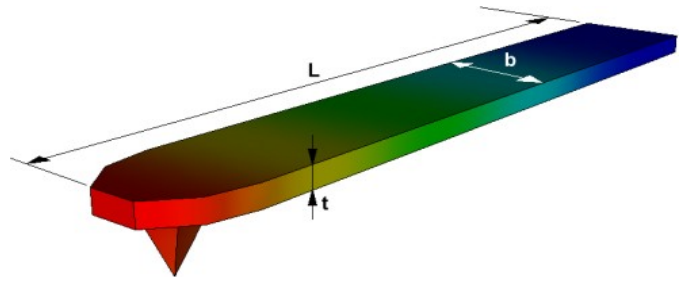


## KLever



### - Calculation of the Spring Constant $k$ and the Torsional Spring Constant $k_t$

*KLever* was written to analyze data of measured cantilevers used for atomic force microscopy. Since cantilevers oscillate because of their temperature the amplitude of a frequency area can be measured. Therefrom the quality factor and resonance frequency can be determined to use them for the calculation of the spring constant as well as the torsional spring constant.

The spring constant is calculated using the normal Sader method [1]:

$$k = 0.1906pb^2LQ(2\pi f_r)^2\Gamma_{im}(2\pi f_r)$$

The torsional spring constant is calculated using the torsional Sader method [1]:

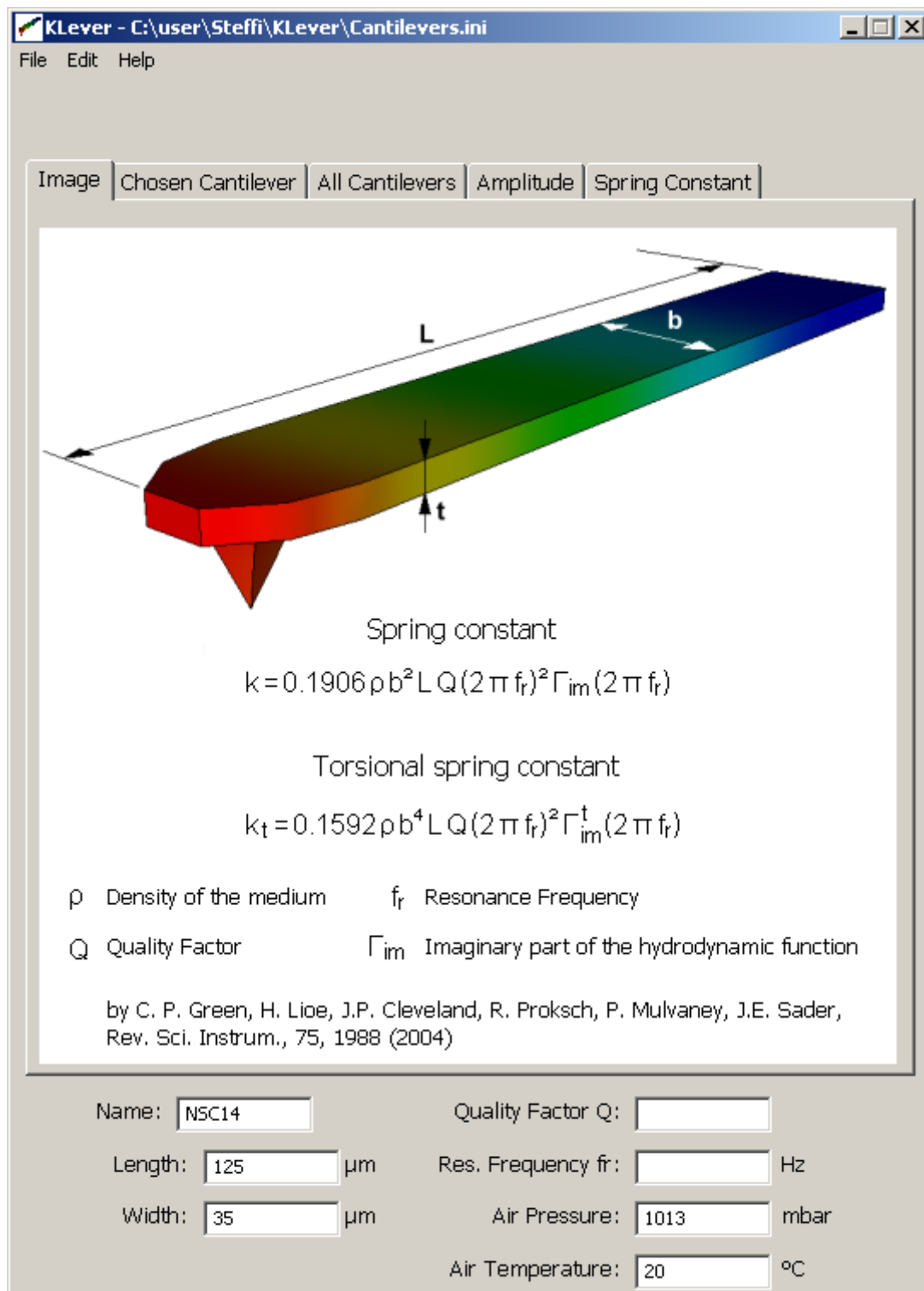
$$k_t = 0,1592pb^4LQ(2\pi f_r)^2\Gamma_{im}^t(2\pi f_r)$$

