheel pinion $z_2 = 13 z_1$
5. Third wheel $z_3 = 80$
6. Seconds wheel pinion $z_4 = 8$
7. Seconds wheel $z_4 = 96$
8. Escape wheel pinion $z_6 = 8$
9. Escape wheel $z_E = 20$
10. Barrel $M_{\max} = 12.26\text{Nmm}$
11. Barrel efficiency $M24/M0 = 0.80$
12. Gear train efficiency loss 10% per wheel
13. Standards for balance geometry NIHS 34-04

Calculating the following values

1. Determining the moment of inertia of the balance wheel
2. Available diameters

12.1.6 Exercise 6 Torque of the mainspring

An optimized balance wheel is to be used from a chronograph movement for a pocket watch movement with a tourbillon. How does the spring of the pocket watch movement change? (IWC Chrono 89360 => IWC Jones Tourbillon)

1. Barrel $z = 96$
2. Great wheel pinion $z' = 12$
3. Great wheel $z_1 = 80$
4. Third wheel pinion $z_2 = 10$
5. Third wheel $z_3 = 75$
6. Seconds wheel pinion $z_4 = 10$
7. Seconds wheel $z_4 = 120$
8. Escape wheel pinion $z_6 = 10$
9. Escape wheel $z_E = 20$
10. Pr Chrono = $1.62\mu\text{W}$
11. ρ Chrono = 4656
12. Moment of inertia chronograph $I = 12\text{ mgcm}^2$
13. Barrel efficiency $M24/M0 = 0.85$
14. Gear train efficiency loss 7% per wheel

Calculating the following values

1. Determining the maximum torque of the spring for the existing balance wheel

12.1.7 Exercise 7: Spring dimension

1. Pr = $0.709\mu\Omega$
2. Frequency $f = 3.5\text{ Hz}$



3. Gear Ratio $\rho = 3780$
4. Escape wheel $z_E = 20$
5. Overall efficiency of the gear train $\eta = 0.60$
6. Spring thickness $\sigma_{\max} = 2.943 \times 10^3 \text{ N/mm}^2$
7. Barrel efficiency $M24/M0 = 0.80$
8. Barrel revolutions $N = 10$
9. Inner diameter of barrel 9.5mm
10. Innerspring diameter 2.60mm
11. Repeat between radius spring core / spring thickness 14

Calculating the following values

1. Determining the dimension of the springs e, l, h

12.1.8 Exercise 8: Energy balance

1. Movement diameter 28mm
2. Frequency $f = 5 \text{ Hz}$
3. Barrels $N = 8$
4. Gear train barrel – great wheel pinion 95 and 15
5. Gear train great wheel – third wheel pinion 80 and 10
6. Gear train third wheel – Seconds wheel pinion 75 and 10
7. Escape wheel pinion and escape wheel 7 and 20
8. Inner diameter barrel 9.5mm
9. Transmission ratio between radius spring core / spring thickness 12
10. Mainspring Efficiency 24H $\beta = 0.83$
11. Gear train efficiency $\eta = 0.71$
12. Height of the spring $h = 1.6 \text{ mm}$
13. $\sigma_{\max} = 3.5 \times 10^9 \text{ N/m}^2$

Calculating the following values

1. Number of teeth Seconds wheel
2. Determining the dimension of the spring e, l
3. Moment of inertia min and max of the balance wheel

12.1.9 Exercise 9 Energy balance 21.3

1. Barrel $z = 107$
2. Great wheel pinion $z' = 18$
3. Great wheel $z_1 = 77$
4. Third wheel pinion $z_2 = 13$
5. Third wheel $z_3 = 90$
6. Seconds wheel pinion $z_4 = 9$
7. Seconds wheel $z_4 = 108$
8. Escape wheel pinion $z_6 = 9$
9. Escape wheel $z_E = 20$
10. Frequency $F = 4 \text{ Hz}$
11. Power reserve $d = 49 \text{ h}$
12. Height of spring 1.3mm
13. Inner diameter barrel 10.65mm
14. K factor spring $k = 10$
15. Efficiency of the gear train $\eta = 0.7$
16. Barrel efficiency $M24/M0 = 0.80$
17. $\sigma_{\max} = 3.24 \times 10^9 \text{ N/m}^2$

Calculating the following values

1. Determining the escapement and the moment of inertia of the balance

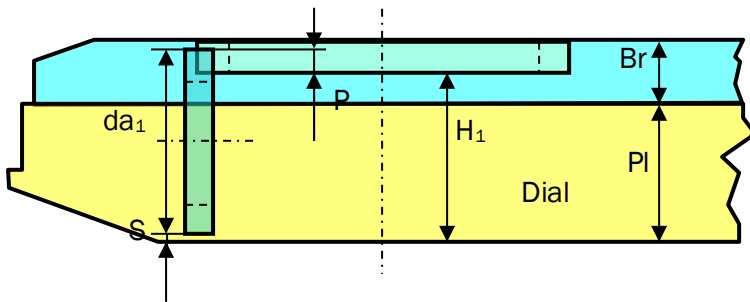
2. Convert to an escapement with 21 teeth and 5 Hz = > number of teeth Seconds wheel and drive escape wheel

12.1.10 Exercise 10 Mechanical hand-wound movement crown wheel

1. Coordinates center 50,000; 50,000, ratchet wheel 46,684; 51,440, Crown wheel 50,000; 56.350
2. Number of teeth ratchet wheel 45
3. Number of teeth winding pinion 18
4. Ratchet wheel module - Crown wheel 0.15
5. Safety distance winding pinion and mainplate dial side 0.15mm
6. Support ratchet wheel on barrel bridge 0.70mm
7. Thickness of the mainplate 2.2mm

Calculating the following values

1. Number of teeth crown wheel
2. Tooth engagement depth p crown wheel - winding drive



12.1.11 Exercise 11: Ratchet wheel

1. Number of teeth crown wheel $z_2 = 25$
2. Module ratchet wheel - crown wheel $m = 0.14$
3. Centre distance ratchet wheel - crown wheel $a = 4.69\text{mm}$
4. Crown wheel support $H_1 = 2.05\text{mm}$
5. Safety distance winding pinion and mainplate dial side $s = 0.15\text{mm}$
6. Tooth engagement of winding pinion - crown wheel $P = 0.28\text{mm}$

Calculating the following values

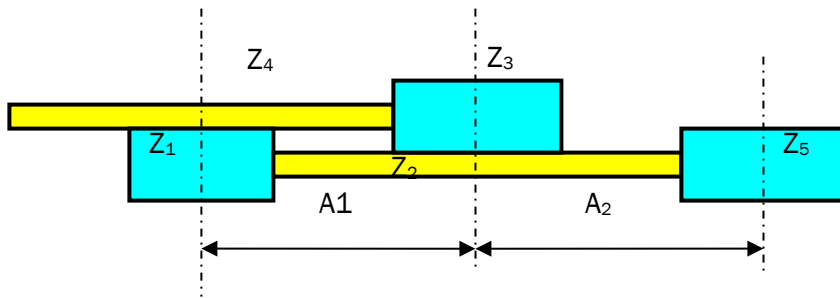
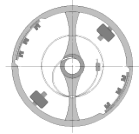
1. Number of teeth: ratchet wheel, winding pinion
2. Winding pinion module

12.1.12 Exercise 12: Hand setting wheels

1. Minute wheel $z_2 = 40$
2. Minute wheel pinion $z_3 = 10$
3. Distance between minute wheel and canon pinion $a_1 = 3.85\text{mm}$
4. Number of revolutions setting wheel $n_5 = 5/6 \text{ t/h}$