The formulas are only suitable if rectangular cantilevers were measured. Furthermore the length should be much higher than the width of the used cantilever. The viscosity is calculated for air as usual used medium for measurements.

[1] C.P. Green, J.P. Cleveland, R. Proksch, P. Mulvaney, J.E. Sader, Rev. Sci. Instrum., 75, 1988 (2004)

## Getting started

When the program is started the following window opens:



At the top there are five sliders (**Image**, **Chosen Cantilever**, **All Cantilevers**, **Amplitude** and **Spring Constant**). The first one shows the **formulas** by Sader to calculate the **spring constant** and the **torsional spring constant**.

The chosen parameters can be find below:

- **name**, **length** and **width** of the measured cantilever,

- calculated **quality factor** and **resonance frequency**,
- **pressure** and **temperature** of the used medium.

The parameters can be changed all the time. In doing so the field changes the color to silver till the editing is ready.

**!!!** Please note the belonging unit when a parameter is changed. Otherwise the calculation of the spring constant and the torsional spring constant may be incorrect.

An edited field appears **red** if the type of the written text does not make sense in this field (for example: letters instead of numbers).

The name of the cantilever is **yellow** if it was not found in the table at the second tab.

### **Menu bar**

By pressing **Open** an Ini- or Data-File can be chosen to fill either the table at the second page or the amplitude diagram at the fourth tab.

**Save** is only working for the amplitude diagram. It is saved as a Data-File.

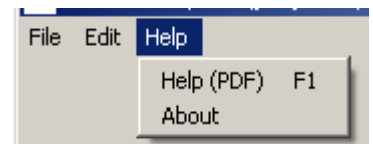
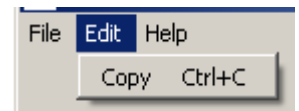
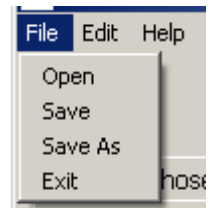
**Save as** can be used to define save path and file name. The file is saved according to the filter type:

- \*.ini saves the table
- \*.bmp saves the amplitude diagram as a picture
- \*.dat saves the amplitude diagram as a Data-File

**Exit** closes the whole program.

**Copy** moves the visible picture or data to the clipboard to use it elsewhere.

**About** shows the version of the program and some more information.



## Choose cantilever

The second slider shows this table:

Image Chosen Cantilever All Cantilevers Amplitude Spring Constant										
Open			Append			Save				
	Name	fr [kHz]			k [N/m]			L [ $\mu$ m]	w [ $\mu$ m]	t [ $\mu$ m]
		min	typ	max	min	typ	max			
1	NSC14	110	160	220	1.8	5.7	12.5	125	35	2
2	NSC15	265	325	400	20	46	75	125	35	4
3	NSC16	150	170	190	25	45	60	230	40	7
4	CSC17	8.5	12	15	0.05	0.15	0.3	460	50	2
5	NSC18	60	75	90	2	3.5	5.5	230	40	3
6	NSC19	52	80	113	0.17	0.6	1.7	125	35	1
7	NSC35_A	165	210	240	3.5	7.5	12.5	110	35	2
8	NSC35_B	240	315	405	6.5	14	27.5	90	35	2
9	NSC35_C	120	150	190	2.5	4.5	8.5	130	35	2
10	NSC36_A	65	105	150	0.25	0.95	2.5	110	35	1
11	NSC36_B	95	155	230	0.45	1.75	5	90	35	1
12	NSC36_C	50	75	105	0.15	0.6	1.5	130	35	1
13	CSC37_A	33	41	49	0.35	0.65	1.2	250	35	2
14	CSC37_B	17	21	24	0.1	0.3	0.4	350	35	2
15	CSC37_C	23	28	34	0.2	0.35	0.7	300	35	2
16	CSC38_A	14	20	28	0.02	0.08	0.2	250	35	1
17	CSC38_B	7	10	14	0.01	0.03	0.08	350	35	1
18	CSC38_C	9.5	14	19	0.01	0.05	0.1	300	35	1
19	NSC12_A	165	210	240	3.5	7.5	12.5	110	35	2

At the beginning common cantilevers along with their **resonance frequencies**, **spring constants**, **lengths** and **widths** are registered.

The selected cell is colored **green**. If the name of a cantilever is already defined the associated row of the table is colored **blue**. Otherwise the first row is focused. That happens as well if the defined name is not part of the table. The parameter field below appears **yellow** then. Once another cantilever is selected the name, length and width are written into the parameter fields below. Alternatively the length and width can be changed by yourself. If the added cantilever exists already its row is not colored but the first with the same name instead.

You can **open** another Ini-File containing defined cantilevers if it looks like this:

Other cantilevers can also be typed into the table below the others or added by pressing **Append**.

The fields appear **red** if the inserted term does not fit in this column. Rows that are not filled completely are moved down after the last correct entry.