Calculating the following values

1. Calculation of the missing number of teeth with identical modulus
2. Module
3. Center distance a_2

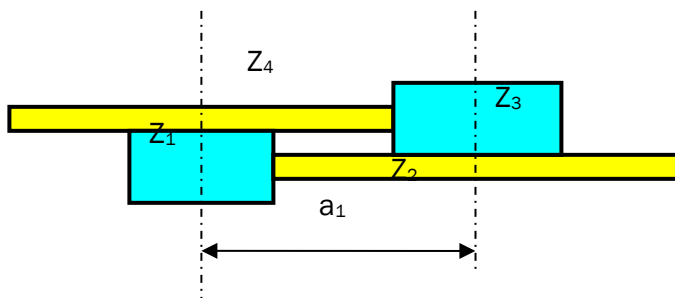


12.1.13 Exercise 13 Hand setting wheels

1. Number of teeth canon pinion $z_1 = 14$
2. Module canon pinion $m_1 = 0.16$
3. Center distance, center - minute wheel = 4.00mm

Calculating the following values

1. Calculating the missing number of teeth
2. Module



12.1.14 Exercise 14 Mainspring dimension

1. Length of spring $l = 360\text{mm}$
2. Maximum torque $M_{\max} = 17.17 \times 10^{-3}\text{Nm}$
3. Rapport $k = 11.2$
4. Revolutions $N = 6.5$
5. Spring material $\sigma_{\max} = 2.94 \times 10^9\text{N/m}^2$

Calculating the following values

1. Calculating the spring h, R, r, e

12.1.15 Exercise 15 Change the number of revolutions of the barrel

1. Length of spring $l = 360\text{mm}$
2. Height of spring $h = 1.05\text{mm}$
3. Thickness of spring $e = 0.18\text{mm}$
4. Maximum torque $M_{\max} = 17 \times 10^{-3}\text{Nm}$
5. Revolutions $N = 6.5$
6. Maximum speed $N = 6.5$
7. Spring material $\sigma_{\max} = 2943\text{N/mm}^2$
8. Inner diameter of the barrel $D = 13.6\text{mm}$
9. Diameter of spring core $d = 4.04\text{mm}$

Calculating the following values

1. For a well-known calibre, we want to increase the rotational speed of the barrel to $N = 8$.
2. What dimensions of the barrel need to be changed if $k = 10$?

12.1.16 Exercise 16: Energy balance

1. Barrel $z = 108$
2. Great wheel pinion $z' = 19$
3. Large-bottom wheel $z_1 = 77$
4. Third wheel pinion $z_2 = 13$
5. Third wheel $z_3 = 90$
6. Seconds wheel pinion $z_4 = 9$
7. Seconds wheel $z_4 = 108$
8. Escape wheel pinion $z_6 = 9$
9. Escape wheel $z_E = 20$
10. Frequency $F = 4\text{Hz}$
11. Power reserve $d = 56\text{h}$
12. Height of spring 1.4mm
13. Inner diameter barrel 10.85mm
14. Factor k of spring $k = 10$
15. Gear train efficiency $\eta = 0.93$ per intervention
16. Barrel efficiency $m^2/4/M0 = 0.83$
17. $\sigma_{\max} = 3.24 \times 10^9 \text{ N/m}^2$
18. Nivarox 20.5

Calculating the following values

1. Determining the moment of inertia of the balance
2. Determining the dimension of the sliding spring and its values

12.1.17 Exercise 17 Sliding spring

1. Barrel $z = 109$
2. Great wheel pinion $z' = 19$
3. Great wheel $z_1 = 77$
4. Third wheel pinion $z_2 = 13$
5. Third wheel $z_3 = 90$
6. Seconds wheel pinion $z_4 = 9$
7. Seconds wheel $z_4 = 108$
8. Escape wheel pinion $z_6 = 9$
9. Escape wheel $z_E = 20$
10. Frequency $F = 4\text{Hz}$
11. Power reserve = 54 h
12. Height of spring 1.5mm
13. Inner diameter barrel 10.90mm
14. Factor $k = 10$
15. Gear train efficiency $\eta = 0.92$ per intervention
16. Barrel efficiency $m^2/4/M0 = 0.86$
17. $\sigma_{\max} = 3.24 \times 10^9 \text{ N/m}^2$
18. Nivarox 20.3

Calculating the following values

1. Determining the thickness of the Spring
2. Determining the moment of inertia of the balance
3. Determining the dimension of the sliding spring and its values



12.1.18 Exercise 18 Mainspring dimension

1. $P_r = 0.719 \mu\Omega$
2. Frequency $f = 4 \text{ Hz}$
3. Gear train ratio $\rho = 3780$
4. Escape wheel $z_E = 20$
5. Overall gear train efficiency $\eta = 0.718$
6. Spring thickness $\sigma_{\max} = 2.943 \times 10^3 \text{ N/mm}^2$
7. Barrel efficiency $M_{24}/M_0 = 0.84$
8. Barrel revolutions $N = 10$
9. Inner diameter of barrel 9.5 mm
10. Spring diameter 2.40 mm
11. Ratio between radius spring core / spring thickness 12

Calculating the following values

1. Determining the dimension of the spring e, l, h
2. Mathematically or with the tables

12.1.19 Exercise 19: Failure of parts

1. Lifetime of parts $T = 20'000 \text{ h}$

Calculating the following values

1. After what time will 5 out of 100 wheels fail if there are random failure mechanisms and an exponential law of life?
2. After what time will 1 wheel fail?
 $t = -T \cdot \ln(1-F)$

12.1.20 Exercise 20 Mechanical hand-wound movement, setting lever spring

1. Thickness $b = 0.30 \text{ mm}$
2. Width $h_1 = 0.35 \text{ mm}$
3. Width $h_x = 0.30 \text{ mm}$
4. Length $l = 4.4 \text{ mm}$
5. Length $x = 1.2 \text{ mm}$
6. Excursion $f = 0.18 \text{ mm}$
7. Modulus of elasticity $E = 0.21 \times 10^{12} \text{ N/m}^2$
8. Tensile strength $\sigma_B = 1.85 \times 10^9 \text{ N/m}^2$

Calculating the following values

1. Safety coefficient $n = ?$

$$h = h_x - 2 \cdot x \cdot \tan \beta$$

$$\tan \beta = \frac{h_1 - h_x}{2(l - x)}$$

$$F = \frac{f \cdot E \cdot b \cdot \tan^2 \alpha}{12 \cdot [a + b - c + d - e]} \quad f = \frac{12 \cdot F}{E \cdot b \cdot \tan^2 \alpha} [a + b - c + d - e]$$

$$\sigma_f = \frac{6 \cdot F \cdot l}{b \cdot h_1^2}$$

$$n = \frac{\sigma_e}{\sigma_f} \geq 1$$

12.1.21 Exercise 21: Failure of parts after a certain period of operation

1. $\lambda = 4 \times 10^{-5} \text{h}^{-1}$
2. $b = 1$

Calculating the following values

1. How high is the loss after an operating time of 1000h?

$$F(t) = 1 - e^{\left(\frac{-t}{T}\right)^b}$$

12.1.22 Exercise 22: Failure of parts with an average service life

1. Homologation time 240h
2. Failure rate 5%
3. Acceleration factor 8

Calculating the following values

1. What is the average lifespan T?

$$T = \frac{-t}{\ln(1-F)}$$

12.1.23 Exercise 23 Failure of parts, reliability

1. MTBF = 18000h
2. Service life $t_1 = 1500\text{h}$
3. Service life $t_2 = 15000\text{h}$

Calculating the following values

1. How high is the reliability?

$$R(t) = e^{-\lambda t}$$

12.1.24 Exercise 24 Failure of parts, service interval

1. MTBF $\geq 43800\text{h}$, $t=43800\text{h}$
2. Reliability ≥ 0.80 (20% failure)
3. Service Interval Wish 5 years

Calculating the following values

1. What is the service interval or MTBF if no more than 20% of the parts should fail?

$$T = \frac{-t}{\ln(1-F)}$$

12.1.25 Exercise 25 Failure of parts, service life

1. Warranty period 2 years
2. Reliability ≥ 0.95 (5% failure)

Calculating the following values

1. How long does the service life T of the parts have to be?

12.1.26 Exercise 26 Calculating a hairspring

1. $I = 18 \text{ mgsm}^2$
2. Inner radius 0.5mm
3. 14 turns
4. Winding distance 0.1557mm
5. 4 coils for winding