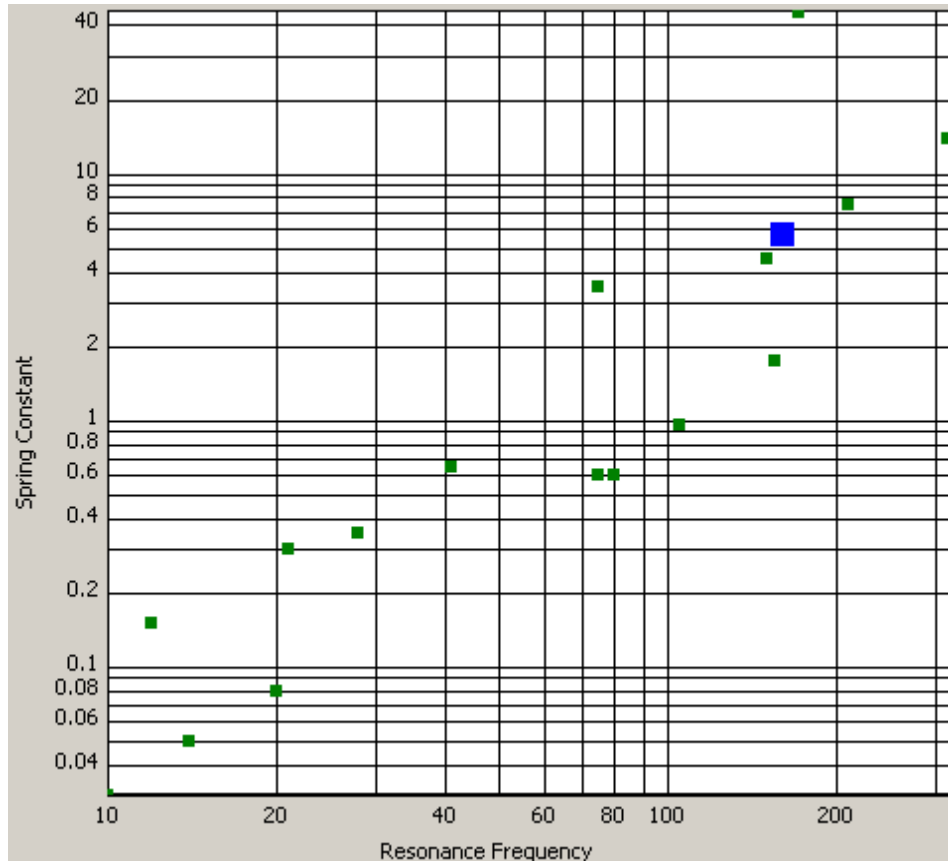
```
[1]
Name=NSC14
ResonanceFrequencyMin=110
ResonanceFrequencyTyp=160
ResonanceFrequencyMax=220
SpringConstantMin=1.8
SpringConstantTyp=5.7
SpringConstantMax=12.5
Length=125
width=35
Thickness=2
```

```
[2]
Name=NSC15
ResonanceFrequencyMin=265
ResonanceFrequencyTyp=325
```

The table can be **saved** as an Ini-File. At the first time the path and file name can be chosen. After that the existing file is overwritten unless **Save As** at the menu bar is used.

### All cantilevers

This slider shows the **spring constant** vs. the **resonance frequency** of all defined cantilevers like this:



The **blue** point displays the chosen cantilever and the **green** points show the others. The scale can be changed between **linear** and **logarithmic** by clicking  Logarithmic

### Amplitude

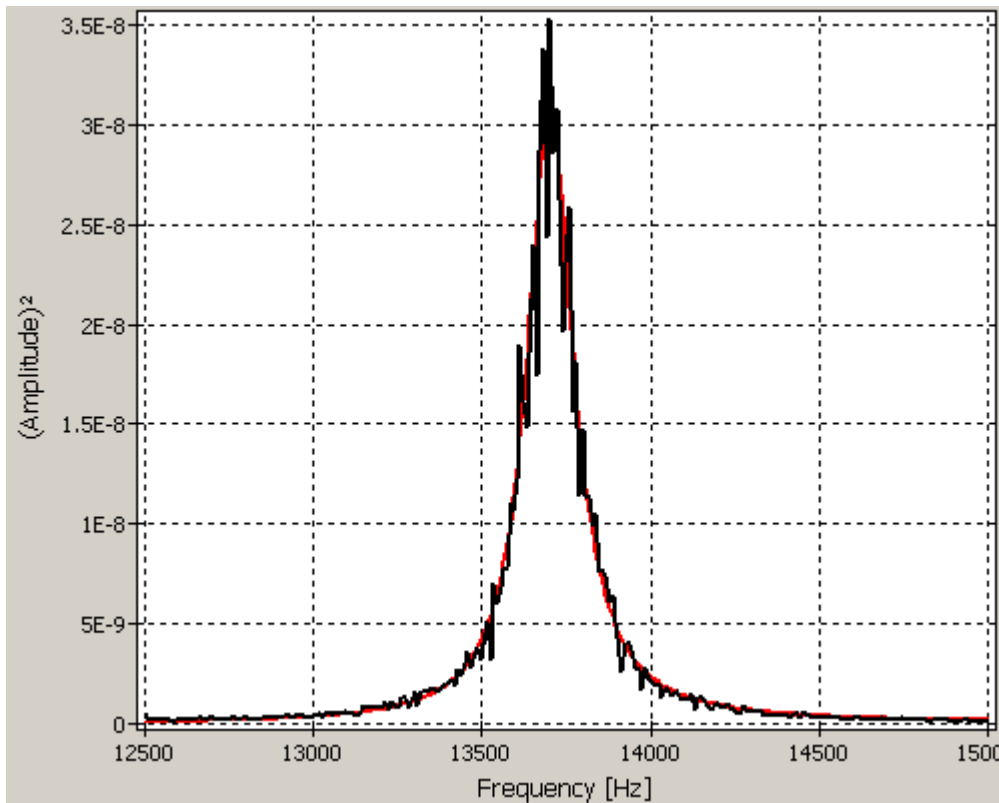
At this tab the resonance frequency and quality factor of the measured cantilever can be calculated. The diagram shows the amplitude vs. frequency.