Calculating the following values

1. Length, width and height of the hairspring `se_spirale.xls`

$$M = \frac{E \cdot e^3 \cdot h}{12 \cdot L}$$

$$I = \frac{M}{4 \cdot \pi^2 \cdot f^2}$$

12.1.27 Exercise 27 Automatic calculation

8. Barrel 102
9. great wheel pinion 17
10. Great wheel 72
11. Third wheel 75
12. Seconds wheel pinion 9
13. Seconds wheel 120
14. Escape wheel pinion 10
15. Escape wheel 20
16. Frequency 4
17. Escapement efficiency 0.45
18. Quality-Factor Escapement 230
19. Oscillating wheel mass 3.4g
20. Inertia 27.64 gmm²
21. Automatic gear train efficiency 0.41
22. Ratio automatic gear train 154

Calculating the following values

1. Gear train ratio
2. Power reserve
3. Pr on the escape wheel uW and erg/s
4. Moment of inertia of the balance wheel
5. Brake angle of the oscillating wheel

12.1.28 Exercise 28 O-Ring

We are looking for the correct thickness of an O-Ring for the following application

1. $d_1 = 2.60$
2. $A = 3.98 \pm 0.010$
3. $B = 2.83 +0.005/-0.010$
4. $L = 0.9$

$d_2 = ?$

Compression min / max ?

12.1.29 Exercise 29 O-Ring

We are looking for the correct thickness of an O-Ring for the following application

1. $d_1 = 2.60$
2. $A = 3.98 \pm 0.010$
3. $B = 2.83 +0.005/-0.010$
4. Seal compression 20%

$d_2 = ?$

12.1.30 Exercise 30 Case 3 bar

We design a case for a diving depth of 3 bar. The glass has a diameter of 28mm, the case back of 26mm.

1. How thick should the flat glass be, if the maximum deformation does not exceed 0.1mm?
2. How thick should the caseback be, if the maximum deformation does not exceed 0.05mm?

12.1.31 Exercise 31 Dial feet

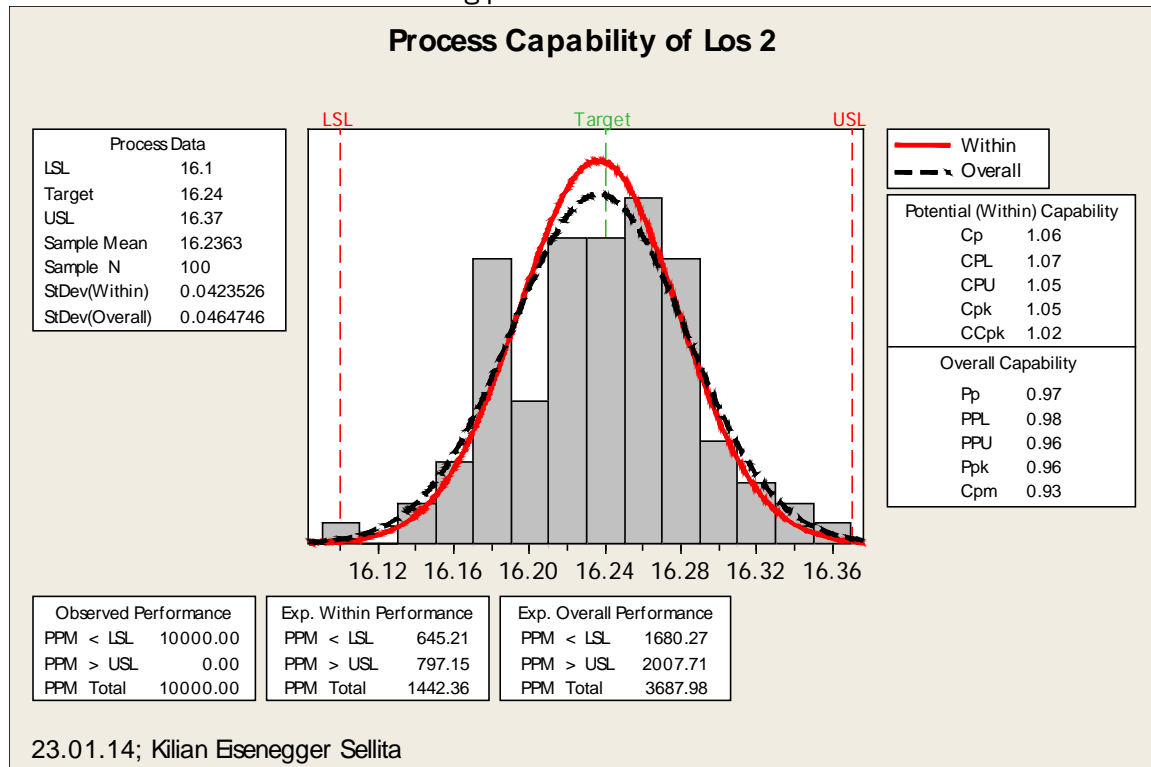
One dial with a weight of 5g gets a choc of 5000g. The dial has 2 feet. What is the shear force in N per dial foot?

12.1.32 Exercise 32 Press and clearance fit without burr formation

For a pin of 0.701 ± 0.003 mm diameter, we need a press fit of 0.007mm and a clearance fit of 0.010mm. The hole diameter has a tolerance of ± 0.002 mm. What is the minimum and maximum pressure as well as the clearance?

12.1.33 Exercise 33 Analysis of skill scores

What can be said about the following process?

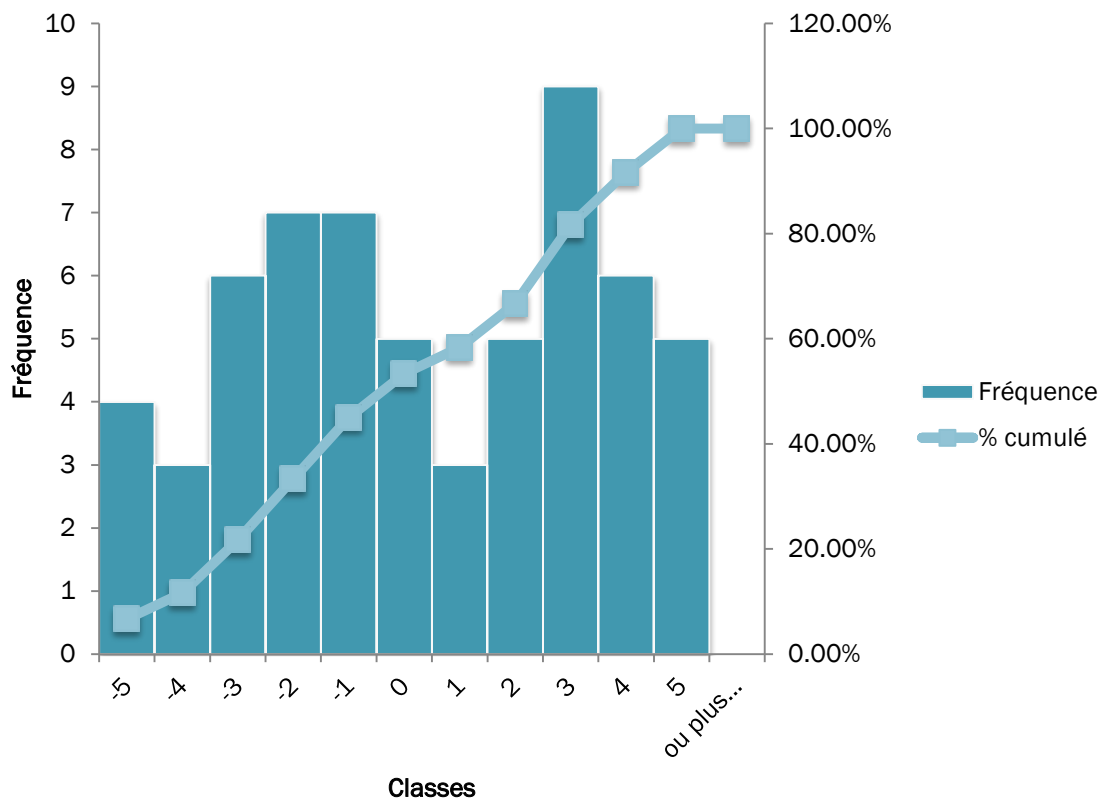


12.1.34 Exercise 34 Process analysis

What can be said about the following process regarding centring and dispersion?



Histogramme



12.1.35 Exercise 35 Initial sample inspection

List the advantages of using the ISO method of initial sample inspection instead of carrying out a normal incoming inspection.

12.1.36 Exercise 36 Weibull distribution

What is meant by early failures of products?

- Random failures
- Wear
- Assembly errors
- Adjustment error

12.1.37 Exercise 37 Process evaluation

If the machine manufacturer has a short-term capability of ± 0.004 mm, how great is the long-term capability?

12.1.38 Exercise 38 Reliability

What is reliability of a product?

- Behavior under specified application conditions
- Lifetime
- Price-performance ratio

12.1.39 Exercise 39 QFD

What is the advantage of QFD analysis?

- FMEA becomes superfluous

- b) The selection process is carried out neutrally in a team
- c) You work faster without a team

12.1.40 Exercise 40 FMEA

What is the advantage of an FMEA?

- a) You work faster without a team
- b) The potential mistakes are avoided
- c) The FMEA replaces the QFD

12.1.41 Exercise 41 CPK

How big must the CPK if you consider the Six Sigma practice?

- a) ≥ 1
- b) ≥ 1.33
- c) ≥ 1.5
- d) ≥ 2

12.1.42 Exercise 42 CP

How big does the CP have to be, considering the Six Sigma practice?

- a) ≥ 1
- b) ≥ 1.33
- c) ≥ 1.66
- d) ≥ 2

12.1.43 Exercise 43 Process evaluation

Which component uses the most manufacturing processes?

- a) Screw
- b) Wheel including pinion
- c) Bridge

12.1.44 Exercise 44 ISO

Why is Six Sigma complementary to ISO?

12.1.45 Exercise 45 DOE design of experiments

What do we achieve with a design of experiment??

12.1.46 Exercise 46 New technologies

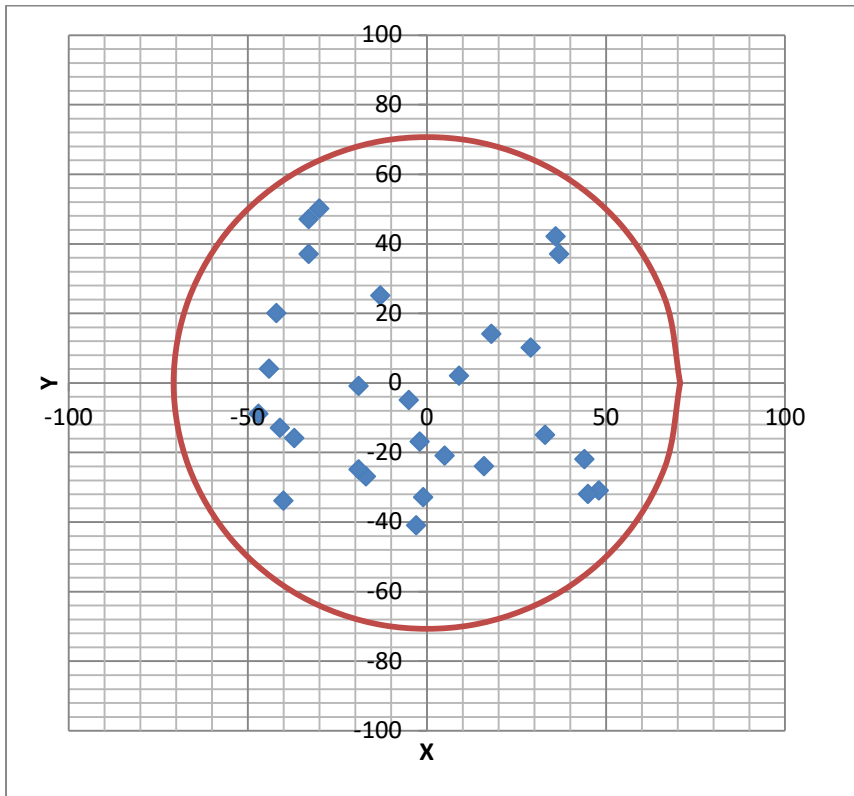
For which components are new technologies used today? how silicon is used?

12.1.47 Exercise 47 Measure

How many times more accurate does a measuring device have to be compared to the test dimension?

12.1.48 Exercise 48 Drill whole distribution

What can be said about the following distribution?



12.1.49 Exercise 49 Sampling and process analysis

What is the difference between a sample and a process analysis?

12.2 Solutions

12.2.1 Solution 1: Mainplate diameter

$$R_{enc} = 14\text{mm}$$

$$S = 0.09\text{mm}$$

$$DN = 11.93\text{mm} + 0.25\text{mm} \times 2 + 0.03\text{mm} \times 2 = 12.49\text{mm}$$

$$HF = 2.4\text{mm}$$

NIHS 20-02

Z _{pinion}	Pignon driven				Drive wheel			
	2 ha1	2 hf1	rho1	S1	2 ha2	2 hf2	rho2	S2
0	1.64	3.20	1.05	1.1	2.40	2.80	2.00	1.60
7	1.64	3.30	1.05	1.1	2.50	2.70	2.00	1.60
8	1.52	3.40	0.95	1.1	2.60	2.60	2.00	1.60
9	1.52	3.45	0.95	1.1	2.65	2.55	2.00	1.60
10	1.52	3.50	0.95	1.1	2.70	2.50	2.00	1.60
11	1.44	3.60	0.85	1.1	2.80	2.40	2.00	1.60

$$m = \frac{d_n}{z - h_f}$$

$$d_n = m(z - h_f)$$

$$\frac{d_n}{z - h_f} = \frac{2(R_{enc} - s)}{2Z + z + 2h_a}$$

$$m = \frac{2(R_{enc} - s)}{2Z + z + 2h_a}$$

m1 = 0.166 z₁ = 75 dn1 = 12
 m² = 0.140 z₂ = 90 dn2 = 12.2
 m3 = 0.122 z₃ = 105 dn3 = 12.5

12.2.2 Solution 2: Seat diameter

R_{enc} = 8.6mm
 Z = 78
 z = 12
 m = 0.098

NHS	56702	Roue				
Zroue/zpig- non		3	4	5	6	6.5
		2	3	4	5	6
Zpignon		2 ha2	2 ha2	2 ha2	2 ha2	2 ha2
0		2.52	2.56	2.58	2.60	2.61
7		2.67	2.72	2.75	2.76	2.77
8		2.80	2.86	2.90	2.92	2.93
9		2.93	2.99	3.02	3.05	3.06
10		3.05	3.11	3.14	3.17	3.18
12		3.25	3.32	3.36	3.40	3.41
14		3.44	3.51	3.56	3.60	3.61
15		3.52	3.60	3.65	3.69	3.70
16		3.60	3.69	3.73	3.78	3.79

$$S = 8.6 - \frac{0.098}{2}(2 \cdot 78 + 12 + 3.41) = 0.20091mm$$

$$S = R_{enc} - \frac{m}{2}(2Z + z + 2h_a)$$

12.2.3 Solution 3: Seat diameter

Z = 72
 z = 9
 m = 0.124
 S = 0.05mm
 2_{ha} Wheel 20-02 2.65mm
 2_{ha} Wheel 56.702 3.09mm

$$R_{enc} = m \frac{Z + z}{2} + \frac{m}{2}(Z + 2h_a) + S$$

$$R_{enc} = 0.124 \frac{72 + 9}{2} + \frac{0.124}{2}(72 + 2.65) + 0.05 = 9.7003mm$$

$$S = R_{enc} - \frac{m}{2}(2Z + z + 2h_a) \quad S = 9.7003 - \frac{0.124}{2}(2 \cdot 72 + 9 + 3.09) = 0.02272mm$$