Press **Open amplitude** and choose a Data-File which looks like this:

12509.77	1.54639910761034E-5
12519.53	1.40790043587913E-5
12529.30	1.44775494845817E-5
12539.06	1.24328389574657E-5
12548.83	1.34522551888949E-5
12558.59	1.57596787175862E-5
12568.36	1.59864903253037E-5

The button **Open power** can be used if the saved data is already the power of the amplitude.

Your measured points are shown as a black graph and the fitted curve appears **red**:



The fitted graph is calculated according to the following formula:

$$A^2(\omega) = A_{\text{white}} + \frac{(A_0 \omega_0^2)^2}{(\omega_0^2 - \omega^2)^2 + \frac{(\omega_0^2 \omega^2)}{Q^2}}$$

$A_{\text{white}}$ : noise during the measurement

$A_0$ : amplitude at  $\omega=0$

$\omega_0$ : resonance frequency

$\omega$ : frequency

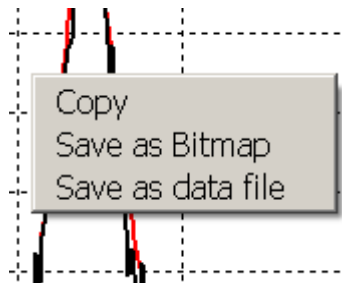
$Q$ : quality factor of the cantilever

The cantilever oscillates because of its temperature. This movement is unsorted and happens when the temperature is higher than 0 K. The resulting amplitude is measured at different frequencies. The power is shown as the black graph. Its highest point is at the resonance frequency of the cantilever. The noise parameter ( $A_{\text{white}}$ ) must be added to / subtracted from the power of the amplitude to get the noisy-free parameters.

The quality factor and resonance frequency can be calculated by the formula shown above. They appear in the associated fields below when the fitting is done.

The parameters can be changed to see what differences may occur. The “**Fitting**” button can be pressed again if the calculated values are required.

By a right mouse click on the diagram you can **copy** or **save** it:



The saved **Data-File** looks like this:

12578,13	1,54043209477095E-5	1,69199201494702E-5
12587,89	1,32003360704402E-5	1,69527609144581E-5
12597,66	1,22920591820730E-5	1,69865292301968E-5
12607,42	1,33685025502928E-5	1,70211876889996E-5
12617,19	1,64034991030348E-5	1,70568404767347E-5

The first column is the frequency area (X-axis). The second column represents the power of the amplitude (Y-axis). And the **red** graph is saved as the third column (Y-axis).

### Spring Constant

At the last tab the **spring constant** as well as the **torsional spring constant** of the measured cantilever can be calculated by clicking on the button. The used parameters are shown in the formula at the first page.

The field appears silver if a required parameter was edited.

The diagram shows the **spring constant** vs. its associated **resonance frequency** (blue point). The green rectangle exhibit the **tolerance range** of the calculated spring constant.

This diagram can be **copied** to use it elsewhere.

**!!!** The values for the tolerance range are taken from the previous table if the right cantilever is chosen.