NIHS 20-02

Pignon Mené

Roue Mena-
nte



Zpig- non	2 ha1	2 hf1	rho1	S1	2 ha2	2 hf2	rho2	S2
0	1.64	3.20	1.05	1.1	2.40	2.80	2.00	1.60
7	1.64	3.30	1.05	1.1	2.50	2.70	2.00	1.60
8	1.52	3.40	0.95	1.1	2.60	2.60	2.00	1.60
9	1.52	3.45	0.95	1.1	2.65	2.55	2.00	1.60
10	1.52	3.50	0.95	1.1	2.70	2.50	2.00	1.60
11	1.44	3.60	0.85	1.1	2.80	2.40	2.00	1.60

NHS	56702	Roue							
Zroue/zpig- non		3	4	5	6	6.5	7	7.5	8
		2	3	4	5	6	7	8	9
Zpignon		2 ha2	2 ha2	2 ha2	2 ha2	2 ha2	2 ha2	2 ha2	2 ha2
0		2.52	2.56	2.58	2.60	2.61	2.62	2.62	2.63
7		2.67	2.72	2.75	2.76	2.77	2.78	2.78	2.79
8		2.80	2.86	2.90	2.92	2.93	2.94	2.94	2.94
9		2.93	2.99	3.02	3.05	3.06	3.07	3.07	3.09
10		3.05	3.11	3.14	3.17	3.18	3.19	3.20	3.21
12		3.25	3.32	3.36	3.40	3.41	3.42	3.43	3.44
14		3.44	3.51	3.56	3.60	3.61	3.62	3.63	3.64
15		3.52	3.60	3.65	3.69	3.70	3.71	3.72	3.74
16		3.60	3.69	3.73	3.78	3.79	3.80	3.81	3.82

12.2.4 Solution 4: Barrel

$$R_{enc} = 23.3$$

$$z = 8$$

$$m = 0.135$$

$$S = 0.175$$

$$XP = 0.25$$

$$st = 0.0475$$

$$m = \frac{2(R_{enc} - S)}{2Z + z + 2h_a}$$

$$2Z = \frac{2(R_{enc} - S)}{m} - z - 2h_a \quad 2Z = \frac{2(11.65 - 0.175)}{0.135} - 8 - 2 = 160$$

$$Z = 80$$

$$D_f = m(Z - 3) \quad D_i = D_f - 2ep - 2st$$

$$D_f = 0.135 (80 - 3) = 10.395 \text{ mm}$$

$$D_i = 10.395 - 2 \times 0.25 - 2 \times 0.0475 = 9.8 \text{ mm}$$

ETA

Pignon et
roue

2 ha1 2 hf1

2	3
---	---

12.2.5 Solution 5: Energy balance

$$\rho = \frac{z \cdot z_1 \cdot z_3 \cdot z_5}{z' \cdot z_2 \cdot z_4 \cdot z_6} \quad \rho = \frac{96 \cdot 78 \cdot 80 \cdot 96}{16 \cdot 13 \cdot 8 \cdot 8} = 4320$$

$$f = \frac{z_1 \cdot z_3 \cdot z_5 \cdot z_E}{3600 \cdot z_2 \cdot z_4 \cdot z_6} \quad f = \frac{1}{60} \cdot \frac{z_5 \cdot z_E}{z_6} \quad f = \frac{1}{60} \cdot \frac{96 \cdot 20}{8} = 4Hz$$

$$\eta = 0.904 = 0.6561$$

$$Pr = M_{\max} \frac{2\pi \cdot \eta \cdot \beta \cdot f}{z_E \cdot \rho} \quad Pr = 12.26 \cdot 10^{-3} \cdot \frac{2\pi \cdot 0.6561 \cdot 0.80 \cdot 4}{20 \cdot 4320} = 1.87 \cdot 10^{-6} W = 1.87 \mu W$$

$$I = 12- 18 \text{ mgcm}^2$$

l sup.	l	d1	h1	d2	h2	d3	h3	d4	h4	d5	h5
0	1.4	5.45	0.44								
1.5	1.6	5.45	0.50	5.60	0.46						
1.7	1.8	5.45	0.56	5.60	0.52	5.80	0.44				
1.9	2	5.45	0.64	5.60	0.58	5.80	0.50	6.00	0.44		
2.12	2.24	5.60	0.66	5.80	0.56	6.00	0.50	6.15	0.46		
2.37	2.5	5.80	0.64	6.00	0.56	6.15	0.52	6.30	0.48		
2.65	2.8	6.00	0.64	6.15	0.58	6.30	0.54	6.50	0.48		
2.975	3.15	6.15	0.66	6.30	0.60	6.50	0.54	6.70	0.48		
3.35	3.55	6.30	0.68	6.50	0.62	6.70	0.54	6.90	0.50		
3.775	4	6.50	0.70	6.70	0.62	6.90	0.56	7.10	0.50	7.30	0.46
4.25	4.5	6.70	0.70	6.90	0.64	7.10	0.56	7.30	0.52	7.50	0.46
4.75	5	6.90	0.70	7.10	0.62	7.30	0.58	7.50	0.52	7.75	0.46
5.3	5.6	7.10	0.70	7.30	0.64	7.50	0.58	7.75	0.52	8.00	0.46
5.95	6.3	7.50	0.66	7.75	0.58	8.00	0.52	8.25	0.46		
6.7	7.1	7.75	0.66	8.00	0.58	8.25	0.52	8.50	0.46		
7.55	8	8.00	0.66	8.25	0.60	8.50	0.52	8.75	0.48		
8.5	9	8.25	0.66	8.50	0.60	8.75	0.54	9.00	0.48		
9.5	10	8.50	0.66	8.75	0.60	9.00	0.54	9.25	0.48	9.50	0.44
10.6	11.2	8.75	0.66	9.00	0.60	9.25	0.54	9.50	0.50	9.75	0.44
11.85	12.5	9.00	0.66	9.25	0.60	9.50	0.56	9.75	0.50	10.00	0.44
13.25	14	9.25	0.66	9.50	0.62	9.75	0.56	10.00	0.50	10.30	0.46
15	16	9.75	0.64	10.00	0.58	10.30	0.52	10.60	0.48		
17	18	10.00	0.66	10.30	0.60	10.60	0.54	10.90	0.48		

Diameter balance = 10.9mm for I = 18 mgcm²

12.2.6 Solution 6: Torque of the spring

$$\rho = \frac{z \cdot z_1 \cdot z_3 \cdot z_5}{z^1 \cdot z_2 \cdot z_4 \cdot z_6} \quad \rho = \frac{96 \cdot 80 \cdot 75 \cdot 120}{12 \cdot 10 \cdot 10 \cdot 10} = 5760$$

$$\beta = 0.85$$

$$\eta = 0.93^6 = 0.6469$$

Ratio = 5760, 2 additional procedures

Searched M_{max} for Jones Tourbillon

$$Pr = M_{\max} \frac{2\pi \cdot \eta \cdot \beta \cdot f}{z_E \cdot \rho}$$

$$M_{\max} = Pr \cdot \frac{z_E \cdot \rho}{2\pi \cdot \eta \cdot \beta \cdot f}$$

$$M_{\max} = 1.62 \cdot 10^{-3} \cdot \frac{20 \cdot 5760}{2\pi \cdot 0.6469 \cdot 0.85 \cdot 4} = 13.504 Nmm$$



12.2.7 Solution 7: Spring dimension

$$e_1 = R \frac{N + k - \sqrt{2N^2 + 4kN}}{k^2 - N^2 - 2kN} = 0.092111mm$$

$$e_2 = \frac{1}{N} \left(\sqrt{2(R^2 + r^2)} - R - r \right) = 0.091455mm$$

$$L = \frac{\pi(R^2 - r^2)}{2e} = 358.49812mm$$

$$L_{tot} = L \left(\frac{-0.006 \cdot 2 \cdot r}{e} + 1.33 \right) = 415.65144mm$$

$$M_{max} = \frac{e^2 \cdot h}{6} \sigma_{max} \quad Pr = M_{max} \frac{2\pi \cdot \eta \cdot \beta \cdot f}{z_E \cdot \rho} \quad Pr = \frac{e^2 \cdot h}{6} \sigma_{max} \cdot \frac{2\pi \cdot \eta \cdot \beta \cdot f}{z_E \cdot \rho}$$

$$h = \frac{Pr \cdot 6 \cdot z_E \cdot \rho \cdot 10^{-3}}{e^2 \cdot 2 \cdot \pi \cdot \eta \cdot \beta \cdot f \cdot \sigma_{max}} \quad h = \frac{0.709 \cdot 6 \cdot 20 \cdot 3780 \cdot 10^{-3}}{0.092^2 \cdot 2 \cdot \pi \cdot 0.60 \cdot 0.80 \cdot 3.5 \cdot 2943} = 1.223mm$$

12.2.8 Solution 8: Energy balance

$$Z_4 = \frac{f \cdot z_5}{N_4 \cdot Z_5} \quad Z_4 = \frac{f \cdot z_5 \cdot 60}{Z_5} = 105$$

$$\rho = \frac{Z_f \cdot Z_m \cdot Z_k \cdot Z_s}{z_m \cdot z_k \cdot z_s \cdot z_a} = 5700$$

$$e = R \frac{N + k - \sqrt{2N^2 + 4kN}}{k^2 - N^2 - 2kN} = 0.111mm$$

$$L_{tot} = \frac{\pi(R^2 - r^2)}{2e} (-0.006 \cdot 2 \cdot k + 1.33) = 347.32mm$$

$$M_{max} = \frac{e^2 \cdot h}{6} \sigma_{max} = 11.589Nmm$$

$$Pr = M_{max} \frac{2\pi \cdot \eta \cdot \beta \cdot f}{z_E \cdot \rho} = 1.78\mu W$$

Nivarox 20.3 n% = 37.5

Moment of inertia 7.5 - 12 mgcm²

12.2.9 Solution 9 Energy balance 21.3

$\rho = 4225$

$$N = 3600 \cdot d \frac{f}{z_E \cdot \rho} \quad N = 3600 \cdot 49 \frac{4}{20 \cdot 4225} = 8.350$$

$N = 8.35$

$$e = R \frac{N + k - \sqrt{2N^2 + 4kN}}{k^2 - N^2 - 2kN}$$

$e = 0.134mm$

$L = 311.346mm$

$L_{tot} = 376.7mm$

$M_{max} = 12.641Nmm$

$Pr = 2,105 \mu\Omega$

n% = 38 for Nivarox 20.3

$i = 10 - 14 \text{ mgcm}^2$

For a frequency of 5Hz, the gear train is for 20.3

Seconds wheel = 120

Escape wheel pinion = 8

For 21.3

Seconds wheel = 100

Escape wheel pinion = 7

12.2.10 Solution 10: Crown wheel

NIHS 20-25 (= NHS 56704)

Z	2 ha	2 hf	rho	s
0	2.32	3.50	1.856	1.41
9	2.34	3.50	1.872	1.41
10	2.38	3.50	1.904	1.41
12	2.40	3.50	1.92	1.41
14	2.44	3.50	1.952	1.41
17	2.48	3.50	1.984	1.41
21	2.52	3.50	2.016	1.41
26	2.54	3.50	2.032	1.41
35	2.58	3.50	2.064	1.41
55	2.62	3.50	2.096	1.41
135	2.64	3.5	2.112	1.41

$$z_1 = 18$$

$$z_3 = 45$$

$$m = 0.15$$

$$s = 0.15$$

$$H_1 = 2.2\text{mm} + 0.7\text{mm} = 2.9\text{mm}$$

$$a = \sqrt{x^2 + y^2}$$

$$a = \sqrt{(50 - 46.684)^2 + (56.35 - 51.44)^2} = 5.925\text{mm}$$

$$a = m \frac{z_2 + z_3}{2} \quad z_2 = \frac{2a}{m} - z_3 \quad z_2 = \frac{2 \cdot 5.925}{0.15} - 45 = 34$$

$$m = \frac{m_1 \cdot z_2}{z_2 + 2ha_2 - 4} \quad m_1 = \frac{m}{z_2} (z_2 + 2ha_2 - 4) \quad m_1 = \frac{0.15}{34} (34 + 2.54 - 4) = 0.1436$$

$$H_1 + P - s = m_1 (z_1 + 2ha_1) \quad P = S + m_1 (z_1 + 2ha_1) - H_1$$

$$P = 0.15 + 0.1436(18 + 2.48) - 2.9 = 0.191\text{mm}$$

12.2.11 Solution 11: Ratchet Wheel

NIHS 20-25 (= NHS 56704)

Z	2 ha	2 hf	rho	s
0	2.32	3.50	1.856	1.41
9	2.34	3.50	1.872	1.41
10	2.38	3.50	1.904	1.41
12	2.40	3.50	1.92	1.41
14	2.44	3.50	1.952	1.41
17	2.48	3.50	1.984	1.41
21	2.52	3.50	2.016	1.41
26	2.54	3.50	2.032	1.41
35	2.58	3.50	2.064	1.41
55	2.62	3.50	2.096	1.41
135	2.64	3.5	2.112	1.41

$$m_1 = \frac{m}{z_2} (z_2 + 2ha_2 - 4) \quad m_1 = \frac{0.14}{25} (25 + 2.52 - 4) = 0.1317$$



Assumption $2ha_1 \sim 2.5$

$$z_1 = \frac{H_1 + P - s}{m_1} - 2ha_1 \quad z_1 = \frac{2.05 + 0.28 - 0.15}{0.1317} - 2.5 = 14$$

$$a = m \frac{z_2 + z_3}{2} \quad z_3 = \frac{2a}{m} - z_2 \quad z_3 = \frac{2 \cdot 4.69}{0.14} - 25 = 42$$

12.2.12 Solution 12: Hands setting wheels

System of equations with 2 unknowns.

$$12 \cdot z_1 \cdot z_3 = z_2 \cdot z_4 \quad z_1 + z_2 = z_3 + z_4$$

$$12 \cdot z_1 \cdot 10 = 40 \cdot z_4$$

$$120 \cdot (z_4 - 30) = 40 \cdot z_4 \quad z_1 + 40 = 10 + z_4$$

$$z_1 = z_4 - 30$$

$$80 \cdot z_4 = 3600$$

$$z_4 = 45$$

$$z_5 = \frac{\frac{15}{40}}{\frac{5}{6}} \cdot 40 = 18 \quad m = \frac{2a}{z_1 + z_2} = 0.14$$

$$a = m_{1-2} \frac{z_1 + z_2}{2} = m_{3-4} \frac{z_3 + z_4}{2} \quad a_2 = m \frac{18 + 40}{2} = 4.06 \text{ mm}$$

12.2.13 Solution Hands setting wheels

$$z_2 = \frac{2a}{m} - z_1 \quad z_2 = \frac{2 \cdot 4}{0.16} - 14 = 36$$

$$\frac{z_2 \cdot z_4}{z_1 \cdot z_3} = 12 \quad 12 \frac{z_1}{z_2} = \frac{z_4}{z_3} = 12 \frac{14}{36} = 4.666 \quad \frac{9}{42}$$

$$m = \frac{2a}{z_3 + z_4} \quad m = \frac{2 \cdot 4}{9 + 42} = 0.156$$

12.2.14 Solution 14: Spring dimension

$$\frac{e}{R} = \frac{N + k - \sqrt{2N^2 + 4kN}}{k^2 - N^2 - 2kN} \quad \frac{e}{R} = \frac{6.5 + 11.2 - \sqrt{2 \cdot 6.5^2 + 4 \cdot 11.2 \cdot 6.5}}{11.2^2 - 6.5^2 - 2 \cdot 11.2 \cdot 6.5} = 0.027$$

$$e = 0.027 \cdot R \quad r = k \cdot e \quad r = k \cdot 0.027 \cdot R = 0.302 \cdot R$$

$$l = \frac{\pi(R^2 - r^2)}{2 \cdot e} \quad l \cdot e = \frac{\pi}{2}(R^2 - r^2)$$

$$360 \cdot 0.027 \cdot R = \frac{\pi}{2}(R^2 - (0.302 \cdot R)^2)$$

$$9.708 \cdot R = \frac{\pi}{2}(R^2 - 0.091 \cdot R^2) = \frac{\pi}{2}(0.9088 \cdot R^2)$$

$$9.708 = 1.4275 \cdot R = 6.8 \text{ mm}$$

$$e = 0.027 \cdot 6.8 = 0.183 \text{ mm}$$

$$r = 0.302 \cdot R = 2.05 \text{ mm}$$

$$M_{\max} = \frac{e^2 \cdot h}{6} \sigma_{\max} \quad h = \frac{6 \cdot M_{\max}}{e^2 \cdot \sigma_{\max}} \quad h = \frac{6 \cdot 17.17 \text{ E} - 3}{0.000183^2 \cdot 2.94 \text{ E} 9} = 0.001046 \text{ m} = 1.046 \text{ mm}$$

12.2.15 Solution 15: Change the number of revolutions of the barrel

$$e = R \frac{N + k - \sqrt{2N^2 + 4kN}}{k^2 - N^2 - 2kN} \quad e = 6.8 \frac{8 + 10 - \sqrt{2 \cdot 8^2 + 4 \cdot 10 \cdot 8}}{10^2 - 8^2 - 2 \cdot 10 \cdot 8} = 0.174 \text{ mm}$$

$$k = \frac{r}{e} \quad r = k \cdot e = 10 \cdot 0.174 = 1.74 \text{ mm}$$

$$L = \frac{\pi(R^2 - r^2)}{2e} \quad L = \frac{\pi(6.8^2 - 1.74^2)}{2 \cdot 0.174} = 391.1 \text{ mm}$$

$$M_{\max} = \frac{e^2 \cdot h}{6} \sigma_{\max} \quad M_{\max} = \frac{0.174^2 \cdot 1.05}{6} \cdot 2943 = 15.52 \text{ Nmm} = 15.52 \cdot 10^{-3} \text{ Nm}$$

12.2.16 Solution 16: Energy balance

$$\rho = \frac{108 \cdot 77 \cdot 90 \cdot 108}{19 \cdot 13 \cdot 9 \cdot 9} = 4040$$

$$N = 3600 \cdot 56 \frac{4}{20 \cdot 4040} = 9.98$$

$$e = 5.425 \frac{9.98 + 10 - \sqrt{2 \cdot 9.98^2 + 4 \cdot 10 \cdot 9.98}}{10^2 - 9.98^2 - 2 \cdot 10 \cdot 9.98} = 0.122 \text{ mm}$$

$$L = \frac{\pi(5.425^2 - 1.22^2)}{2 \cdot 0.122} = 359.766 \text{ mm}$$

$$M_{\max} = \frac{0.122^2 \cdot 1.4}{6} 3.24 \cdot 10^3 = 11.25 \text{ Nmm}$$

$$\text{Pr} = 11.25 \frac{2\pi \cdot 0.748 \cdot 0.83 \cdot 4}{20 \cdot 4040} = 2.17 \mu\text{W}$$

$$l_s = 10.85 \cdot \pi \cdot 0.90 = 30 \text{ mm} \quad e_s = 0.122 \cdot 1.50 = 0.185 \text{ mm} \quad M_{\text{glis}} = 11.25 \cdot 1.35 = 15.18 \text{ Nmm}$$

12.2.17 Solution 17: Sliding spring

$$\rho = \frac{109 \cdot 77 \cdot 90 \cdot 108}{19 \cdot 13 \cdot 9 \cdot 9} = 4077$$

$$N = 3600 \cdot 56 \frac{4}{20 \cdot 4077} = 9.5364$$

$$e = 5.45 \frac{9.95 + 10 - \sqrt{2 \cdot 9.95^2 + 4 \cdot 10 \cdot 9.95}}{10^2 - 9.95^2 - 2 \cdot 10 \cdot 9.95} = 0.123 \text{ mm}$$

$$L = \frac{\pi(5.45^2 - 1.23^2)}{2 \cdot 0.123} = 360.48 \text{ mm}$$

$$M_{\max} = \frac{0.123^2 \cdot 1.5}{6} 3.24 \cdot 10^3 = 12.24 \text{ Nmm}$$

$$\text{Pr} = 12.24 \frac{2\pi \cdot 0.716 \cdot 0.86 \cdot 4}{20 \cdot 4077} = 2.32 \mu\text{W}$$



$$l_s = 10.9 \cdot \pi \cdot 0.90 = 30.8 \text{ mm} \quad e_s = 0.123 \cdot 1.50 = 0.184 \text{ mm} \quad M_{glis} = 12.24 \cdot 1.35 = 16.5 \text{ Nmm}$$

12.2.18 Solution 18 Spring Dimension

$$e_1 = R \frac{N + k - \sqrt{2N^2 + 4kN}}{k^2 - N^2 - 2kN} = 0.0988 \text{ mm}$$

$$e_2 = \frac{1}{N} \left(\sqrt{2(R^2 + r^2)} - R - r \right) = 0.0988 \text{ mm}$$

$$L = \frac{\pi(R^2 - r^2)}{2e} = 336.366 \text{ mm}$$

$$L_{tot} = L \left(\frac{-0.006 \cdot 2 \cdot r}{e} + 1.33 \right) = 393.54 \text{ mm}$$

$$M_{max} = \frac{e^2 \cdot h}{6} \sigma_{max} \quad Pr = M_{max} \frac{2\pi \cdot \eta \cdot \beta \cdot f}{z_E \cdot \rho} \quad Pr = \frac{e^2 \cdot h}{6} \sigma_{max} \cdot \frac{2\pi \cdot \eta \cdot \beta \cdot f}{z_E \cdot \rho}$$

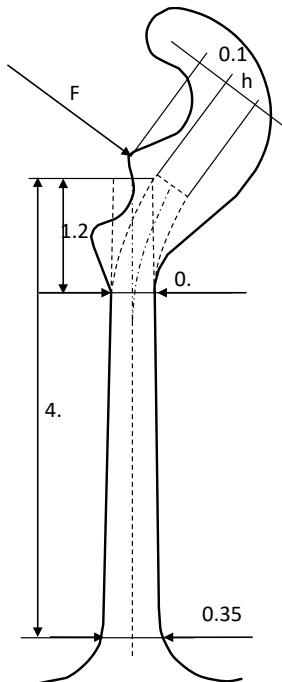
$$h = \frac{Pr \cdot 6 \cdot z_E \cdot \rho \cdot 10^3}{e^2 \cdot 2 \cdot \pi \cdot \eta \cdot \beta \cdot f \cdot \sigma_{max}} = 0.75 \text{ mm}$$

12.2.19 Solution 19: Failure of parts

$$-25000 \cdot \ln(1 - 0.10) = 2634h$$

$$-25000 \cdot \ln(0.99) = 251h$$

12.2.20 Solution 20 Setting lever spring



$$F = \frac{f \cdot E \cdot b \cdot \tan^2 \alpha}{12 \cdot [a + b - c + d - e]} = 0.1214 \text{ daN}$$

$$n = \frac{\sigma e}{\sigma f} = 1.69$$

12.2.21 Solution 21: Failure of parts

$$F(t) = 1 - e^{-\left(\frac{t}{T}\right)^b}$$

$$T = 1/\lambda = 1 / 0.00004 = 25,000 \text{ h}$$

$$F(t) = 1 - e^{-1000/25000} = 0.039 = 3.9\%$$

12.2.22 Solution 22: Mean lifespan

$$T = \frac{-t}{\ln(1-F)} = \frac{-250h}{\ln(0.95)} = 4873.9h$$

$$T_{\text{real}} = 8 \times T = 38991.45 = 4.45 \text{ years}$$

12.2.23 Solution 23: Reliability

$$\lambda = \frac{1}{MTBF} = \frac{1}{18000}$$

$$R(1500) = e^{-\frac{1}{18000} \cdot 1500} = 0.92$$

$$R(15000) = e^{-\frac{1}{18000} \cdot 15000} = 0.43$$

12.2.24 Solution 24 Service interval

$$T = \frac{-t}{\ln(0.80)} = \frac{-43800}{\ln(0.80)} = 196286h = 22.4 \text{ Jahre}$$

12.2.25 Solution 25: Lifetime

$$2 \times 365 \times 24 = 17520h$$

$$T = \frac{-t}{\ln(0.95)} = 341565h = 38 \text{ Jahre}$$

12.2.26 Solution 26: Hairspring

Radius inside	0.5	Mm
Distance	0.1557	Mm
Number of rounds	14	
Length	139.85	Mm
Radius outside	2.68	Mm

$$l = \pi \cdot (R_{\text{Aussen}} + R_{\text{innen}}) \cdot \omega$$

$$M = I \cdot 4 \cdot \pi^2 \cdot f^2 = \frac{18 \cdot 4 \cdot \pi^2 \cdot 4^2}{1000000} = 0.001136 \text{ Nmm}$$

$$h = \frac{I \cdot 4 \cdot \pi^2 \cdot f^2 \cdot 12 \cdot l}{E \cdot e^3} = \frac{18 \cdot 10^{-7} \cdot 4 \cdot \pi^2 \cdot f^2 \cdot 12 \cdot 139.85}{173000 \cdot \frac{0.1557}{4}} = 0.187 \text{ mm}$$



12.2.27 Solution 27: Automatic

$$\rho = \frac{102 \cdot 72 \cdot 75 \cdot 120}{17 \cdot 12 \cdot 9 \cdot 10} = 3600$$

$$d = \frac{N \cdot z_e \cdot \rho}{3600 \cdot f} = \frac{9 \cdot 20 \cdot 3600}{3600 \cdot 4} = 45$$

$$P_r = 9.5 Nmm \cdot \frac{2 \cdot \pi \cdot 0.72 \cdot 0.8 \cdot 4Hz}{20 \cdot 3600} = 1.91 \mu W$$

Mmax must be multiplied by 1.35 because of the gliding bride.

$$M_r = \frac{9.5 Nmm \cdot 1.5}{0.41 \cdot 154} = 0.2257 Nmm$$

$$s = \frac{M_r}{G} = \frac{0.2257 Nmm}{0.0334 N} = 6.75 mm$$

$$\sin(\varepsilon) = \frac{M_{\max}}{\eta \cdot i \cdot G \cdot s} = \frac{9.5 Nmm}{0.41 \cdot 154 \cdot 0.0334 N \cdot 6.757 mm} = 41^\circ$$

12.2.28 Solution 28 O-Ring

d1 Inner Diameter	2.6000	-0.0500	0.0500
d2 Cord diameter	0.7500	-0.0300	0.0300
A \emptyset	3.9800	-0.0100	0.0100
B \emptyset	2.8300	-0.0100	0.0050

Compression mean value	0.7439 Mm
Crimping min	0.7066 Mm
Crimping max	0.7820 Mm
Percent Mean	22.71 %
Percent min	19.69 %
Percent max	25.19 %
Groove length	0.9000 Mm

12.2.29 Solution 29 O-Ring

d1 Inner Diameter	2.6000	-0.0500	0.0500
d2 Cord diameter	0.7271	-0.0300	0.0300
A \emptyset	3.9800	-0.0100	0.0100
B \emptyset	2.8300	-0.0100	0.0050

Compression mean value	0.7187 Mm
Crimping min	0.6818 Mm
Crimping max	0.7565 Mm
Percent Mean	20.00 %
Percent min	16.76 %
Percent max	22.67 %
Groove length	0.8725 Mm

12.2.30 Solution 30: Case

Possion Number	Modulus of elasticity
0.300	210000
0.340	105000
0.330	70000
0.240	60000

Thick glass e	1.1277394	Mm
Thick bottoms e	0.5182987	Mm
pressure p	0.3	N/mm ²

$$1 \text{ bar} = 1\text{E}5 \text{ N/m}^2 = 10 \text{ N/cm}^2 = 0.1 \text{ N/mm}^2$$

12.2.31 Solution 31 Dial Feet

$$F = \frac{5000 \cdot G \cdot 9.81}{1000 \cdot n} \quad F = \frac{5000 \cdot 5 \cdot 9.81}{1000 \cdot 2} = 122.625N$$

12.2.32 Solution 32: Fit

B		C				A			
∅ Sift/ Goupille	Tol +/-	∅ Lochpassung	Min	Max	Tol +/-	∅ Spielpassung	Min	Max	Tol +/-
0.701	3	0.694	0.692	0.696	2	0.711	0.709	0.713	2
		-0.007	-0.002	-0.012		0.010	0.005	0.015	

12.2.33 Solution 33 Process capability

The process is in the middle but has too much dispersion.

12.2.34 Solution 34 Process capability

2 lots mixed. The mean value fluctuates too much. No normal distribution.

12.2.35 Solution 35: Initial item inspection

A full test will be carried out. The tolerances must be adapted to the real process. Critical mass for incoming inspection will be evaluated.

12.2.36 Solution 36: Weibull Distribution

Installation and adjustment errors

12.2.37 Solution 37: Long-term capability

±0.006mm

12.2.38 Solution 38: Reliability

Behavior under specified application conditions

12.2.39 Solution 39 QFD

The selection process is carried out neutrally in a team

12.2.40 Solution 40 FMEA

The potential mistakes are avoided

12.2.41 Solution 41 CPK

1.5

12.2.42 Solution 42 CP

2.0



12.2.43 Solution 43: Process evaluation

Wheel including pinion

12.2.44 Solution 44 ISO

ISO describes the processes and Six Sigma improves them.

12.2.45 Solution 45 DOE

The DOE shortens the number of tests. Interim solutions can be calculated.

12.2.46 Solution 46 Technologies

Hairspring, lever, escape wheel

12.2.47 Solution 47 Test equipment

5 times more accurate

12.2.48 Solution 48 Drilling pattern

The spread is too large.

12.2.49 Solution 49 Sampling and process analysis

In the process analysis, the mean value dispersion is considered. For this purpose, several solutions are measured. For sample analysis, it is sufficient to measure 30 parts.

13 Updates

Updates on the Exercises, programs and the book can be found on the author's homepage. watch-making.com

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This companion book with Exercises and solutions to the book Movement Design and Case Design is aimed at watch technicians or engineers who design a mechanical movement from scratch. Basic knowledge of watch technology is required. (watchmaker, precision mechanic...) With a few exceptions, the physical, mathematical formulas are not derived but simply applied. Many calculations are performed with Excel spreadsheets. For this reason, prepared Excel tables are also used for the available documents. Current data is available on the watchmaking.com page. The calculations can also be performed on programmable calculators.



Kilian Eisenegger, Six Sigma Blackbelt was born in Lucerne in 1965. He attended the watchmaking school, the technical school in La Chaux-de-Fonds and did various additional training courses up to becoming a lecturer for adult educators on a part-time basis. He spent several years in the development department at the Swatch Group, Technical Director at IWC, Managing Director of the Manufacture Horlogère Vallée de Joux, Technical Director Sellita and

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